DOI: 10.23977/infse.2024.050413
ISSN 2523-6407 Vol. 5 Num. 4

The Security and Economic Evaluation Method of Industrial Control System Based on BP Neural Network

Jianfeng Huang[1,*], Jiaxuan Hu[2]

[1]*Electronics and Information Engineering, North China Institute of Science and Technology, Langfang, 065201, China*
[2]*Electric Power College, Inner Mongolia University of Technology, Hohhot, 010080, China*
[*]*Corresponding author*

Keywords: BP neural network, Industrial control system, Evaluating, Simulation, Insert

Abstract: In recent years, with the deepening of the integration of industrialization and intelligence, the disadvantages of the traditional industrial system, low processing efficiency and the inability to make accurate judgments in the face of complex situations are gradually prominent. At the same time, the industrial system is also faced with increasing threats of security, the economy and other factors. Based to the problems of industrial systems and the current situation and characteristics of industrial control systems, this paper proposes an evaluation method of industrial control systems based on BP neural network. First, the industrial database is formed based on the industrial field sensor, and the BP neural network model is established to comprehensively analyze the system. Then, the effectiveness of this method is verified through numerical simulation and simulation prediction, realizing the risk prediction of a complete industrial control system. The experimental results show that this method can make a comprehensive analysis of various factors of the industrial control system, and accurately predict the specific factors with risks in the system, with high computational efficiency and strong accuracy.

1. Introduction

The Industrial Control System (ICS) is the of a variety of control systems used for industrial production[1]. With the rapid development of artificial intelligence, deep learning and other application technologies, and with the continuous in-depth connection and combined application of industrialization and intelligent industry, the traditional industrial control system has no longer met the needs of the current industrialization era. In the trend from closed to open, this has brought security risks to the industrial Internet[2]. Through the alarm analysis, it is found that the causes of alarm flooding are mostly unscientific alarm design, unreasonable setting of control configuration and alarm parameters[3]. From the economic level, the traditional industrial control system makes it difficult to control the current economic factors and is more likely to lose control and repair, causing substantial damage. Therefore, in view of the security and economic factors of the industrial control system, this paper carries out deep learning and drill based on BP neural network, and evaluates the security factors and economic factors of the industrial control system, which is helpful to provide an effective analysis and prediction of the current existing risks in the system.

In essence, the evaluation of security protection capability is to evaluate whether the inherent security attributes and security guarantee methods of the system itself meet the special security requirements of the application scenario based on specific security objectives and adopting certain theories and methods[4]. In recent decades, the awareness of paying attention to the system evaluation has been continuously strengthened, and the evaluation method of industrial control system also has a high development and innovation. There are three types of comprehensive reliability assessment methods: exact method, classical method[5].At present, the reference performance in the evaluation literature of industrial control system mainly includes stability indicators, reliability, maintainability, communication ability, durability, accuracy, real-time and other indicators. The industrial control safety prevention and control system adopts the three-layer structure of data collection, dynamic perception and centralized management. The management deployment is designed as a company-level management platform to realize the receiving and issuing of edge network events and notification information. The security management platform collects the reported data of all edge platforms and makes comprehensive analysis, forming a comprehensive visualization of the industrial information security situation[6]. It has been widely used in military industry, aerospace and energy fields, involving national defense security, biopharmaceutical, water conservancy and hydropower, petroleum exploitation, metallurgy, chemical materials, transportation, new agricultural production and large-scale manufacturing industry.[7]

Due to the characteristics of private components in the industrial control field and complex scenarios, the traditional identification method based on protocol specification and program implementation respectively have the problems of strong scenario dependence and high identification cost of identification methods, which are unable to quickly identify the operation fields when the scenario and protocol are unknown[8]. This paper mainly considers two factors in evaluating the industrial control system: Safety and economy. For security considerations, the traditional method is only for the industrial control system information domain or assess the risk of the physical domain, it not only has obvious inertia and lag problem, but also has slow and time-varying characteristics[9]. In view of the economic consideration, the traditional algorithm only considers the cost and system loss, and there are rigid problems. In order to address the above shortcomings, this paper considers taking the BP neural network to predict the system, the principle is simple, the prediction effect is good, the use is flexible, and can be better applied in industrial field practice.

The main advantage of neural network control is that for the complex industrial control system, which uses its own adaptive ability to obtain the relationship between the parameters, and the obtained results are very close to the actual situation. In this study, a method for evaluating the safety and economic parameters of industrial control system based on BP neural network is proposed. BP neural network is established by combining the strain detection data of industrial control systems to analyze the risk factors of the system. Finally, it can test the accuracy and effectiveness of the method through numerical simulation and simulation.

2. Industrial Control System

2.1 The model of the industrial control system

The model in this paper mainly includes three aspects: data extraction, risk identification, and risk assessment, as shown in the Figure 1. In an industrial control system, data collection is the basic part of evaluating an industrial control system. At present, the modern industrial control system has a huge architecture, including some complex parts and various data types. Therefore, a variety of sensor types are used in the industrial control system to collect the data of the industrial site, forming the database of the industrial control model in this paper.

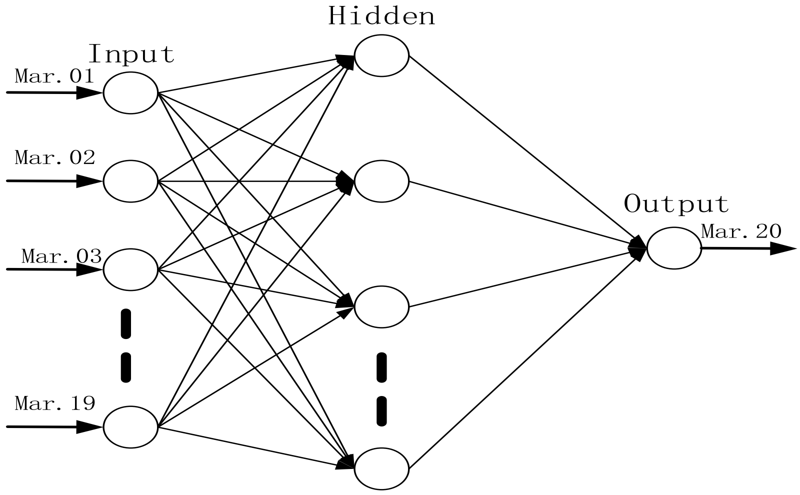

Figure 1: Neural network structure

2.2 Data preprocessing of industrial control system

Due to the diversified forms of data in industrial sites, including temperature, humidity, human factors, etc., a considerable part of the data is not directly related to the research content, which needs to be deleted. In addition, a part of the data cannot be directly used, so data and process data are needed to take methods for simplifying. Therefore, the data in the database needs to be preprocessed, namely. In the face of complex results that may appear in industrial sites, to achieve economy and timeliness, this probability needs to be calculated based on the known data. The industrial control system evaluation itself is a multi-factor prediction problem, so it needs reasonable and unified data. This paper proposes a simple data processing method, which uses the already obtained data to synthesize new data, and follows the principle of data utilization and constructs the database.

Step 1: Standardization processing. Unify the format and unit standards of the data, and convert the required data types into numerical types for later utilization. The normalization method used in this paper is the z-score normalization.

1). The arithmetic mean x_i and standard deviation S_i of each index were obtained,

2). Standardization processing:

$$z_{ij} = \frac{(x_{ij} - x_i)}{s_i} \tag{1}$$

where z_{ij} is the standardized variable value, x_{ij} is the actual variable value.

3). Adjustment the positive and negative signs before the inverse indicator:

The normalized variable values fluctuate around 0. Greater than 0 means higher than average, and less than 0 means lower than average.

Step 2: Normalization processing: After the collection of data in the industrial system, although the data has been standardized, the data is still very different and needs to be normalized. The system converts the obtained data values into the interval of [0,1]. Through data preprocessing, it can effectively reduce the complexity of the system data, improve computing efficiency, and also improve the accuracy and efficiency of the model. The input sample data x is normalized.

$$Z = \frac{(Z_{max} - Z_{min})(x - x_{min})}{x_{max} - x_{min}} \tag{2}$$

where Z is the normalized data, Z_{max}=1, Z_{min}= -1. X_{max} is the maximum sensor response value, X_{min} is the minimum sensor response value.

2.3 System parameter

(1) Safety parameters of the system

The sources of safety parameters in this article are described below Table 1.

Table 1: Factor of safety

Hardware parameters (**AV**)	Software parameters (**AC**)	Man's activity ***(PR)***	Electromagnetic compatibility (EMC)	Environment effects ***(P)***
temperature, pressure, humidity, dust prevention, mechanical faults such as valve and alarm faults.	communication protocol vulnerability, virus invasion, hacker attack, supply chain attack.	equipment operation error, legal outreach, without authorization to control.	power interference.	conflagration, unexpected power failure.

The formula for calculating the difficulty of security risk utilization is proposed in (3).

$$\mathrm{Base}score(p)=\frac{8.22\times AV\times AC\times PR\times UI}{10} \tag{3}$$

(2) Economic performance parameters of the system are described below Table 2.

Table 2: Economic factors

Property (**I_a**)	Personnel(**I_b**)	Information(**I_c**)
total assets, labor cost, asset load, administration cost	technical backbone, labor workers, core management	core technology, business data

The variables λ_1, λ_2, λ_3 are introduced to distinguish the asset loss, personnel loss, and information security loss caused by the event. The loss L is calculated by (4).

$$L=\lambda_1 I_a+\lambda_2 I_b+\lambda_3 I_c \tag{4}$$

where λ_1, λ_2, λ_3 represent the weighting coefficient corresponding to asset loss, personnel loss and information security loss respectively, (I_p) shows the normalization result of personnel loss, (I_s)represents the loss of information security confidentiality, integrity and availability, and (I_a) represents the asset loss, which is obtained from the following equation:

$$I_a=a_1\times\frac{N_1}{N}+a_1\times\frac{N_1}{N},a_1+a_2=1 \tag{5}$$

where(I_a)represents the importance of the asset, N_1 and N_2 represent the number of assets that can still run after the event and the number of assets that cannot run, N represents the total number of assets, a_1 and a_2 are the corresponding weighting coefficient, where a_1 + a_2 = 1.

2.4 Data analysis

The risk value of the system is the risk value of the system, as follows Table 3:

Table 3: Risk value of the system ICA.

Range of risk values	Risk grade	Action requirements
0-0.2	Low	no need to act
0.2-0.4	Medium-low	optional
0.4-0.6	Middle	optional
0.6-0.8	Medium-high	take improvement measures
0.8-1	High	take improvement measures immediately

3. The BP neural network

3.1 BP neural network

BP neural network is a widely used neural network model, the working principle is based on an error backpropagation algorithm. This neural network model has the advantages of learning and adaptive ability, able to model and deal with complex nonlinear problems. This paper proposes a method to use the BP neural network prediction algorithm for data learning to provide accurate and reliable evaluation results.

The BP neural network is a forward network. It has an input layer, an output layer, and one or more hidden layers, with no forward connection between neurons in the same layer and different layer neurons. According to the approximation theory of multilayer forward networks, three-layer neural networks with sigmoid non-linear activity functions can map with arbitrary precision from the input space to the output space with a sufficient number of hidden neurons. Therefore, this paper only discusses the three-layer forward neural network.

The training process of BP neural network mainly includes two aspects: forward propagation of signal and backpropagation of weight bias correction.

1) Forward propagation of the signal: in the process of forward propagation, the input data is weighted by multiple layers to obtain the output result.

Input net_i for the *i*th node of the hidden level:

$$net_i = \sum_{j=1}^{M} w_{ij} + \theta_i \tag{6}$$

Output O_i for the *i*th node of the hidden level:

$$o_i = \Phi(net_i) = \Phi(\sum_{j=1}^{M} w_{ij} + \theta_i) \tag{7}$$

Input net_k for the *i*th node of the input level:

$$net_k = \sum_{i=1}^{q} w_{ki} y_i + a_k = \sum_{i=1}^{q} w_{ki} \varphi(\sum_{j=1}^{M} w_{ij} + \theta_i) + a_k \tag{8}$$

Input o_k for the *i*th node of the input level:

$$o_k = \Psi\left(net_k\right) = \Psi[\sum_{j=1}^{M} w_{ki} \phi(\sum_{j=1}^{M} w_{ij} x_i + \theta_i) + a_k] \tag{9}$$

2) Backpropagation of error: in the process of backpropagation, the difference between the output and the actual result is calculated, and the difference is calculated as the gradient of each weight and

bias through the backpropagation algorithm, to update the value of the weight and bias.

The error backpropagation algorithm is a neural network training algorithm based on gradient descent, which x_i represents the input of the j th node in the input layer, j=1,2, M,w_{ij} represents the weights between the i th node in the hidden layer and the input layer j and the nodes, θ_i represents the threshold of the i th node in the hidden layer, Φ represents the incentive function of the hidden layer, w_{ki} represents the weights between the k th node in the output layer and the i th node in the output layer, i=1,2, q, a_k represents the threshold of the k th node in the output layer, k=1,2, L, Ψ represents the incentive function of the output layer, o_k represents the output of the k th node in the output layer.

For each sample p the quadratic type error criterion function E_p is shown by (10).

$$E_p = \frac{1}{2}\sum_{k=1}^{L}(T_k - o_k)^2 \tag{10}$$

The total error criterion function of the system for the p training samples follows by (11)

$$E_p = \frac{1}{2}\sum_{p=1}^{K}\sum_{k=1}^{L}(T_k^p - o_k^p)^2 \tag{11}$$

For each single cycle, the model corrects the weights and bias once. The output layer weight correction $\triangle w_{ki}$, the output layer threshold correction $\triangle a_k$, the hidden layer weight correction $\triangle w_{ij}$, and the hidden layer threshold correction $\triangle \theta_i$.

$$\Delta \mathrm{w}_{\mathrm{ki}} = -\eta \frac{\partial \mathrm{E}}{\partial \mathrm{w}_{\mathrm{ki}}}$$

$$\Delta \mathrm{a}_k = -\eta \frac{\partial E}{\partial a_k} \tag{12}$$

$$\Delta \mathrm{w}_{\mathrm{ij}} = -\eta \frac{\partial \mathrm{E}}{\partial \mathrm{w}_{ij}}$$

$$\Delta \theta_i = -\eta \frac{\partial E}{\partial \theta_i} \tag{13}$$

Output layer weight adjustment formula:

$$\Delta \mathrm{w}_{\mathrm{ki}} = -\eta \frac{\partial \mathrm{E}}{\partial \mathrm{w}_{\mathrm{ki}}} = -\eta \frac{\partial \mathrm{E}}{\partial \mathrm{o}_{\mathrm{k}}} \frac{\partial o_k}{\partial net_k} \frac{\partial net_k}{\partial w_{ki}} \tag{14}$$

Output layer threshold adjustment formula:

$$\Delta \mathrm{a}_{\mathrm{k}} = -\eta \frac{\partial \mathrm{E}}{\partial a_k} = -\eta \frac{\partial E}{\partial o_k} \frac{\partial o_k}{\partial_{net_k}} \frac{\partial net_k}{\partial_{a_k}} \tag{15}$$

Implied layer weight adjustment formula:

$$\Delta w_{ij} = -\eta \frac{\partial E}{\partial w_{ij}} = -\frac{\partial E}{\partial o_i} \frac{\partial o_i}{\partial_{net_i}} \frac{\partial_{net_i}}{\partial w_{ij}} \tag{16}$$

Implied layer threshold adjustment formula:

$$\Delta\theta_i = -\eta\frac{\partial E}{\partial \theta_i} = -\eta\frac{\partial E}{\partial \theta_i}\frac{\partial o_i}{\partial net_i}\frac{\partial net_i}{\partial w_i} \tag{17}$$

The final obtained formula is:

$$\Delta w_{ki} = \eta\sum_{p=1}^{K}\sum_{k=1}^{L}(T_k^p - 0_k^k)^2 \bullet \Psi'(net_k) \bullet y_i \tag{18}$$

$$\Delta a_k = \eta\sum_{p=1}^{K}\sum_{k=1}^{L}(T_k^p - 0_k^k)^2 \bullet \Psi'(net_k) \tag{19}$$

$$\Delta w_{ij} = \eta\sum_{p=1}^{K}\sum_{k=1}^{L}(T_k^p - 0_k^k)^2 \bullet \Psi'(net_k) \bullet w_{ki} \bullet \phi'(net_i) \bullet x_j \tag{20}$$

$$\Delta\theta_i = \eta\sum_{p=1}^{K}\sum_{k=1}^{L}(T_k^p - 0_k^k)^2 \bullet \Psi'(net_k) \bullet w_{ki} \bullet \phi'(net_i) \tag{21}$$

3.2 Index analysis

(1) Safety indicators

1) Construction of the judgment moment of the target layer and the secondary index.

a) Through the MATLAB solution, the CRITIC weight method is used to obtain the elements in the second level index to determine the importance of the interaction, to obtain the weight vector w_0 $(0.2633, 0.3478, 0.1963, 0.1925)^T$.

b) Obtain the judgment matrix between the target layer and the second level index, and the pairwise comparison matrix is as follows Table 4:

Table 4: Comparison matrix of safety indicators

M	**Attack vector(AV)**	**Accident (A)**	**Environment effects(E)**	**Human error(D)**
Attack vector(AV)	1	-0.9959	0.4709	0.1247
Accident (A)	-0.9959	1	-0.4483	-0.1030
Environment effects(E)	0.4709	-0.4483	1	0.3330
Human error(D)	0.1247	-0.1030	0.3330	1

c) The consistency check is calculated by the consistency check formula of hierarchical analysis, obtaining CR= -1.1236 <0.1, which passes the consistency test.

2) Build the judgment matrix between two-level indexes and three-level indexes.

a)Through MATLAB solution, the CRITIC weight method obtains the weight vector w_1 $(0.3921,0.3378,0.2701)^T$,$w_2(0.3800,0.3266,0.2933)^T$,$w_3(0.5988,0.4012)^T$,$w_4(0.3001,0.3235,0.1736,0.2028)^T$,

b) Obtain the judgment matrix between attack vector (*AV*) and *P*, accident and *P*, environmental impact (*E*) and *P*, and human error impact (*D*) and *P*, the comparison matrix is shown below in Table 5-7.

Table 5: Attack-vector judgment matrix

Attack vector(AV)	P_1	P_2	P_3
P_1	1	-0.0150	0.1304
P_2	-0.0150	1	-0.2094
P_3	0.1304	-0.2094	1

Table 6: Accident judgment matrix

Accident(A)	**P_4**	**P_5**	**P_6**
P_4	1	-0.0377	0.0955
P_5	-0.0377	1	-0.3121
P_6	0.0955	-0.3121	1

Table 7: Environment effects judgment matrix

Environment effects(E)	**P_7**	**P_8**
P_7	1	0.0034
P_8	0.0034	1

(2) Economic indicator

1) Construction of the judgment moment of the target layer and the secondary index.

a) Through MATLAB solution, the CRITIC network weight method is used to determine the importance of the interaction, and the weight vector w^0 (0.2511,0.3898,0.3591) ^{T},

b) Obtain the judgment matrix between the target layer and the second level index, and the pairwise comparison matrix is as follows,

c) The consistency check is calculated by the consistency check formula of hierarchical analysis, obtaining CR= -1.9231 <0.1, which passes the consistency test.

2) Build the judgment matrix between two-level indexes and three-level indexes.

a)Through MATLAB solution, the CRITIC weight method obtains the weight vector w_1 $(0.1427,0.4563,0.1569,0.1510,0.0931)^T$,$w_2(0.3217,0.3189,0.1780,0.1814)^T$,$w_3(0.3385,0.3187,0.3427)^T$.

b)The judgment matrix between asset loss (I_a) and P, personnel loss (I_b) and P, information loss (I_c) and P, and the comparison matrix is as follows Table 8-10:

Table 8: Economic Indicators comparison matrix

Capital loss(I_a)	**P_1**	**P_2**	**P_3**	**P_4**	**P_5**
P_1	1	-0.10	0.56	0.23	0.82
P_2	-0.10	1	-0.71	-0.03	-0.09
P_3	0.56	-0.71	1	0.62	0.75
P_4	0.23	-0.03	0.62	1	0.75
P_5	0.82	-0.09	0.75	0.75	1

Table 9: Economic loss judgment matrix

Personnel loss (Ib)	**P_6**	**P_7**	**P_8**	**P_9**	**P_{10}**
P_6	1	-0.01	0.16	0.12	0.82
P_7	-0.01	1	-0.23	-0.74	-0.09
P_8	0.16	-0.23	1	0.82	0.75
P_9	0.12	-0.74	0.82	1	0.79
P_{10}	0.82	-0.09	0.75	0.75	1

Table 10: Information loss judgment matrix

Information loss (Ic)	P_{11}	P_{12}	P_{13}
P_{11}	1	-0.79	0.01
P_{12}	-0.79	1	-0.06
P_{13}	0.01	-0.06	1

4. Parameter setting

4.1 Establishment of the Dataset

By consulting the relevant literature, the safety and economic parameters of the corresponding industrial control system are compiled, and then used for backpropagation artificial neural network (BP neural network) after review and modification. The safety parameters entered in the dataset included 11 key feature parameters and auxiliary decision feature parameters. Among them, there are 6 key feature parameters and 5 auxiliary decision feature parameters.

The economic parameters input into the data set include 13 key feature parameters and auxiliary decision parameters, including 8 key feature parameters and 5 auxiliary decision feature parameters. Based on the safety and economic parameters of the industrial control system, 7 system parameters of data set are determined. There are 5860 pieces of industrial control data in the data set. After the data are rounded by 75% and 25%, the sample set is divided into training samples and test samples respectively.

Neural network parameter settings.

First, the structure of the neural network was determined as 3 layers, where the number of input nodes is 24, the number of hidden layer nodes is 13, and the number of output nodes is 7. Since the output ranges between 0 and 1, the value domain of the selected activation function of the output layer should also meet this requirement. In this study, the activation function of the output layer is "logsig". The hidden layer activation function is set to "tansig", the training times are set to "1000", the training error is set to "110-6", the learning efficiency is set to 0. 001, and the training function is set to "trainlm". The hidden layer activation function is set to "logsig". With attack vectors, unexpected events, environmental impact, human error impact, asset loss, personnel loss, and information loss as input, use BP neural network outputs the corresponding parameters, and uses these output parameters for industrial control system process simulation.

4.2 Analysis of simulation result

To realize the comprehensive evaluation of the industrial control system, this paper is conducted from both safety and economy.

(1)Analysis of the degree of influence

There are various types of indicators involved in the system, and under the influence of different parameters, the impact on an industrial control system will also be different, sometimes, and even will bring great changes to the analysis and evaluation of the system. Therefore, in the case of constructing a large amount of data, the correlation matrix and weight ratio of safety parameters and economic parameters are obtained through the matrix operation of MATLAB.

Through the calculation integration, the safety parameters (Figure 2) and economic parameters in (Figure 3) are obtained.

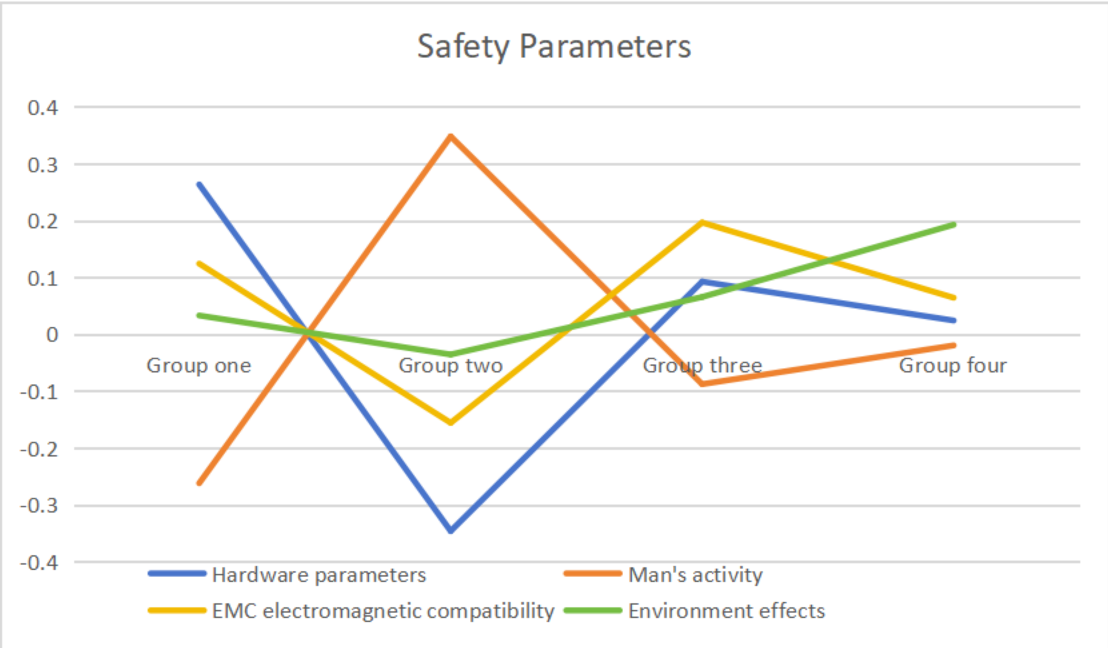

Figure 2: Safety Parameters

It can be seen that in the industrial control system, human error on the system is relatively stable compared with the other three parameters, attack vector, unexpected events and environmental impact in different systems.

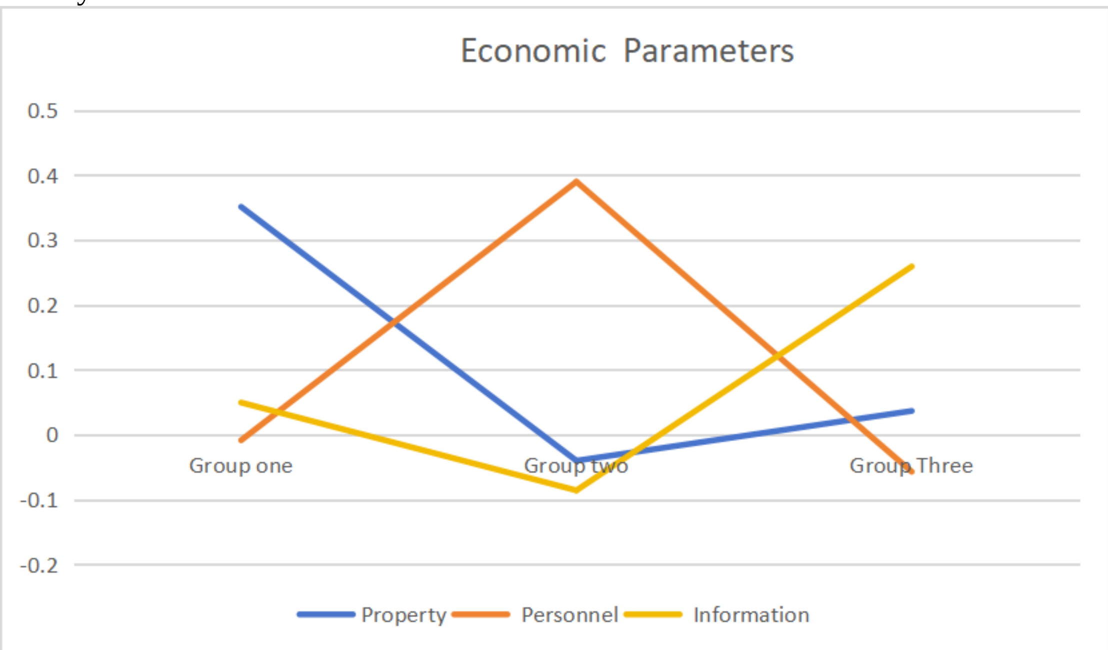

Figure 3: Economic Parameters

Under the condition of economic parameters, system collected considerable data sources such as total assets, load rate, technical backbone and labor cost, and further drew the status map of economic parameters by constructing the correlation matrix and obtaining the weight. It can be seen that the change degree of asset loss, personnel loss and information loss is quite large in different systems, so the system needs to consider three factors when studying the economic indicators. This also further verified that this paper in the economic index data collection the comprehensive, and effective.

(2) Comprehensive comparison of the system

In terms of security, the system will simulate the output data, further integrate the attack vector, accident, environmental impact, human error impact factors, judge and sum the output value, and further get the parameter analysis and evaluation of the safety of the industrial system presented in this paper, as shown in Figure 4 below.

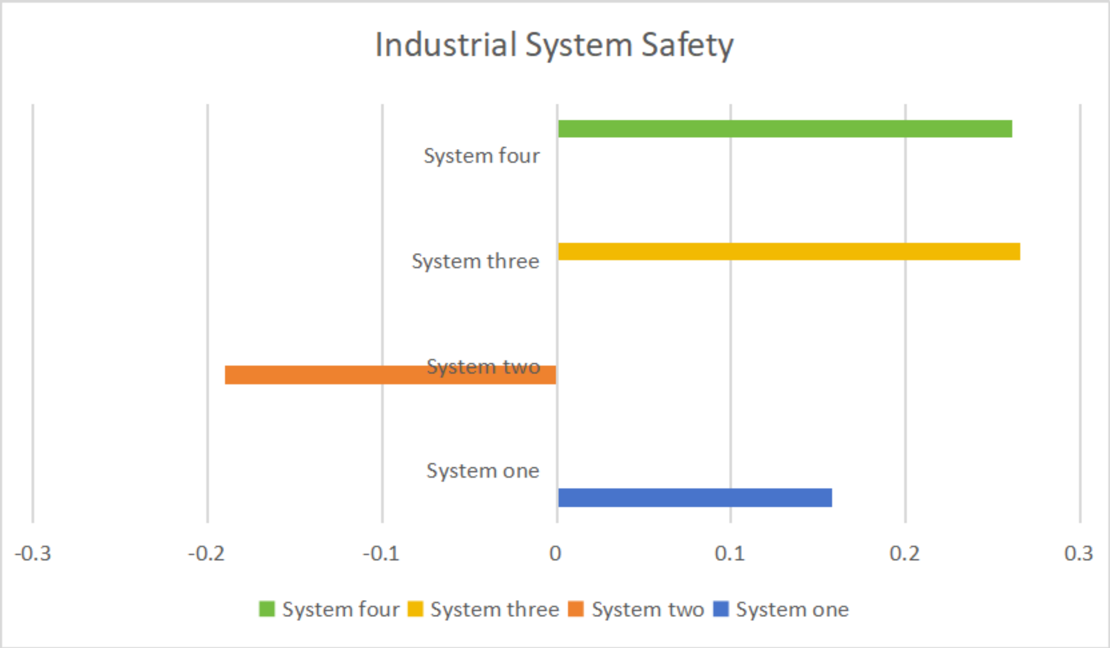

Figure 4: Industrial system safety

It can be seen that among the four systems judged by the safety parameters, the comprehensive results of system 1, system 3 and system 4 are positive, indicating that the three systems are currently under safe and controllable condition, and the comprehensive score of system 3 is the highest, indicating that the safety degree of system 3 is the highest. As for system 2, the results obtained by system synthesis are negative values, indicating that system 2 has security vulnerabilities, and it needs to be solved urgently.

In terms of economy, this paper comprehensively considers the influence of asset loss, personnel loss, information loss and other parameters, integrates and processes the data, simulates the output results, and obtains the analysis and judgment of the economy of the industrial system in the following Figure 5.

In Figure 5, it can be seen that for the three systems of economy, the comprehensive value results are all positive, which proves that these three systems can obtain economic benefits in terms of economy, but the results of economic benefits for these three systems are different. System 1 has the highest economic benefit. For system 2 and system 3, improvement methods can be sought to make the system achieve higher economic performance.

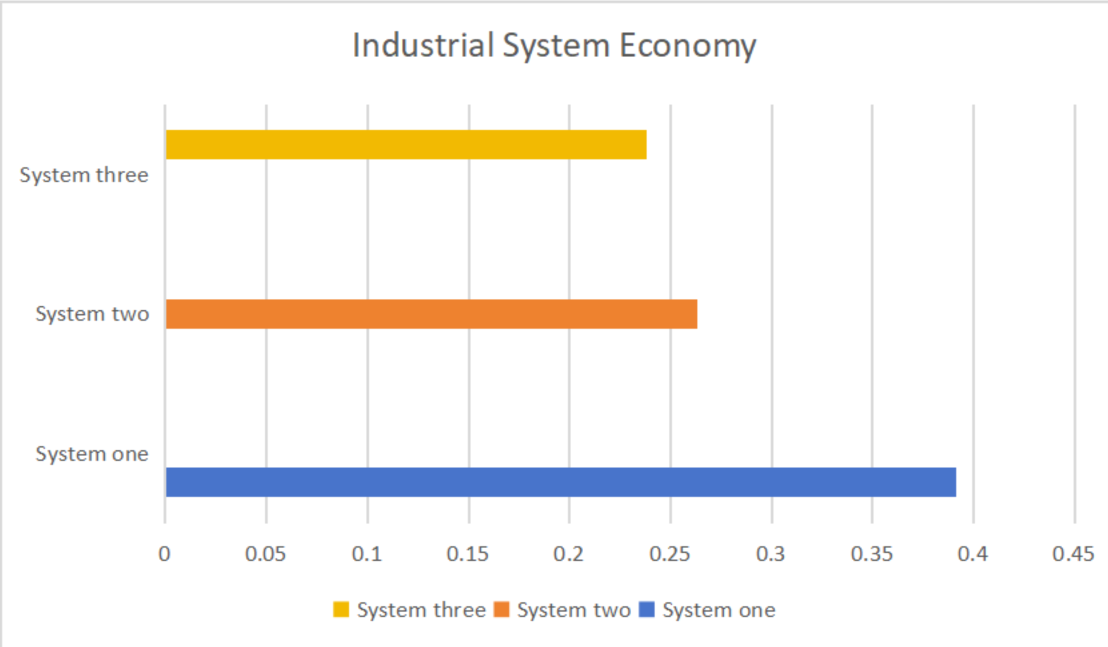

Figure 5: Industrial system economy

5. Conclusions

This paper proposes a comprehensive evaluation method based on the BP neural network, starting with the application of security and economy of the industrial control system. A prediction method can be applied to industrial control systems. The validity and accuracy of the proposed evaluation method are verified by comparing the practical application data and the simulation experiment results. The experimental results show that this method can effectively evaluate the performance and characteristics of industrial control systems, and provide important support and guarantee for the development of industrial control systems. In practical application, this method can effectively reduce the occurrence of industrial site safety accidents and improve the industrial economy.

References

[1] Bhamare D, Zolanvari M, Erbad A, et al. Cybersecurity for industrial control systems: A survey[J]. computers & security, 2020, 89: 101677.
[2] Yang Yiqian, Zhang Longshan. Problems and measures of industrial control network information security protection under the background of big data [J]. Network Security and Informatization, 2023 (3): 119-121.
[3] Zhong Jianfang, Cheng Meilin, Xiao Renyong. Exploration of alarm optimization and management of industrial control system in desert oil and gas field [J]. China Instrument, 2024 (07): 68-70.
[4] Sang Yi, Long Ping, Liu Xingli. Discussion on the reliability evaluation method of industrial control system [J]. Automation and Instrumentation, 2011 (1): 122-123. DOI:10.3969/j.issn.1001-9227.2011.01.046.
[5] Gao Tao. "Security of Industrial Automation and Control Systems- -Part 3-2: Information Security Risk Assessment for System Design," standards analysis [J]. China Standardization, 2022 (6): 89-96,111.
[6] Liu Guanquan, Liu Haicheng, Wang Xuejiang, et al. Research on the deployment of industrial control safety in the production centralized control system [J]. Metallurgical Automation, 2024, 48 (S1): 333-336.
[7] Yang Lixia, Li Jie, Xu Lei, et al. Research on security risk assessment of industrial control system based on multi-attribute decision-making [J]. Consumer Electronics, 2022 (3): 90-92.
[8] Qin Lang, Chen Xingshu, Zhu Yi, et al. Industrial control protocol operation field identification based on steady state properties [J / OL]. Engineering Science and Technology, http://kns-cnki-net.webvpn.ncist.edu.cn/kcms/detail/51.1773.tb.20240605.1409.010.html.Liao
[9] Shi Libin. Design of real-time control system for running status of thermal instrument of thermal power unit [J]. Automation and instrumentation, 2024, 39(05):126-129+164.