Coal Mine Safety Evaluation with V-Fold Cross-Validation and BP Neural Network

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***Abstract*—A suit of coal mine safety evaluation indexes have been propounded under the study of current situation about coal mine safety assement. Coal mine safety evaluation system based on BP neural network has been established by employing MATLAB neural network toolbox, and the actual index data will be utilized to validate marking effect through using V-fold Cross-validation technique, and then this will be applied to coal mine safety evaluation system to provide grounds for safety production and management in coal mine.**

***Index Terms*—safety evaluation, BP neural network, v-fold cross-validation technique**

I. Introduction

Scientific implementation of the evaluation on coal mine safety is an important way for advancing execution, monitoring and reducing coal mine accidents effectively, and it is also the regulation guarantee for establishing long-term safety production mechanism and achieving stable improvement about the coal mine working condition. Enhancing researches and applications on coal mine safety is a pressing problem to be resolved indeed.

Current evaluation methods of coal mine safety are mainly comprehensive qualitative scoring methods(such as method of safety check list), which means to mark according to the actual indicator data with reference to existent evaluation index system and finally form security evaluation result. Because coal mine safety system is a very complex and dynamic non-linear time-varying system, it’s difficult for comprehensive qualitative scoring methods to grasp the non- linearity. Therefore, the comprehensive qualitative scoring methods encounter the following drawbacks in practice:

- The weight indicators lack adaptability.
- There exists subjectivity in man-made scoring to a large extent.
- Manual evaluation of the results causes hysteresis.

Static evaluation method fails in various mine production environment.

Neural network is essentially a nonlinear transformation system of information which possesses a strong non-linear processing capability and a wide range of adaptability, learning ability and mapping capability [1]. Its modeling mechanism is called as data-driven "black box", meanwhile, the evaluation index weights lie in the network structure and input-output data mapping relationship implicitly. Thus a trained neural network is competent to self-coordinate the weight of all the evaluation indicators with no need to go as the traditional ways do [2]. As a result, it solves the problem of variable weights in safety evaluation process and reduces the impact of human factors so as to ensure that the result of the evaluation is full of the objectivity and authenticity. Naturally, neural network is able to carry out real-time dynamic evaluation intelligently. Using of MATLAB neural network toolbox, the neural network learning, training and evaluating process can be easily achieved, which leads to effective evaluation of coal mine safety status.

II. Research on BP Neural Network for Nonlinear Economic Modeling

A. BP Neural Network Modeling Step

Neural network is a powerful modeling tool emergently in recent years, in which BP neural network is the most successful and most widely used in the current time as a neural network. K..

Funahashi theoretically proved that, with a hidden layer (assuming that sufficient hidden layer nodes) of the BP neural network can approximate any arbitrary continuous function accuracy. Through training, BP neural network can form mapping relationship from input to output $y = f(x_1, x_2, \cdots x_n)$, in order to establish the system model which has a same law for the capacity with the correct answers. As a result ,BP neural network is data-driven "black box" model, the importance of influencing factors implicit in the network structure and input-output relationship of the data mapping, the trained BP neural network of the importance of influencing factors weights with self-coordination ability, without the traditional modeling methods to evaluate the impact of factors for the weight, thus it has reduced the impact of human factors of modeling the process to better ensure that the model of objectivity and authenticity of the

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results. Common with a hidden layer of BP neural network model as shown in Figure 1：

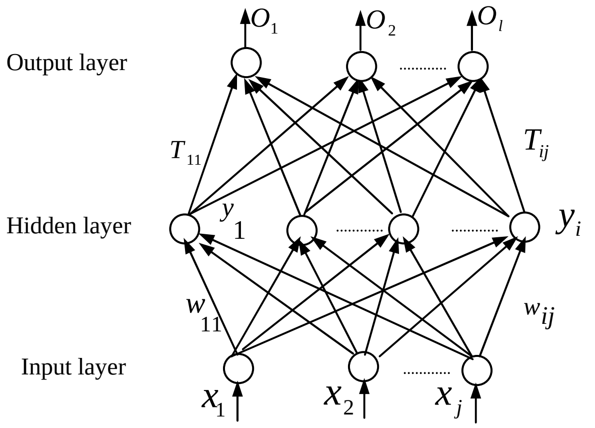

Figure 1. BP neural network model with a hidden layer

BP neural network using non-linear modeling can regard the complex non-linear economic system as a black box to measure input and output data samples into the BP neural network. Through the samples of study, through amendments to the right value, network can determine its internal expression, so the image and the object of that input to the output of is approaching, the entire network can simulate the system on the external characteristics. As a result of BP neural network the distribution of the information, the input variables affect the output variables in the study sample was automatically recorded , and the internal expression of the entire network showed, thus dispense with the usual pre-modeling of the variables analyzed. The basic steps of structuring BP neural network model are:

- Determining the BP neural network input vector, output vector dimension, hidden layers and nodes;
- Determining the transfer function of hidden layer and output layer transfer function relationship;
  3) E-learning is divided into learning samples and test paragraph;
- Training network, fitting time series study to minimize the error sum of squares;
- The data with test trained network model,, using the non-linear model to deal with economic issues.

B. BP Algorithm Processes

1974, Werbos in his doctoral dissertation first mentioned hidden layer containing the multi-layer back propagation network BP algorithm, effectively overcome the multi-layer network can not solve non-linear classification of defects. 1986, Rvmelhaot , Mcclell and others gave a detailed mathematical derivation of BP algorithm,and investigated its capacity and potential of the extensive and in-depth, systematically solved the multi-layer feedforward network link, and improved the BP neural network application performance .

The basic idea of BP algorithm is the use of LMS learning algorithm, the learning process in the network using gradient search techniques, the use of error back-propagation to fix the right value, in order to achieve the actual network output and desired output to minimize the mean square deviation. Specific calculation process is as follows:

(1) calculating the output of output node O_l

- Entering the input node as follows: x_j
- Calculating the output of hidden node:

$$y_i = f(\sum_j w_{ij} x_j - \theta_i)$$

where, w_{ij} is combined weights between the input node and the hidden node, θ_i is threshold between input node and hidden node.

- Calculating the output node output:

$$O_l = f(\sum_i T_{ij} y_i - \theta_l)$$

where, T_{ij} is combined weights between the input node and the hidden node, θ_i is threshold between input node and hidden node.

(2) Amending weight between the hidden node and the output node

- The desired output of the output node: t_l
- Error controlling

Error of all samples tested:

$$E = \sum_{k=1}^{P} e_k < \varepsilon$$

One sample error:

$$e_k = \sum_{l=1}^{n} \left| t_l^{(k)} - O_l^{(k)} \right|$$

P is the sample size , n is the output nodes. In this system, n=1.

- Calculation of error:

$$\delta_l = (t_l - O_l) * O_l * (1 - O_l)$$

- The right to amend the value of:

$$T_{li}(k+1) = T_{li}(k) + \eta \delta_l y_i$$

where, k is the number of iterations. η is the learning rate, which decide each cycle of training arising from the right to change the value, select the scope of generally between 0.01 to 0.8.

(3) Amending weights between the input node and the hidden node:

- Calculation of error:

$$\delta_i' = y_i (1 - y_i) \sum_l \delta_l T_{li}$$

- To amend the right of values:

$$w_{ij}(k+1) = w_{ij}(k) + \eta' \delta_i' x_j$$

This algorithm is an iterative process; each round will be adjusted weight again, so a round of iteration until the desired output and calculation of the output error is less than the value of a permit. The end of learning training, model is built.

III. ESTABLISHMENT OF COAL MINE SAFETY EVALUATION INDEX SYSTEM

Constructing coal mine safety evaluation index system is the first step to establish safety assessment model, which is an important course in the entire evaluation process, either. As a multilevel nature system with high degree of complexity, uncertainty, and openness, coal mine safety evaluation indexes refer to numerous factors [3]. The interdependence and interactions as well as mutual promotions and mutual constraints among factors require not one or more indicators alone but a more comprehensive, scientific index system so that it can fully reflect the security situation in coal mines and emphasize the crux of the work safety precautions.

In this paper, coal mine safety evaluation system is confirmed as the following principles:

- Scientific principles: the choice of indicators and the selection and calculation of data must be based on the scientific theory which is generally accepted.
- The principle of quantitative and qualitative analysis: In order to evaluate mine security situation comprehensively, part of the qualitative indicators reflecting basic characteristics of information systems must be quantitative and standardized, and then the results of quantitative analysis should be analyzed qualitatively to make quantitative data with practical significance.
- The principle of combining stability and dynamic properties: the indicators that can reflect the state of mine safety must have long-term characters and stability, meanwhile, the state of coal mine safety is a conflict about danger and control, therefore, the indicators themselves are characterized by dynamic property.
- The principle of maneuverability: the indicators selves must not only be clear, but their data quantization and collection also need to be simple, easy-to-operate and reliable. Hence these indicators must be composite indicators which can reflect the status of coal mine safety or indicators of strong representation.
- Systemic principles: the index system should be capable of reflecting the security situation in coal mines roundly and seizing the main factors that can reflect the direct effects as well as the indirect effects, which ensure comprehensiveness and credibility in the process of security assessment.

Overall, coal mine safety is influenced by many factors, that is to say, coal production systems is a system composed of personnel, machinery, equipment and extremely complex space. Natural factors and non-natural factors coexist, dust, gas, water damage, roof, staff negligence, as well as mechanical and electrical accidents comprise the main forms of disaster[4]. The mechanism of these incidents is different; nevertheless, the factors that caused the accident are interrelated. As is known to all, various calamities interrelated occur at any time and anywhere. Through a thorough study of current coal mine safety evaluation field, the coal mine safety evaluation index system is shown in table 1 in accordance with the principles mentioned above in this paper.

TABLE I.
COAL MINE SAFETY EVALUATION INDEX SYSTEM

Overall target	Sub-targets
Coal mine safety evaluation system	Mine geological factors
	Mine disaster factors
	Mine hazard factors
	Environmental condition factor
	Production staff quality
	Factors of production equipment
	Management factors

IV. COAL MINE SAFETY EVALUATION SYSTEM MODEL AND BP NEURAL NETWORK DESIGN

BP algorithm was firstly propounded by Rumelhart in 1985 and acquired wide employ in the fields of pattern recognition for its powerful nonlinear mapping ability. BP neural network is an algorithm which is successfully and commonly used in evaluation in artificial neural networks. The evaluation method based on BP neural network is to achieve infinite fitting and approach among the complicated function relationships between the results and expectation values derived from coal mine safety evaluation through using function approximation capabilities of neural network and train the neural network. The three-layer BP neural network with a hidden layer (assuming that there are sufficient hidden layer nodes) is able to approximate any continuous function to arbitrary accuracy Therefore, in numerous theoretical researches and practical applications involving BP neural network, a relatively simple BP neural network with three-tier structure is commonly considered. The topology structure of this model is designed to 7-15-1 BP neural network, and its network structure parameters are: the number of input-layer nodes is seven, and there is only one hidden layer, as well as the number of output-layer nodes, subsequently the number of hidden-layer nodes is 15. MATLAB neural network toolbox includes many toolbox functions for the analysis and design of neural network[6]. This article selects the hidden layer activation function Log-Sigmoid for data input and output characteristics of the coal mine safety evaluation system, which is illustrated with the following function:

$$f(x_1)=\text{logsig}(x_1)=\frac{1}{1+e^{-x_1}} \qquad (1)$$

Accordingly, purelin transform function is chosen as output layer activation function:

$$f(x_2)=\text{purelin}(x_2)=x_2 \ . \qquad (2)$$

The design of coal mine safety evaluation system grounded on the analysis of safety evaluation property and BP neural network function is shown in Figure 2.

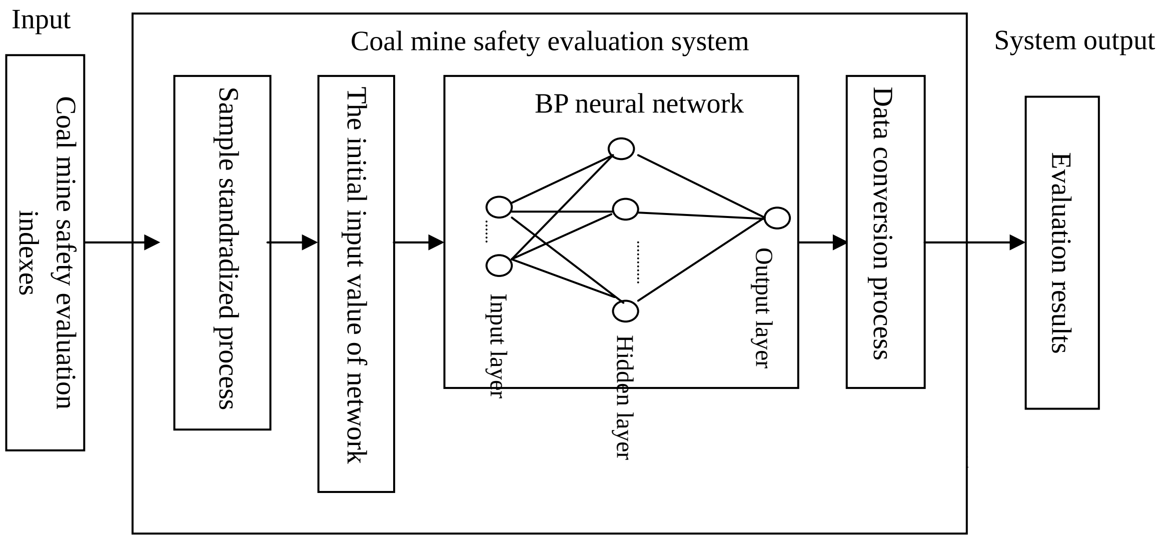

Figure 2. Flow chart of BP neural network training process

IV. THE REALIZATION OF MATLAB IN BP NEURAL NETWORK MODEL

After determining the structure of BP neural network, the network is trained by inputting and outputting sample sets, which means to learn and amend threshold value and weight of network aimed at the realization for the given relationship between input and output mapping through network. BP neural network training process is divided into two phases: the first phase is known to enter the study sample, and then calculate the nerve element output from the first layer of the network backwards by setting up the network structure, the weight and the threshold values of the previous iteration. The task in second phase is amending weights and threshold values from the last layer forwards through calculating the impact of weights and threshold values on total error(grads). Then the weights and threshold values should be amended accordingly. Repeat the two courses above by turns until it reaches the convergence.

The evaluation of coal mine safety on the basis of BP neural network can be well-realized in the neural network toolbox which is developed in MATLAB environment[7]. The initialization of the BP neural network comes first. When designing, the BP neural network can be initialized by utilizing function initff with informed input variables, the number of all layers' neurons and activation function. The subsequent assignment is training BP neural network, which can be carried out by function trainbp, trainbpm and trainlm. Although the usage of those functions resembles each other, the learning rules adopted vary. Function trainbp uses standard BP algorithm, and function trainbpm uses heuristic methods for improvement. However, neither of these two methods is very practical. Function trainlm uses an effective optimization algorithm Levenberg-Marquardt method which is able to shorten training time and enhance accuracy, but it needs larger memory space when training. Next the generalization capability of BP neural network should be boosted. Generalization capability is a significant indicator for performance of the neural network. An over-trained neural network may match training sample set to a larger extent, but a newly input sample vector may have a much more different output from that of target vector, that is to say, neural network does not have or do have generalization capability of a sort. MATLAB neural network toolbox is embedded two methods which are used to enhance promoting ability of neural network: Regularization Method and Early stopping Method. These two methods can be selected in accordance with the different circumstance. Finally, it comes to the output of BP neural network. Taking the optimal weights and threshold values which are acquired by learning into consideration, different output functions should be chosen in accordance with various outputs of output functions. BP neural network based on coal mine safety evaluation system is programmed in MATLAB language and then run in the MATLAB user environment.

The program includes three modules: pre-processing module, BP neural network training module, performance testing and application module, and all of these procedures are linked by input and output interfaces. The training module calls pre-processing module to generate data files which will be called by performance testing and application module. BP neural network training process module is shown in Figure 3.

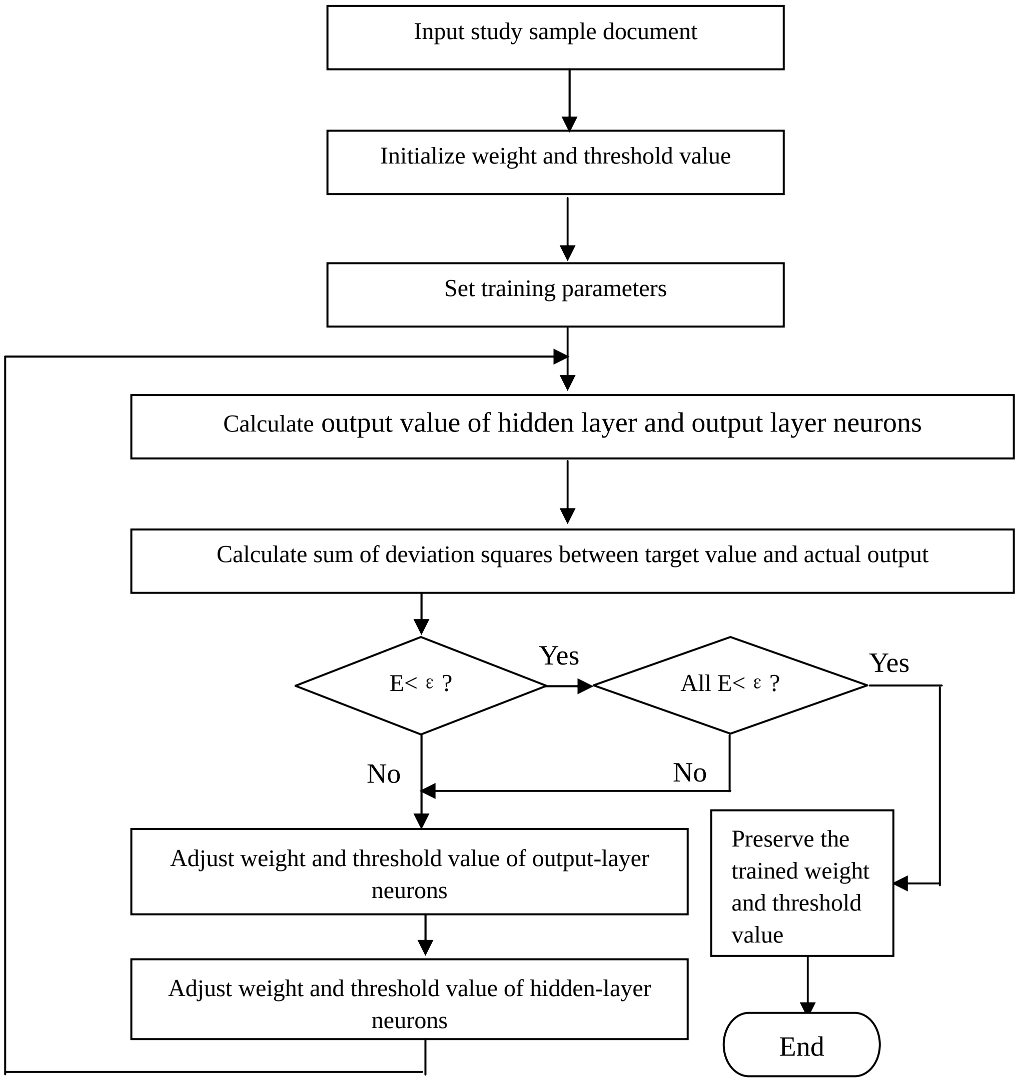

Figure 3. Flow chart of BP neural network training process

BP neural network model realization can be achieved by hardware or software. Hardware means that the neural computer is extremely difficult to achieve, so far there has not been the world the true meaning of the neural computer. At present, more commonly used methods is software, BP network principle simple, easy to implement in the algorithm, it is suitable to calculate for personal computers. There are many companies and research units to design the common BP neural network procedures to facilitate the people use, but the effect is not very satisfactory, and compared to the traditional statistical model, BP neural network model needs more time to design.

The authors, after many years of practical development and application, hold that: Matlab provides BP neural network toolbox is one of the best develop software. Using Matlab can easily achieve the BP neural network modeling. Matlab by Mathworks has introduced high-performance applications in science and technology, which have been widely used in the academic and industrial realm. Compared with VB, C + + and other programming languages, Matlab program has features such as readability with strong, debugging simply. Matlab has a powerful function because it provides many toolboxes that are based on BP artificial neural network theory, constructed with Matlab language of the theory involved in the formula for computing, matrix operation and the majority of subprogram equation to design and train BP neural network. The software can model designers according to their own needs to call the toolbox of BP neural network design and training process, allows designers out of the red tape program ,focuses on the question to think and solve problems, thereby enhancing the model design the efficiency and quality.

The main procedure statement is as follows：

```
clc
disp_freq=10；
max_epoch=8000；
err_goal=0.01；
lr=0.01；
momentum=0.9；
```

```
lr_inc=1.05;
lr_dec=0.7;
tp=[ disp_freq max_epoch err_goal lr momentum lr_inc lr_dec];
[w1, b1, w2, b2, tr, te ]=trainbpx (w1, b1, f1, w2, b2, f2, p, t, tp );
save out.mat w1, b1, w2, b2
pause
clc
plottr(tr, eg);
pause
```

The above procedure is the statement of a model of neural network modeling module, in general, the needs of the three sub-modules (such as data pre-processing module, modeling module, performance testing and application of sub-modules) to complete the procedures for BP algorithm design, as MATLAB software designers , according to their own needs, call the toolbox of BP neural network design modeling process, as shown in Figure 1 of the BP algorithm process, in MATLAB simply call the three main functions initff, trainbpx and simuff to complete all the calculation process , in the above example, trainbpx statement has completed a non-linear economic system modeling of the task module, the results of modeling (ie, neural network weights and thresholds) stored out.mat documents to pendo performance testing and application calls.

V. Test the Generalization Capability of Network with V-fold Cross-Validation Method

Generalization capability of BP neural network is referred to as the competence that network can still give the correct input-output relationship when giving the non-training samples in original sample sets. Because people have not any concern for the fitting ability of the known input and output (training) samples but for the reflection extent on the unknown system output when given known information in practical application. Therefore, the generalization capability of network has become the crux to success and is also regarded as the most significant indicator to measure the property of BP neural network. The neural network without generalization capability will be unpractical.

Traditional BP neural network method adopts Split-sample Validation method to establish and examine evaluation system model (only divide the sample into two parts: one is modeling sample, and another is testing sample), the established model for coal mine safety evaluation exists the defects of poor generalization capability and lower accuracy. In this paper, good consideration has been given to the characteristic of coal mine safety accidents in small sample [8], and a totally new V-fold Cross-Validation method will be adopted to establish and test coal mine safety assessment model. Compared with traditional Split-sample Validation method, V-fold Cross-Validation Methods disrupts samples and reuse disordered samples in order to use limited sample resources to reduce deviation of evaluation [5]. Hypothesizing sample volume N can be conveyed as follows:

$$N = v * n. \qquad (3)$$

where v&n are integers.

Sample is divided into v sub-samples at random and each volume is n. Every time a v-1 sample set is used to train neural network, thus there are $(v-1)*n$ samples for total sample set. And the rest sample subset is arranged as test sample to test neural network. The prediction accuracy of model is obtained by calculation. The average of these prediction accuracy values represents the prediction accuracy of the whole model, which can reduce the estimate deviation so as to evaluate generalization capability of the model more effectively. V-fold Cross-validation method is shown in Figure 4.

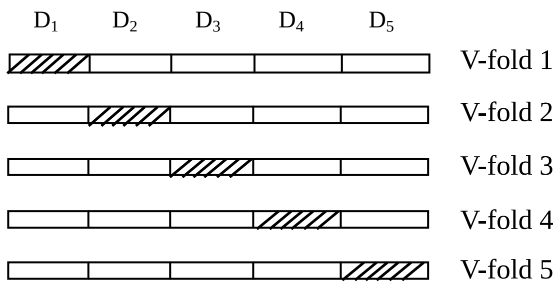

Figure 4. V-fold Cross-validation method

The data in Table 2 are the results by pre-processing. In this paper, the safety indicator data selected from five coal mines attached to Huainan Mining Group are on research. Then normalization method is employed to pre-process these data. MATLAB can process the original data files through calling its own relevant data processing function; the data processed are stored in train.dat (data of learning sample set) and test. dat (data of testing sample set) files. The learning rate of this network lr = 0.1, training deviation is 10-3, and the maximum of iterations is 2×103.

The sample is divided into five groups by traditional Split-sample Validation method. And the first forth groups function as learning samples, definitely the fifth group functions as evaluation data. The evaluation results are shown in table 3.

Network will be trained and tested with V-fold Cross-Validation method, training data and evaluation results are shown in table 4.

TABLE II.
Data for the Neural Network Training and Simulating

Mine No.	1	2	3	4	5
Mine geological factors	0.9000	0.9300	0.9200	0.9200	0.9300
Mine disaster factors	0.9000	0.9200	0.9300	0.9100	0.9070
Mine hazard factors	0.9150	0.9200	0.9450	0.9050	0.9250

Environmental condition factor	0.9000	0.9000	0.9100	0.8700	0.8850
Production staff quality	0.9500	0.9500	0.9300	0.9100	0.9200
Factors of production equipment	0.9350	0.9200	0.9100	0.9000	0.9100
Management factors	0.9100	0.9100	0.9100	0.8700	0.8900
Evaluation of targets	0.9128	0.9175	0.9190	0.8935	0.9343

TABLE III.
EVALUATE DATA WITH SPLIT-SAMPLE VALIDATION METHOD

Evaluated objects	Evaluation of targets	Goal of network training	Deviation（%）
Mine 5	0.9343	0.9125	1.330

TABLE IV.
TRAINING DATA FOR V-FOLD CROSS-VALIDATION METHOD

Evaluated objects	Evaluation of targets	Goal of network training	Deviation（%）
Mine 1	0.91275	0.9110	0.286
Mine 2	0.9175	0.9116	0.590
Mine 3	0.9190	0.9118	0.783
Mine 4	0.8935	0.9078	1.450

TABLE V.
EVALUATING DATA WITH V-FOLD CROSS-VALIDATION METHOD

Evaluated objects	Evaluation of targets	Goal of network training	Deviation（%）
Mine 5	0.9343	0.9267	0.961

As can be seen from the above data, deviation of network has declined from 0.961 percent to 1.330 percent after using V-fold Cross-Validation method to learn the network. Generalization capability of neural network has been strengthened because of smaller deviation and higher evaluation accuracy. This fact illustrates that the established model for coal mine safety evaluation is of higher accuracy.

VI. CONCLUSIONS

Coal mine safety evaluation system based on BP neural network model is presented and established according to BP algorithm. MATLAB is employed to design structure of BP neural network and compile application procedure for coal mine safety evaluation system, which conducts training and testing samples. The training and testing for neural network implemented by V-fold Cross-Validation method result in the reduction in deviation from 0.961 percent to 1.330 percent, which verifies the coal mine safety evaluation system which is on the ground of BP neural network model is able to assess the unknown samples with high accuracy and reflect the actual level of coal mine safety with its evaluation results. In summary, BP neural network is feasible and effective method for coal mine safety evaluation. Apparently coal mine safety evaluation system established and tested by V-fold Cross-Validation method takes on higher evaluation accuracy and can effectively decrease the judging deviation when appraising the coal mine safety. Eventually it cab be applied to practical evaluation of coal mine safety.

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