Neural Computing and Applications (2021) 33:739–754
https://doi.org/10.1007/s00521-020-05099-9

S.I. : DPTA CONFERENCE 2019

Performance evaluation of manufacturing collaborative logistics based on BP neural network and rough set

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Received: 5 March 2020 / Accepted: 4 June 2020 / Published online: 19 June 2020

Abstract
The collaborative logistics in manufacturing industry has a greater impact on its operation effect, and there are many hidden factors. In order to improve the performance evaluation of manufacturing collaborative logistics, this study builds a combined performance evaluation model based on BP neural network and rough set. Moreover, this study uses the rough set attribute reduction theory to screen and optimize the evaluation indicators to obtain the key performance indicator set, and then uses BP neural network to predict and evaluate the key performance indicator data, which greatly reduces the number of training times and shortens the learning time. In addition, in this study, a case analysis was used to solve the performance evaluation model of manufacturing collaborative logistics based on rough set and BP neural network, and corresponding strategies were given. The research results show that the method proposed in this paper has certain effects.

Keywords BP neural network · Rough set · Manufacturing · Collaborative logistics · Performance evaluation

1 Introduction

The logistics industry is getting more and more attention from the state and the government, and the logistics industry has become an important part of the national economy. Moreover, the focus will be on reducing logistics costs, strengthening the construction of logistics infrastructure networks, and strengthening logistics standardization. At the same time, it is clearly stated that e-commerce logistics engineering is one of the twelve key projects for the long-term development of the logistics industry. This indicates that the development of China's logistics industry has entered a new stage, and quality and efficiency have become the focus. In addition, various ministries and commissions have issued a series of guidelines and development policies for the development of the logistics industry, which have greatly promoted the development of China's logistics industry.

With the rapid development of China's economy and the improvement in residents' consumption level, the total consumption of industrial products in our country has been increasing, and the supporting logistics has gradually received people's attention. However, the level of development of China's industrial products is still in its infancy, and the loss rate of China's manufacturing industry in production, transportation, storage and other logistics links is about 25–30%, with an annual loss of 300 billion yuan. In contrast, the loss rate in developed countries is controlled below 5%. It can be seen that the improvement in logistics quality is not only an important indicator of the country's comprehensive strength, but also the key to improving the quality and safety of industrial products, avoiding waste of resources, and enhancing the international competitiveness of our industrial products [1].

In recent years, the consumption of industrial products has been increasing. In order to promote the circulation of industrial products, relevant departments have issued a number of favorable policies for industrial product logistics. Meanwhile, we must actively create a good environment for logistics development, and we need to take the market as the guide, the enterprise as the main body, and the advanced logistics technology as the support to strengthen government guidance and policy support. In addition, we need scientific planning, unified layout, and accelerate promotion and application of logistics concepts,

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technologies, standards, and equipment [2]. In recent years, various cities have actively developed industrial product logistics based on policy content. The levels of infrastructure, transportation conditions, and logistics technology have risen by one level, but there is currently no good measurement method for specific implementation effects [3].

In order to confirm the implementation effect of the policy and provide a reference for the next industrial product logistics planning, relevant departments hope to have a special subject to study the effect of policy implementation. Based on this, this article conducts special research on industrial product logistics and focuses on performance evaluation of logistics. Based on the selection of appropriate logistics indicators, a basic logistics performance evaluation system is constructed, policy implementation performance is quantitatively measured, and comprehensive improvement suggestions are proposed based on the analysis results to provide a reference for the high-quality development of logistics.

The performance analysis of logistics includes the performance of logistics itself and the performance of industrial product logistics to promote regional economic development. Due to the relationship between time and data collection, the performance referred to in this article refers to the performance of the flow itself, and it refers to the analysis of the logistics operation after the implementation of the policy. At the same time, the performance evaluation of logistics in this article mainly refers to the evaluation of the relative efficiency between logistics performance and the relative comparison of development levels.

The purpose of this research is to comprehensively evaluate the coordination performance of the supply chain, that is, to give an evaluation result of the effectiveness of the coordination of the supply chain, and further study the evaluation methods to provide a certain guiding significance for the evaluation of the coordination performance of the supply chain: by reviewing the relevant literature, starting from the factors affecting the coordination of the supply chain, constructing an evaluation index system based on the principles of evaluation index construction, using multiple evaluation methods to evaluate, giving a comprehensive evaluation result of the supply chain coordination performance, and comparing the various methods.

2 Related work

Foreign research on logistics performance evaluation mainly includes the construction and improvement in logistics performance evaluation system and the selection of indicators of logistics performance evaluation system. Beker [4] established the third-party logistics performance evaluation from the perspective of marketing based on the management activities that affect the performance of logistics outsourcing relationships. Dittes [5] developed a model that describes the supply chain elasticity of the supply chain to predict the ability of the supply chain to respond to supply disruptions, cost increases, and demand changes, and to quantify the probability of a bullwhip effect. Jia [6] focused on the ultimate purpose of refrigerated transport systems and explained the specific work of modeling food temperature, microbial growth, and other parameters during food transport. Edirisinghe [7] proposed a strategy using balanced scorecards and analysis network processes (ANP) to describe the type of organization of a logistics center and established a framework for measuring the performance of logistics centers. Alvarado [8] established a benchmark framework for the company's cold chain performance. The method based on Delphi–AHP–TOPSIS divides the entire benchmark into three stages, which helps decision makers better understand the complex relationship of related cold chain performance factors in decision-making, and used the delay strategy to evaluate the performance of logistics and ecological supply chain, and found that the delay strategy of logistics and packaging can improve the logistics performance at the same time, and help reduce the impact of carbon dioxide emissions on the environment during transportation. Rahim [9] used logistics performance index (LPI) and carbon dioxide emissions to evaluate the efficiency between transportation and logistics performance, and used DEA to build a low-carbon logistics performance system. Lee [10] customized a multi-criteria evaluation framework to evaluate the performance of the Thessaloniki intermodal city logistics terminal using a multi-stakeholder comparison planning method of pairwise comparison.

Tuan [11] took the tomato supply chain from the Netherlands to Germany as the object and selected four categories of performance measurement standards of efficiency, flexibility, responsiveness, and food quality to build a conceptual model of supply chain performance. Qi [12] believed that in addition to relevant microbiological analysis, food safety performance in the agricultural food chain should also be evaluated, and showed that nine food companies in Europe have developed and verified food safety performance systems based on seven indicators and corresponding evaluation grids. Khan [13] used customer satisfaction, customer value added (CVA), total cost analysis, profitability analysis, strategic profit model, and shareholder value to measure and sell the value provided to customers, and analyzed the value these standards bring to shareholders, customers, and suppliers. Chew [14] found that the main factors for evaluating the performance of reverse logistics are environmental legislation, technology, cost, and external relations, and the small shoe industry in Brazil's Ceara State was used as the evaluation object to evaluate the priority of the reverse logistics indicators. Mamun [15] combined the balanced scorecard model and non-financial performance indicators to form a set of multi-criteria decision models and implemented an analysis network process (ANP) method to analyze the correlation of the indicators.

From the perspective of green cold chain logistics, Zhu [16] constructed a performance evaluation model for cold chain logistics of agricultural products in Hunan Province based on FAHP. Ullah [17] built a fresh e-commerce cold chain logistics performance evaluation index system, constructed a network structure evaluation model based on the network analytic method, and combined the fuzzy comprehensive evaluation method to conduct performance evaluation of e-commerce cold chain logistics. Arredondohidalgo [18] used the FAHP model to evaluate the performance of Xinjiang's agricultural cold chain logistics system, analyzed the development of Xinjiang's agricultural cold chain logistics, and made corresponding suggestions based on the results.

Michelberger [19] established the quality safety, cost, efficiency, and social benefit goals of aquatic product cold chain transportation, determined the index weights using AHP and entropy method, and established the performance evaluation index model of aquatic product cold chain transportation. The results reflect the demands of system participants and the operating conditions of the company's cold chain transportation. Jie [20] designed a customer service performance evaluation model of fresh-chain e-commerce cold chain logistics based on a service quality perception model and conducted an empirical analysis using the AHP–entropy weight method to prove the effectiveness of the model.

From the perspective of the green supply chain, Zhonggao [21] based on the input index, output index, and environmental variables using fuzzy comprehensive evaluation to analyze the output index's expected specific index weights and constructed a three-stage DEA model for the performance evaluation of cold chain logistics enterprises. Taking the green supply chain as the landing point, the input–output index and the environmental impact index are selected to construct a three-stage DEA evaluation model based on the fuzzy comprehensive evaluation method. Combining previous studies, Octavia [22] selected input and output indicators from the internal and external environment, economic benefits, and risk assessment to provide a comprehensive index reference for agricultural cold chain logistics. Jianxiang [23] selected input and output indicators corresponding to Henan agricultural cold chain logistics and used DEA to evaluate the performance of Henan agricultural cold chain logistics, considering pure technical efficiency, scale efficiency, and scale returns from multiple perspectives.

Considering the three aspects of economic performance, cold chain logistics operations, and customer service satisfaction, Naseem [24] proposed the performance evaluation index system of food cold chain logistics enterprises based on matter-element method, which is used to evaluate the performance position of food cold chain enterprises in the entire industry. Based on the fuzzy matter-element model, Wen cm in Lu [25] evaluated the performance of agricultural cold chain logistics enterprises and solved the problems of large number of indicators and strong evaluation uncertainty in the existing performance indicator evaluation system. Moreover, she believed that the entropy weight method can continue to be used to improve the evaluation system and make the evaluation model more widely used.

This article analyzes the problems in supply chain coordination, research on supply chain coordination performance, and the main factors affecting relationship coordination, and preliminarily builds a supply chain coordination performance evaluation system based on the principles and methods of evaluation system construction. Secondly, this paper uses empirical analysis method to analyze and verify the supply chain coordination performance evaluation system constructed by questionnaire data analysis and finally determines the supply chain coordination performance evaluation system. Finally, according to the characteristics of each evaluation index, the measurement method of each index is given.

3 Evaluation method of supply chain coordination performance based on fuzzy evaluation

3.1 Determining the weights of supply chain coordination performance evaluation index based on AHP

The determination of indicator weights is the core issue of supply chain coordination performance evaluation. It can be divided into three methods: the weighting method based on the "function-driven" principle, the weighting method based on the "difference-driven" principle, and the comprehensive integration weighting method. The index weight determination method based on the "function-driven" principle is a method by which the evaluation subject determines the index's weight coefficient based on the relative importance of the evaluation index through objective or subjective means. However, in the operation of the system, it is affected by the environment or the subjective desires of the evaluators and presents different characteristics, which makes the determination of the index weights more difficult. Therefore, the index weight coefficients are mainly determined by subjective means. Analytic hierarchy process (AHP) combines quantitative and qualitative methods, is simple and practical, and requires less quantitative data, so it is widely used. Due to the complex and changeable characteristics of the supply chain coordination system, this paper uses the analytic hierarchy process to determine the weight coefficient of the supply chain coordination performance index.

The selection of supply chain coordination performance evaluation indicators is the basis of supply chain coordination performance evaluation. According to the characteristics of supply chain coordination, 18 indicators are selected to build a supply chain coordination performance evaluation system. They are: increase rate of average inventory turnover, average safety stock reduction rate, average on-time delivery rate, average inventory pass rate, timely settlement rate of payment, frequency of information communication, timeliness rate of information transmission, accuracy rate of information transmission, flexible supply quantity, flexible supply time, flexible supply variety, feedback problem processing speed, feedback problem resolution rate, benefit sharing mechanism rationality, cooperative relationship satisfaction, length of cooperation, collaborative decision-making and planning of supply chain members, and corporate credibility. In addition, the measurement method of each index is given.

The analytic hierarchy Process (AHP) was proposed by US operations researcher TLSatty (1990) for the US Department of Defense in the 1970s to study the issue of "allocation according to the size of national contributions of various ministries of industry," which is a multi-attribute decision-making method combining qualitative analysis and quantitative analysis. The analytic hierarchy process is to form an orderly hierarchical structure through the factors that affect the system and the relationships between the factors, and then divide these factors into different levels, and establish a judgment matrix by comparing the importance of the factors within each level, and obtain the relative weights of the factors at each level. Finally, the comprehensive weight of each factor relative to the overall target is obtained according to the relative weight, which provides a basis for the evaluation subject or decision maker.

The main process of analytic hierarchy process is as follows:

1. The hierarchical structure model is established. That is, the indicators are layered according to different attributes according to actual problems, so that indicators of the same level belong to the indicators of the previous layer and dominate the indicators of the next layer. According to the actual situation of the research questions, this article divides them into the following three categories:

Target layer The evaluation system is the supply chain coordination performance.

Criterion layer It is a decomposition of the goals, that is, logistics coordination performance, information flow coordination performance, capital flow coordination performance, workflow coordination performance, and coordinated development capabilities.

Indicator layer It is a specific indicator that measures each criterion layer.

2. The pairwise comparison matrices are constructed

According to the hierarchical structure model established in the first step, the judgment degree A is obtained by comparing and judging the importance of the indicators at each level with respect to the upper-layer indicators (according to the scale shown in Table 1).

$$A = \begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{pmatrix} \tag{1}$$

In the matrix, a_{ij} represents the ratio of the importance of index i to index j.

3. The eigenvalues and eigenvectors of the judgment matrix are solved, and the judgment is further checked for consistency. The eigenvector solution process is as follows:

After the elements of each column of the judgment matrix are normalized, the following result can be obtained:

$$\overline{a_{ij}} = \frac{a_{ij}}{\sum_{k=1}^{n} a_{kj}} (i,j = 1,2,3,\ldots,n) \tag{2}$$

After the normalized matrix is added by rows, the following result can be obtained:

$$\overline{\omega_i} = \sum_{k=1}^{n} \overline{a_{ij}} (k = 1,2,3,\ldots,n) \tag{3}$$

By normalizing the vector obtained in the previous step, a feature vector ω is obtained.

$$\omega_i = \frac{\overline{\omega_i}}{\sum_{j=1}^{n} \overline{\omega_j}} (i = 1,2,3,\ldots,n) \tag{4}$$

According to the judgment matrix A and the feature vector ω, the maximum feature root $\lambda_{\max}$ is calculated:

Table 1 Reference table for grading scale

Assignment	Description
1	Indicates that indicator A is of equal importance compared to B
3	Indicates that indicator A is slightly more important than indicator B compared to indicator B
5	Indicates that indicator A is significantly more important than indicator B compared to indicator B
7	Indicates that indicator A is more important than indicator B compared with indicator B
8	Index A is more important than Index B
2, 4, 6, 8	Correspond to the intermediate situation of the above two adjacent judgments
Reciprocal	If index A and index B are compared to judge aij, then index B and index A need to be judged to be 1/aij

$$\lambda_{\max} = \sum\nolimits_{i=1}^{n} \frac{(A\omega)_i}{n\omega_i} \tag{5}$$

Among them, $(A\omega)_i$ represents the ith element of the vector $A\omega$.

Consistency check process: The consistency index CI is calculated.

$$CI = \frac{\lambda_{\max} - n}{n-1} \tag{6}$$

The average random consistency index RI was selected. The results are shown in Table 2 for the average consistency index RI value.

The random consistency ratio (CR) is calculated.

$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}}$. When $\mathrm{CR} < 0.10$, the judgment matrix A is considered to have acceptable inconsistency; that is, the judgment matrix A has satisfactory consistency. Otherwise, it is considered that the initially established judgment matrix is unsatisfactory and needs to be re-assigned and gradually revised until the consistency test passes.

3.2 Evaluation model of supply chain coordination performance based on fuzzy evaluation

Fuzzy comprehensive evaluation refers to the method of making a comprehensive evaluation of the system by considering the influence of multiple factors on the evaluation system under uncertainty or fuzzy environment.

Table 2 RI value of average consistency index

n	RI
2	O
3	0.5149
4	0.8931
5	1.1185
6	1.2494
7	1.345
8	1.42
9	1.4616
10	1.4874

Fuzzy comprehensive evaluation model.

The factor set $U = \{u_1, u_2, u_3, \cdots, u_n\}$ represents the set of factors of the object being evaluated. In this article, it represents the set of the bottom-level indicators of the supply chain coordination performance evaluation. The judgment set $V = \{v_1, v_2, v_3, \cdots, v_m\}$ represents a set of reviews. This article uses five review levels: very bad, bad, general, good, and excellent, that is, $V = \{G_1, G_2, G_3, G_4, G_5\}$. The single-factor judgment is the judgment of a single factor $u_i\,(i = 1, 2, 3, \ldots, n)$. Get the fuzzy set on y $(r_{i1}, r_{i2}, \cdots, r_{im})$

$$\begin{aligned} &f: U \to F(V) \\ &u_i \mapsto (r_{i1}, r_{i2}, \ldots, r_{im}) \end{aligned} \tag{7}$$

Therefore, fuzzy mapping can determine a fuzzy relation matrix R, which is called a judgment matrix.

$$R = \begin{pmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{pmatrix} \tag{8}$$

R represents the set of memberships that factor u_i belongs to fuzzy set v_i. The calculation of the fuzzy relation matrix in this paper is determined one by one by the value of the factor and its membership function belonging to the fuzzy set v_i. The determination of the membership function can be determined according to the experimental method of fuzzy statistics. In this paper, the weight vector $\omega = (\omega_1, \omega_2, \omega_3, \cdots, \omega_n)$ is determined using the AHP method. Therefore, the fuzzy comprehensive evaluation model can be expressed as:

$$\begin{aligned} E = \omega \circ R = \omega \circ \begin{pmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{pmatrix} \\ = (e_1, e_2, \cdots, e_m) \end{aligned} \tag{9}$$

Among them, "∘" represents the fuzzy operator. This paper uses real number multiplication. Moreover, e_i represents the degree to which the comprehensive evaluation result belongs to the comment set v_i.

The fuzzy evaluation result E is a vector. In order to be able to compare the evaluation results of multiple systems, this paper uses the principle of maximum membership to process them. For example, when evaluating a system whose fuzzy evaluation result vector is $E = (0.37, 0.28, 0.42, 0.10, 0.2)$, the evaluation result can be determined to be G_3 according to the principle of maximum membership; that is, the comprehensive evaluation result of the system is average.

4 Evaluation method of supply chain coordination performance based on BP neural network

4.1 Evaluation model of supply chain coordination performance based on BP neural network

This paper uses BP neural network to evaluate the supply chain coordination performance, which is an approximation process of Boolean vectors using training samples. The supply chain coordination performance evaluation system based on BP neural network trains the network by solving the minimization problem of training samples to continuously modify the weights and thresholds of each layer of the network. After the network training is completed, that is, the network structure is stable and the weights are determined, the evaluation results can be given to the newly input data. At this time, when we enter the index value of the supply chain coordination performance at any time, the system will automatically give the corresponding evaluation result level.

This article divides the evaluation levels into five levels:

$$\{\text{very bad, difference, general, good, excellent}\} = \{G_1, G_2, G_3, G_4, G_5\}$$

It can be expressed as a vector as:

$$G_1 = (1,0,0,0,0), \quad G_2 = (0,1,0,0,0), \quad G_3 = (0,0,1,0,0), \quad G_4 = (0,0,0,1,0), \quad G_5 = (0,0,0,0,1)$$

The training samples of the neural network can be obtained based on the historical data of the enterprise or other evaluation methods. The process of performance evaluation of supply chain coordination based on BP neural network is shown in Fig. 1.

1. Determine the number of levels of the BP neural network. Kolmogorov has demonstrated that a three-layer BP neural network consisting of a hidden layer can approximate an arbitrary function with arbitrary precision. Therefore, this paper uses a three-layer BP neural network structure as the structure of the supply chain coordination performance evaluation system, where the transfer function is $y = \frac{1}{(1+\arctan(x))}$.
2. Determine the number of neurons in the input layer and the output layer of the BP neural network. The number of neurons in the input layer and output layer of the BP neural network is determined by the problem to be solved. The number of neurons in the input layer of the BP neural network corresponds to the number of supply chain coordination performance evaluation indicators. Because this article uses 18 evaluation indicators to measure the supply chain coordination performance, the number of neurons in the input layer of the BP neural network is 18. The number of neurons in the output layer of the BP neural network corresponds to the level of the supply chain coordination performance evaluation results. As mentioned in the previous article, this article uses five levels as the results of supply chain coordination performance evaluation: When the expected output is $G_1 = (1,0,0,0,0)$, it means that the supply chain

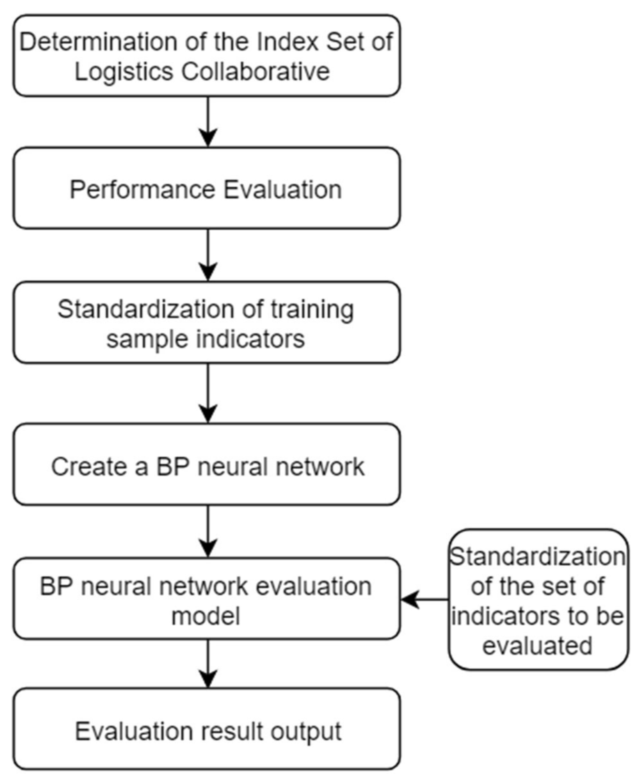

Fig. 1 Performance evaluation process of supply chain coordination based on BP neural network

coordination performance level is "very bad." When the expected output is $G_2 = (0, 1, 0, 0, 0)$, it means that the supply chain coordination performance level is " bad." When the expected output is $G_3 = (0, 0, 1, 0, 0)$, it means that the supply chain coordination performance level is " general." When the expected output is $G_4 = (0, 0, 0, 1, 0)$, it means that the supply chain coordination performance level is " good." When the expected output is $G_5 = (0, 0, 0, 0, 1)$, it means that the supply chain coordination performance level is " excellent."

3. Determine the number of hidden layer neurons in the BP neural network. The essence of using BP neural network to evaluate the coordination performance of supply chain in this paper is to approximate a function with a three-layer BP neural network, and the number of hidden neurons in the BP neural network affects the accuracy of the function to be approximated and the function itself. If the number of hidden layer neurons is too small, the learning error of the BP neural network is large; that is, the obtained neural network is unstable. If there are too many neurons in the hidden layer, overfitting will occur, and the generalized ability of the obtained neural network is relatively weak. There is no uniform method for determining the number of hidden layer neural networks, so it is mainly determined through experience. $k = \sqrt{n + m} + a$. In the formula, k represents the number of neurons in the hidden layer of the BP neural network, n represents the number of neurons in the input layer, m represents the number of neurons in the output layer, and a represents a constant in $[0, 1]$. In this paper, the number of hidden neurons in the BP neural network is determined to be 10 based on the formula and running the program several times.

The essence of the BP algorithm is to solve the problem of minimizing the error function. It uses the steepest descent method in the nonlinearity, that is, to modify the weights according to the negative gradient direction of the error function, and it has the disadvantages of low learning efficiency and easy fall into local optimum. In order to reduce these errors, there are many improved methods of BP neural networks such as quasi-Newton method, conjugate gradient method, gradient descent method, and gradient descent method with momentum factor.本In this paper, the gradient descent method with momentum factor is used to train the BP neural network. The algorithm flow of the BP neural network is shown in Fig. 2.

The BP neural network algorithm is as follows:

We assume that (P, T) is the training sample pair. Among them, P represents the input vector of the BP neural network input layer, T represents the expected output vector of the BP neural network output layer, η represents the learning factor, α represents the momentum factor, n_{in} represents the number of neurons in the input layer, n_h represents the number of neurons in the hidden layer, n_{out} represents the number of neurons in the output layer,x_{ij} represents the input from the input layer neuron i to the hidden layer neuron j, ω_{ij} represents the connection weight from the input layer neuron i to the hidden layer neuron j, v_{jk} represents the connection weight from hidden layer neuron j to output layer neuron k, and θ_i represents the threshold of neuron i.

S1 A BP neural network with n_{in} input layer neurons, n_h hidden layer neurons, and n_{out} output layer neurons was created.

S2 All BP neural network connection weights and thresholds are initialized. Generally, a smaller random number is used for initialization.

S3 Any set of data in the training sample is taken as an example to perform the following process. The output of

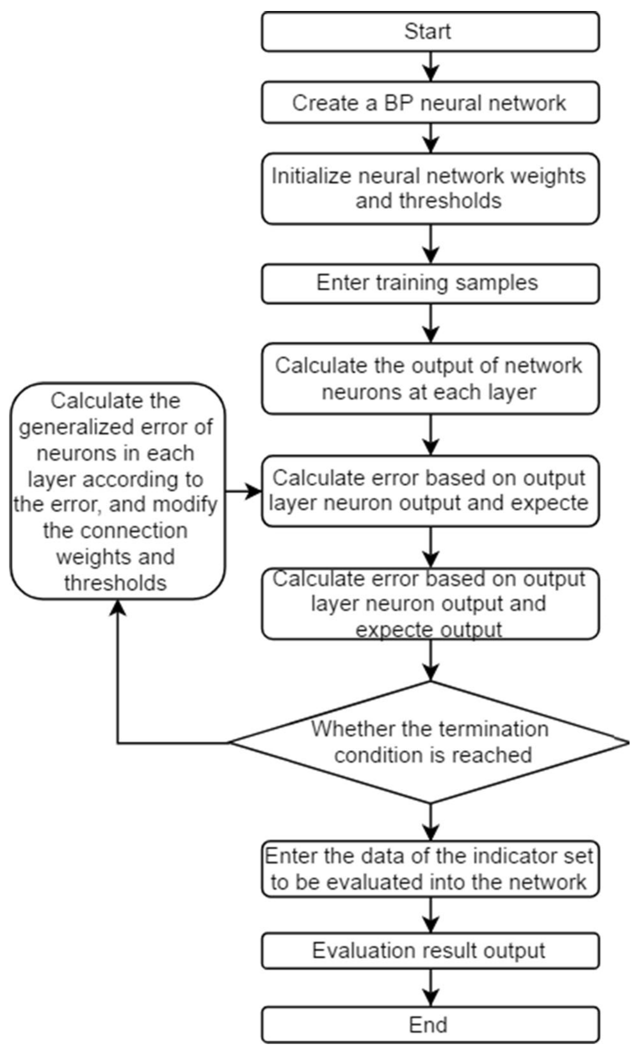

Fig. 2 BP neural network algorithm flowchart

the output layer neuron y_k, $y_k = f\left(\sum v_{jk} O_j + \theta_k\right)$, is calculated. Among them, O_j represents the output of the hidden layer, that is, $O_j = f\left(\sum \omega_{ij} x_i + \theta_j\right)$, and $f(\cdot)$ represents the transfer function. This article uses the Tansig function, that is, $f(\cdot) = \frac{1}{(1+\arctan(x))}$.

S4 The generalized error or local gradient $\delta_k = (y_k - T_k) y_k (1 - y_k)$ of the output layer neuron k is calculated.

S5 The generalized errors or local gradients $\delta_j = O_j\left(1 - O_j\right) \sum_{k=1}^{n_{\text{out}}} \delta_k v_{jk}$ of hidden layer neurons are calculated. Among them, δ_k represents a generalized error of the output layer neuron k.

S6 According to the generalized error δ_k of the output layer and the output O_j of each neuron in the hidden layer, the connection weight v_{jk} and the threshold θ_k are modified.

$$v_{jk}(n+1) = \alpha v_{jk}(n) + \eta \delta_k O_j \tag{10}$$

$$\theta_k(n+1) = \alpha \theta_k(n) + \eta \delta_k \tag{11}$$

S7 According to the generalization error δ_j of the hidden layer and the input of each neuron in the input layer, the connection weight ω_{ij} and the threshold θ_j are modified.

$$\omega_{ij}(n+1) = \alpha \omega_{ij}(n) + \eta \delta_j P_i \tag{12}$$

$$\theta_j(n+1) = \alpha \theta_j(n) + \eta \delta_j \tag{13}$$

In the formula, k represents the input of the neuron i in the input layer.

S8 S3 to S7 are repeated until the termination condition is satisfied. Generally, the maximum number of iterations and the minimum allowable error are set as the program termination conditions.

S9 The data of the set of indicators to be evaluated are input into the trained network, and the network automatically outputs the evaluation results.

5 Performance evaluation model based on BP neural network

The BP neural network can reduce the difference between the expected output and the actual output through repeated iterative processing to achieve a good fitting effect. The performance evaluation index system for the integrated operation of industrial product supply chains contains multiple qualitative and quantitative indicators. For quantitative indicators, because there are different dimensions such as number, hours, and percentages, and there are also large differences in order of magnitude, and BP neural network has requirements on the input data and requires the order of magnitude of the data in each dimension in the network to avoid prediction distortion, the input data must be normalized. After normalizing the existing historical evaluation indicators and result data, the training is input to the input layer of the BP neural network. When the error between the output value and the expected value is within the acceptable range, the BP neural network training is mature. Then, the test samples can be input into the trained BP neural network for prediction. After that, the prediction evaluation result is output and the result analysis is obtained.

The data normalization method can convert all the data that needs to be input into numbers in the $(-1, 1)$ interval, and weaken the difference of the order of magnitude, and avoid the phenomenon of prediction distortion caused by the order of difference.

For qualitative indicators, the qualitative indicators can be quantified according to the hexadecimal scoring method. If the indicator is considered to be excellent, it is scored 5 point; if the indicator is considered to be good, it is scored 4 point; if the indicator is considered to be general, it is scored 3 point; if the indicator is considered to be bad, it is scored 2 point; and if the indicator is considered to be very bad, it is scored 1 point. Then, it is normalized.

The data normalization processing formula for quantitative indicators is:

$$x_i^* = (x_i - x_{\min})/(x_{\max} - x_{\min}) \tag{14}$$

In the formula, $x_{\min}$ is the minimum number in the input data sequence, and $x_{\max}$ is the maximum number in the input data sequence. After the data are normalized, the BP neural network model can be trained.

When designing the evaluation model of BP neural network, we must first design the network structure. In this part, we first need to determine the network structure level and then determine the number of neurons contained in each level.

1. Determine the network structure level

This paper uses a single-hidden-layer neural network structure, which includes an input layer, a hidden layer and an output layer.

2. Determine input and output layer neurons

The number of neurons in each layer of the BP neural network is determined by the service evaluation subject. In this paper, BP neural network is used for performance evaluation learning prediction, so the number of input neurons is the number of evaluation indicators in the index system, and the number of output neurons is the grade coefficient of performance evaluation:

$$V = \{1: \text{ Very poor, 2: Poor; 3: Medium, 4: Good, 5: Very good}\}$$

Therefore, there is only one neuron output.

3. Determine hidden layer neurons

In practical applications, trial-and-error methods, network structure growth methods, or formulas are often used to determine the best values of neurons in the hidden layers of neural networks.

The calculation formula often used to find the optimal number of hidden layer neurons is:

$$K < \sum_{i=0}^{n} C_h^i orh = (n+m)^{0.5} + a \tag{15}$$

In the formula, K is the number of samples, n is the number of neurons in the input layer, m is the number of neurons in the output layer, h is the number of neurons in the hidden layer, and a is a constant between 1 and 10.

The general process of BP algorithm performing neural network training is as follows:

(1) *Initialization* Set output layer connection weight v_{jt} and threshold r_t, hidden layer connection weight ω_{ij} and threshold θ_j;

(2) *The training set of BP network is provided* According to the training order, the input set and output set of the training set are given;

(3) *The Algorithm enters the cycle* The output and output values of the network are calculated. The input s_j^k and output b_j^k of each node in the hidden layer, and the input l_t^k and output c_t^k of each node in the output layer are:

$$s_j^k = \sum_{i=1}^{n} a_i^k \omega_{ij} - \theta_j, b_j^k = \left(1 + e^{-s_j^k}\right)^{-1}, \quad j = 1, 2, \ldots, p \tag{16}$$

$$l_t^k = \sum_{j=1}^{p} b_j^k v_{jt}, c_t^k = \left(1 + e^{-l_t^k}\right)^{-1}, \quad t = 1, 2, \ldots, q \tag{17}$$

(4) *Error Back Propagation* In this part, according to the principle of gradient descent, the connection layers and thresholds of each layer are adjusted to calculate the mean square error E_k of the deviation between the expected output of the network and the calculated output, the error d_t^k of each node of the output layer, and the error h_j^k of each node of the hidden layer. The formula is, respectively:

$$E_k = \sum_{t=1}^{q} \frac{\left(y_t^k - c_t^k\right)^2}{2} \tag{18}$$

$$d_c^k = \left(y_t^k - c_t^k\right) c_t^k \left(1 - c_t^k\right), t = 1, 2, \cdots, q \tag{19}$$

$$h_j^k = \left[\sum_{t=1}^{q} d_j^k v_{jt}\right] b_j^k \left(1 - b_j^k\right), j = 1, 2, \cdots, q \tag{20}$$

(5) *The weights and thresholds is corrected* In this part, the output layer connection weight v_{jt} and threshold r_t and the hidden layer connection weight ω_{ij} and threshold θ_j are continuously modified by the error d_j^k of each node in the output layer and the error h_j^k of each node in the hidden layer. The formula is, respectively:

$$v_{jt}(N+1) = v_{jt}(N) + \alpha d_t^k b_j \tag{21}$$

$$r_t(N+1) = r_t(N) - \alpha d_t^k \tag{22}$$

$$\omega_{ij}(N+1) = \omega_{ij}(N) + \beta h_j^k a_i^k \tag{23}$$

$$\theta_j(N+1) = \theta_j(N) - \beta h_j^k \tag{24}$$

(6) If the global network error is less than the specified value, the algorithm proceeds to step (7); otherwise, the algorithm proceeds to step (3);

(7) The output layer is calculated.

This thesis uses the neural network toolbox of MATLAB (the version used in this article is MATLAB R2019a) to implement the BP algorithm and mainly refers to the series of books on intelligent control and MATLAB implementation written by Guoyong Li. Transfer functions are a core part of neural networks. The MATLAB neural network toolbox actually writes a variety of typical neural network transfer functions in MATLAB language and turns the user's complicated programming and calculation of the required network into a free call to the required transfer function. The common multilayer neural network structure transfer functions include logsig, tanSig, hardlim, softmax, and purelin.

In this paper, the hidden layer transfer function selects logsig (N), which means that the output value of the hidden layer neurons is in the $(0, 1)$ interval. The output layer selects purelin (N), which means that the output value of the neuron is not limited. For the relevant parameters, the maximum number of learning iterations (the maximum number of steps) of the network can be set to 10,000, the target accuracy can be set to 0.0000000, and the learning efficiency can be set to 0.05. Because the single gradient descent method is liable to fall into a local minimum or fail to converge, this problem is solved by adding a momentum constant. The adjustment of network weights and thresholds in this paper is done by a traingdm method with momentum, and the momentum constant is set to 0.9.

6 Test analysis

On the one hand, the supply chain promotes the rapid development of enterprises, and at the same time, it puts forward new requirements for supply chain member companies, such as the need for each supply chain member company to share market demand and supply, product design and manufacturing information, and improve collaborative design and collaborative manufacturing ability. Due to the characteristics of multiple participants, multiple links, and decentralized decision-making in the supply chain, the external environment and adverse factors in the supply chain have increased the impact on the supply chain, making supply chain coordination more complex and changeable. Supply chain coordination is a way of effective cooperation between different entities (internal and external) in the supply chain system. Without coordination, the supply chain cannot achieve the effect of synchronous, fast, and timely response to market demand. For a long time, the theoretical community has conducted a lot of research on supply chain coordination issues and proposed various supply chain coordination strategies and technologies, but the research on the evaluation of the effects of supply chain coordination strategies and the evaluation methods of supply chain coordination performance is relatively less. The evaluation of supply chain coordination performance is an important part of supply chain coordination management. Only scientific and effective supply chain coordination performance evaluation can make supply chain coordination management more effective, promote supply chain coordination and orderly development, and improve the supply chain and overall operational efficiency.

The Bank's research takes Company A as an example for analysis. There are three data acquisition channels for the performance evaluation indicators of its collaborative logistics center. The second channel is to obtain the data of Company A's Zhejiang Provincial Transshipment Center through internal inspection of its Galaxy system. The third channel is data obtained by inquiring the managers of each transfer center (data such as actual floor area and actual investment amount). The weight value of each indicator obtained through calculation and analysis is shown in Table 3, and its statistical graph is shown in Fig. 3.

By calculating the standardized decision matrix, the positive ideal solution and the negative ideal solution are found from it. The weighted normalized decision matrix is calculated to select the positive and negative ideal solutions. The results are shown in Table 4 and Fig. 4.

The distances between the performance evaluation indicators of each transfer center and the positive and negative ideal solutions are calculated and standardized, as shown in Table 5 and Fig. 5.

According to the calculation steps of the PROMETHEE method, the positive and negative flows of each evaluation object are calculated and standardized, as shown in Table 6 and Fig. 6.

By combining the positive and negative distances and positive and negative flow values of the evaluation object with the positive and negative ideal solutions, the advantages and disadvantages of each evaluation object can be calculated. On this basis, calculate the difference between the two as the overall priority of each evaluation object, which is the performance evaluation result of Company A, as shown in Table 7 and Fig. 7.

According to Table 7 and Fig. 7, the ranking of the performance evaluation results of each transfer center is 4>7>2>1>3>6>5>8. The evaluation results horizontally indicate that the seven evaluation indicators of transfer time rate, complaint rate, number of lines, number of vehicles, actual investment amount, number of loading and unloading ports, and number of security accidents have a large impact on performance and largely determine the performance level of the transfer center. From a vertical perspective, it shows that Hangzhou's overall performance is the best, and operation center 8′s overall performance is the worst.

Table 3 Combination weights of performance indicators

Index	Weights
Actual investment	0.062
Actual area	0.045
Reasonable transfer site selection	0.036
Reasonable site selection	0.024
Number of vehicles	0.077
Number of lines	0.085
Number of operations staff	0.017
Number of handling equipments	0.025
Departure rate	0.036
On-time arrival rate	0.042
Transfer time	0.094
Complaint rate	0.071
Education level	0.016
Employee training times	0.03
Staff execution	0.014
Information system level	0.012
Network performance	0.013
Number of loading ports	0.054
Warehouse area	0.045
Lost rate	0.024
Damage rate	0.013
Number of security incidents	0.058
Logistics intensity	0.021
Average daily volume	0.044
Cost per ton-km	0.017
Cost rate	0.025

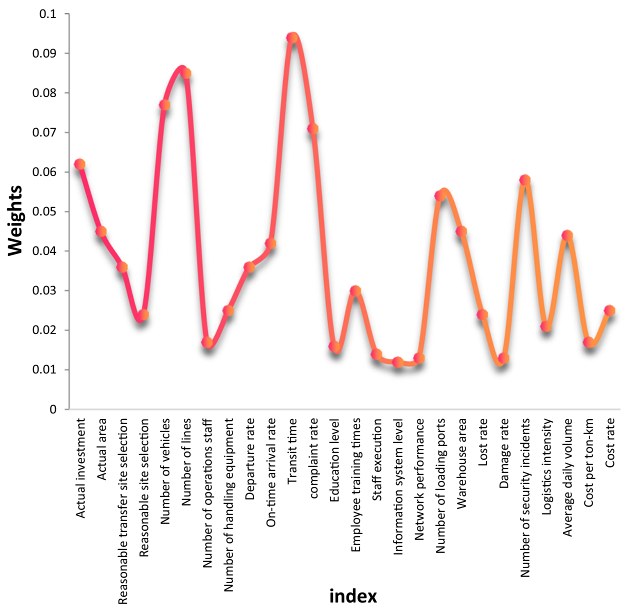

Fig. 3 Statistical chart of combined weights of performance indicators

At the same time, according to the performance evaluation results of the transfer centers in Zhejiang Province of Company A and the development strategy of each transfer center in Zhejiang Province of Company A, the development strategy of Company A is to determine 4 as a first-level transfer center. (Note: the first-level transfer center is the highest level, followed by the second-level transfer center, the third-level center, etc.) 7, 2, 1, and 3 are secondary transfer centers, and 6, 5, and 8 are tertiary transfer centers.

In summary, the ranking of the performance evaluation results of the transshipment centers in Zhejiang Province of A Company obtained through the performance evaluation index system and performance evaluation methods of A transfer companies in Zhejiang Province is highly consistent with the development strategy of A Company. At the same time, the performance evaluation results of the transshipment centers in Zhejiang Province of Company A were solicited by the management of the transshipment centers of Company A in Zhejiang Province. The results were also recognized, indicating that the performance index system and performance evaluation method of the logistics transshipment center proposed in this article are feasible. The parameters of 1–8 logistics operation centers are counted, and the results are shown in Fig. 8.

The overall performance result of operation center 1 is ranked four. The ranking of various indicators in the secondary indicator layer was analyzed in detail to explore its advantages and disadvantages. The results are shown in Fig. 9.

Table 4 Positive ideal solution and negative ideal solution

Index	Positive ideal solution	Negative ideal solution
1	0.062	0
2	0.045	0
3	0.036	0
4	0.024	0
5	0.016	0
6	0.03	0
7	0.014	0
8	0.012	0
9	0.013	0
10	0.077	0
11	0.085	0
12	0.017	0
13	0.025	0
14	0.054	0
15	0.045	0
16	0.036	0
17	0.042	0
18	0.094	0
19	0.071	0
20	0.024	0
21	0.013	0
22	0.058	0
23	0.021	0
24	0.044	0
25	0.017	0
26	0.025	0

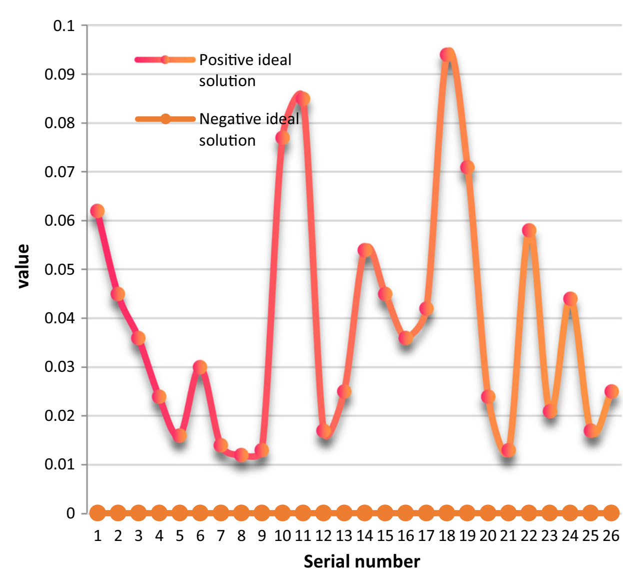

Fig. 4 Distribution diagram of positive and negative ideal solutions

Table 5 Distance between the performance index of each evaluation transfer center and the positive and negative ideal solutions

	di+	di′+	di−	di′−
1	0.14	0.115	0.107	0.116
2	0.138	0.113	0.112	0.122
3	0.155	0.127	0.091	0.1
4	0.08	0.066	0.19	0.207
5	0.181	0.148	0.114	0.124
6	0.181	0.148	0.098	0.107
7	0.147	0.121	0.128	0.139
8	0.207	0.17	0.086	0.094

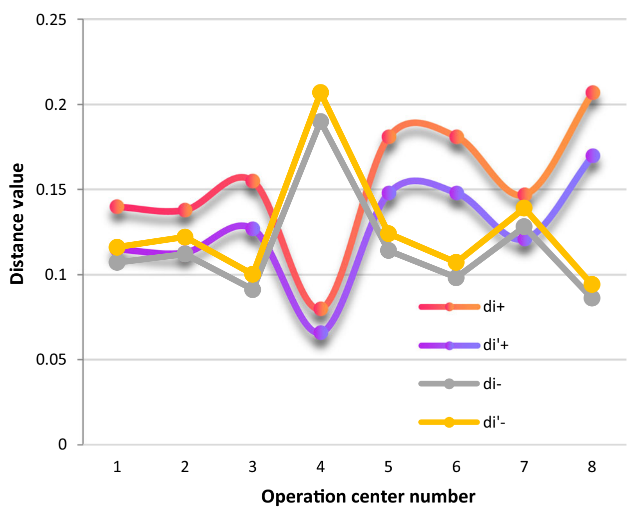

Fig. 5 Statistical chart of the distance between the performance index of each evaluation transfer center and the positive and negative ideal solutions

Table 6 Positive and negative flow values and standardized values of each transfer center

	Φi+	Φi′+	Φi−	Φi′−
1	1.416	0.139	1.082	0.106
2	1.202	0.118	0.9	0.088
3	0.868	0.085	1.093	0.107
4	3.344	0.326	0.708	0.07
5	0.752	0.074	1.756	0.172
6	0.765	0.075	1.517	0.149
7	1.322	0.13	0.877	0.086
8	0.618	0.061	2.354	0.23

Figure 9 shows that Jinhua transfer center ranks first in the development of basic categories, distribution conditions, various service capabilities, and informatization

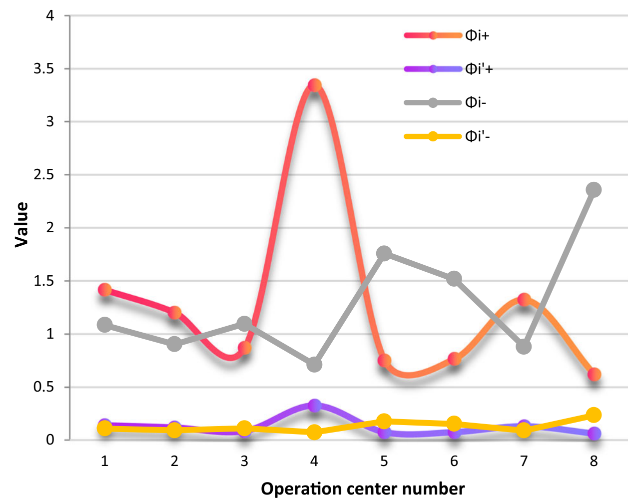

Fig. 6 Diagram of positive and negative flow values and standardized values of each transfer center

Table 7 Advantages and disadvantages of performance evaluation of each transfer center

	Si+	Si−	Ci
1	0.129	0.11	0.0209
2	0.12	0.098	0.0223
3	0.091	0.115	−0.023
4	0.279	0.068	0.2113
5	0.094	0.162	−0.067
6	0.088	0.148	−0.059
7	0.133	0.1	0.0341
8	0.0742	0.206	−0.1307

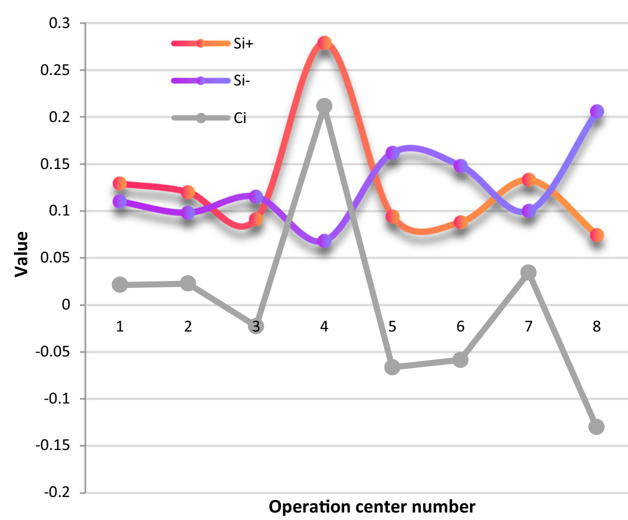

Fig. 7 Statistical chart of the advantages and disadvantages of the performance evaluation of each transfer center

levels, and has good development potential. However, its overall quality of employees ranks seventh, so it is necessary to pay attention to recruiting experienced and educated managers, and to strengthen the training of various types of employees and strengthen employee management. Among them, the operation level, service quality category, operation efficiency category, and economic benefit category are ranked lower. Therefore, the manager of Jinhua transfer center should pay attention to the forecast of cargo volume, calculate the cost of each line, reasonably plan the line, and also pay attention to on-site management.

Transfer center 2 ranked third in overall performance results. The ranking of various indicators in the secondary indicator layer was analyzed in detail to explore its advantages and disadvantages. The results are shown in Fig. 10.

Figure 10 shows that the ranking of the distribution conditions of transfer center 2 in development category is the last. Therefore, the layout of the outlets should be reasonably planned, and if possible, the transfer center address can be re-selected to increase its development potential. The comprehensive quality of employees ranks first, so the manager of this transfer center should pay attention to employee training and employee motivation in order to retain talents. The economic efficiency index ranks sixth, so the management can start with a reasonable allocation of personnel to ensure that the operation of the transfer center is normal and that the manpower is not idle. In general, other performance evaluation indicators of this transfer center rank high, and secondary transfer centers of the same level can learn from Taizhou transfer centers.

Transfer center 3 ranked fifth in overall performance results. The ranking of various indicators in the secondary indicator layer was analyzed in detail to explore its advantages and disadvantages. The results are shown in Fig. 11.

Figure 11 shows that transfer center 3 ranks fifth in the distribution conditions of development potential category.

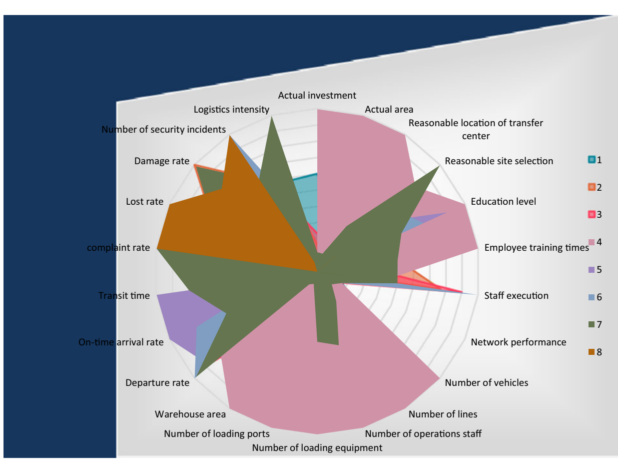

Fig. 8 Comprehensive results of performance evaluation of logistics operation center

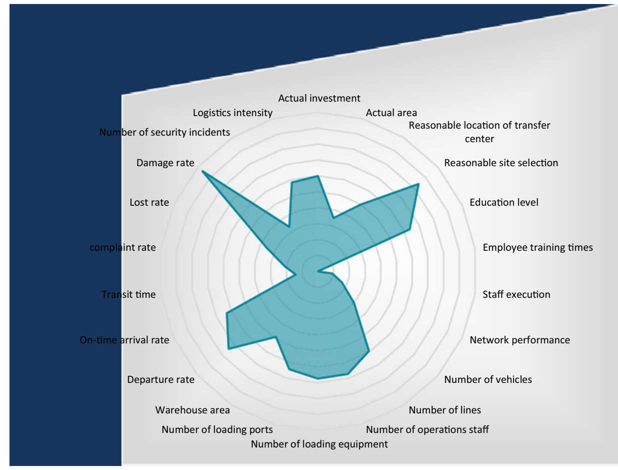

Fig. 9 Ranking of the secondary indicator layer of transfer center 1

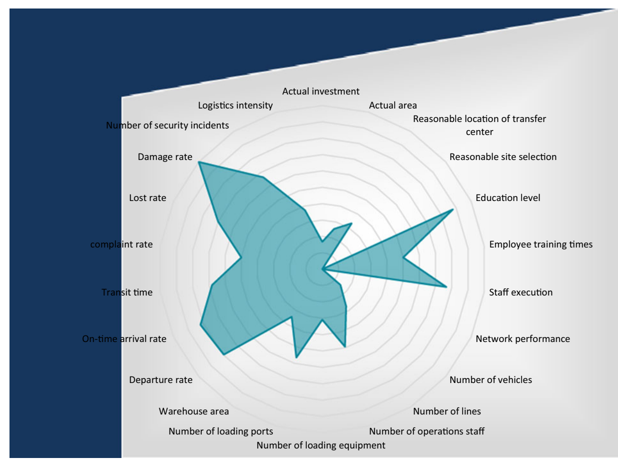

Fig. 10 Ranking of the secondary indicator layer of transfer center 2

Therefore, it should reasonably plan the layout of outlets, and if possible, it can re-select the address of the transfer center to increase its development potential. It has the worst performance in service quality and operational aging. The transfer center and Jinhua transfer center have the same problem. Therefore, it should pay attention to the forecast of cargo volume and calculate the cost of each line, plan the route reasonably, and also pay attention to the on-site management, and the manager can learn its management mode from the similar transfer center.

Transit center 7 ranked second in overall performance results. The ranking of various indicators in the secondary indicator layer was analyzed in detail to explore its advantages and disadvantages. The results are shown in Fig. 12.

Figure 12 shows that transfer center 7 ranks seventh in the development foundation category of the development potential category, ranks fourth in the distribution condition category and comprehensive staff quality category,

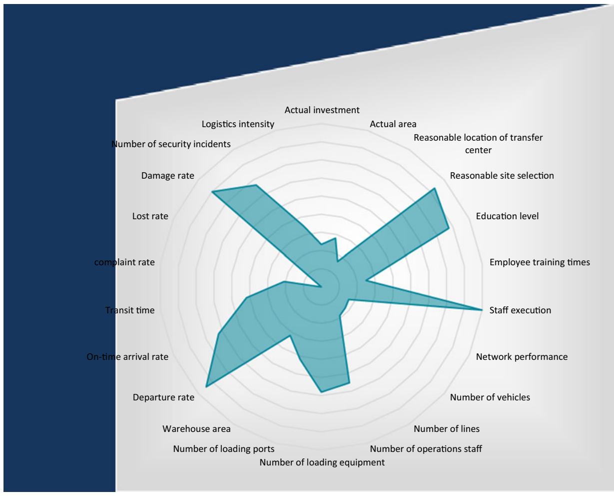

Fig. 11 Ranking of the secondary indicator layer of transfer center 3

and ranks fifth in warehousing service capacity in the service capacity category. Its storage service capacity is insufficient, so it is necessary to reasonably plan the layout of the warehouse, and if necessary, it needs to expand or build a new site. However, its operation limitation category, service quality category, and economic benefit category are among the top four among the major operation level categories. This shows that managers should increase investment in human, financial, and material resources in the transshipment center. At the same time, managers need to look at the transshipment center from a development perspective to achieve their long-term strategies and short-term goals.

Transit center 4 ranked first in overall performance results. The ranking of various indicators in the secondary indicator layer was analyzed in detail to explore its advantages and disadvantages. The results are shown in Fig. 13.

Figure 13 shows that the development potential category of Hangzhou transit center ranks first in the development potential category, the distribution condition category, and the employee's comprehensive quality category, with great development potential. As a result, human, financial, and material resources are tilted toward the transfer center, resulting in the service capacity of the transfer center ranking first. However, its operation time limit, service quality, and security guarantee of the operation level category rank in the bottom. Therefore, the transshipment center should pay attention to safety management, and safety is the primary issue.

Transfer center 6, transfer center 5, and transfer center 8 are tertiary transfer centers. The ranking of various indicators in the secondary indicator layer was analyzed in detail to explore its advantages and disadvantages. The results are shown in Fig. 14.

Figure 14 shows that compared with operation center 6 and operation center 5, operation center 8 has weak development potential and the worst service capability, but its cost control and service quality are relatively good. Operation center 8 should be viewed with a long-term development perspective, and its good operation level will attract more business outlets to join. Operation center 8 should appropriately recruit employees, increase the amount of investment, set up additional lines, or cooperate with other transfer center lines. The development potential of operation center 5 and various service capabilities are in an advantageous position. However, its service quality, cargo damage rate, and loss rate index scores are low, which reflects the chaotic management of its transfer center personnel. Operation center 5 should strengthen the monitoring of operating staff and take stock of warehouse goods in time to reduce the loss rate. The distribution and

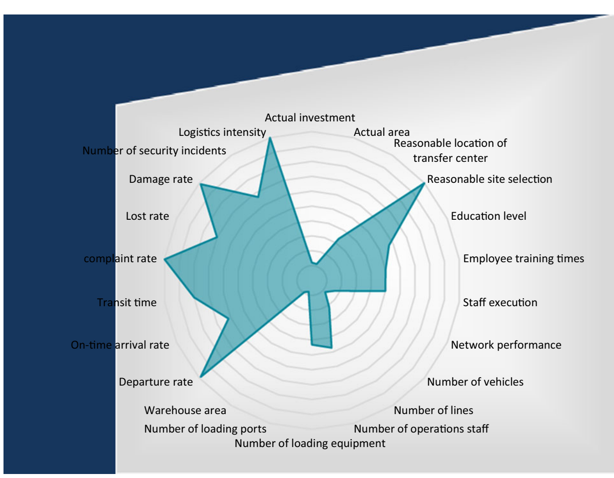

Fig. 12 Ranking of the secondary indicator layer of transfer center 7

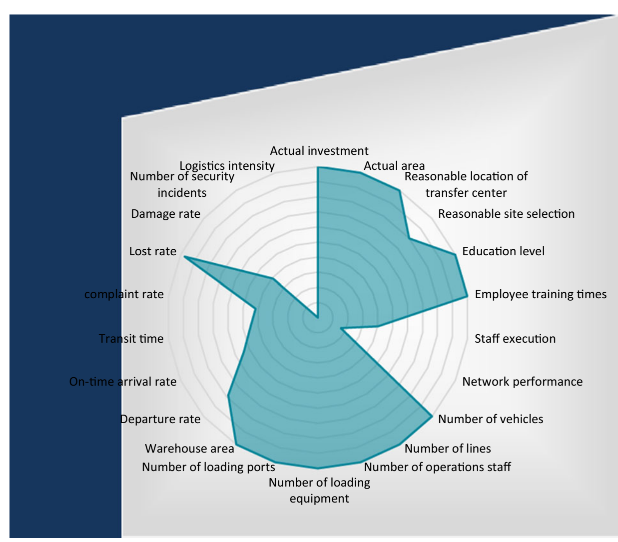

Fig. 13 Ranking of the secondary indicator layer of transit center 4

distribution conditions of operation center 6 development potential category ranked the penultimate among the three-tier transfer centers. It should reasonably plan the layout of the outlets, and if possible, it can re-select the address of the transfer center to increase its development potential.

7 Conclusion

Because each component of the evaluation result of collaborative logistics performance based on fuzzy evaluation method reflects the degree of membership of the result to a certain level, it also reflects the changing trend of the coordination performance of the supply chain coordination performance when certain factors change. At the same time, fuzzy evaluation results often appear that several component data in a vector are similar; that is, the membership of the evaluation results belonging to grade X and grade Y is very close. In this study, rough sets and BP neural networks are used to evaluate the effectiveness of collaborative logistics coordination performance. Decision makers in collaborative logistics can use this as a basis and combine with actual conditions to choose appropriate evaluation methods to accurately, effectively, and conveniently measure the effectiveness of supply chain coordination, and provide valuable information for supply chain coordination management. In addition, in this study, a case analysis was used to solve the performance evaluation model of manufacturing collaborative logistics based on rough set and BP neural network, and corresponding strategies were given. The research results show that the method proposed in this paper has certain effects. The evaluation result of the supply chain coordination performance only reflects the effect of the supply chain coordination performance in a certain stage in the past. How to predict the supply chain coordination performance according to the existing conditions or the current status of the supply chain so that it can be better applied to supply chain coordination decision-making needs further research

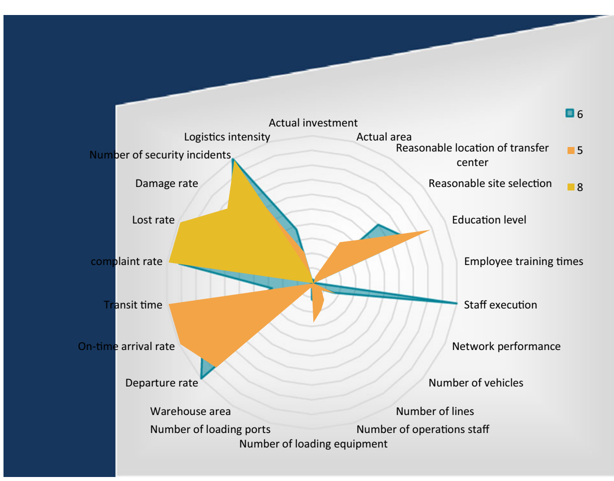

Fig. 14 Ranking of transfer center 6, transfer center 5, and transfer center 8

Compliance with ethical standards

Conflict of interest The authors have no conflict of interests.

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