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On Evaluation Model of Circular Economy for Iron and Steel Enterprise Based on Support Vector Machines with Heuristic Algorithm for Tuning Hyper-parameters

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Abstract: With more severe resource scarcity and environmental problems, the evaluation of circular economy in microcosmic level has become the focus of the academic world. Based on the concept of circular economy, this paper not only structures the evaluation index system of circular economy for iron and steel enterprises, builds the evaluation model of circular economy for iron and steel enterprises based on Support Vector Machine (SVM) with Radial Basis Function (RBF) kernel, but achieves the optimization of kernel function parameters, penalty factors and insensitive parameters based on a heuristic algorithm for tuning hyper-parameters. Furthermore, the evaluation model is tested for circular economy evaluation in the major iron and steel enterprises in China. The research demonstrates that the evaluation results of heuristic algorithm with SVM are more accurate, and this model is more suitable for iron and steel enterprises to evaluate circular economy, compared with the evaluation method of BP neural network.

Keywords: Heuristic algorithm for tuning hyperparameters, support vector machines, iron and steel enterprise, circular economy, evaluation model

1 Introduction

As an innovative economy model in the 21st century, circular economy has developed rapidly in recent years. Development based on circular economy will be essential for China to reach an overall well-off society by sustaining fast-paced economic growth, to mitigate negative ecological impact, and to creat more job opportunities. The term "circular economy" as mentioned in this paper is a generic term for the reducing, reusing and recycling activities conducted in the process of production, circulation and consumption. The basic principal is 3R, i.e.,reducing, reusing and recycling [1]. In less than a decade, the concept of circular economy has been introduced into China and has started to flourish. Since more and more government officials and enterprise estate managers talk frequently about the subject, its analysis and appraisal have become key topics in circular economy research. Internationally there have been many research achievements in the development of the analysis and evaluation of circular economy. According to the objective of evaluation, they can be divided into three categories: the macro-level (international/ country-based, etc.), the regional-level (province/ county-based, etc.), and the micro-level (enterprise-based, etc.), which covers regions, industries and some specific industry is. Several methods are applied to perform such evaluations, mainly including those using the following procedures [2–8]: principal component analysis, improved GA neural network, fuzzy comprehensive evaluation analysis, gray clustering analysis, data envelopment analysis, SVM, etc. Based on the research achievements, we have developed several methods and models for analysis [9–13]: life cycle analysis, energy analysis, the ecological footprint, material flow analysis, input-output analysis, ranking model, capital accumulation model, etc. In spite of many research achievements in the evaluation of the circular economy development, there are also limitations in the past research achievements: (1) The microscopic evaluation is much less developed than the macroscopic evaluation; (2) Indicators primarily rely on physical information, and do not include value information; (3) The relation between indicator system and circular economy is fuzzy. Therefore, we must make the optimal

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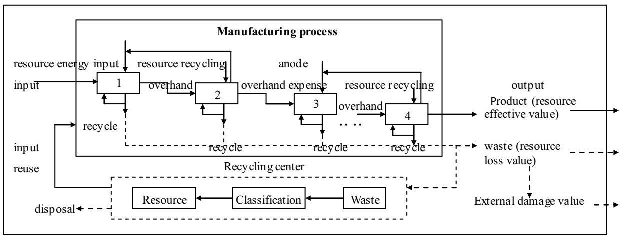

Fig. 1: Principle of Material Flow and Value Flow of Resource in Flow Manufacturing Enterprises under Circular Economy.

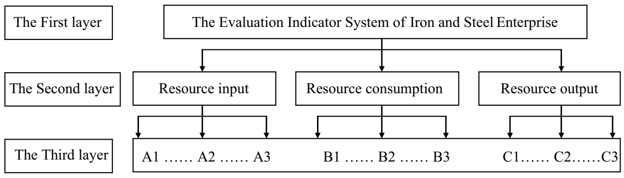

Fig. 2: The Hierarchical Structure Model of Evaluation Indicator System in Iron and Steel Enterprises.

choice to improve the efficiency and the accuracy of the comprehensive evaluation of circular economy in the Iron and Steel Industry.

2 The Construction of Evaluation Indicator System of Circular Economy in Iron and Steel Enterprises

In flow manufacturing enterprises, the materials generally include different elements (e.g. Fe-Iron in iron and steel plant), and the value of these elements changes along with the movement of raw materials in the specific enterprise (Figure 1).

Generally, after initial resources are acquired by an enterprise (Figure 1), they flow along the production processes until eventually, they are turned into new resources, namely finished products and wastes (partial refluxes, re-use and other partial disposals). Part of a resource may circulate in the interior processes of the enterprise or return to its original state. The resource value flows in the enterprise along with the associated physical forms.

Therefore, based on the mechanism of material flow and value flow of resources in flow manufacturing enterprises, this paper identifies raw material inputs, resource consumption in production process, and product outputs of an enterprise. Then, the paper determines the corresponding value of resource flow for the resource “entrance”, “circulation” and “export”. It further constructs comprehensive indicator systems for an enterprise subject to circular economy. The “entrance” indicator mainly focuses on resource productivity (output value/ resource inputs) and resource consumption of unit product. It reflects the economic nature of resources and the public wealth produced by unit resource consumption. It also identifies the relative degree of reduction of resource inputs as a function of the scale with which an enterprise adopts the reduction principles of circular economy. The “circulation” indicator emphasizes the yield ratio of the added value (value added/output value) and the ratio of internal recycling or re-use. It also establishes the re-use principle that can be quantified by calculating the relative proportions of the added value to the output value as well as from the ratios of resource re-use in an enterprise. The “export” indicator mainly attaches importance to eco-efficiency (pollutant discharge/ value added) and to the comprehensive utilization of waste. The waste utilization is directly connected to the pollutants that are converted into new resources. And the recycling principles are embodied in the waste utilization.

The principles of evaluation indicator systems include scientific, availability, independent, integrity, hierarchical, simplicity, dynamics, and general principles. Among them, there are four important basic principles:

(1) Scientific Principle.
It should be scientific and rational not only in the arrangement of structures of evaluation index system of circular economy in iron and steel enterprises, but also in the selection of indicators, the data sources of indicators and the evaluation method.

(2) Representation Principle
Typical and representative indexes should be selected because circular economy in iron and steel enterprises is involved in a wide range of fields and its evaluation index can not cover all the content.

(3) Operational Principles
First, index and related materials should be easily obtained; Second, the data source related to the evaluation index should be comparable and easily proceeded.

(4) Completeness Principle
As the circular economy in Iron and Steel enterprises is a complex system, index design should embody the industry characteristics of Iron and Steel enterprises to reflect the circular economy of the iron and steel enterprises systematically and objectively.

This paper constructs a comprehensive indicator system based on the principles of a circular economy by adopting a hierarchical structure model (Figure 2).

Based on the basic principles of technical process and environmental cost accounting, this paper calculates the resource loss cost and external environmental damage cost, which are advantageous in establishing the indicator system. After the determination of indicator forms, the selection of the primary indicators and any amendments to the indicator system, it determines its hierarchical structure. Through the collection of data and information from its iron and steel production, it determines the 60 primary indicators using mathematical statistics (e.g. frequency statistics, theory analysis, expert consultation,

Table 1: The Evaluation Indicator System of Circular economy in Iron and Steel Enterprises

first-level indicator	second-level indicator	third-level indicator
Evaluation Indicator System of Circular economy in Iron and Steel Enterprises (A)	resource input and consumption index B1	ratio of resource comprehensive yield C1
		main resource consumption of unit product (iron ore) C2
		energy consumption of unit value output C3
		comprehensive cost of unit product C4
	resource flow and recycling index B2	added value of unit value output C5
		ratio of industrial waste recycling C6
		ratio of interior energy utilization (coal gas, waste heat, etc) C7
		comprehensive cost loss of unit value output C8
	resource output and management index B3	comprehensive ratio of rolled steel into production C9
		“three-wastes” discharge of unit product C10
		disposal cost of unite waste C11
		external environmental damage cost of unite value output C12
		certification of environmental management system (qualitative) C13

* C9 is qualitative indicator.

etc.). It then rejects 24 of the indicators which are neither feasible nor accurate. It also eliminates further 23 indicators after principal component analysis and independent analysis, and finally leaves 13 indicators. The evaluation indicator system is shown in Table 1.

1st – resource input and consumption index:

(1) C1-total yield [market price*(finished products + semi-finished products + other products)] resulting from all resource inputs and consumption (e.g. Auto steel, electric steel, stainless steel, special steel, steel tube, etc.) in the production system.

(2) C2-unit consumption of main resource (iron ore).

(3) C3-total energy input per year/total value output per year.

(4) C4-comprehensive cost of unit product including total material cost, energy cost and system cost, etc.

2nd – resource flow and recycling index:

(1) C5-total value added per year/total value output per year.

(2) C6-recycling industrial waste consumption of Iron and steel enterprises per year/total industrial waste consumption of Iron and steel enterprises per year.

(3) C7-quantity of internal energy utilization per year/quantity of total energy utilization and energy loss per year (coal gas, waste heat, etc).

(4) C8-comperhensive cost loss per year (i.e. negative product cost)/total value output per year (covers resource cost loss and resource effective cost).

3rd – resource output and management index:

(1) C9-comprehensive ratio of rolling steel into production: steel content in the input of iron ore/steel content in the output of qualified steel products.

(2) C10-the discharge of wastewater, gas emission and solid waste per year/steel production per year.

(3) C11-this indicator reflects the pure profit loss, which explains the financial influence of the enterprise resulting from waste disposal.

(4) C12-external environment damage cost which occupies the proportion of the total product value output of Iron and steel enterprises. The numerator of the indicator (external environment damage cost) is the economic impact assessment value of environmental pollution (air pollution, water pollution, light pollution, noise, solid waste etc.) which is produced in production and operation activities (material supply, production, goods sale, resource recycling, waste discharge, etc.)of Iron and steel enterprises. It also includes the ecological damage originating from over-consumption of natural resources.

(5) C13-the establishment and certification of environmental management system.

3 The Construction of Circular Economy Evaluation Model for Iron and Steel Enterprises Based on Support Vector Machines with Heuristic Algorithm

3.1 Support Vector Machine

Support Vector Machine (hereafter referred to as SVM) is a new machine learning method proposed by Vapnik et al. in 1995 based on the VC dimension theory of statistical learning theory and structural risk minimization principle [14, 15]. With minimum structural risk instead of the traditional experience risk, in finite sample situation, SVM can get the global optimum by solving quadratic optimization problems, thus greatly reducing the arbitrariness of algorithm design. Compared with the neural network method, SVM effectively solves the model selection and learning problem, nonlinear problem, the curse of dimensionality and local minimum problems. Besides, SVM has peculiar advantage in resolving the small samples, nonlinear and high dimensional pattern recognition problem. Currently, SVM algorithm has been widely applied in pattern recognition, regression estimation, probability density estimation, dimensionality reduction, etc. [16–18].

The evaluation of circular economy for iron and steel enterprise is a typical non-linear, high-dimensional pattern classification problem, as well as a multi-link, multi-level system. It is difficult for the whole system to unify description because there are some complex relationships between inputs and outputs of each subsystem, and the correlation is strong. The evaluation method of circular economy for iron and steel enterprises based on SVM with heuristic algorithm for tuning hyper-parameters proposed in this paper has verified the feasibility and rationality of the method by empirically analyzing and comparing the evaluation results based on the BP neural network model.

3.2 The Parameters Determination of Support Vector Machine with Heuristic Algorithm for Tuning Hyperparameters

The heuristic algorithm for tuning hyper-parameters is an optimization algorithm by Jingxu LIU, et al. in 2007 [19]. This paper determines the parameters of support vector machine based on a heuristic algorithm for tuning hyper-parameters. The paper also optimizes the parameters of kernel function, the penalty factor and insensitive parameters of evaluation model based on SVM with the kernel function of the RBF (Radial Basis). The main idea of optimization to the parameters of SVM based on heuristic algorithm for tuning hyper-parameters is as follows: First, for a fixed ε, find a better set of combinations (C,σ) in evaluation model by using stepwise search methods; Second, identify the best ε in evaluation model in the obtained better combinations (C,σ); Then, find the best group in these groups of the better combination (C,σ) with the best ε; Finally, determine the optimal values of precise parameters with a local search algorithm near the best points based on the evaluation model of support vector machine based on a heuristic algorithm for tuning hyper-parameters.

Specific steps of the algorithm are as follows:

(1) Set the ranges and interval values for parameters C, ε and σ:

$$[C_1,C_2,\ldots,C_m]\times[\varepsilon_1,\varepsilon_2,\ldots,\varepsilon_n]\times[\sigma_1,\sigma_2,\ldots,\sigma_l].$$

Assume that the values of parameters in accordance with the serial number in ascending order;

(2) the initial C, ε and σ: $\varepsilon\leftarrow\varepsilon_1$, $C\leftarrow C_1$, $\sigma\leftarrow\sigma_1$, set $i=j=1,k=0$.
Calculation the CV error: $E(C_1,\varepsilon_1,\sigma_1)$, $E0\leftarrow E(C_1,$ ε_1, $\sigma_1)$;

(3) fixed C_i, ε_1, search for the best σ_j:
If $E(C_i,\varepsilon_1,\sigma_{j+1})<E_0$, and $j<l$:
Calculation of $E(C_i,\varepsilon_1,\sigma_{j+1})$;
$E0\leftarrow E(C_i,\varepsilon_1,\sigma_{j+1})$, $j\leftarrow j+1$, iteration;
If $j=l$: recording the combination (C_i,σ_j): $k\leftarrow k+1, P_k\leftarrow(C_i,\sigma_j)$, to switch 5;
Otherwise: turn 4;

(4) fixed ε_1, σ_j, search for the best C_i:
Calculation of $E(C_{i+1},\varepsilon_1,\sigma_j)$;
If $E(C_{i+1},\varepsilon_1,\sigma_j)<E_0$, and $i<m$:
$E0\leftarrow E(C_{i+1},\varepsilon_1,\sigma_j)$, $i\leftarrow i+1$;
Calculation of $E(C_{i+1},\varepsilon_0,\sigma_j)$, iteration;
If $i<m$: $k\leftarrow k+1$, $P_k\leftarrow(C_i,\sigma_j)$;
$E0\leftarrow E(C_{i+1},\varepsilon_1,\sigma_j)$,
$i\leftarrow i+1, j\leftarrow j+1$, turn 3;
Otherwise: $k\leftarrow k+1$, $P_k\leftarrow(C_i,\sigma_j)$, turn 5;

(5) the value of fixed parameters C and σ at $P1$, search for the best $\varepsilon 0$:
Calculation of $E(P_1,\varepsilon_1)$, $E0\leftarrow E(P_1\ ,\varepsilon_1)$;
H from 1 to n loop:
If $E(P_1,\varepsilon_h)<E_0$: $E_0\leftarrow E(P_1,\varepsilon_h)$;

(6) Parameter ε value to ε_0, to find the optimal combination in the group (C,σ):
Calculation of $E(P_1,\varepsilon_0)$, $E0\leftarrow E(P_1,\varepsilon_0)$;
K cycle from 1 to p (p is a number of combination (C, σ)):
If $E(P_k,\varepsilon_0)<E_0$: $E_0\leftarrow E(P_k,\varepsilon_0)$;

(7) Search for the exact combination with optimal parameters.
Partial search algorithm for LS:
$LS\leftarrow(C_0,\varepsilon_0,\sigma_0)$;
Run LS algorithm;
Back to the optimal parameter values.

Compared with the other algorithms, the algorithm mentioned above can find the approximate optimal solution by ladder searching method, and then use the local algorithm to strike more accurate solutions to improve the efficiency of parameter optimization.

The choice of parameters of circular economy evaluation model for iron and steel enterprises need to determine the range of parameters in SVM. As it is selected as a three-dimensional input data for circular economy evaluation model of iron and steel enterprises in this paper, according to the empirical formula [20] of σ in the range of $[0.1\ \sqrt{d},\sqrt{d}]$ and the d being the dimension of input data, the paper selected σ in the range of [0.1,3]. Insensitive factor ε can also be obtained by the empirical formula $\varepsilon=3\sigma_N\sqrt{\ln N/N}$. N is the sample size of the training set, σ_N is the standard deviation of noise, $\sigma_N=\frac{N^{0.2}k}{N^{0.2}k-1}\cdot\frac{1}{N}\sum_{i=1}^{N}(\overline{y_i}-y_i)^2$, and the range of k generally belongs to [2, 7], from which the ε can be calculated in the range of $[0.005,2]$. As penalty factor C is set to $C\in[d\cdot10^{-1.5},d\cdot10^{25}]$ based on experience, the range of penalty factor in the evaluation model of circular economy is set to $[0.05,280]$ in this paper. Finally, we can obtain the parameters $(C=15,\sigma=0.015,\varepsilon=0.22)$ for evaluation model of circular economy based on the SVM with RBF function.

At the same time, the parameters coming from search algorithm are substituted into the evaluation model of circular economy, and the testing set is applied in testing the accuracy of evaluation model. In this paper, two error indicators are used to measure evaluation effect: the mean square error (MSE) and mean absolute percentage error (MAPE) with the expression as follows:

$$MSE = \sqrt{\sum_{i=1}^{M} (\overline{y_i} - y_i)^2 / M} \qquad (1)$$

$$MAPE = \frac{1}{M} \sum_{i=1}^{M} \left| \frac{\overline{y_i} - y_i}{y_i} \right| \qquad (2)$$

The coefficients $\overline{y_i}$ is the predicted value of evaluation model, coefficients y_i is the true value and M is the number of test data. With 40 selected in the paper, the final calculation results is the MSE $= 0.0589$ and MAPE $= 0.0415$. From the analysis results of MSE and the MAPE, we know that the evaluation accuracy and the stability of the model are ideal. Therefore, it can achieve the goal of adaptive optimization of kernel function parameters, penalty factor and insensitive parameters by heuristic algorithm for tuning hyper-parameters, thus obtaining a very good result for the evaluation model of circular economy in iron and steel enterprises.

3.3 The Evaluation Model of Circular Economy Based on Support Vector Machine

The basic idea of SVM is to transform the input space into a high-dimensional space through a non-linear transformation of the inner product function definition, in search of the non-linear relationship of the input and output variables in this high-dimensional space. SVM has a two-tier structure: the first layer is used to select the kernel function to determine the number of support vectors; the second layer is used to build optimal classification surface layer in the corresponding feature space. And it initially researches fitting and regression problems for linear function of linear sample points in SVM, and then gradually extends to non-linear and multi-classification problem. This paper only take the regression vector machine as an example with the details for the other related models and principles in related documents [21–25].

It can be transformed into the dual problem for optimal classification surface of the second layer by utilizing the Lagrange optimization method, which means to solve the maximum value of following function with the constraints $\sum_{i=1}^{n} y_i a_i = 0$ and $a_i \geqslant 0 (i = 1, 2, \ldots, n)$:

$$Q(a) = \sum_{i=1}^{n} a_i - \frac{1}{2} \sum_{i,j=1}^{n} a_i a_j y_i y_j (x_i x_j) \qquad (3)$$

In the formula, a_i is the Lagrange multiplier corresponding to each sample. It can obtain the uniqueness by solving the secondary function optimization problems under inequality constraints. The optimal classification function can be obtained:

$$f(x) = \text{sgn}(\omega x + b) = \text{sgn}\left\{\sum a_i^* y_i (x_i x) + b^*\right\} \qquad (4)$$

Nonlinear problems can be transformed to linear problems in a high-dimensional space through the nonlinear transformation. and then the space is transformed to find the optimal classification surface. According to the functional theory, if some kernel functions $K(x_i, x_j)$ are used to satisfy the Mercer condition, linear classification can be achieved after a non-linear transformation, without knowing the form of transformation nor increasing the complexity of calculation. The formula of objective function (3) is changed into:

$$Q(a) = \sum_{i=1}^{n} a_i - \frac{1}{2} \sum_{i,j=1}^{n} a_i a_j y_i y_j K(x_i x_j) \qquad (5)$$

Classification function is changed into:

$$f(x) = \text{sgn}(\omega x + b) = \text{sgn}\left\{\sum a_i^* y_i K(x_i x_j) + b^*\right\} \qquad (6)$$

Currently, the most commonly used kernel functions of SVM are mainly four types:

Linear Function:

$$K(x_i, x) = x_i x \qquad (7)$$

Polynomial Function:

$$K(x_i, x) = (x_i x + 1)^d \qquad (8)$$

Radial Basis Function:

$$K(x_i, x) = \exp(-|x - x_i|^2 / 2\sigma^2) \qquad (9)$$

Sigmoid Function:

$$K(x_i, x) = \tanh(k x_i x + \theta) \qquad (10)$$

Based on grade standards for circular economy evaluation of iron and steel enterprises, it can be simulated to generate a sufficient number of evaluation index sequence by using random technology. Set the lower limits a_j^k and upper limits b_j^k of evaluation index value in the evaluation Rank k and y_j^k is the corresponding evaluation level, stochastic simulation formula for evaluation index is as follows:

$$x_{ij}^k = rand(n_k)(a_j^k - b_j^k) + b_j^k \qquad (11)$$

i means index sequence capacity generated by an evaluation level; k means evaluation rank number; j means evaluation index number.

It generate n_k group (x_{ij}^k, y_i^k) for the evaluation rank k by formula (11), then rearrange the subscript, and get the new sequence (x_{ij}, y_i) which are taken as training samples.

In order to evaluate classification more accurately, we can assume that there are x_{ij} evaluation index in system evaluation and the evaluation grade is y_i, of which i means the capacity of indicators sequences, $i = 1,2,...,N$ and j means the numbers of evaluation index, $j = 1,2,...,M$ with x_{ij} represents the input SVM model and y_i represents the output in SVM model.

The Matlab7.0 Software is applied in programming calculation in this paper. The software is featured by relatively simple adjustments for parameters and fast calculation, and therefore is widely applied in research fields.

4 Empirical Analysis

4.1 Standardization Processing of Data

The indicators will be incomparable due to the various types of indicators in evaluation index system. Therefore, differences generated from different dimensions through the standardization of each indicator should be eliminated. Assume that there are m items of evaluation factors in evaluation system of circular economy for iron and steel enterprises, as the index value of evaluation criteria and the index value of the monitoring samples, x_i will be normalized as follows

$$xs_i = \begin{cases} x_i B \max x_i & (a) \\ \min x_i B x_i & (b) \end{cases} \tag{12}$$

xs_i means the standardized processing value of evaluation factors i. It process the indicators with smaller value and more excellent quality according to formula (a); it processes the indicators with greater value and more excellent quality according to formula (b). In order to generate more learning samples, linear interpolation is needed for standardized data evaluation in the adjacent intervals, and then learning samples between the various known levels would be generated randomly, out of which some are selected as training samples, and other parts are as testing samples.

4.2 The Determination of Evaluation Standards

In accordance with the advanced standard of foreign and domestic steel companies as well as the relevant standards of domestic steel industry, the standards of indicators and evaluation levels are listed as follows:

The grade standards of qualitative indicators are determined by questionnaire and expert advice, and standardized assignments are between [0,1]. For example, the maximum value for certification of environmental management system is assigned 1, and the minimum value for certification of environmental management system is assigned 0.

Table 2: The Grades and Standards of Evaluation

Grade	X1	X2	X3	X4	X5	X6
I	$\geqslant 1.80$	< 1.25	< 1.20	< 3000	$\geqslant 0.45$	$\geqslant 0.9$
II	$\geqslant 1.65$	< 1.30	< 1.25	< 3400	$\geqslant 0.40$	$\geqslant 0.7$
III	$\geqslant 1.50$	< 1.35	< 1.30	< 3800	$\geqslant 0.30$	$\geqslant 0.5$
IV	< 1.50	$\geqslant 1.35$	$\geqslant 1.30$	$\geqslant 3800$	< 0.30	< 0.5

Continue Table 2

Grade	X7	X8	X9	X10	X11	X12	X13
I	$\geqslant 30.0$	< 0.10	$\geqslant 1.05$	< 2.00	< 150	< 0.01	$\geqslant 0.95$
II	$\geqslant 25.0$	< 0.20	$\geqslant 1.00$	< 2.50	< 180	< 0.03	$\geqslant 0.75$
III	$\geqslant 20.0$	< 0.30	$\geqslant 0.90$	< 3.00	< 200	< 0.05	$\geqslant 0.5$
IV	< 20.0	$\geqslant 0.30$	< 0.90	$\geqslant 3.00$	$\geqslant 200$	$\geqslant 0.05$	< 0.5

Table 3: The Data Table of Testing Sample

No.	X1	X2	X3	X4	X5	X6
1	1.686	1.223	1.254	3454	0.343	0.653
2	1.674	1.443	1.336	4289	0.233	0.445
3	1.974	1.092	1.109	2847	0.536	0.975
4	2.265	1.281	1.045	2944	0.465	0.943
5	1.532	1.193	1.283	3532	0.385	0.843
6	1.754	1.584	1.423	3953	0.194	0.354
7	1.679	1.232	1.231	3185	0.404	0.843
8	1.765	1.247	1.243	3253	0.349	0.835
9	1.5789	1.383	1.284	4195	0.238	0.443
10	1.624	1.283	1.332	3685	0.345	0.353
11	2.153	1.143	1.129	2549	0.509	0.944
12	1.574	1.284	1.294	3495	0.354	0.743
13	1.695	1.287	1.285	3365	0.315	0.543
14	2.287	1.123	1.084	2653	0.494	0.945
15	1.467	1.213	1.223	3576	0.843	0.795
16	1.932	1.492	1.439	4369	0.215	0.396
17	1.547	1.305	1.184	3454	0.410	0.693
18	2.071	1.319	1.253	3365	0.375	0.724

4.3 Result Analysis

Empirical analysis is exercised in this paper for domestic major iron and steel enterprises in China, and statistical data comes from the China Statistical Yearbook and the related documents of iron and steel industry. The paper selects 50 iron and steel enterprises as samples, out of which 32 are randomly selected as learning samples, and 18 as testing samples. The data table of testing samples is listed in Table 3.

Learning process adopts the method of voting decisions. If the current learning training results show that the testing sample x belongs to evaluation scale i, the scores of evaluation scale i plus 1, otherwise, the number of votes of class j plus 1, and finally the class with maximum score is taken as the level of x.

Compared with other parameters, the numerical limit of the radial basis function is relatively less, and its model is more practical, and the sample can be nonlinearly mapped to a higher dimensional space to solve the non-linear relationship between the classes and attributes.

Continue Table 3

No.	X7	X8	X9	X10	X11	X12	X13
1	23.59	0.183	0.939	2.543	184	0.023	0.694
2	18.84	0.325	0.833	3.398	227	0.058	0.384
3	32.74	0.084	1.143	1.585	133	0.005	0.853
4	35.34	0.090	1.082	1.778	103	0.008	0.934
5	22.23	0.122	1.054	2.786	175	0.021	0.734
6	17.43	0.323	0.824	3.782	232	0.065	0.345
7	27.85	0.158	0.984	2.259	163	0.028	0.545
8	21.93	0.115	0.943	2.785	185	0.054	0.834
9	17.75	0.374	0.714	3.463	248	0.048	0.432
10	24.63	0.136	1.074	2.634	234	0.035	0.434
11	33.54	0.095	1.076	1.589	113	0.010	0.965
12	26.64	0.268	1.028	2.834	193	0.021	0.589
13	25.58	0.158	1.003	2.344	235	0.039	0.534
14	31.83	0.094	1.095	1.421	120	0.011	0.865
15	28.75	0.163	1.034	2.214	185	0.013	0.743
16	15.66	0.328	0.779	3.829	239	0.063	0.385
17	29.05	0.165	1.043	2.348	176	0.024	0.628
18	32.04	0.288	1.024	2.094	183	0.014	0.492

Table 4: The Results of Comparative Analysis

No.	BP	SVM	No.	BP	SVM
1	0.743744	II	10	0.803232	II
2	0.593404	IV	11	0.840493	I
3	0.847389	I	12	0.719832	III
4	0.874932	I	13	0.784304	II
5	0.653543	III	14	0.864398	I
6	0.553244	IV	15	0.649349	III
7	0.694832	III	16	0.600132	IV
8	0.764923	II	17	0.684394	III
9	0.574924	IV	18	0.753949	II

Therefore, with the radial basis function as nucleus, arithmetic program is compiled with Matlab7.0 and the results are calculated with the BP neural network model. The results of the comparison are shown in Table 4:

From the table above, the evaluation results by the two methods are basically identical. Compared with the evaluation results of the model of BP network, the evaluation results of support vector machine are more realistic, and more suitable for enterprise to evaluate circular economy.

5 Conclusion

As a new development pattern, circular economy is an important strategic path for an enterprise to develop sustainably. It is necessary to build a reasonable evaluation system that maches the circular economy and sustainable development strategy of an enterprise. Based on SVM with Radial Basis Function (RBF) kernel and combined with the characteristics of iron and steel enterprises, this paper structures an evaluation index system of circular economy and an evaluation analysis model by a heuristic algorithm for tuning hyper-parameters in iron and steel enterprises. The evaluation model is tested for circular economy evaluation in some major iron and steel enterprises in China. Compared with the evaluation method of BP neural network, this model is more accurate, intuitive, and more suitable for iron and steel enterprises to evaluate circular economy. Thus, it provides a scientific tool to evaluate the status of the circular economy in iron and steel enterprises. And, the model can be widely used in iron and steel industry. In addition, it provides a good reference for other businesses and industries. It is evident that with the in-depth research of circular economy evaluation in the iron and steel enterprises, the evaluation will gradually be more accurate and complete.

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