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Original Research Article

Researchon fuzzy evaluation of waste logistics system in industrial park based on BP neural network

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ABSTRACT

According to the design principle of evaluation index, combined with the requirements of system operation efficiency and benefit, the development of eco city and eco industrial park, this paper puts forward the evaluation index system of waste logistics system in the park with 22 secondary indexes from the five aspects of system input, system capacity, operation efficiency, treatment efficiency and environmental performance, reasonably determines the index weight by using analytic hierarchy process, and selects 12 industrial parks as the object for example analysis, and use the proposed index system to carry out fuzzy evaluation and obtain the input and evaluation results of fuzzy evaluation. Then, according to the fuzzy evaluation process, build a three-layer BP neural network, train the BP network with the input and output of fuzzy evaluation, and obtain the BP network that can perform fuzzy evaluation. The example analysis shows that the evaluation results of the BP network for each park are the same as those of fuzzy evaluation. It is a convenient, reliable, and effective scientific tool to evaluate the performance of the waste logistics system in the park.

***Keywords*: industrial park; waste logistics; analytic hierarchy process; fuzzy evaluation; BP neural network

1. Introduction

Logistics performance evaluation is an important means to promote the development and improvement of logistics systems and improve the quality and efficiency of these systems. At present, research on logistics performance evaluation mainly focuses on the quality or benefit of regional logistics, the logistics industry, and logistics enterprises. The comprehensive evaluation methods mainly include fuzzy evaluation methods, analytic hierarchy processes, principal component analysis methods, gray correlation analysis methods, and BP neural network methods. The fuzzy evaluation system of express service quality[1], fuzzy evaluation model of forest product logistics enterprise benefit[2], BP neural network evaluation model[3–5], etc. The scientificity and application value of the evaluation model are demonstrated, and various evaluation methods have their advantages and disadvantages. In order to overcome the shortcomings of the single evaluation method, some scholars have adopted the

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combined evaluation method. Cai combined the fuzzy evaluation method with the BP neural network to establish a BP neural network evaluation method based on the fuzzy evaluation method so that the BP neural network has expert evaluation ability[6]. Zhu and Li used the fuzzy evaluation method and the BP neural network method to carry out empirical evaluation and compared the two methods[7,8]. Jiang used neural networks to determine the weight value in fuzzy comprehensive evaluation and proposed a combined model of neural networks and fuzzy comprehensive evaluation[9]. Zou and others constructed a smart city development potential evaluation model based on gray correlation theory and BP neural networks, and an example verified the scientificity and rationality of this method[10]. Chen introduced the principal component analysis method and BP neural network algorithm into the evaluation process, established the evaluation model of the PCA-BP neural network, and evaluated the line network layout scheme[11].

To sum up, the combination method based on fuzzy evaluation is highly scientific and operable, which can solve the problems of subjective and objective evaluation. At the same time, it can use expert experience to obtain the necessary data and overcome the disadvantages of traditional evaluation. There are many qualitative and quantitative indicators used in the evaluation of the waste logistics system in the park, and the evaluation is fuzzy and complex, so the fuzzy evaluation method should be used. The above combination method research focuses on the BP network experimental research on evaluation problems. This study intends to build a park waste logistics system evaluation system based on a BP neural network by establishing a reasonable park waste logistics system evaluation index system so as to provide scientific and effective fuzzy evaluation tools for park managers.

2. Design of evaluation index system of waste logistics system in Industrial Park

The waste logistics system in the park is a social system that takes the waste treatment and disposal enterprises as the core and provides waste treatment services for the production enterprises in the park. The setting of evaluation indexes and standards is complex. A set of index system reflecting different evaluation requirements must be designed according to the design principles and requirements of the index system.

2.1. Design principles and requirements of index system

The design of the index system of waste logistics system in the park must follow five principles, including a combination of scientificity, systematicness, comparability, operability, and qualitative and quantitative principles. At the same time, the operation efficiency and benefit requirements of the system, the requirements of the eco-city and eco-industrial park for the system, and the sustainable development requirements of cities, parks, and enterprises must be considered. Specifically, in order to make the index system fully reflect the technical and economic characteristics and sustainable development requirements of the system and comprehensively reflect the development status and level of system infrastructure, operation capacity, and service level, it is necessary to actively introduce eco-city evaluation indicators, including environmental governance and environmental quality indicators, eco-environmental health indicators, and low-carbon leading indicators[12–14]. The introduction of reduction indicators includes the emission of solid waste with an industrial added value of RMB 10,000, the packaging consumption of products with an industrial added value of RMB 10,000, the reuse indicators include the percentage of reusable types of products and packaging in the total, the R&D funds for reusable functions, etc., and the recycling indicators include the reuse rate of industrial solid waste, the primary or secondary recycling rate of products and packaging, etc., so as to meet the requirements for the development of eco-industrial parks.

2.2. Selection and analysis of evaluation indicators

According to the above index design principles and requirements and the relevant indexes and requirements of the issued national eco-industrial demonstration park standard (HJ274-2015), treatment efficiency and environmental performance, design necessary new indicators, and design a two-level performance evaluation index system for the waste logistics system in the park. The index system includes 5 categories and 22 secondary indicators, as shown in **Table 1**, and the specific evaluation index analysis is shown in **Table 2**.

All enterprise indicators in **Table 1** are measured by the average value of relevant enterprises in the park. The data in the column "requirements" is formulated with reference to the national eco-industrial demonstration park standard (HJ274-2015), waste management standard, relevant research results, and expert opinions. If "requirements" is blank, it means that the quantitative data in this index needs to be prepared according to the actual development level of the park.

2.3. Weight analysis of evaluation index

This study uses analytic hierarchy process (AHP) to determine the index weight.

Weight analysis of primary index layer

According to **Table 1** and **Table 2**, the evaluation problems are hierarchized to obtain the two-tier structure of the evaluation problems, namely, the primary index layer and the secondary index layer; use the 1–9 scale method to determine the evaluation scale, as shown in **Table 3**.

Table 1. Performance evaluation index system of waste logistics system in industrial park

Primary index	Secondary index	Nature	Company	Requirement
System input (A1)	Degree of environmental protection investment in the park meeting the needs (A11)	Forward	%	≥10
	Publicity coverage of waste logistics in the park (A12)	Forward	%	
	Soundness of waste logistics regulations in the park (A13)	Forward	%	
	Research and development funds for reusable functions of enterprise products (A14)	Forward	RMB 10,000	
	Processing enterprise technology R & D investment (A15)	Forward	RMB 10,000	
System capability (A2)	Perfection of waste logistics information platform in the park (A21)	Forward	%	≥60
	Extent to which infrastructure meets waste logistics needs (A22)	Forward	%	≥70
	Waste recycling degree in the park (A23)	Forward	%	≥70
	Application degree of processing enterprise information system (A24)	Forward	%	≥75
	Handle the soundness of enterprise quality management system (A25)	Forward	%	≥70
Operational efficiency (A3)	Industrial agglomeration degree of the park (A31)	Forward	%	≤0.1
	Coupling degree of industrial waste in the park (A32)	Forward	%	
	Solid waste production per unit industrial added value (A33)	Negative direction	Ton/ RMB 10,000	
	Packaging consumption per unit of industrial added value (A34)	Negative direction	Ton/ RMB 10,000	
	Proportion of reusable products and packages (A35)	Forward	%	
Treatment efficiency (A4)	Degree of cooperation between processing enterprises (A41)	Forward	%	
	Waste logistics function and service level (A42)	Forward	%	
	Proportion of waste logistics cost (A43)	Negative direction	%	≤25
Environmental performance (A5)	Comprehensive utilization rate of industrial solid waste (A51)	Forward	%	≥70
	Resource recycling degree (A52)	Forward	%	≥30
	Primary or secondary recycling rate of products and packaging (A53)	Forward	%	
	Public environmental satisfaction (A54)	Forward	%	

According to the assignment D_{ij} in **Table 3**, D_{ij} meets the conditions $D_{ij} > 0$, $D_{ij} = 1/D_{ji}(i \neq j)$, $D_{ii} = 1(i,j = 1,2,\cdots,n)$.

The opinions of eight experts and scholars were consulted in the form of interview. The 1–9 scale method was used for pairwise comparison and assignment, and the table was filled in. The assignment was taken as the element value of the judgment matrix to obtain the pairwise comparison judgment table of the primary index layer, as shown in **Table 4**.

Table 2. Performance evaluation index analysis of waste logistics system in Industrial Park

System investment A1: measure the investment of parks and enterprises in the construction of waste logistics system	1. A11 refers to the extent to which the environmental protection projects invested in the park eliminate solid waste pollution and recycle resources 2. A12 = (number of publicity participants/employed population in the park) × 100% 3. A13 = (number of solid waste management system documents/4) × 100%, solid waste management system documents include domestic waste, general industrial solid waste, hazardous solid waste, sewage sludge, etc 4. A14 refers to the funds invested by the production enterprises in the park in product technology research and development according to the reuse principle 5. A15 refers to the R & D investment of processing enterprises serving the park in processing technology
System capability A2: measure the capacity of the park and treatment enterprises to carry out waste treatment and information services	1. A21 refers to the waste logistics information website established by the park on relevant websites and its perfection 2. A22 refers to the degree to which the quantity and capacity of grade roads, landfills, special facilities for loading, unloading and handling meet the operation needs of waste logistics 3. A23 refers to the type and proportion of waste that can be treated by the treatment enterprises serving the park, which is required to reach 70% of the total waste 4. A24 = (number of information management functions/4) × 100%, enterprise information management functions include enterprise management information system, intranet, website and information service, online transaction, etc 5. A25 = (quantity of quality management documents/8)× 100%, the total number of quality management documents is 8, including product and packaging standards and technical specifications, product process flow chart, process operation instructions and key measures, list of main facilities and equipment and safe operation procedures, list of monitoring and measuring equipment, production inspection procedures, quality requirements and personnel list of quality management personnel, product quality and reputation of suppliers, etc
Operation efficiency A3: measure the operation efficiency of waste logistics system in the park	1. A31 refers to the horizontal and vertical industrial links among enterprises in the park, measured by the industrial agglomeration index[15] 2. A32 refers to the degree to which the main industries in the park use the complementary relationship of waste to treat waste, A32 = (quantity/total amount of waste in the park) × 100% 3. A33 refers to the amount of industrial solid waste produced by industrial enterprises in the park 4. A34 refers to the number of product packages produced by industrial enterprises in the park 5. A35 = types of reusable articles produced by enterprises in the park/types of all articles
Processing efficiency A4: measures the efficiency of production and logistics services of processing enterprises	1. A41 = number/total number of enterprises with cooperative relations among enterprises in the park 2. A42 refers to the integrity of waste packaging, loading and unloading, transportation, storage, information and other functional services provided by the treatment enterprise to the production enterprise 3. A43 = waste logistics cost of treatment enterprise/cost of treatment enterprise
Environmental performance A5: measure the environmental performance achieved by the waste logistics system in the park	1. A51 = comprehensive utilization of industrial solid waste/total production of industrial solid waste 2. A52 = industrial added value of resource recycling/industrial added value of the park 3. A53 = recycled amount/total amount of products and packages produced by enterprises in the park 4. A54 refers to the satisfaction of the park public with the park environment

Table 3. Scale value and its meaning

Importance of element I compared with element J	Evaluation scale
Equally important	1
Slightly important	3
Obviously important	5
Strongly important	7
Extremely important	9
The degree of importance is between the above situations	2, 4, 6, 8

Table 4. Comparison and judgment of two levels of primary index

	System input A1	System capability A2	Operational efficiency A3	Treatment efficiency A4	Environmental performance A5
System input A1	1	1/3	1/5	2	1/7
System capability A2	2	1	1/2	3	1/5
Operational efficiency A3	5	2	1	4	1/3
Treatment efficiency A4	1/2	1/3	1/4	1	1/9
Environmental performance A5	7	5	3	9	1

According to **Table 4**, the judgment matrix A of primary index layer can be established:

$$A = \begin{bmatrix} 1 & 1/3 & 1/5 & 2 & 1/7 \\ 2 & 1 & 1/2 & 3 & 1/5 \\ 5 & 2 & 1 & 4 & 1/3 \\ 1/2 & 1/3 & 1/4 & 1 & 1/9 \\ 7 & 5 & 3 & 9 & 1 \end{bmatrix} \tag{1}$$

According to the formula $CI = (\lambda_{max}–n)/(n–1)$, calculate the consistency index CI of matrix A, where λ_{max} is the maximum eigenvalue of matrix A, and n is the order of matrix A. $eig(A)$ is calculated in Matlab $\lambda_{max} = 5.0361$, its corresponding $tzxl\_A$ = [0.1059, 0.2020, 0.3823, 0.0780, 0.8920], the λ_{max} is brought into the CI calculation formula, and $CI = 0.09$ can be obtained. According to **Table 5**, the value of the average random consistency index RI can be obtained, i.e., $RI = 1.12$.

Table 5. Average random consistency index RI

N	1	2	3	4	5
RI value	0. 00	0. 00	0. 58	0. 90	1.12
N	6	7	8	9	
RI value	1.24	1. 32	1. 41	1. 45	

Calculate the random consistency ratio $CR = CI/RI = 0.0081 < 0.1$, which shows that the judgment matrix A has satisfactory consistency. For eigenvector $tzxl\_A$ after normalization, the weight W = [0.0638, 0.1217, 0.2303, 0.0470, 0.5372] of each index of the primary index layer can be obtained, that is, the weight W_1 of the system input index is 0.0638, the system capacity W_2 is 0.1217, the operation efficiency W_3 is 0.2303, the treatment efficiency W_4 is 0.0470, and the environmental performance W_5 is 0.5372.

Weight analysis of secondary indicators

Similarly, the judgment matrix A_1 of the system input layer, the judgment matrix A_2 of the system capability layer, the judgment matrix A_3 of the operation efficiency layer, the judgment matrix A_4 of the processing efficiency layer and the judgment matrix A_5 of the environmental performance layer can be established as follows:

$$A_1 = \begin{bmatrix} 1 & 9 & 5 & 3 & 2 \\ 1/9 & 1 & 1/3 & 1/5 & 1/6 \\ 1/5 & 3 & 1 & 1/3 & 1/2 \\ 1/3 & 5 & 3 & 1 & 1/2 \\ 1/2 & 6 & 2 & 2 & 1 \end{bmatrix} \tag{2}$$

Table 6. Weight calculation and test results of secondary index layer

Secondary index layer	Maximum eigenvalue λmax	Weight vector W_{ij}	Consistency index CI	Uniformity Ratio CR	Whether Accept
System input A1	5.1177	[0.4458, 0.0382, 0.0935, 0.1800, 0.2425]	0.0294	0.0263	Yes
System capability A2	5.1448	[0.1449, 0.4507, 0.2750, 0.0459, 0.0835]	0.0362	0.0323	Yes
Operational efficiency A3	5.0705	[0.1518, 0.2630, 0.4611, 0.0830, 0.0411]	0.0176	0.0157	Yes
Treatment efficiency A4	3.0070	[0.0879, 0.6694, 0.2427]	0.0035	0.0061	Yes
Environmental performance A5	4.0816	[0.5527, 0.2713, 0.1143, 0.0617]	0.0272	0.0302	Yes

$$A_2 = \begin{bmatrix} 1 & 1/4 & 1/3 & 5 & 2 \\ 4 & 1 & 2 & 7 & 5 \\ 3 & 1/2 & 1 & 5 & 3 \\ 1/5 & 1/7 & 1/5 & 1 & 1/2 \\ 1/2 & 1/5 & 1/3 & 2 & 1 \end{bmatrix} \quad (3)$$

$$A_3 = \begin{bmatrix} 1 & 1/2 & 1/4 & 2 & 5 \\ 2 & 1 & 1/2 & 3 & 7 \\ 4 & 2 & 1 & 5 & 8 \\ 1/2 & 1/3 & 1/5 & 1 & 2 \\ 1/5 & 1/7 & 1/8 & 1/2 & 1 \end{bmatrix} \quad (4)$$

$$A_4 = \begin{bmatrix} 1 & 1/7 & 1/3 \\ 7 & 1 & 3 \\ 3 & 1/3 & 1 \end{bmatrix}$$

$$A_5 = \begin{bmatrix} 1 & 3 & 4 & 7 \\ 1/3 & 1 & 3 & 5 \\ 1/4 & 1/3 & 1 & 2 \\ 1/7 & 1/5 & 1/2 & 1 \end{bmatrix} \quad (5)$$

The function can be used to obtain the maximum eigenvalue of each judgment matrix of the secondary index layer and its corresponding eigenvector. According to the formula calculation, the corresponding random consistency ratio *CR* can be obtained. The weight analysis results of the secondary index layer are shown in **Table 6**.

Finally, calculate the consistency index of the total ranking of the hierarchy, $CI = \sum_{j=1}^{5} W_j \, CI_j = 0.0251$, $RI = \sum_{j=1}^{5} W_j \, RI_j = 0.9764$, hierarchical total sort $CR = CI/RI = 0.0257 < 0.10$, and the overall consistency test is passed, so the weight distribution of the secondary index is reasonable.

3. Construction and analysis of evaluation model based on BP neural network

Compared with traditional methods, BP neural network has the advantages of strong operability, high fitting accuracy and strong scientificity[16]. The evaluation model based on BP neural network has important application value.

3.1. Principle of BP neural network

Structure of BP neural network

The BP neural network, namely back propagation neural networks, is a multi-layer feedforward neural network that adopts an error-back propagation learning algorithm. The typical three-layer BP network structure is shown in **Figure 1**.

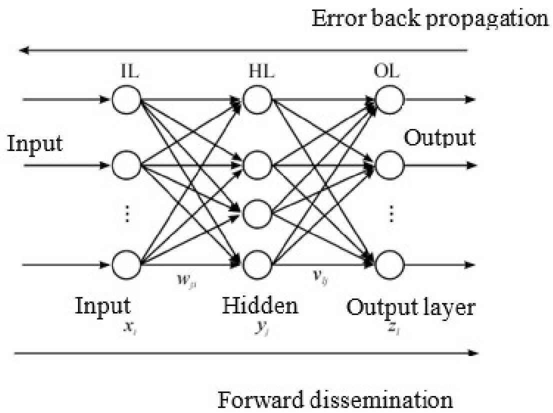

Figure 1. BP network structure.

As can be seen from **Figure 1**, the three-layer BP network is divided into an input layer (IL), a hidden layer (HL), and an output layer (OL). There is no correlation between nodes in the same layer and no forward connection between neurons in different layers.

BP learning algorithm

Make the connection right between IL layer node x_i and HL layer node y_j w_{ji}, and the connection right between HL layer node y_j and OL layer node z_l v_{lj}, θ_j is the threshold of HL layer node θ_l is the threshold of OL layer node, and the output function of HL layer node is:

$$y_j = f\left(\sum_i w_{ji} \, x_i - \theta_j\right) = f(net_j) \quad (6)$$

The output function of OL layer node is:

$$z_l = f\left(\sum_j v_{lj} \, y_j - \theta_l\right) = f(net_l) \quad (7)$$

Among them, $f(x)$ is the transfer function, which is generally sigmoid type function. For example, the function $f(x) = 1/(1 + e^{-x})$. The S-type transfer function can be used to deal with and approach the nonlinear input and output relationship.

When the expected value of the output node is t_l, the error e of the output node is:

$$E = \frac{1}{2}\sum_l (t_l - z_l)^2 = \frac{1}{2}\sum_l \left(t_l - f\left(\sum_j v_{lj}\, y_j - \theta_l\right)\right)^2 = \frac{1}{2}\sum_l \left(t_l - f\left(\sum_j v_{lj}\, f\left(\sum_i w_{ji}\, x_i - \theta_j\right)\right)\right) \quad (8)$$

The training process for the BP network is as follows:

First, initialize the weight and threshold of the network, that is, give w_{ji}, v_{lj}, θ_j and θ_l other initial values. Generally, any number is selected in the interval (–1, 1) as the initial connection weight and threshold of the BP neural network.

Second, input the learning sample t_l and calculate the output values of each layer according to the output function, including y_j and z_l. The sample signal is transmitted from the input layer to the output layer through the hidden layer, and the output signal is generated at the output end. In the process of forward signal transmission, the weight of the network is fixed, and the state of neurons in each layer only affects the state of neurons in the next layer. If the desired output cannot be obtained at the output layer, the error signal will be transferred to back propagation.

Third, the gradient descent algorithm and error-back propagation are used to correct the network weight and threshold. The difference between the actual output and the expected output of the network is the error signal. The error signal starts from the output end and propagates backward layer by layer. The weight and threshold of the network are adjusted by the error feedback. Through the continuous correction of the weight, the actual output of the network is closer to the expected output. The adjustment rules for the hidden layer and output layer for network weight and threshold are as follows:

$$v_{lj}(k+1) = v_{lj}(k) + \Delta v_{lj} = v_{lj}(k) + \eta\delta_1 y_j \quad (9)$$

$$w_{ji}(k+1) = w_{ji}(k) + \Delta w_{ji} = w_{ji}(k) + \eta'\delta_j' x_i \quad (10)$$

$$\theta_l(k+1) = \theta_l(k) + \Delta\theta_l = \theta_l(k) + \eta'\delta' \quad (11)$$

$$\theta_j(k+1) = \theta_j(k) + \Delta\theta_j = \theta_j(k) + \eta''\delta_j' \quad (12)$$

$$\delta_l = (t_l - z_l)\cdot f'(net_l) \quad (13)$$

$$\delta_j' = f'(net_j)\cdot\sum_l \delta_l\, v_{lj} \quad (14)$$

where k is the number of iterations, and $k+1$ represents step $k+1$; η、η' is the learning rate or step size. $\sum_l \delta_l\, v_{lj}$ represents the error δ_l of the output node z_l. The error of the hidden layer node is propagated back to node y_j through weight v_{lj}.

Fourth, continuously calculate the error E according to the training and compare it with the expected error accuracy. If the actual calculated error is within the specified range, the learning ends. Otherwise, increase the learning times once and return to step 2. Adjust the step size and threshold according to the rules for further learning until the specified error accuracy or training times are reached.

3.2. Construction of evaluation model

When applying BP neural network to fuzzy evaluation, the actual index data of the evaluation index system can be used as the input vector x_i of the neural network, the corresponding fuzzy evaluation results can be used as the output z_l of the neural network, and the network can be trained with enough samples to obtain the corresponding output value of different groups of measured indexes. The output value is compared with the expected fuzzy evaluation result value. When the error is less than a certain set value, the weight coefficient value and threshold held by the neural network are the final weight and threshold obtained by the network through adaptive learning. Once the training of the BP neural network is completed, it will become an effective fuzzy evaluation tool. By inputting the actual index value into the network, the fuzzy evaluation of the target can be made automatically.

The construction of the BP neural network includes the following three steps: first, determine the number of network layers and the number of neurons in each layer. Since the BP neural network only needs a three-layer BP neural network to complete the mapping from m dimension to n dimension, the three-layer BP neural network with one hidden layer can be selected for design and training. The number of input layer nodes is equal to the number of evaluation indicators, and the number of output layer nodes is the performance evaluation result, which is 1. The number of hidden layer nodes can be calculated and determined according to the empirical formula:

$$m = \sqrt{w + n} + a \tag{15}$$

Of which: m is the number of neurons in the hidden layer, n is the number of neurons in the input layer, w is the number of neurons in the output layer, and a is any integer from 0 to 10. Second, determine the transfer function. Generally, sigmoid function is adopted for the hidden layer and purelin linear function is adopted for the output layer. Third, create a network, set training parameters, input data to the network, and train the network until a BP network that meets the expected output is obtained.

4. Case analysis

This case selects 12 industrial parks in Chongqing as the evaluation object to analyze and evaluate the performance of the waste logistics system of each park in 2015. The evaluation follows the following steps: collect data according to the proposed index system. The fuzzy evaluation method is applied to evaluate the park, and the fuzzy evaluation results are obtained. Build the BP neural network according to the evaluation needs, complete the network training, and carry out verification analysis.

Table 7. Measured values of waste logistics system indicators in the park in 2015 (1)

Park / Index	A12 /%	A13 /%	A15/RMB 10,000	A23/%	A24 /%	A25 /%	A33/(ton/RMB 10,000)	A51/%
1	5	75	200	75	50	62.5	0. 10	90
2	3	50	120	60	50	50.0	0. 10	75
3	12	75	280	95	100	87.5	0. 06	95
4	7	75	150	85	75	75.0	0. 10	80
5	4	50	125	75	50	62.5	0. 10	80
6	15	100	300	100	100	100.0	0. 05	100
7	12	75	200	85	100	100.0	0. 06	90
8	6	75	140	60	75	87. 5	0. 10	85
9	9	75	160	80	75	87. 5	0. 09	90
10	10	75	120	95	100	75.0	0. 07	95
11	12	100	270	90	100	100.0	0. 06	100
12	8	75	180	75	75	87.5	0. 10	80

4.1. Data collection

There are two kinds of index data sources for the waste logistics system in the park. One is to obtain the index value through investigation and calculation according to the actual data. The second is expert scoring. For quantitative and qualitative indicators lacking data, the expert survey method is adopted to obtain data; that is, 8 experts vote and score the index level of the selected park. There are eight indicators to obtain data by means of investigation. 12 industrial parks are represented by numbers 1–12, respectively. The measured values of 8 indicators are shown in **Table 7.**

At present, the statistical work on the industrial park has just started. Most indicators lack data and are difficult to calculate quantitatively. It is necessary to obtain 14 indicators using the expert scoring method. During expert scoring, eight experts are invited to vote and score the relevant indicators of 12 industrial parks one by one. The number of cells in **Table 5**. From left to right, it represents the number of votes of experts whose evaluation grade of the indicator is excellent, good, general, qualified, or unqualified. Each cell totals 8 votes. The statistical results of expert scoring are shown in **Table 8.**

Table 8. Measured values of waste logistics system indicators in the park in 2015 (2)

Index \ Park	1	2	3	4	5	6	7	8	9	10	11	12
A11	12230	01241	32300	03320	00440	43100	33200	13310	05300	13310	35000	04310
A14	05300	02213	34100	13310	01431	35000	44000	14300	06200	12500	35000	15200
A21	12500	03222	44000	02600	02501	35000	52100	14210	04400	12500	43010	13310
A22	13220	11420	42200	12311	02501	42110	33110	13220	04310	14300	43100	12320
A31	06200	11420	35000	11510	12500	25100	34100	12320	11420	12500	34100	03410
A32	14210	01610	53000	12410	02600	53000	35000	12311	03410	06200	62000	13310
A34	11600	12500	62000	02600	12410	71000	61100	06110	15200	12500	71000	16100
A35	06110	03410	53000	07010	03500	51110	61100	13400	06110	11510	61100	16010
A41	11600	13400	26000	06110	04400	80000	71000	11600	11600	13400	34010	05300
A42	06200	13400	35000	11600	11600	51200	25100	11510	06110	12500	32210	11510
A43	07001	03500	43100	07010	05300	61100	80000	14300	15200	12410	61010	14300
A52	12500	04400	33110	11600	13400	44000	34100	12410	07010	11600	53000	03500
A53	03500	10610	42110	10511	04310	62000	44000	14300	15200	03500	61010	12500
A54	04400	01340	52100	11420	11510	43100	51110	16100	06110	13400	71000	08000

4.2. Fuzzy evaluation

Determining factor set, evaluation set and weight set

Determine the factor set according to the index system. The main factor set a includes five factors A_i (i = 1, 2, 3, 4, 5) corresponding to the primary index layer. The sub factor set A_{ij} (j is 5, 5, 5, 3, 4 respectively) includes $A_{1j} = \{A_{11}, A_{12}, A_{13}, A_{14}, A_{15}\}$, $A_{2j} = \{A_{21}, A_{22}, A_{23}, A_{24}, A_{25}\}$, $A_{3j} = \{A_{31}, A_{32}, A_{33}, A_{34}, A_{35}\}$, $A_{4j} = \{A_{41}, A_{42}, A_{43}\}$, $A_{5j} = \{A_{51}, A_{52}, A_{53}, A_{54}\}$, corresponding to the secondary index layer.

The evaluation set adopts five grades, with $V_k = \{v_1, v_2, v_3, v_4, v_5\}$ = {excellent, good, general, qualified and unqualified}.

According to the above analysis, the main factor weight set $W = (W_i)$ (i = 1, 2, 3, 4, 5) = [00638, 01217, 02303, 00470, 05372]. The sub factor weight set is W_{ij} (I = 1, 2, 3, 4, 5), where W_{1j} = [04458, 00382, 00935, 01800, 02425], W_{2j} = [01449, 04507, 02750, 00459, 00835], W_{3j} = [01518, 02630, 04611, 00830, 00411], W_{4j} = [00879, 06694, 02427], W_{5j} = [05527, 02713, 01143, 00617].

Comprehensive evaluation

(1) Index data processing.

According to the data source of indicators, different processing methods are adopted for qualitative and quantitative indicators. For the quantitative indicators in **Table 7**, the experts determine the evaluation rules according to the requirements of the relevant indicators and the actual situation. The evaluation grade of each indicator is uniquely determined. The determined grade is 8 votes, and the other 4 grades are 0. For the qualitative indicators in **Table 8**, the grade shall be determined according to the number of expert votes, and the evaluation rules of various indicators in **Table 7** shall be determined according to the analysis of experts, as shown in **Table 9**.

Table 9. Quantitative index evaluation rules

Index / Score	A12	A13	A15	A23	A24	A25	A33	A51
Unqualified	< 7	< 70	< 120	< 70	< 70	< 70	> 01	< 70
Qualified	[7,8)	[70,80)	[120,170)	[70,80)	[70,80)	[70,80)	[01,009)	[70,80)
Commonly	[8,9)	[80,90)	[170,220)	[80,90)	[80,90)	[80,90)	[009,008)	[80,90)
Good	[9,10)	[90,100)	[220,270)	[90,100)	[90,100)	[90,100)	[008,007)	[90,100)
Excellent	≥10	100	≥270	100	100	100	≦007	100

Table 10. Index evaluation grade voting of waste logistics system in the park

Index / Park		1	2	3	4	5	6	7	8	9	10	11	12
System input (A1)	A11	12230	01241	32300	03320	00440	43100	33200	13310	05300	13310	35000	04310
	A12	00008	00008	80000	00080	00008	80000	80000	00008	08000	80000	80000	00800
	A13	00080	00008	00080	00080	00008	80000	00080	00080	00080	00080	80000	00080
	A14	05300	02213	34100	13310	01431	35000	44000	14300	06200	12500	35000	15200
	A15	00800	00080	80000	00080	00080	80000	00800	00080	00080	00080	80000	00800
System capability (A2)	A21	12500	03222	44000	02600	02501	35000	52100	14210	04400	12500	43010	13310
	A22	13220	11420	42200	12311	02501	42110	33110	13220	04310	14300	43100	12320
	A23	00080	00008	08000	00800	00080	80000	00800	00008	00800	08000	08000	00080
	A24	00008	00008	80000	00080	00008	80000	80000	00080	00080	80000	80000	00080
	A25	00008	00008	00800	00080	00008	80000	80000	00800	00800	00080	80000	00800
Operational efficiency (A3)	A31	06200	11420	35000	11510	12500	25100	34100	12320	11420	12500	34100	03410
	A32	14210	01610	53000	12410	02600	53000	35000	12311	03410	06200	62000	13310
	A33	00080	00080	80000	00080	00080	80000	80000	00080	00800	80000	80000	00080
	A34	11600	12500	62000	02600	12410	71000	61100	61100	15200	12500	71000	16100
	A35	06110	03410	53000	07010	03500	51110	61100	13400	61100	11510	61100	16010
Treatment efficiency (A4)	A41	11600	13400	26000	06110	04400	80000	71000	11600	11600	13400	34010	05300
	A42	06200	13400	35000	11600	11600	51200	25100	11510	06110	12500	32210	11510
	A43	07001	03500	43100	07010	05300	61100	80000	14300	15200	12410	61010	14300
Environmental performance (A5)	A51	08000	00080	08000	00800	00800	80000	08000	00800	08000	08000	80000	00800
	A52	12500	04400	33110	11600	13400	44000	34100	12410	07010	11600	53000	03500
	A53	03500	10610	42110	10511	04310	62000	44000	14300	15200	03500	61010	12500
	A54	04400	01340	52100	11420	11510	43100	51110	16100	06110	13400	71000	08000

According to **Table 9**, the quantitative indicators in **Table 7** are evaluated, and the number of expert votes is 8. The results are combined with **Table 8** to obtain the number of votes for the evaluation level of waste logistics system indicators in the park. See **Table 10** for the initial value of the indicators required for fuzzy evaluation.

(2) Fuzzy analysis.

Let the subordinate degree of the sub factor A_{ij} to the evaluation set V_k be r_{ik}, $r_{ik} = V_{ik}/N$, V_{ik} is the number of experts who believe that A_{ij} belongs to V_k, $N = 8$, calculate the subordinate degree of the sub factor A_{ij} to each evaluation grade respectively, and obtain the fuzzy evaluation matrix r_i ($i = 1, 2, 3, 4, 5$) of each sub factor as follows:

$$r_1 = \begin{bmatrix} 0.125 & 0.25 & 0.25 & 0.375 & 0 \\ 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0.625 & 0.375 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \end{bmatrix} \tag{16}$$

$$r_2 = \begin{bmatrix} 0.125 & 0.25 & 0.625 & 0 & 0 \\ 0.125 & 0.375 & 0.25 & 0.25 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \tag{17}$$

$$r_3 = \begin{bmatrix} 0 & 0.75 & 0.25 & 0 & 0 \\ 0.125 & 0.5 & 0.25 & 0.125 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0.125 & 0.125 & 0.75 & 0 & 0 \\ 0 & 0.75 & 0.125 & 0.125 & 0 \end{bmatrix} \tag{18}$$

$$r_4 = \begin{bmatrix} 0.125 & 0.125 & 0.75 & 0 & 0 \\ 0 & 0.75 & 0.25 & 0 & 0 \\ 0 & 0.875 & 0 & 0 & 0.125 \end{bmatrix} \tag{19}$$

$$r_5 = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 \\ 0.125 & 0.25 & 0.625 & 0 & 0 \\ 0 & 0.375 & 0.625 & 0 & 0 \\ 0 & 0.5 & 0.5 & 0 & 0 \end{bmatrix} \tag{20}$$

According to the sub factor weight set W_{ij} (i = 1, 2, 3, 4, 5) and r_i, the fuzzy evaluation matrix R of the main factor can be obtained by using the formula $R_i = W_{ij} \cdot r_i (i = 1,2,3,4,5)$:

$$R = \begin{bmatrix} 0.0557 & 0.2239 & 0.4214 & 0.2607 & 0.0382 \\ 0.0745 & 0.2052 & 0.2032 & 0.3877 & 0.1294 \\ 0.0433 & 0.2866 & 0.1711 & 0.4991 & 0 \\ 0.0110 & 0.7254 & 0.2333 & 0 & 0.0303 \\ 0.0339 & 0.6942 & 0.2718 & 0 & 0 \end{bmatrix} \quad (21)$$

According to the main factor weight set W and matrix R, using the formula $V = W \cdot R$, the evaluation results of Park 1 can be obtained:

$$V= \{0.0413, 0.5123, 0.2480, 0.1788, 0.0196\} \quad (22)$$

Quantify the evaluation set. V_k five grades {excellent, good, average, qualified, and unqualified} are set, corresponding to [90–100], [80–90], [70–80], [60–70], and [0–60], respectively, and the middle value is taken for calculation, that is, 95 points, 85 points, 75 points, 65 points, and 30 points are taken, respectively, so the fuzzy evaluation score of Park 1 is 78.2791, which belongs to "average".

Similarly, fuzzy evaluation can be carried out for parks 2–12, and the evaluation values are summarized in **Table 11**.

Table 11 shows that the evaluation values of Parks 6 and 11 are 92.2036 and 92.1256, respectively, and the evaluation results are excellent. The evaluation results for Parks 3, 7, 9, and 10 are good. The evaluation results of Parks 1, 4, 5, 8, and 12 are general, and the evaluation results of Park 2 are qualified. The evaluation results reflect the actual level of waste logistics development in each park.

4.3. Constructing BP neural network

BP network structure design

As mentioned above, a three-layer BP neural network can complete the mapping from any n-dimension to any m-dimension with any accuracy. Therefore, the BP evaluation model adopts a three-layer structure, including an input layer, a hidden layer, and an output layer. The number of neurons in the input layer is 22, corresponding to 22 secondary indicators. The number of neurons in the output layer is 1, corresponding to the fuzzy evaluation results. The number of neurons in the hidden layer is determined by the empirical formula (10). The structure of the BP model is shown in **Figure 2**.

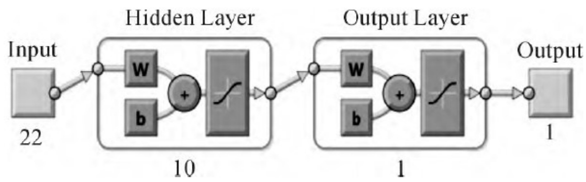

Figure 2. BP neural network structure.

Matlab software (2012 Edition) uses the function feedforwardnet to establish BP network, and its calling format is Net = feedforwardnet (hidden sizes, trainfcn), where net is the BP network to be generated. Hiddensizes refers to the number of neurons in the hidden layer, which is 10 by default. Trainfcn refers to the BP network training function, which is Levenberg Marquardt algorithm ('trainlm') by default.

Table 11. Fuzzy evaluation value of waste logistics system in the park

Park 1-6	**1**	**2**	**3**	**4**	**5**	**6**
Fuzzy evaluation value	73.769 4	68.942 3	87.455 7	74.558 1	73.874 9	92.203 6
Park 7-12	7	8	9	10	11	12
Fuzzy evaluation value	87.253 1	74.458 2	80.946 6	82.929 4	92.125 6	75.959 6

(1) Determine input and output items.

The data in **Table 10** is divided into two parts. Park 1–10 are selected as the training samples, and park 11 and 12 are the test samples. Divide the cell data in **Table 10** by 8 one by one to obtain the corresponding index grade membership table. According to the membership table and grade quantization standard [95, 85, 75, 65, 30], the quantitative values of each secondary index can be calculated. These values, together with the fuzzy evaluation results in **Table 10** (excluding test samples), constitute the input and output items of the BP neural network, as shown in **Table 12.**

Table 12. Input and output items of BP neural network

Index \ Park		Input item									
		1	2	3	4	5	6	7	8	9	10
	An	76.2500	65.6250	85	76.2500	70	88.7500	86.2500	80	81.2500	80
	A12	30	30	95	65	30	95	95	30	85	95
System input (A1)	A13	65	30	65	65	30	95	65	65	65	65
	A14	81.2500	59.3750	87.5000	80	76.2500	88.7500	90	82.5000	82.5000	80
	A15	75	65	95	65	65	95	75	65	65	65
	A21	80	74.3750	90	77.5000	71.8750	88.7500	90	81.2500	80	80
	A22	78.7500	76.2500	87.5000	73.1250	71.8750	86.2500	85	78.7500	78.7500	82.5000
System capability (A2)	A23	65	30	85	75	65	95	75	30	75	85
	A24	30	30	95	65	30	95	95	65	65	95
	A25	30	30	75	65	30	95	95	75	75	65
	A31	82.5000	76.2500	88.7500	77.5000	80	86.2500	87.5000	77.5000	76.2500	80
	A32	81.2500	75	91.2500	78.7500	77.5000	91.2500	88.7500	73.1250	77.5000	82.5000
Operational efficiency (A3)	A33	65	65	95	65	65	95	95	65	75	95
	A34	78.7500	80	92.5000	77.5000	78.7500	93.7500	91.2500	91.2500	83.7500	80
	A35	81.2500	77.5000	91.2500	82.5000	78.7500	87.5000	91.2500	81.2500	91.2500	77.5000
	A41	78.7500	81.2500	87.5000	81.2500	80	95	93.7500	78.7500	78.7500	81.2500
Treatment efficiency (A4)	A42	82.5000	81.2500	88.7500	78.7500	78.7500	88.7500	86.2500	77.5000	81.2500	80
	A43	78.1250	78.7500	88.7500	82.5000	81.2500	91.2500	95	82.5000	83.7500	78.7500
	A51	85	65	85	75	75	95	85	75	85	85
Environmental performance (A5)	A52	80	80	85	78.7500	81.2500	90	87.5000	78.7500	82.5000	78.7500
	A53	78.7500	76.2500	86.2500	70.6250	78.7500	92.5000	90	82.5000	83.7500	78.7500
	A54	80	71.2500	90	76.2500	77.5000	88.7500	87.5000	85	81.2500	81.2500
Output item		73.7694	68.9423	87.4557	74.5581	73.8749	92.2036	87.2531	74.4582	80.9466	82.9294

Using the data in **Table 12** for fuzzy evaluation is equivalent to the above fuzzy evaluation. The input and output items in **Table 12** can be used to obtain the output items of [targets = [inputs] × 10], 22 lines × 10 column matrixes, representing 22 secondary indicators and 10 parks. Targets = [1 × 10] = [737694, 689423, 874557, 745581, 738749, 922036, 872531, 744582, 809466, 829294] is one line, and the matrix of 10 columns represents the expected output of 10 parks.

(2) Set network parameters.

Use the vector inputs and targets as the input and output items of the BP network YQPJ_net to be generated. Due to the small momentum of the object. Net selects trraingdx as the training function. The hidden layer transfer function is the log-signal transfer function "logsig". The transfer function of the output layer is a pure linear function called "purelin". The learning function is the gradient descent learning method with momentum "learngdm". The performance function is the mean square error function "MSE" After the data items and network parameters are set, the command YQPJ can be called according to the designed network structure. Net = feed-forward net (10); generate the evaluation model YQPJ_net.

(3) training network.

YQPJ_net training parameters can take the default value using the function net. The training parameters set by trainparam are shown in **Table 13.**

After the training parameters are set, the train function is used to train the network. The calling format is: [YQPJ_net, tr] = train (YQPJ_net, inputs, targets), where inputs and targets are input and output items, respectively. YQPJ on the left and right of the equal sign_Net represent the neural network after training and before training, respectively. TR means to store the error information and step information in the process of network training.

Repeated training networks YQPJ_net, through 155 iterations of 10 training samples, ends network training when the maximum number of failures reaches 10, and the training accuracy reaches 906e-7. The network performance is shown in **Figure 3**, the training state is shown in **Figure 4**, and the fitting effect between input and expected output is shown in **Figure 5.**

Table 13. YQPJ_net training parameters

Project	Numerical training	Parameter
Maximum training times	1,000	Net. Trainparam Epochs=1,000
Maximum training time	Infinity	Net. Trainparam Time=inf
Minimum gradient	10-5	Net. Trainparam Min_ grad=1e-5
Maximum number of failures	10	Net. Trainparam Max_ fail=10
Learning rate	0.01	Net. Trainparam Lr=0.01
Learning rate lr	Growth ratio	1.05net. Trainparam Lr_ inc=1.05
Learning rate lr	Suppression ratio	0.5net. Trainparam Lr_ dec=0.5
Function increases maximum ratio	1.04	Net. Trainparam Max_ perf_ inc=1.04
Momentum factor	0.5	Net. Trainparam Mc=0.5

Figure 3 shows that the network verification performance reaches its best in 144 times, and the prediction error is 0010756. **Figure 4** shows YQPJ_net at the end of training (at 155 epochs): gradient = 0019835, validation checks = 10 times, and learning rate = 00019195. **Figure 5** shows that the correlation coefficient of the training group and verification group is $r = 1$, the correlation coefficient of the test group is $r = 1$, the comprehensive correlation coefficient of sample input and output is $r = 099829$, and the evaluation model, YQPJ_net, has achieved a good convergence effect.

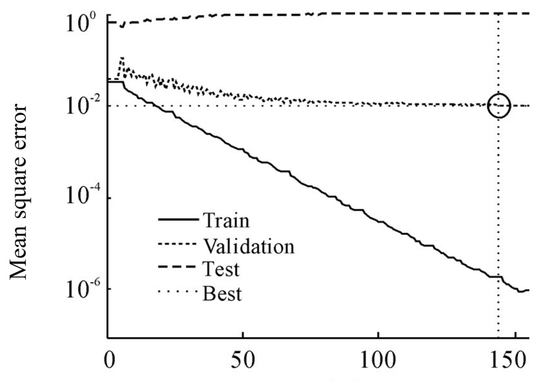

Figure 3. YQPJ_net training accuracy.

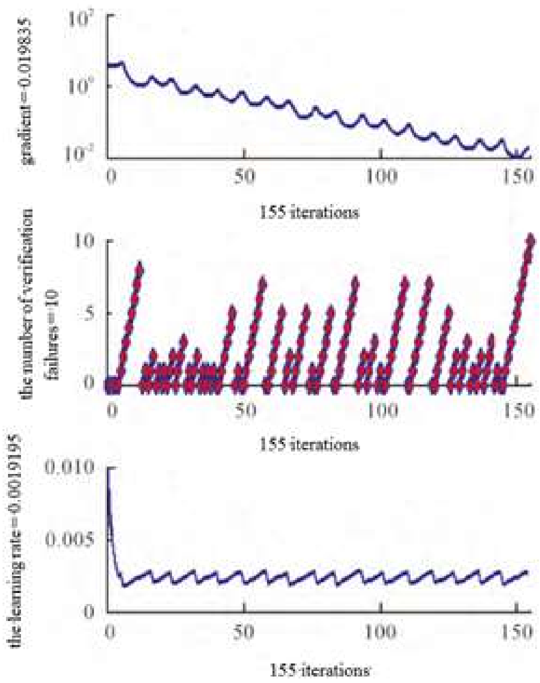

Figure 4. YQPJ_net training status.

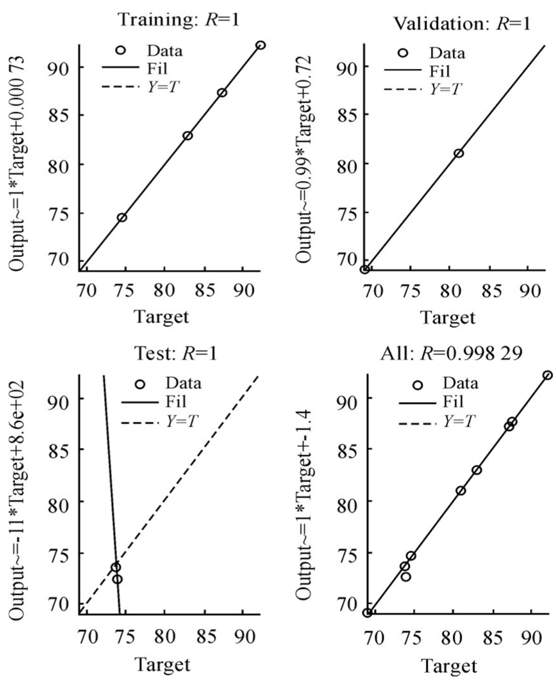

Figure 5. YQPJ_ net regression effect.

Complete YQPJ_ net training, the function sim is used for simulation test, and its calling format is outputs = sim (YQPJ_net, inputs), outputs represents network simulation output Network YQPJ_ Net simulation output Park 1–10 evaluation value is [737 899, 689 240, 874 513, 745 186, 739 637, 920 900, 873 914, 744 786, 809 371, 829 534], and the error with the actual evaluation value is [0020 476, 0018 339, 0004 380, 0039 489, 0088 766, 0113 600, 0138 340, 0020 357, 0009 471, 0024 015]. Net output error is only 0138 340, the error is acceptable, so YQPJ_net can be effectively used for fuzzy evaluation.

(4) Test analysis.

After quantifying the data from test sample parks 11 and 12 in **Table 9**, the input item test of the model can be obtained. Test is a matrix of 22 rows × 2 columns, representing 22 secondary indicators and 2 test parks call command. Result = YQPJ_ net (test), run YQPJ_ net can get the test value result = [909 794, 771 387] of Park 11 and 12. Compared with the fuzzy evaluation value [921 256, 759 596], the error is [11 462, 11 791]. The evaluation result is the same, that is, park 11 is excellent and park 12 is averagely visible, YQPJ_ net evaluation result is the same as the fuzzy evaluation result; the maximum error is only 155%, and the error is within the acceptable range, YQPJ_ net has high evaluation efficiency and a small error, and it can accurately complete fuzzy evaluation.

5. Conclusions

The construction of a waste logistics system evaluation system in the park is an important means to eliminate waste pollution in the industrial park and maintain the urban environment and residents' health. According to the index design principles and relevant requirements, this paper designs the waste logistics system evaluation index system of the secondary park from the five aspects of system input, system capacity, operation efficiency, treatment efficiency and environmental performance, and uses the analytic hierarchy process to determine the weight of indicators at all levels and give greater weight to environmental performance indicators, so as to promote the industrial park to continuously improve the level of comprehensive utilization of waste and resource recycling, strengthen the construction of industrial agglomeration and waste coupling system in the park to realize ecological and sustainable development. In the case analysis, the secondary index system is applied to the fuzzy evaluation of 12 parks to obtain the BP network based on the fuzzy evaluation method. The example analysis shows that the evaluation results of the BP evaluation model for each park are the same as the fuzzy evaluation results, and the error is within the acceptable range. It is a convenient and effective scientific tool to evaluate the performance of the waste logistics system in the park. The BP evaluation model can provide a relevant basis for government and enterprise decision-making and has a wide range of applications.

In order to effectively build the waste logistics system evaluation system in the park, the following policy suggestions are put forward:

First, build a perfect waste logistics system in the park. Industrial parks are an important part of regional economic growth, and industrial parks are also a major source of pollution in cities. The waste logistics system in the park is a social system that provides waste treatment services for the production enterprises in the park. Its core is the waste treatment and disposal enterprises in the park. The key problem is waste processing, reuse, and final treatment. The waste logistics system in the park has outstanding social and environmental benefits. In order to achieve sustainable development of the industrial park, on the one hand, it is necessary to strengthen the development of waste logistics in the park, eliminate waste pollution in the park, and improve the utilization technology and treatment level of waste in the industrial park. On the other hand, the government must compensate for the environmental benefits generated by the treatment and disposal of enterprises.

Second, correctly evaluate the index weight of the evaluation system of the waste logistics system in the park. The evaluation of the waste logistics system in the park involves many factors, and the setting of evaluation indexes and standards is complex. To ensure the objectivity and accuracy of evaluation results, we must rely on reasonable index system principles, requirements, and effective algorithms to minimize the impact of subjective factors. Therefore, a set of index systems reflecting different evaluation requirements should be designed to make the evaluation results better reflect the status of the waste logistics system in the park from the park itself, the external environment, and other aspects, so as to better evaluate the performance of the waste logistics system in the logistics park, promote the development and improvement of the logistics system, and improve the quality and efficiency of the logistics system.

Third, improve the construction of laws, regulations, and systems. According to relevant national laws and regulations and national eco-industrial demonstration park standards, formulate and promulgate scientific and perfect park waste management regulations and implementation rules, standardize park waste treatment and renewable resource utilization activities from the aspects of environmental protection, qualification license, capital investment, waste processing, reuse, and final treatment, and ensure the effective and standardized operation of the park waste logistics system.

Conflict of interest

The authors declare no conflict of interest.

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