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Early Warning Research on Unsafe Behavior of Coal Mine Operators Based on GA-BP Neural Networks

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Abstract In order to better realize the early warning of unsafe behaviors of coal mine operators and reduce the occurrence of un-safe accidents, 57 representative accident samples occurring under Pingxian Mining, Guoneng Yulin, Xinneng Mining, and Huainan Mining were selected, and on the basis of BP (back propagation) neural network model, genetic algorithms were adopted to optimize the optimized models, and the optimized models were applied to the coal mine opera-tors' unsafe behavior warning. The results show that: the BP neural network optimized by genetic algorithm has obvious advantages in global search ability and convergence ability; in the early warning of coal mine operators' unsafe behaviors, the error of the BP neural network model optimized by genetic algorithm is 0.1523, and that of the pre-optimization model is 0.23589, and the prediction result has higher degree of fitting, smaller error, and strong model generalization ability. Therefore, the BP neural network unsafe behavior warning model optimized by genetic algorithm has reliable prediction effect and prediction accuracy.

Keywords genetic algorithm, BP neural network, coal mine operators, safety warning

1. Introduction

As one of the leading energy industries in China, the supply and demand of coal has gradually increased since the 21st century due to the rapid development of China's macro-economy. With the increase of global demand for coal, coal mine resources are gradually depleted, mining is gradually developed to the deep, and coal mine accidents occur frequently, which bring great losses to people's lives and property safety. Relevant research shows that the current occurrence of coal mine accidents in China is mainly due to human unsafe behaviors, some coal mines even due to human unsafe behaviors caused by the number of accidents up to 91%, so we can start from the study of coal mine operators' unsafe behaviors, timely prevention and control when there are signs appearing, and take appropriate actions to reduce the likelihood of coal mine accidents. At present, the research on the early warning of unsafe behavior of coal mine operators is not comprehensive enough, so this paper takes coal mine operators as the research object, based on the complexity of the coal mine safety production system, studies the relevant literature at home and abroad, and carries out a systematic analysis of the research on the unsafe behavior of human beings and the early warning of related problems.

There are many scholars who have carried out research related to the early warning of unsafe behaviors of operators. Xu Yangguang [1] constructed an early warning system for employees' unsafe behaviors from three aspects, namely, safety supplies, hazardous areas, and irregular operations; Yang Deping [2] et al. constructed an early warning system for the safety ability assessment of special equipment operators based on the causes of unsafe behaviors of the operators; and Shi Juan [3] et al. constructed a neural network early warning model based on the early warning index system of the un-safe behaviors in four aspects of the man-machine-environment-control, and early warned the workers of their unsafe behaviors; Chang Dingyi [4] constructs a safety warning model to warn the behavior of wind power operation and maintenance personnel; Hu Jinqiu [5] et al. use the advantages of line-of-sight tracking technology in personnel status monitoring to introduce it into the research of the identification or warning method of the unsafe behavior of operators in the oil and gas industry, in order to explore the feasibility of realizing the intelligent warning of the unsafe behavior of the operators in this field; Li Hongxia et al. [6] use the Random Forest model to predict the unsafe behaviors of miners; Qi Kai et al. use a random forest model to predict the unsafe behaviors of miners. Qi Kai et al. [7] use single-class technology, support vector machine, particle swarm algorithm, combined gray model, fractional order operator and other methods to construct a network cluster behavior early warning system, and define the rules of network cluster behavior risk identification, monitoring and control, prediction and warning, and risk rating; Ouyang Zhuang [8] et al. construct a set of deep learning-based driver distracted driving behavior early warning algorithm, which can realize the all-round accurate monitoring of driver concentration; Ouyang Zhuang and others construct a set of deep learning-based driver distracted driving behavior warning algorithm, which can realize the all-round accurate monitoring of driver concentration. The algorithm can realize all-round accurate monitoring of driver concentration; Fang Weili et al. [9] establish a strong correlation rule between behavior detection and unsafe behavior composition including intrusive monitoring technology, personal monitoring technology, and multi-cooperative monitoring technology; Yu Yuqing et al. [10] con-struct subway construction personnel accident early warning system with the help of localization technology and building information modeling technology, and realize the intelligent management and control of unsafe behavior; Luo Zhongxiang et al. [11] collect driver's information and information from driver through the devices such as driver simulators, wireless physiological instruments and ocular dynamometer. [12] collect driving behavior and physiological and psychological data of drivers through driving simulators, wireless physiological instruments and eye-tracking instruments, etc., and analyze the changes of driving behavior under different application conditions of the early warning system through the simulation of different scenarios; Ruiting Zhang et al. analyze the structure of the video early warning system, and put forward the method of video early warning, prevention, control and analysis of the unsafe behaviors of miners in the two types of working scenarios of the mine, namely, aboveground and belowground; Lujie Zhou et al. [13] develop the early warning control system for the unsafe behaviors of the employees of the coal mine, and realize the intelligent control of unsafe behaviors. Zhou Lujie et al. [14] developed an early warning control system for coal mine employees' unsafe behaviors, realized the control function and early warning function of unsafe behaviors, put forward corresponding countermeasures, and provided an informatization means for behavioral safety management; Li Wenjing et al. established an automatic early warning system for video monitoring of unsafe behaviors of under-ground coal mine workers by combining deep learning, which facilitates the construction of intelligent mines and the management of behavioral safety in underground mines; Zhang Yu et al. [15] In order to realize the intelligent early warning of miners' unsafe behaviors, we Constructing the ontology of miners' unsafe behavior influencing factors; Cui Ning et al. [16] Constructing the coal mine diamond model and the Thurley model to establish the human factor warning mechanism. It can be found that in the field of coal mining, there are few research on the causes of accidents and early warning of accidents from the unsafe behavior of operators. Therefore, on the basis of the existing results, this paper constructs a BP neural network model optimized using genetic algorithm to provide early warning of unsafe behaviors of operators in coal mines in China.

2. Construction of a system of early warning indicators

Coal mine accident early warning is affected by many factors, so the early warning indicator system is a complex dynamic system containing four major factors: personnel, environment, management and equipment. According to these factors, combined with the actual problems of coal mines and seeking the opinions of many experts and researching a large amount of data, it is determined that individual behavior A, mechanical equipment factors B, organizational management factors C, external environment D, emergency response capability E is the first level indicator, and 16 second level warning indicators are established under it. The index system of unsafe behavior of coal mine operators is shown in Figure 1.

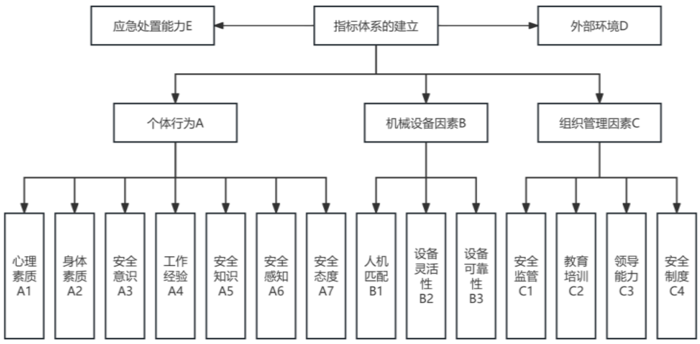

Figure 1: Early warning indicator system for unsafe behavior of coal mine operators

3. GA-BP Neural Network

3.1 BP Neural Network

BP (Back propagation) neural network is a multilayer feedforward neural network trained according to the error back propagation algorithm, which is to add a number of layers (one or more) of neurons between the input layer and the output layer, these neurons are called the hidden units, they do not have a direct connection with the outside world, but the change of their state can affect the relationship between the input and the output, and there can be a number of nodes in each layer The network has two learning processes, forward and reverse, forward propagation, the input signal acts on the output node through the hidden layer, and after a nonlinear transformation, it produces an output signal, if the actual output does not match the desired output, then it is transferred to the reverse propagation process of the error, and the two are repeated until the requirements are met. The structure of the BP neural network is shown in Figure 2.

From Figure 2, the input layer contains m neurons, and the input vector $X=(x_1,x_2,...,x_j,...,x_m)^T$,xj denotes the input of the jth neuron; wij denotes the connection weight of the jth neuron in the input layer to the ith neuron in the hidden layer, i=1,2,.... .n; θ_i denotes the threshold value of the ith neuron in the hidden layer; the output layer contains L neurons, the output vectors $d=(d_1,d_2,d_3,...,d_k,...,d_L)^T$, d_k denote the output of the kth neuron in the output layer; w_{ki} denotes the connection weight value of the kth neuron in the output layer with the ith neuron in the hidden layer; b_k denotes the threshold value of the kth neuron in the output layer.

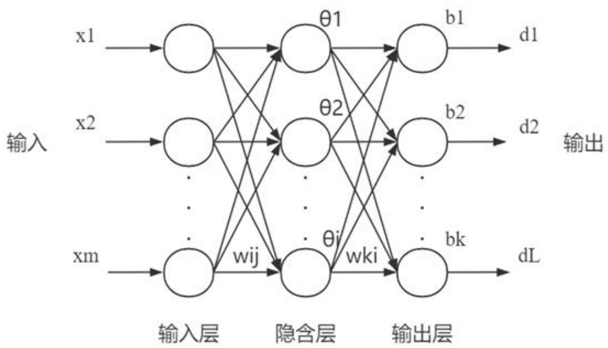

Figure 2: 3-layer BP neural network

In the forward propagation process, the input of the input layer is the input vector X, and the output is also the input vector X, i.e., the input is equal to the output; the input of the hidden layer is the weighted sum of the input vector X and the connection weights w_{ij} and the threshold value θ_i , e.g., the input of the ith neuron of the hidden layer R_i is.

$$R_i = \sum_{j=1}^{m} w_{ij} x_j - \theta_i \tag{1}$$

The output of the hidden layer requires an activation function to further process the input, e.g. the output of the ith neuron of the hidden layer y_i is.

$$y_i = f(R_i) \tag{2}$$

where $f(R_i)$ is the activation function

The input to the output layer is the weighted sum of the output y of the hidden layer with the connection weights w_{ki} , and the threshold b_k, e.g. the input to the kth neuron of the output layer S_k is.

$$S_k = \sum_{i=1}^{n} w_{ki} y_i - b_k \tag{3}$$

The output of the output layer also requires further processing by the activation function, e.g., the output of the kth neuron of the output layer d_k is:

$$d_k = \varphi(S_k) \tag{4}$$

where $\varphi(S_k)$ is also the activation function.

Backpropagation begins with the calculation of the error by the output layer, and the weights and thresholds are adjusted in reverse layer by layer along the network according to the gradient descent method, e.g., the error of the kth neuron in the output layer is.

$$e_k = Z_k - d_k \tag{5}$$

where Z_k denotes the desired output of the kth neuron in the output layer.

The error e for each iteration is:

$$e = \frac{1}{2} \sum_{k=1}^{L} e_k^2 \tag{6}$$

Then the total error E is:

$$E = \frac{1}{2} \sum_{n=1}^{n} \sum_{k=1}^{L} e_k^2 \tag{7}$$

where, n denotes the number of iterations; the gradient of the error to the output layer weights and thresholds are $\frac{\partial E}{\partial w_{ki}}, \frac{\partial E}{\partial b_k}$, respectively,

The gradient of the implicit layer weights and thresholds are $\frac{\partial E}{\partial \theta_i}, \frac{\partial E}{\partial w_{ij}}$ and then this gradient is adjusted inversely, and finally through a series of calculations to make the error within everyone's acceptable range.

3.2 Genetic algorithms

Genetic algorithm is a model of the process of biological evolution that simulates the mechanism of natural selection and genetics of Darwin's theory of biological evolution. The algorithm mathematically converts the problem-solving process into a process similar to the crossover and mutation of chromosomal genes in biological evolution by using computer simulation operations.

It has the following steps:

Determine the way the code

It is possible to flatten all parameters into the form of a single chromosome to prevent falling into local minima.

Generation of initial populations

Multiple chromosomes are randomly generated and a fitness function is calculated for each chromosome to assess the merit of an individual or solution.

Inheritance, crossover, mutation

The chromosomes with higher fitness are selected to increase the diversity of the population through crossover and mutation, and finally the chromosomes after genetic crossover and mutation are formed into a new population for the next iteration, and the chromosomes with the highest fitness are picked as the final result after a certain number of iterations.

3.3 Construction of Early Warning Model for Unsafe Behavior

Based on the neural network theory to construct the unsafe behavior warning model, the structure of the neural network should be determined beforehand, from the previous section, the BP neural network structure in accordance with the previous section, the network layers are connected sequentially, the nodes of the same layer are not connected, to de-termine the structure of the network that is needed to determine the number of network layers and the number of nodes in each layer. The number of BP neural network's input and output layers are 1, the number of implied layers can be greater than 1, and the number of implied layers is greater than 1. Excessive number of hidden layers will affect the convergence speed of the network, due to the simplicity of the data set of this early warning model, the 3-layer BP neural network early warning model with small workload is constructed.

In this paper, the BP neural network model is used to warn coal mine operators of unsafe behaviors, which actually responds to the nonlinear relationship between the influencing factors of unsafe behaviors and the consequences of un-safe behaviors. Therefore, based on the influencing factor index system, the 16 secondary index system constructed in the previous chapter can be used as the number of nodes in the input layer.

The number of nodes in the hidden layer has a great impact on the computational power of the network and its performance. It is generally believed that too many points can improve the network accuracy, but it will take a longer time. Too few nodes may be difficult to form a complex judgment ability, resulting in problems that cannot converge and are less fault-tolerant. Currently, the number of nodes in the hidden layer is mostly calculated based on empirical formulas, and the common range formula is:

$$L = \sqrt{w + y} + x \qquad (8)$$

Where: l is the number of nodes in the implicit layer, w is the number of nodes in the input layer, y is the number of nodes in the output layer, and x is a constant from 1 to 10.

The number of nodes in the output layer is determined by the goal to be achieved by the actual problem. In this paper, the purpose of this paper is to warn of unsafe behaviors and construct an early warning model to predict the risk value of unsafe behaviors of each operator, so the number of nodes in the output layer is taken to be 1, which indicates the risk value of unsafe behaviors.

Optimization of the neural network using genetic algorithm, after finding the optimal weights and thresholds by GA calculation, the optimization path is shown in Figure 3.

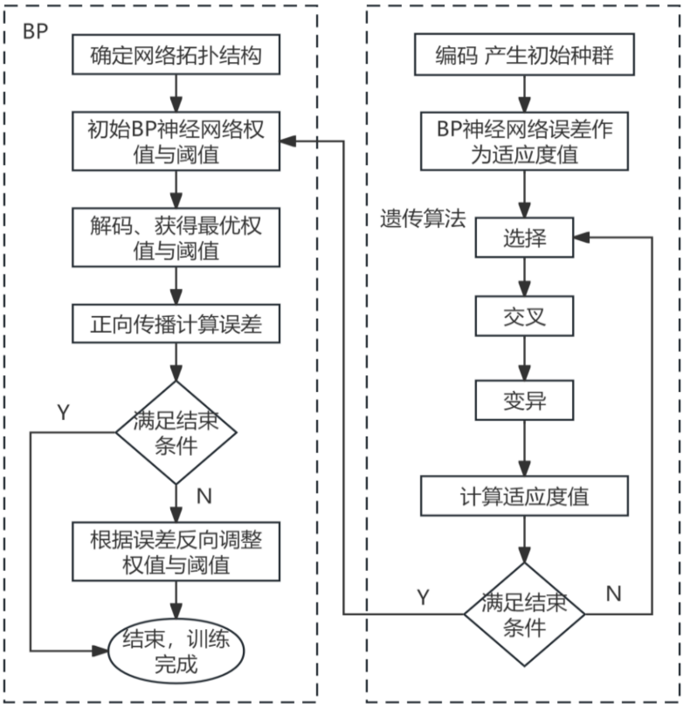

Figure 3: Flow of genetic algorithm to optimize BP neural network

4 Application examples and analysis

4.1 Model data collection

The BP neural network model mapping the nonlinear relationship between the indicators of factors influencing unsafe behaviors and their risk values requires a large amount of data for training, validation, and testing. Based on the con-sideration of data quantification, this paper adopts the literature survey method to collect indicator data and unsafe behavior data.

Table 1: Early Warning Questionnaire for Risk of Unsafe Behavior

System of indicators	Description of the indicator system
Psychological quality A1	You can be calm in the face of emergencies
Physical fitness A2	Energetic during operations, no major illnesses
Security Awareness A3	Have good work habits and be able to better recognize unsafe behaviors
Work experience A4	Experience in similar operations and familiarity with the work in charge
Security knowledge A5	Knowledge of processes and regulations for safe operation
Security Perception A6	Anticipate the occurrence of unsafe incidents
Safety attitude A7	Proactively comply with safety rules, implement safe operations, and work in strict accordance with safety procedures.
Man-machine matching B1	Easy and safe operation of the machine reduces the risk of injury to the operator.
Equipment flexibility B2	Easy and simple machine operation
Equipment reliability B3	The likelihood that the equipment will function as required under the specified conditions over a period of time
Security Supervision C1	Regular security inspections
Education and training C2	Regular safety training for employees
Leadership C3	Positively responding to leadership organization and command
Security system C4	Strictly follow the rules and regulations
Operating environment D	Poor operating environments can lead to unsafe behaviors
Emergency response capacity E	Operators' ability to respond to emergencies

In order to ensure the credibility and validity of the content of the questionnaire, after preliminary investigation and research, based on the 16 indicators of secondary influencing factors of unsafe behaviors constructed in the above section, referring to the relevant literature at home and abroad, and combining with the opinions of the experts, we compiled the questionnaire of risk warning of unsafe behaviors, Table 1, and on the basis of the system of evaluating indexes and the corresponding theoretical profiling, we selected 57 representative samples of accidents occurring under the Pingxin Mining Industry, Guoneng Yulin, Xinneng Mining and Huainan Mining Industry. Under the 57 representative accident samples occurred, 80% as training data, and another 20% samples were selected as test data.

In order to speed up the network training and enhance the comparability between the indicators, the sample data are standardized and normalized before the model training, and the sample data are restricted to the intervals of [0,1] and [-1,1].

Table 2: Selected statistical data on early warning indicators of unsafe behaviors

Serial number	A1	A2	A3	A4	A5	A6	A7	B1	B2	B3	C1	C2	C3	C4	D	E
1	12	9	13	12	10	12	9	10	10	12	11	12	12	11	11	10
2	11	9	14	10	12	13	8	10	10	13	9	13	9	12	12	9
3	9	13	12	11	11	11	11	9	11	11	10	11	11	8	8	11
4	10	11	13	10	12	14	10	10	11	14	11	9	10	12	9	13
5	14	9	14	9	13	12	3	8	12	9	12	9	10	9	9	9
6	8	10	10	12	11	10	12	14	10	10	10	12	11	11	10	8
7	10	10	13	8	10	10	13	11	13	11	11	10	12	10	9	10
8	13	14	10	11	10	9	12	10	11	13	8	11	11	11	8	13
9	8	9	9	11	9	10	11	13	10	10	9	13	9	10	10	10
10	9	10	12	9	10	12	10	10	9	9	11	12	13	12	10	9
11	12	11	11	10	10	9	11	9	13	11	8	11	11	12	12	8
12	7	13	14	9	12	12	12	11	12	12	8	9	10	11	11	10
13	10	8	10	10	9	13	12	13	11	11	12	10	12	9	12	8
14	13	9	13	12	11	10	9	12	12	13	9	10	9	10	10	12
15	9	9	14	11	14	11	14	10	13	9	10	13	9	11	12	11
16	11	10	9	13	9	10	10	9	10	8	13	9	10	12	11	9
17	13	13	10	12	10	11	13	8	9	13	9	10	8	12	10	11
18	10	14	12	12	11	10	10	12	13	12	9	12	10	9	9	13
19	9	9	10	10	9	14	9	13	12	10	11	11	12	10	12	11

4.2 Model training

The neural network was trained using Matlab programming, 46 of the 57 data were used as the training set and 11 as the test set, the data were imported, the number of nodes in the hidden layer was set to 6, the number of iterations was set to 20, the population size was set to 10, the crossover probability was set to 0.4, and the probability of variation to 0.05, and the training was started after the parameters had been set.

The comparison graphs of the warning results and errors of BP neural network before and after optimization are shown in Figure 4. As can be seen from the figure 4, the error of the optimized BP neural network warning is lower, the error of the BP neural network before optimization is 0.23589, and the error of the optimized model is 0.1523, and the result of the warning is better, which proves that the use of genetic algorithms can improve the shortcomings of BP neural net-work and improve the accuracy of its prediction, so that the model can be used for the safety warning of the unsafe behaviors of the coal mine operators.

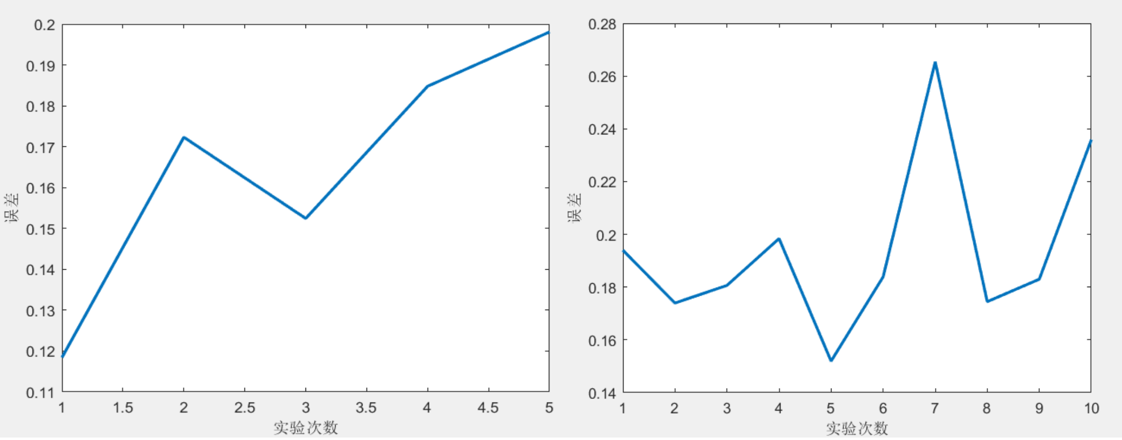

Figure 4: Comparison of BP neural network warning results and errors before and after optimization

5. Conclusion

(1) Aiming at the actual situation of domestic coal mines, 16 warning indicators were selected to construct the warning indicator system of unsafe behavior of coal mine operators, and through genetic algorithm and BP neural network, the early warning model of coal mines based on GA-BP neural network was established, which reduces the inaccuracy of the results obtained because of incomplete indexes and the deviation from the actual situation.

(2) The GA-BP neural network early warning model of unsafe behavior of coal mine operators is constructed to predict the consequences of coal mine accidents. Matlab programming software is used to train the data, and the GA-BP neural network model is compared with the BP neural network model, and the results show that the BP neural network early warning model optimized by the genetic algorithm is more accurate, and it can be used to predict the consequences of unsafe behavior of coal mine operators. The results show that the BP neural network warning model optimized by the genetic algorithm is more accurate and can be used to warn the unsafe behavior of coal mine workers.

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