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Evaluation and selection of transportation outsourcing service providers: a case of a small and medium-sized third-party logistics enterprise

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Abstract: To mitigate the impact of subjective biases and evaluation methodologies on the assessment outcomes of transportation outsourcing service providers, this study focuses on small and medium-sized third-party logistics firms. It employs the Total Rank Difference Test (TRDT) method for evaluating and analyzing service providers. The research begins by synthesizing extant evaluation indices from domestic and international sources to construct a comprehensive evaluation system tailored for third-party logistics service providers. This system encompasses ten primary indices, including safety management, cargo damage compensation, emergency response capabilities, and reputation, along with thirty-three secondary indices. To validate the efficacy of this evaluation system, the study utilizes four prominent evaluation techniques—Analytic Hierarchy Process (AHP), Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS), Fuzzy Comprehensive Evaluation (FCE), and Fuzzy Technique for Order Preference by Similarity to an Ideal Solution (Fuzzy-TOPSIS). It incorporates the entropy weighting method to assign index weights, thereby minimizing subjective influence. A consistency-based evaluation model for third-party logistics service providers is established and subjected to the TRDT to assess the reliability of the four evaluation methods. Lastly, the evaluation model is applied to Topchains, a case study, to test its practical utility in assessing transportation outsourcing service providers. The findings reveal that safety management, cargo damage compensation, support services, emergency response, and cooperation quality are pivotal factors in evaluating transportation outsourcing providers. Furthermore, Fuzzy Comprehensive Evaluation and Analytic Hierarchy Process demonstrate strong consistency, yielding stable and reliable results.

Keywords: Logistics engineering; Service provider evaluation index; Total rank difference test; Small and medium-sized enterprises; Third-party logistics

1 Introduction

With the rapid development of China's economy, the demand for logistics and transportation is also increasing, and third-party logistics enterprises have gained the opportunity for rapid development and formed a large market scale. While the rapid development of third-party logistics enterprises, many logistics enterprises choose to outsource part of their business to improve their core competitiveness. Therefore, the adoption of a scientific and objective evaluation method to analyze and evaluate and select transportation outsourcing service providers has become an urgent task for the rapid development of third-party logistics enterprises.

The issue of partner evaluation selection is well researched at home and abroad. Liu JC establishes a two-way selection model based on entropy power method and Gale-Shapley algorithm to study the selection problem of wind storage supply chain partners, which improves the reliability and stability of the selection results [1]; Mishra et al. proposed a combined framework combining additive ratio assessment (ARAS) methods, q-rung orthogonal pair fuzzy sets and information measures to implement a multi-criteria SRP selection problem in the setting of q-ROFSs [2]; Negoro uses game theory to study partner selection for firms entering the market [3]. By collating the literature on service provider evaluation indexes in different periods, it is found that the research on service provider evaluation indexes has been relatively mature, but the research indexes mainly focus on several perspectives such as quality, cost, service and cooperation, and there are fewer studies that comprehensively consider compensation and security perspectives for evaluation.

From the analysis of partner evaluation indexes above, it is clear that existing studies mostly use a combination of qualitative and quantitative approaches, combining one or two research methods for evaluating and selecting service providers, but there is a lack of discussion on the integration and selection of multiple evaluation methods. Liu Jun simultaneously considered quantitative and qualitative factors, and jointly applied Analytic Hierarchy Process (AHP) and fuzzy goal planning to evaluate service providers in four dimensions: scale, quality, service and speed [4]; Tian Lin et al. combined fuzzy network analysis and Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) to determine the priority of service providers [5]. Hekmat et al. have used Data Envelopment Analysis (DEA) to evaluate the selection of service

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providers in industries such as third party logistics, cloud computing services, dentistry, and the payment industry [6-10]. Artificial Neural Network (ANN) algorithms have also been widely used in service provider selection problems in industries such as automotive, infrastructure construction, tobacco, and steel manufacturing [11-14]. In summary, the research on evaluation methods at home and abroad has been very mature and widely used, but it is mostly based on the study of indicators with a single attribute, ignoring the diversity of indicator attributes in the evaluation system, and the existing results are still blank for the study of evaluation model selection.

Therefore, this paper constructs an evaluation system with cargo damage compensation, safety management, transportation quality and other factors as evaluation indexes for the characteristics of transportation outsourcing service providers of third-party logistics enterprises, uses the entropy weight method to determine the index weights, and proposes a selection method based on total rank difference test to select evaluation models such as AHP, TOPSIS, FCE and Fuzzy-TOPSIS. Combining the information of the case companies, the constructed evaluation system and evaluation model of transportation outsourcing service providers of third-party logistics enterprises are validated to realize the decision evaluation of transportation outsourcing service providers of third-party logistics enterprises.

2 Evaluation index system

2.1 Evaluation index selection

With reference to relevant literature at home and abroad, combined with the actual research situation of TOPCHAINS (a small and medium-sized third-party logistics enterprise), the evaluation system of transportation outsourcing service providers of third-party logistics enterprises is constructed from ten dimensions based on the principles of comprehensiveness, relevance, scientificity and feasibility, as shown in Table 1.

2.2 Evaluation index weight

At present, the methods to determine the index weight include expert evaluation method, entropy weight method, analytic hierarchy process, principal component analysis and so on. In order to avoid the influence of subjective factors, the objective assignment-entropy weight method is used to select, that is, according to the dispersion degree of each index data, the entropy weight of each index is calculated by using information entropy, and the objective index weight is obtained [15]. The calculation process is as follows:

Calculate information entropy:

$$E_j = -K\sum_{i=1}^{n} q_{ij}\ln q_{ij},\ \ j = 1,2,\dots,m, \tag{1}$$

where, $E_j \in [0,1]$; $K = \dfrac{1}{\ln n}$; $q_{ij} = \dfrac{h_{ij}}{\sum_{i=1}^{n} h_{ij}}$; n indicates the number ofservice providers to be evaluated; m is the total number of evaluation indicators; h_{ij} is the score of the jth indicator of the ith service provider.

Determining weights:

$$w_j = \frac{1 - E_j}{m - \sum_{j=1}^{m} E_j}, \tag{2}$$

where, $w_j \in [0,1]$, 且$\sum_{j=1}^{m} w_j = 1$.

3 Evaluation model

3.1 Evaluation model based on AHP

The Analytic Hierarchy Process combines qualitative and quantitative analysis methods to transform factors with different objectives and difficult to quantify into a single objective and different levels of structure for the project [16]. Using AHP to select service provider, the calculation process is as follows:

Build judgment matrix:

$$\boldsymbol{A} = \left(a_{ij}\right)_{n*n} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix}, \tag{3}$$

where, a_{ij} is the relative importance of service provider j to service provider I, $a_{ji}=1/a_{ij}$.

Determine the weight vector:

$$\boldsymbol{W} = (w_1, w_2, \cdots, w_n). \tag{4}$$

Solving for the maximum eigenvalue:

$$\lambda_{\max} = \sum_{i=1}^{n} \frac{AW}{nw_i} \tag{5}$$

Calculate consistency metrics:

$$I_{\mathrm{C}} = \frac{\lambda_{\max} - n}{n-1}. \tag{6}$$

Calculate consistency ratio:

$$R_{\mathrm{c}} = \frac{I_{\mathrm{C}}}{I_{\mathrm{R}}}, \tag{7}$$

where, I_{R} is the average random consistency index and takes the following values in Table 2.

3.2 Evaluation model based on TOPSIS

TOPSIS is a method of ranking evaluation objects according to their proximity to a desired target, and is an evaluation of the relative merits of existing objects [17]. The selection of service providers is performed using TOPSIS with n service providers to be evaluated, each with m indicators, and the raw data x_{ij} represents the score of the jth indicator of the ith service provider. The calculation process is as follows:

Standardization of data:

$$y_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} {x_{ij}}^2}}. \tag{8}$$

Constructing a weighted normalization matrix:

$$z_{ij} = w_j y_{ij},\ \ \sum_{j=1}^{m} w_j = 1. \tag{9}$$

Determine the positive and negative ideal solutions:

$$L^+ = \begin{cases} \max z_{ij},\ \ j \text{ is a benefit-based indicator} \\ \min z_{ij},\ \ j \text{ is a cost-based indicatora} \end{cases}, \tag{10}$$

$$L^- = \begin{cases} \min z_{ij},\ \ j \text{ is a benefit-based indicator} \\ \max z_{ij},\ \ j \text{ is a cost-based indicator} \end{cases}. \tag{11}$$

Calculate the distance between the evaluated object and the positive and negative ideal solutions:

$$s^+ = \sqrt{\sum_{j=1}^{m} (z_{ij} - L_j^+)^2}, \tag{12}$$

$$s^- = \sqrt{\sum_{j=1}^{m} (z_{ij} - -L_j^-)^2}. \tag{13}$$

Calculate close degree：

$$Q_i = \frac{s_i^-}{s_i^- + s_i^+}. \tag{14}$$

Table 1 Evaluation system of transportation outsourcing service providers of third-party logistics enterprises.

First-level indexes	Second-level indexes	Definition of indexes
Reputation level (A_1)	Record of dishonesty of legal person (A_{11}) The dishonesty record of the service provider (A_{12}) Administrative penalty record of service provider (A_{13}) Legal dispute cases (A_{14})	The evaluation obtained by the service provider in the process of providing services due to compliance with the agreement.
Safe management level (A_2)	Number of full-time safety management personnel (A_{21}) Number of effective safety management systems (A_{22}) Number of regular safety training sessions (A_{23}) Number of major accidents within three years (A_{24})	Service Provider 's ability to ensure the safety of transport personnel and equipment and effectively complete transport tasks.
Cargo damage compensation level (A_3)	Equipped with full and complete insurance (A_{31}) Set up full-time insurance claims personnel (A_{32}) Have complete cargo damage compensation measures (A_{33})	The ability of service providers to deal with and compensate for the loss of logistics enterprises and customers in a timely manner.
Capacity level (A_4)	The scale of its own ordinary cars (A_{41}) The scale of its own special vehicles (A_{42}) The scale of the cooperative society ordinary car (A_{43}) The scale of cooperative social special vehicles (A_{44})	The satisfaction degree of the transportation equipment of the service provider to the transportation demand of the logistics enterprise.
Transportation quality (A_5)	On-time departure rate (A_{51}) Vehicle arrival punctuality rate (A_{52}) Goods intact rate (A_{53})	The satisfaction degree of the service provided by the service provider to the transportation demand of the logistics enterprise.
Necessary service (A_6)	Service network density (A_{61}) Completeness of transportation lines (A_{62})	Service providers provide supporting services to meet the diversified transportation requirements of logistics enterprises.
Emergency response and emergency handling capacity (A_7)	Timeliness of vehicle scheduling (A_{71}) Ability to solve emergencies (A_{72}) Emergency order response degree (A_{73})	Service providers to meet the changing needs of logistics enterprises and the ability to respond to emergency orders.
Communication level (A_8)	In-transit information notification speed of goods (A_{81}) Degree of acceptance of corporate supervision (A_{82}) Professional training frequency (A_{83})	The ability of service providers to maintain close contact with logistics enterprises and provide timely and effective feedback
Collaboration competence (A_9)	Service Adjustment and Innovation Capability (A_{91}) Business information confidentiality (A_{92}) Frequency of customer contact violations (A_{93}) Industry experience accumulation level (A_{94})	The ability of service providers to undertake outsourcing business and negotiate with enterprises on the basis of recognizing the values of logistics enterprises.
Financial position (A_{10})	Asset liquidity (A_{101}) Debt ratio (A_{102}) Earnings position (A_{103})	The ability of service providers to regularly or permanently update services or equipment to meet transportation needs and ensure smooth operations.

Table 2 I_R correction values.

Order of matrix	1	2	3	4	5	6	7	8	9
I_R	0	0	0.515	0.893	0.119	1.249	1.345	1.420	1.462

3.3 Evaluation model based on FCE

Fuzzy Comprehensive Evaluation (FCE) uses the affiliation theory of fuzzy mathematics to transform qualitative evaluation into quantitative evaluation, which can better solve fuzzy and difficult to quantify problems, and is suitable for solving non-deterministic problems [18]. Using FCE for the selection of service providers. The calculation process is as follows:

Establishing indicator sets and evaluation level sets:

$$U = \{u_1, u_2, \cdots, u_i, \cdots u_m\} \tag{15}$$

$$V = \{v_1, v_2, \cdots, v_k, \cdots, v_l\} \tag{16}$$

where, u_i indicates the i-th indicator of the evaluation object; v_k denotes the kth evaluation level, generally 3−5 levels, and 5 levels are selected for this paper, l =5.

Construct a fuzzy comprehensive evaluation matrix $\boldsymbol{R}$:

$$r_{ij} = \exp\left\{-\left(\frac{x_{ij} - a_k}{\sigma}\right)^2\right\}, k = 1,2,3,4,5, \tag{17}$$

$$\boldsymbol{R} = \left(r_{ij}\right)_{m*n} = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix}, \tag{18}$$

where, a_k denotes the central value of the kth rank of the evaluation, which in this paper are 1,2,3,4,5.

Determine the weights of each evaluation index:

$$\boldsymbol{W} = (w_1, w_2, \cdots, w_m), \sum_{j=1}^{m} w_j = 1. \tag{19}$$

Perform fuzzy synthesis:

$$\boldsymbol{B} = \boldsymbol{WR} \tag{20}$$

$$= (w_1, w_2, \cdots, w_m) \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix} \tag{21}$$

3.4 Evaluation model based on fuzzy-TOPSIS

Fuzzy TOPSIS is based on TOPSIS and uses fuzzy set theory to replace exact values with fuzzy numbers to represent indicators [19]. In this paper, the ordered trapezoidal fuzzy numbers are used to evaluate the indicators of service providers, a_{ij} = $[f_{ij}(0)$, $f_{ij}(1)$, $g_{ij}(1)$, $g_{ij}(0)]$, $(i = 1,2,\cdots,n, j = 1,2,\cdots,m)$ denotes the score of the jth indicator of the ith service provider, $f_{ij}(0)$, $f_{ij}(1)$, $g_{ij}(1)$ and $g_{ij}(0)$ represent the minimum, minimum mode, maximum mode and maximum value of the score of the jth index of the ith service provider, respectively. The calculation process is as follows:

Data standardization:

$$c_{ij}=\left(\frac{f_{ij}(0)}{\max g_{ij}(0)},\frac{f_{ij}(1)}{\max g_{ij}(0)},\frac{g_{ij}(1)}{\max g_{ij}(0)},\frac{g_{ij}(0)}{\max g_{ij}(0)}\right),\quad \text{(cost-based indicator)} \tag{22}$$

$$c_{ij}=\left(\frac{\min g_{ij}(0)}{f_{ij}(0)},\frac{\min g_{ij}(0)}{f_{ij}(1)},\frac{\min g_{ij}(0)}{g_{ij}(1)},\frac{\min g_{ij}(0)}{g_{ij}(0)}\right),\quad \text{(benefit-based indicator)} \tag{23}$$

where, c_{ij} indicates the standardized index value of the jth evaluation index of the ith service provider.

Weighted standardization:

$$z_{ij}=w_jc_{ij}=[w_jf_{ij}(0),\ w_jf_{ij}(1),\ w_jg_{ij}(1),\ w_jg_{ij}(0)], \tag{24}$$

$$\sum_{j=1}^{m}w_j=1. \tag{25}$$

Determine the positive and negative ideal solutions:

$$Z^+=\left|z_1^+,z_2^+,\cdots,z_m^+\right|, \tag{26}$$

$$Z^-=\left|z_1^-,z_2^-,\cdots,z_m^-\right|, \tag{27}$$

where, $z_j^+=[w_j\cdot\max f_{ij}(0),w_j\cdot\max f_{ij}(1),w_j\cdot\max g_{ij}(1),w_j\cdot\max g_{ij}(0)]$, $z_j^-=[w_j\cdot\min f_{ij}(0),w_j\cdot\min f_{ij}(1),w_j\cdot\min g_{ij}(1),w_j\cdot\min g_{ij}(0)]$.

Calculate the distance between the evaluated object and the positive and negative ideal solutions:

$$d_i^+=\sqrt{\sum_{j=1}^{m}\mathrm{d}\left(z_{ij}-z_j^+\right)}=\sqrt{\sum_{j=1}^{m}(w_j)^2\begin{bmatrix}[f_{ij}(0)-\max f_{ij}(0)]^2+[f_{ij}(1)-\max f_{ij}(1)]^2+\\ [g_{ij}(1)-\max g_{ij}(1)]^2+[g_{ij}(0)-\max g_{ij}(0)]^2\end{bmatrix}},\quad i=1,2,\cdots,n. \tag{28}$$

$$d_i^-=\sqrt{\sum_{j=1}^{m}\mathrm{d}\left(z_{ij}-z_j^-\right)}=\sqrt{\sum_{j=1}^{m}(w_j)^2\begin{bmatrix}[f_{ij}(0)-\min f_{ij}(0)]^2+[f_{ij}(1)-\min f_{ij}(1)]^2+\\ [g_{ij}(1)-\min g_{ij}(1)]^2+[g_{ij}(0)-\min g_{ij}(0)]^2\end{bmatrix}},\quad i=1,2,\cdots,n. \tag{29}$$

Calculate the close degree：

$$I_{\mathrm{R}i}=\frac{d_i^-}{d_i^-+d_i^+}. \tag{30}$$

3.5 The total rank difference test

The four evaluation models above have different principles of merit ranking, and their advantages, disadvantages, and applicability also differ, so the thesis chooses the total rank difference test to carry out the quantitative comparative analysis and selection of the four evaluation model. The total rank difference test (R_{TDT}) is currently used in the identification of hotspots for road safety management, and it assesses the performance of the evaluation method by considering the similarity of the ranking of the identified hotspots between two time periods [20]. In this paper, the total rank difference test is used to assess the performance of the evaluation methods based on the variability of the ranking of the evaluated objects in different methods. The calculation process is as follows:

$$R_{\mathrm{TDT}}=\sum\nolimits_{a=1}^{A}|R_k-R_a|(k=1,2,\cdots,A,k\neq a), \tag{31}$$

where, R_k denotes the ranking of the evaluated object in the evaluation method k; R_a indicates the ranking of the evaluation object in other evaluation methods besides evaluation method k; A indicates the total number of evaluation methods; R_{TDT} indicates the difference in the ranking of the evaluated object in different evaluation methods, and a smaller R_{TDT} value indicates a more stable ranking of the evaluated object.

4 Case study

4.1 Data collection

The paper uses Topchains as a case study. An electronic questionnaire was distributed to the staff of its transportation outsourcing department, and each staff member evaluated and completed the questionnaire for each of the five service providers selected by the company. The five service providers are: Dingheng Logistics in Shenzhen, Xinzhong Logistics in Xiamen, Yunqian Logistics in Shanghai, Juzi logistics in Shenzhen, Chelian logistics in Shenzhen (recorded as service provider a, service provider b, service provider c, service provider d, service provider e, respectively)。

The questionnaire collection work lasted for 2 months. 128 electronic questionnaires were collected, and after carefully checking the information of the completed questionnaires, 23 invalid questionnaires with unreasonable answer logic and failed polygraph questions were deleted, and 105 valid questionnaires were obtained, with a total effective rate of 82.03%.

4.2 Model solving

In the following, five transportation outsourcing service providers are evaluated and selected, and the validity of the service provider selection model is verified based on the total rank difference test. According to the above weight and evaluation model calculation formula, python is used to solve the problem. The calculation results are as follows:

(1) Determine the index weight. Using the Eqs. (1) to (2) to determine the index weight, the results are shown in table 3.

Table 3 Weighting of evaluation indexes based on entropy weighting method.

Index	Weighting(p)	Index	Weighting(p)	Index	Weighting(p)
A_{11}	0.030 3	A_{41}	0.030 2	A_{73}	0.030 4
A_{12}	0.030 4	A_{42}	0.028 7	A_{81}	0.030 3
A_{13}	0.030 4	A_{43}	0.030 4	A_{82}	0.030 4
A_{14}	0.030 4	A_{44}	0.03	A_{83}	0.030 4
A_{21}	0.030 4	A_{51}	0.030 3	A_{91}	0.030 4
A_{22}	0.030 4	A_{52}	0.030 4	A_{92}	0.030 4
A_{23}	0.030 4	A_{53}	0.030 4	A_{93}	0.030 4
A_{24}	0.030 4	A_{61}	0.030 4	A_{94}	0.030 4
A_{31}	0.030 4	A_{62}	0.030 1	A_{101}	0.030 4
A_{32}	0.030 4	A_{71}	0.030 4	A_{102}	0.030 3
A_{33}	0.030 4	A_{72}	0.030 4	A_{103}	0.030 3

(2) Evaluation results of AHP. Eqs. (3)−(7) were applied to rank the selection of transportation outsourcing service providers, and the results are shown in Table 4.

Table 4 Ranking results of service provider selection based on AHP.

Characteristic parameter		Service Provider	Overall score	Ranking results
$\lambda_{\max}$	5.000 3	a	0.207 4	2
I_{C}	0.000 065 6	b	0.197 7	3
I_{R}	0.119	c	0.207 6	1
R_{C}	0.000 552	d	0.190 8	5
Conclusion: CR<0.1, passed the consistency test.		e	0.196 5	4

(3) The evaluation results of TOPSIS. Eqs. (8)−(14) were applied to rank the selection of transportation outsourcing service providers, and the results are shown in Table 5.

(4) The evaluation results of FCE. Eqs. (15)−(21) were applied to rank the selection of transportation outsourcing service providers, and the results are shown in Table 6.

Table 5 Ranking results of service provider selection based on TOPSIS.

Service Provider	Positive ideal solution	Negative ideal solution	Overall Score Index	Ranking results
a	0.057 567	0.053 355	0.481 010	3
b	0.049 585	0.064 616	0.565 807	1
c	0.048 782	0.056 175	0.535 218	2
d	0.079 543	0.022 452	0.220 127	5
e	0.069 912	0.031 360	0.309 659	4

Table 6 Ranking results of service provider selection based on FCE.

Service Provider	Grade V	Grade IV	Grade III	Grade II	Grade I	Overall Results	Ranking results
a	0.008 3	0.028 2	0.088 9	0.447 9	0.426 7	4.256 4	2
b	0	0.037 5	0.155 7	0.516 8	0.290 1	4.059 5	3
c	0.004 1	0.025 5	0.104 7	0.436 3	0.429 4	4.261 5	1
d	0.020 9	0.032 8	0.220 8	0.459 5	0.266 1	3.917	5
e	0.009 8	0.028 1	0.175 6	0.490 1	0.296 5	4.035 4	4

(5) The evaluation results of the fuzzy-TOPSIS. Eqs. (22)−(30) were applied to rank the selection of transportation outsourcing service providers, and the results are shown in Table 7.

Table 7 Ranking results of service provider selection based on Fuzzy-TOPSIS.

Service Provider	Positive distance	Negative distance	Close degree	Ranking results
a	0.225 9	0.341 8	0.602 1	1
b	0.349 7	0.201 4	0.365 5	5
c	0.263 3	0.317 2	0.546 5	2
d	0.392 4	0.328 8	0.455 9	4
e	0.358 7	0.325 3	0.475 6	3

(6) The total rank difference test was used to conduct a comparative analysis of the above four evaluation methods. The ranking results of the above four methods were analyzed and compared, and the evaluation results were selected by applying Eq. (31), and the comparison results are shown in Fig. 1, and the test results are shown in Table 8.

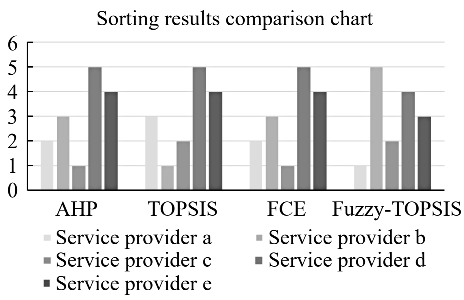

Fig. 1 Comparison of sorting results.

Table 8 Total rank difference test results.

Sorting Methods	AHP	TOPSIS	FCE	Fuzzy-TOPSIS
Test results	10	16	10	20

4.3 Results

(1) Evaluation index analysis

It can be seen from Table 3 that the weight of the scale of self-owned special vehicles is low (p = 0.028 7), indicating that the scale of self-owned special vehicles of service providers is not the main factor affecting the choice of outsourcing logistics enterprises. This should be Topchains own refrigerated trucks, flatbed trucks and air cushion shock absorbers and other special vehicles have basically met the company's special transportation needs.

In addition, the weights of other indicators are similar ($0.03 < p < 0.030\,4$), indicating that the importance of other indicators to the evaluation results of service providers is basically the same. Among them, the secondary index weights of necessary service、emergency response and emergency handling capacity and collaboration competenceare higher, all of which are 0.030 4, indicating that Topchainshas higher requirements for service providers to carry out effective emergency response, provide convenient transportation services and smoothly cooperate.

At the same time, the safe management level and cargo damage compensation level added to the index system are also the key factors affecting the evaluation results of service providers. Among them, safe management level is the basic condition for service providers to carry out production activities safely, and cargo damage compensation level is the basic condition for service providers to protect the rights and interests of logistics enterprises. These two indicators are important basis for reflecting the completeness of service providers ' management system and economic system. The weight of its secondary indicators is large, which is 0.030 4, indicating that Dingchen Logistics not only has high requirements for service providers to carry out effective safety management and provide perfect compensation services, but also attaches great importance to the institutional completeness of service providers.

(2) Evaluation result analysis

As shown in Table 4 and Table 6, the results of ranking service providers by hierarchical analysis and fuzzy comprehensive evaluation method are the same, which are Yunqian Logistics in Shanghai, Dingheng Logistics in Shenzhen, Xinzhong Logistics in Xiamen, Chelian logistics in Shenzhen, and Juzi logistics in Shenzhen in that order.

From Table 5 and Table 7, it can be seen that the service provider ranking results of TOPSIS method and fuzzy TOPSIS method are different, but the relative ranking results for Yunqian Logistics in Shanghai are consistent. The reason is that the fuzzy TOPSIS method integrates the evaluator's selection tendency and the actual level of service providers, resulting in the results being subjectively influenced, which reduces the accuracy and reliability of the results.

From Fig. 1, it can be seen that the relative ranking of Yunqian Logistics in Shanghai, Dingheng Logistics in Shenzhen, and Xinzhong Logistics in Xiamen by hierarchical analysis and fuzzy comprehensive evaluation method is not the same as TOPSIS method, mainly due to the existence of evaluation principles differences. Both the hierarchical analysis method and the fuzzy comprehensive evaluation method rank service providers based on their absolute evaluation, while TOPSIS ranks service providers based on their relative evaluation.

As can be seen from Table 8, the evaluation model based on the fuzzy comprehensive evaluation method and the evaluation model based on the AHP have the highest consistency and are identical, and the total rank difference test is ten. The two models validate each other, indicating that the results of these two models are more reliable and these two models are more applicable.

5 Conclusion

(1) This paper integrates two essential indicators—cargo damage compensation and safety management—into the evaluation index framework, thereby encapsulating the completeness of the enterprise's production management system. It constructs a comprehensive evaluation index system for transportation outsourcing service providers within third-party logistics enterprises, comprising a suite of 10 primary and 33 secondary indicators that encompass cooperation, transportation, safety, and compensation dimensions. By utilizing the entropy weight method to ascertain the weights of these evaluation indexes, the study effectively reduces the influence of subjective factors, thereby enhancing the objectivity and persuasive power of the evaluation system.

(2) The study established an evaluation model for transportation

outsourcing service providers associated with third-party logistics enterprises, utilizing the Total Rank Difference Test (TRDT). The validity of the evaluation outcomes was confirmed by comparing the ranking results across four different evaluation models, thereby offering a scientific reference for third-party logistics enterprises to select suitable transportation outsourcing service providers.

(3) The research indicates that the evaluation model based on the Fuzzy Comprehensive Evaluation method and the model grounded in the Analytic Hierarchy Process (AHP) corroborate each other, with both producing dependable results. Shanghai's Yunqian Logistics is deemed the superior choice, followed by Shenzhen's Dingheng Logistics and Xiamen's Xinzhong Logistics as the second-best options. Shenzhen's Chelian Logistics and Juzi Logistics are recommended as viable alternative providers for transportation outsourcing services.

(4) Future research could benefit from expanding the case and sample size datasets to optimize the existing set of indicators. Consideration might be given to incorporating additional factors such as external market potential, carbon emissions, and compatibility. Furthermore, exploring the integration of evaluation model selection with dynamic, time-sensitive analysis represents a valuable and promising research direction.

Declaration of competing interest

The authors have no competing interests to declare that are relevant to the content of this article.

Data Availability Statement

Some or all Data, models, or code that support the findings of available from the corresponding author upon reasonable request.

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