The Study of Safety Evaluation of the Management in the Chemical Factory based on Artificial Neural Network

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Abstract. This paper presents a methodology to evaluate the safety of the management in the chemical factory with the back propagation neural network (BPNN) and the radial basis function neural network (RBFNN). By comparing the evaluated values with the experts’ scores, the result indicates that the RBFNN is capable of evaluating and predicting the safety in management of the chemical factory.

1. Introduction

The chemical industry plays an important role in the world, which is the fundamental in the economic development of one country. Due to the complexities of the products of the chemical industry, the manufacturing processes in chemical factories have the higher risks than other industries, which are accomplishing with flammable, explosive, high-temperature, high-pressure, harmful chemical productions. Furthermore, with the rapid development of the economy in China, the demand for chemical products has increased and more sophisticated manufacturing processes have been developed. Now, more and more chemical factories become the major hazards in one area. The way used for solving the problems of the safety issues in chemical industry is the executive orders from the administrative agencies with the emphasis of the post-processing of the incidents. However, the most important thing is to find the real reasons and the factors which caused the incidents. With the safety assessment of the factors, the manufacturing process can be monitored in real time and the safety management can be strengthened. Therefore, the safety assessment is needed for the safety manufacture in chemical factories.

The safety assessment was firstly implemented in the developed countries, which was started in the 60s of the last century. In China, the studies in safety assessment were carried out in the last 70s, which is now focusing on the safety assessments of risk factors in the different stage of a project. The studies regarding with the individual project or the chemical technique were also performed. Wang et al. performed the mathematical analysis for evaluating the major risk factors that caused the significant consequence on the chemical project. Chi et al. built a model for evaluating the investment risks by using the fuzzy math to identify and analyze the risk factors [1]. An et al. built a risk index system for the a large chemical project based on the risk sources, and then used this system to assess the risks based on the G-ANP method with the grey theory [2]. Now, the artificial neural network has been used in the studies for evaluating the safety of chemical factories because of the rapid development of the modern math, information technology, artificial intelligence and other disciplines. In China, Luo et al. used the BP neural network to optimize the operating conditions for a chemical
facility [3]. Song et al. used the BP neural network to assess the safety of a chemical factory [4]. Zhou et al. used the BP neural network to study the reliability of the ability in emergency for a chemical industry park [5]. However, the international studies by using the artificial neural network to assess the safety of the chemical factories focused on the individual chemical process or individual chemical technique. For example, Suewatanakul et al. used the BP neural network to analyze the relationship between the fluid velocity and the temperature that had a bias from the normal value [6]. Barton et al. used the recurrent neural network to predict mass of the polymer in the reactor unit [7]. Based on the above studies, the artificial neural network used in the evaluations of the chemical factories is the BP neural network. However, the BP neural network has some limitations. For example, the BP neural network is a local optimization method while the evaluation of a chemical factory is a nonlinear global optimization method. Therefore, the BP neural network may lead to a local maximum or minimum value which results in the training failed. In this paper, the generalized regression neural network and the radial basis function neural network were employed to obtain high accurate in the evaluation of the chemical factory.

2. Methodology

The ANN was one hot topic in the field of artificial intelligence. It establishes a simple model with the different networks consisted of a large number of nodes (neurons) to simulate the information processing of the human brain. Each node (neuron) represents a specific output called as the activation function. The connection between two nodes represents the weighted value for the signal, which can be seen as the memory of the ANN. The output of the ANN finally depends on the connection, the weighted value and the activation function. The common ANNs include the back-propagation neural network (BPNN), the radial basis function neural network (RBFNN) and the general regression neural network (GRNN).

2.1. Back-propagation Neural Network

The BPNN is one of the most popular and successful ANN. A typical BPNN consists of three layers called as the input layer, the hidden layer and the output layer. The connections exit between the input layer and the hidden layer, and between the hidden layer and the output layer (As shown in Figure 1). The BPNN is a feed forward multiple-layer network. The signal is forward-propagation from the input layer to the output layer by passing through the hidden layer. And the error is back-propagation from the output layer to the input layer by passing through the hidden layer with adjusting the weight and the bias. The activation function in the hidden layer is generally the sigmoid function with the amplification of the non-linear effect which results in the nonlinear transformation output in the range of 0 and 1.

![Figure 1 Map of the back-propagation neural network structure](image)
2.2. Radial Basis Function Neural Network
The concept of the BPNN was firstly addressed in 1943. Until 1985, the radial basis function method with the multivariate interpolation was introduced by Powell. The RBFNN is a three-layer forward neural network. The RBFNN consists of one single hidden layer with the radial basis function used as the activation function. The most common radial basis function is the Gaussian function, which is expressed as the following:

\[ k(\|x - x_i\|) = e^{-\frac{\|x-x_i\|^2}{2\sigma^2}} \] (1)

where \( \sigma \) is the parameter to control the width of the function.

2.3. Quantitative assessment of predictions
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)         | ≤0.7     | ≥0.65    |

2.4. Data
The safety of the chemical factory is a complex non-linear problem which included many factors affecting the safety. According to the published literature, the typical factors were chosen from the four major categories: persons, machines, environment, and management. Those factors and the scores graded by the experts can be found in the reference [8].

3. Results
The prediction values by using the BPNN and RBFNN with the experts’ scores were shown in Table 3. The classification of the predictions can be seen in Table 4. The results indicated that the predictions by using the RBFNN were close to the experts’ score compared with the BPNN. By using the RBFNN, the c value is 0.0161, which is smaller than 0.35; and the p value is 1.0, which is greater than 0.95. Therefore, the precision of the predictions by using the RBFNN could reach the level 1. While using the BPNN, the c value is 0.2884 and the p value is 0.67. By checking the Table 2, the precision of the predictions could reach the level 4. The results indicated that the RBFNN was capability of evaluating operation safety of urban rail transit system, while the BPNN cannot predict the operation safety.
Table 3 safety expert rating and artificial neural network evaluation of chemical enterprises

| Sample number | Expert score | BPNN Safety assessment value | BPNN relative error | RBFNN Safety assessment value | RBFNN relative error |
|---------------|--------------|-----------------------------|---------------------|-------------------------------|----------------------|
| 1             | 5            | 3.2882                      | -34.24%             | 4.8837                        | -2.33%               |
| 2             | 5            | 6.7312                      | 34.62%              | 4.902                         | -1.96%               |
| 3             | 4            | 3.7459                      | -6.35%              | 4.0015                        | 0.04%                |
| 4             | 4            | 4.1581                      | 3.95%               | 3.8473                        | -3.82%               |
| 5             | 3            | 2.6378                      | -12.07%             | 3.1378                        | 4.59%                |
| 6             | 3            | 2.3924                      | -20.25%             | 2.8074                        | -6.42%               |
| 7             | 2            | 3.975                       | 98.75%              | 2.1867                        | 9.34%                |
| 8             | 2            | 2.5958                      | 29.79%              | 2.2081                        | 10.41%               |
| 9             | 1            | 0.6293                      | -37.07%             | 1.2558                        | 25.58%               |
| 10            | 1            | 0.6206                      | -37.94%             | 1.391                         | 39.10%               |
| 11            | 1            | 0.5822                      | -41.78%             | 0.8728                        | -12.72%              |
| 12            | 5            | 5.0185                      | 0.37%               | 5.0684                        | 1.37%                |
| 13            | 3            | 3.6857                      | 22.86%              | 2.9145                        | -2.85%               |
| 14            | 4            | 3.8545                      | -3.64%              | 3.9573                        | -1.07%               |
| 15            | 2            | 2.1918                      | 9.59%               | 1.9058                        | -4.71%               |

Table 4 Prediction accuracy analysis of artificial neural network

| Precision index | S1   | S2   | c    | p    | Precision test grade |
|-----------------|------|------|------|------|-----------------------|
| BPNN            | 0.8340 | 2.8922 | 0.2884 | 67% | Fail (Level 4)       |
| RBFNN           | 0.0307 | 1.9128 | 0.0161 | 100%| Excellent (Level 1)  |

4. Conclusion
The paper presented a methodology by employing the RBFNN to evaluate the operation safety of chemical factory. The quantitative assessment of predictions by using RBFNN could reach the level 1, which is very close to the experts’ scores. Therefore, the RBFNN is capable of evaluating the operation safety of urban rail transit very well. The quantitative assessment of the prediction is the level 4 (Fail) which indicated that the BPNN cannot evaluate and predict the operation safety of the chemical factory.

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