The safety evaluation of management in chemical enterprise with generalized regression neural network

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Abstract. In order to better evaluate chemical enterprises, artificial neural networks including the back-propagation neural network, radial basis function neural network and generalized regression neural network were used in this paper. The management in chemical enterprise was evaluated. The expert scores and evaluation values are analyzed. The results show that the generalized regression neural network and the radial basis function neural network can better evaluate and predict the safety of chemical enterprises. The prediction of radial basis function neural network is more accurate.

1. Introduction
Chemical industry plays an important role in the economy. For example, the GDP of chemical industry in Ningbo was 330 billion RMB in 2015, which is 23.9% of the total GDP in Ningbo. Due to the hazard of chemical materials which is characterized as the inflammable, explosive, high pressure and toxic substances, the demand to evaluate the safety in chemical enterprise has received more attention. According to the annual report, in 2017, there were 107 major hazards in the chemical enterprises in Ningbo. The report also showed that there were 14 accidents in the period of “twelfth five-year plan”, which caused 19 deaths and 11.237 million RMB loss.

Currently, the process of the accidents is mainly based on post-event analysis and post-event treatment. However, the safety evaluation of the chemical industry is more important for the relative factors. The accidents can be prevented by evaluating the safety in chemical enterprises. Therefore, the safety evaluation of chemical enterprises is an important part of ensuring the safe production. The safety evaluation was firstly carried out in the developed countries such as United States and United Kingdom since 1960s. In China, the safety evaluation started in late 1970s and early 1980s. The Chinese research focused on the safety evaluation of chemical projects which involved different risk sources of chemical projects and different risks at different stages of the project. Wang et al. analyzed the major risk factors in chemical projects from the aspects of risk identification, risk analysis and risk response [1]. Chi et al. used fuzzy mathematics to construct an evaluation model for chemical project
An et al. established a risk assessment index system for large-scale chemical projects [3]. With the rapid development of modern mathematics, information technology, artificial intelligence, neural network and other disciplines, experts have made great progress in the research and application of safety evaluation. Among the various safety evaluation methods, the artificial neural network is an effective method for evaluating the safety in chemical enterprise. Suewatanakul et al. proposed a method by using BPNN to study the deviation of the temperature and fluid velocity [4]. Barton et al. used ANNs to predict polymer quality in industrial reactor units [5]. The relative research found that BPNN can be used to evaluate the safety of chemical enterprise. However, there are some inevitable defects in the safety evaluation with BPNN. The search in BPNN algorithm is a sort of local optimization method. While chemical enterprise safety assessment is a global extremum problem for solving complex nonlinearities. BPNN has the chance to be the local extremum, which makes network training fail. The generalized regression neural network and radial basis function neural network technology to be adopted in this paper, which can overcome the shortcomings of BPNN and carry out more accurate safety evaluation for chemical enterprises from management.

2. Method

2.1 Radial Basis Function Neural Network (RBFNN)

The radial basis function is a non-linear function that is symmetric and is attenuated from the center point. The most common radial basis function is a Gaussian function which the mathematical expression is as follows:

\[ k(||x - x_c||) = e^{-\frac{||x - x_c||^2}{2\sigma^2}} \]

where \(\sigma\) is the width of the function.

2.2 Generalized Regression Neural Network (GRNN)

Generalized regression neural networks are the ANN which is an improvement based on radial basis function neural networks. Different from the radial basis function, the output of GRNN uses the density function. The output mathematical expression of the generalized regression neural network is:

\[ \hat{Y} = E(y|X) = \frac{\int_{-\infty}^{\infty} y f(X,y)dy}{\int_{-\infty}^{\infty} f(X,y)dy} \]

where \(f(X,y)\) is the joint probability density function.

2.3 Index for quantitative assessment

In order to evaluate the predictions of the ANNs, the error test formulas will be used in the assessment. The formulas are shown in Table 1. The grades of the evaluations with parameters \(c\) and \(p\) were shown in Table 2.

| Table 1. Error test formula |
|-----------------------------|
| Residuals                   | Raw data                   |
| mean difference             | \( \bar{\varepsilon} = \frac{1}{n} \sum_{i=1}^{n} \varepsilon_i \) | \( \bar{X} = \frac{1}{n} \sum_{i=1}^{n} X_i \) |
| variance                    | \( S_1^2 = \frac{1}{n} \sum_{i=1}^{n} (\varepsilon_i - \bar{\varepsilon}) \) | \( S_2^2 = \frac{1}{n} \sum_{i=1}^{n} (X_i - \bar{X}) \) |
| The ratio of posterior difference | \( c = \frac{S_1}{S_2} \)           |
| Small error probability     | \( p = p\{|\varepsilon_i - \bar{\varepsilon}\} < 0.6745S_2 \} \) |
Table 2. Quantitative assessment of predictions

| Precision of Predictions     | $P$   | $c$    |
|------------------------------|-------|--------|
| Excellent (1st level)        | $>0.95$ | $<0.35$ |
| Good (2nd level)             | $>0.8$   | $<0.5$  |
| Poor (3rd level)             | $>0.7$   | $<0.65$ |
| Fail (4th level)             | $\leq0.7$ | $\geq0.65$ |

2.4 Data
The safety evaluation of chemical enterprise is a complex nonlinear prediction object, which shows high complexity and nonlinearity. These complexities and nonlinearities cause the difficult in selecting factors in the safety assessment process of chemical companies. According to the published literature, there are many factors affecting the safety of chemical companies, ranging from a few to dozens. This paper focuses on the comparison and research of several artificial neural network prediction methods in the aspect of management in chemical enterprises. These factors and data in management can be found in the literature [6].

3. Result
Since the measured data is few, in order to verify the selected artificial neural network, we adopt the following method: select all data except a certain sample in the training data of the neural network, and after completing the training, use the sample data as an input. The safety is predicted by the neural network and compared with the measured values. By traversing all the sample data, the prediction data of all sample data can be obtained. The chemical industry safety assessment scores obtained by this method and the expert scores can be seen in Table 3. The classification of the predictions can be seen in Table 4. The results indicated that the predictions by using the GRNN were close to the experts’ score when compared with BPNN. By using the GRNN, the $c$ value is 0.0400, and the $p$ value is 0.93. Therefore, the precision of the predictions by using GRNN could reach the level 2. However, the precision of the prediction by using BPNN is the level 4. The results indicated that the GRNN was capable of evaluating safety of chemical enterprise in management.

Table 3. Safety expert rating and artificial neural network evaluation of chemical enterprises

| Sample number | Expert score | Safety assessment Value | Relative error | Safety assessment Value | Relative error |
|---------------|--------------|-------------------------|----------------|-------------------------|----------------|
| 1             | 5            | 3.2882                  | -34.24%        | 4.6658                  | -6.68%         |
| 2             | 5            | 6.7312                  | 34.62%         | 4.6615                  | -6.77%         |
| 3             | 4            | 3.7459                  | -6.35%         | 4.1242                  | 3.11%          |
| 4             | 4            | 4.1581                  | 3.95%          | 4.0101                  | 0.25%          |
| 5             | 3            | 2.6378                  | -12.07%        | 3.1301                  | 4.34%          |
| 6             | 3            | 2.3924                  | -20.25%        | 2.8357                  | -5.48%         |
| 7             | 2            | 3.975                   | 98.75%         | 2.0803                  | 4.01%          |
| 8             | 2            | 2.5958                  | 29.79%         | 1.8237                  | -8.82%         |
| 9             | 1            | 0.6293                  | -37.07%        | 1.3375                  | 33.75%         |
| 10            | 1            | 0.6206                  | -37.94%        | 1.3538                  | 35.38%         |
| 11            | 1            | 0.5822                  | -41.78%        | 1.3874                  | 38.74%         |
| 12            | 5            | 5.0185                  | 0.37%          | 4.6019                  | -7.96%         |
| 13            | 3            | 3.6857                  | 22.86%         | 2.9641                  | -1.20%         |
| 14            | 4            | 3.8545                  | -3.64%         | 4.2232                  | 5.58%          |
| 15            | 2            | 2.1918                  | 9.59%          | 1.8567                  | -7.17%         |
Table 4 Prediction accuracy analysis of generalized neural network

| Precision index | $S_1$ | $S_2$ | $c$  | $p$  | Precision test grade |
|-----------------|------|------|-----|-----|----------------------|
| BPNN            | 0.8340 | 2.8922 | 0.2884 | 67% | Failure (level 4)    |
| GRNN            | 0.0673 | 1.6813 | 0.0400 | 93% | Good (level 2)       |

4. Conclusion

The safety evaluation in management of chemical enterprises were performed by artificial neural network. The relative errors of the prediction by using BPNN and GRNN are 26.33% and 8.42%. Moreover, the precision of the prediction of GRNN reach level 2. Therefore, GRNN can be used for the evaluating the safety in management of chemical enterprises.

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