A Hydropower Project Quota Establishment Model Based on BP Neural Network

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Abstract - The rapid development of hydropower construction engineering market brings forward the demand for real-time, accurate and efficient project quota, but the current quota establishment method is traditional and mainstream and cannot meet the demand of the market, so looking for a fast and effective method is vital. It is known that there must be some non-linear relationship between the consumption of the quota and its influencing factors. Once we find this relationship, quota establishment work will be easier. The BP neural network technology proposed in this paper suits this job very well, for its powerful non-linear mapping ability it can establish the non-linear mapping from input to output through learning from the training sample, and the feasibility of this method is verified by an example.

Keywords - Hydropower project quota, BP neural network, nonlinear relationship.

I. INTRODUCTION

The hydropower project quota establishment is a very complex and tedious work, the consumption of the labor, material and machine obtained is based on data statistics, analysis, induction, summary from a large number of engineering practice in the past [1], therefore, the quota establishment is always lagging behind the engineering practice. With advances in science and technology, the new construction technology and construction equipment emerge in endlessly, thus leading to the difference between construction programs, although the quota is detailed, it does not contain all of the construction program, and the update of the quota has a cycle, all of these make the quota do not apply in some cases. For example, for the process of “excavators loading earthwork, dump trucks transporting” in "hydropower construction project budget quota" (2004 edition), the largest capacity of excavator bucket is 10m³, the largest load of dump truck is 77t, but with the progress of technology, the capacity of various machinery and equipment is growing, for example, Taiyuan Heavy Industry Group's the latest production of excavators is 55m³, XCMG recently designed and developed the world's largest dump truck, the tonnage of the dump truck is up to 400t, it is a problem to determine the consumption of the labour, material and machine when this occurs.

The hydropower project quota establishment methods which are usually used mainly include Statistical analysis method, technical determination method, experience estimate method and comparative analogy method [2], but these methods are either too complicated or lack of theoretical basis, so finding a convenient quota establishment method currently is an urgent problem. IAHP grey clustering method has been applied to the highway...
engineering construction quota establishment, through analyzing the deficiencies of traditional statistical analysis method, it has proposed the improvement measures, and built a calculation model of the construction quota, the feasibility of the method is verified by an example[3]; The Monte Carlo simulation technique also provides a fast, convenient and reliable method for compiling enterprise quota[4]; When the available sample size for quota establishment is less than normal, you can consider using the methods of linear regression, the AHP contrast estimation to predict the quota consumption data[5]. This paper aims to find out the relationship between the consumption of the quota and its influence factors through BP neural network technology, and provide a reference for quota establishment work.

II. SUMMARY OF THE BP NEURAL NETWORK

BP neural network (Back-Propagation Network) is one of the most widely used network, the use of reverse transmission error learning algorithm is a good idea that realized the multi-layer neural network. The basic principle of BP neural network is that, the learning process consists of positive signal propagation and error back propagation[6]. When the forward propagation, the incoming sample input from the input layer, after processing by each hidden layer step by step, then sending to output layer. If the actual output and the expected output of output layer is inconsistent, then transferred into the error back propagation phase. Error back propagation is that the output error is inputted into the input layer in some form through the output layer and hidden layer step by step, and the error is apportioned to all the units of each layer, thereby obtaining an error signal of each unit, the error signal is used as the basis for correcting the weights of each unit[7]. The weight of each layer adjustment process is carried out repeatedly. The process of constantly adjusting the weights, which is the learning and training process of a network. This process is continued until the network output error reduced to an acceptable level, or to the preset number of learning.

The BP neural network has the following advantages:

(1) Powerful nonlinear mapping ability. In the project, most of the relationship between the input and output are nonlinear, so it is difficult to grasp its internal rules, whereas the BP neural network can form the nonlinear mapping between X-dimensional input layer and Y-dimensional output layer through learning from a large number of input and output samples.

(2) Generalization ability. After training, the BP network can store the nonlinear mapping relationship which is extracted from the samples in the weighting matrix, in a subsequent stage, when input the data which is not seen in the training sample data to the network, the network can also finish the correct mapping from the input layer to the output layer.

(3) Fault tolerance. Another advantage of BP network is that it allows some large error and even individual mistake to exist in the input sample. Because the adjustment process of weight matrix is also a process of extracting statistical properties from a large number of samples, the knowledge that reflect the correct rule is extracted from all samples, the individual error can not influence the adjustment of the weight matrix.

III. ESTABLISH THE BP NEURAL NETWORK ALGORITHM MODEL

A. The BP Network Model

The BP neural network is composed of input layer, hidden layer and output layer[8], where the hidden layer plays a decisive role to the whole neural network, the more number of hidden layer, the higher the precision of the network. However, with the increase of the number of hidden layer, the calculation process of the network is more complex, the time needed for training is more, and the network is easier to fall into local minima. Research has shown that BP neural network with single hidden layer can approximate any closed interval of continuous function[9], so this article selects a single hidden layer of BP neural network. The determination of number of hidden layer neurons can refer to the following formula:

$$m = \sqrt{n + I + a}$$  (1)
where \( n \) is the number of input layer neurons, \( l \) as the number of output layer neurons, \( a \) is a constant between 1 ~ 10;

\[
m = \log_2^n
\]

(2)

where \( n \) is the number of input layer neurons.

A single hidden layer of BP neural network structure as shown in figure:

![Single Hidden Layer of BP Neural Network](image)

The input layer vector is \( X = (x_1, x_2, \ldots, x_i, \ldots, x_n)^T \), the output vector of the hidden layer is \( Y = (y_1, y_2, \ldots, y_j, \ldots, y_m)^T \), the output vector of the output layer is \( O = (o_1, o_2, \ldots, o_k, \ldots, o_l)^T \), the weight matrix between input layer and hidden layer expressed by \( V \), \( V = (V_1, V_2, \ldots, V_j, \ldots, V_m) \), the column vector \( V_j \) is the weight vectors of the \( j \)-th neuron of the hidden layer; the weight matrix between the hidden layer and output layer is denoted by \( W \), \( W = (W_1, W_2, \ldots, W_k, \ldots, W_l) \), the column vector \( W_k \) is the weight vectors of the \( k \)-th neuron of the output layer, \( \theta_j \) is the output threshold of the hidden layer neurons, \( \gamma_k \) is the output threshold of the output layer neurons.

### B. Derivation Algorithm

Before the algorithm is derived, the sample data needs to be processed, because the parameters of the input layer dimension is not consistent. In order to improve the training accuracy and speed, the sample data should be normalized.

The method of normalization processing which is commonly used is as follows:

\[
r_i = \frac{x_{\text{max}} - x_i}{x_{\text{max}} - x_{\text{min}}} \quad i = 1, 2, \ldots, n
\]

(3)

among them, \( x_{\text{max}} \) is the largest numeric of the sample, \( x_{\text{min}} \) is the smallest numeric of the sample. The sample data can be normalized to \([0,1]\) by this method, there are special normalized processing functions in MATLAB, such as premnmx function, the sample data can be normalized to \([-1,1]\) by this function.

For the above model, the following formula could be found when forward propagation:

For the hidden layer:

\[
y_j = f (\text{net}_j) \quad j = 1, 2, \ldots, m
\]

(4)

\[
\text{net}_j = \sum_{i=1}^{n} V_{ij} r_i - \theta_j \quad j = 1, 2, \ldots, m
\]

(5)

For the output layer:

\[
o_k = f (\text{nets}_k) \quad k = 1, 2, \ldots, l
\]

(6)

\[
\text{nets}_k = \sum_{j=1}^{m} W_{kj} y_j - \gamma_k \quad k = 1, 2, \ldots, l
\]

(7)

Researches show that Sigmoid function has good nonlinear mapping effect, therefore it has become a widely used type of transfer function\(^{[10]}\), in this paper, we choose double polarity Sigmoid function:

\[
f (x) = \frac{1 - e^{-x}}{1 + e^{-x}}
\]

(8)

When the output of network is different from the expected output, the output error which is denoted by \( E \) exists, put the error back propagation to correct the weights and threshold of the network, the following formula was established:

\[
E = \frac{1}{2} (d - O)^2 = \frac{1}{2} \sum_{k=1}^{l} (d_k - o_k)^2
\]

(9)

Unfolding this error to the hidden laye:
Further expanding to the input layer:
\[
E = \frac{1}{2} \sum_{k=1}^{l} \left[ d_k - f \left( \sum_{j=1}^{m} \eta_j \sigma_j - \gamma_k \right) \right] \\
(10)
\]

From the above, we know that the error of the network is a function of every layers’ weights and thresholds, so we can change the size of the error through altering weights and thresholds. According to error gradient descent method to adjust weights and thresholds of the network:

\[
\Delta v_{ij} = -\eta \frac{\partial E}{\partial v_{ij}} i=1,2,...,n; j=1,2,...,m \\
(12)
\]

\[
\Delta \theta_j = -\eta \frac{\partial E}{\partial \theta_j} j=1,2,...,m \\
(13)
\]

\[
\Delta w_{jk} = -\eta \frac{\partial E}{\partial w_{jk}} j=1,2,...,m; k=1,2,...,l \\
(14)
\]

\[
\Delta \gamma_k = -\eta \frac{\partial E}{\partial \gamma_k} k=1,2,...,l \\
(15)
\]

Among them, \( \eta \) is the learning rate.

Finally, the weights and thresholds of the network adjustment formula is as follows:

\[
\Delta v_{ij} = \eta \sum_{k=1}^{l} \left( d_k - \sigma_k \right) \cdot f'(net_k) \cdot w_{jk} \cdot f'(net_j) \cdot r_i \\
i=1,2,...,n; j=1,2,...,m \\
(16)
\]

\[
\Delta \theta_j = -\eta \sum_{k=1}^{l} \left( d_k - \sigma_k \right) \cdot f'(net_k) \cdot w_{jk} \cdot f'(net_j) \cdot r_j \\
j=1,2,...,m \\
(17)
\]

\[
\Delta w_{jk} = \eta \sum_{k=1}^{l} \left( d_k - \sigma_k \right) \cdot f'(net_k) \cdot f'(net_j) \\
j=1,2,...,m \\
(18)
\]

\[
\Delta \gamma_k = -\eta \sum_{k=1}^{l} \left( d_k - \sigma_k \right) \cdot f'(net_k) \\
(19)
\]

C. The Improvement of BP Algorithm

When adjusting the weights, BP algorithm adjusted only according to the gradient descent direction of the error at the moment of \( t \), without taking into account gradient direction of \( t \) moments ago, this make training process oscillate and converge slowly \([11]\). In order to improve the training speed of network and prevent falling into local minima, you can add an additional momentum factor which is denoted by \( m_e \) (\( m_e \) usually take about 0.95) to weight adjustment formula, that is to say, when changing every weight (or threshold), you can add a numeric which is proportional to the last weight (or threshold) change in the value, thus we have:

\[
v_{ij} (t+1) = v_{ij} (t) + \Delta v_{ij} + m_e (v_{ij} (t) - v_{ij} (t-1)) \\
t=1,2,... \\
(19)
\]

\[
\theta_j (t+1) = \theta_j (t) + \Delta \theta_j + m_e (\theta_j (t) - \theta_j (t-1)) \\
t=1,2,... \\
(20)
\]

\[
w_{jk} (t+1) = w_{jk} (t) + \Delta w_{jk} + m_e (w_{jk} (t) - w_{jk} (t-1)) \\
t=1,2,... \\
(21)
\]

\[
\gamma_k (t+1) = \gamma_k (t) + \Delta \gamma_k + m_e (\gamma_k (t) - \gamma_k (t-1)) \\
t=1,2,... \\
(22)
\]

IV. EXAMPLE

Now we put the process of “excavators loading earthwork, dump trucks transporting” which is often involved in hydropower project construction process as the research object.
A. Factors Influencing

The working content of the process of "excavators loading earthwork, dump trucks transporting" is dig loading, transportation, unloading and return, this belongs to machinery as the leading process, so this time only consider the effect of mechanical factors.

1) the capacity of excavator bucket. The larger capacity of excavator bucket, the higher the efficiency of construction, and the less machine-team consumption, however, the larger capacity of excavator bucket, the higher the working-day cost, so it should choose the reasonable excavator bucket capacity during construction process.

2) the load of dump truck. The large dump truck load, the greater the amount of each shipment, and therefore the less number of round trips, but similar to excavator, with the increase of the dump truck load, its machine-team price is also higher and higher, so the load is not the bigger, the better during construction process.

3) the category of earth-rock. In hydropower project construction, according to the excavation method, excavation difficulty, strong coefficient, the earth-rock is often divided into 16 grades, in which I-II class is scarification, III class is ordinary soil, IV class is hard soil, V-VI class is soft rock, VII-IX class is secondary-hard stone, X-XVI class is rock.

4) the distance. The distance affects the consumption of dump truck mainly from two aspects, namely, transport loaded and empty back.

B. Model Validation

To verify the feasibility of the method, we can select 35 sample data from the "hydropower construction project budget quota" (2004 edition), the following is a selection of 35 samples.

The sample data is divided into two parts, the first part is the front of 30 groups, as the training sample, the last 5 groups are a part, as the test sample. Put the capacity of excavator bucket, the category of earth-rock, the load of dump truck and the distance as the input of the model, the consumption of excavator and the consumption of dump truck as the output of the model. According to past experience, the number of hidden layer neurons is 10. The training function is trainscg, namely the conjugate gradient method, its advantage is that when the training is not convergence, it will automatically stop training, and the algorithm converges fast (if convergence). Learning function uses learnadm. Before inputting the data in the table to the network, you need to use premmnx function to normalize the data, it can be normalized to [-1,1] by this function, so the incentive function of hidden layer and output layer adopt tansig. Put the processed data to the network for training, then using postmmnx function to anti-normalize the training results, compared with desired output. Training times is tentatively scheduled for 5000. The following figure shows the training convergence curve.

### TABLE 1. The Sample Data of the Quota

<table>
<thead>
<tr>
<th>Serial number</th>
<th>Capacity of excavator bucket (m³)</th>
<th>Category of earth-rock</th>
<th>Load of dump truck (t)</th>
<th>The distance (km)</th>
<th>Consumption of excavator (machine-hour)</th>
<th>Consumption of dump truck (machine-hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>5</td>
<td>3</td>
<td>0.69</td>
<td>9.74</td>
</tr>
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<td>2</td>
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<td>2</td>
<td>10</td>
<td>3</td>
<td>0.69</td>
<td>5.74</td>
</tr>
<tr>
<td>3</td>
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<td>3</td>
<td>10</td>
<td>3</td>
<td>0.79</td>
<td>6.04</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>2</td>
<td>25</td>
<td>2</td>
<td>0.25</td>
<td>2.18</td>
</tr>
<tr>
<td>5</td>
<td>4</td>
<td>2</td>
<td>32</td>
<td>2</td>
<td>0.25</td>
<td>1.72</td>
</tr>
<tr>
<td>6</td>
<td>4</td>
<td>4</td>
<td>32</td>
<td>4</td>
<td>0.33</td>
<td>2.79</td>
</tr>
<tr>
<td>7</td>
<td>6</td>
<td>2</td>
<td>32</td>
<td>2</td>
<td>0.2</td>
<td>1.63</td>
</tr>
<tr>
<td>8</td>
<td>6</td>
<td>4</td>
<td>32</td>
<td>2</td>
<td>0.26</td>
<td>1.8</td>
</tr>
<tr>
<td>9</td>
<td>6</td>
<td>4</td>
<td>50</td>
<td>4</td>
<td>0.26</td>
<td>1.73</td>
</tr>
<tr>
<td>10</td>
<td>8</td>
<td>3</td>
<td>50</td>
<td>3</td>
<td>0.18</td>
<td>1.34</td>
</tr>
<tr>
<td>11</td>
<td>8</td>
<td>2</td>
<td>50</td>
<td>3</td>
<td>0.16</td>
<td>1.27</td>
</tr>
<tr>
<td>12</td>
<td>10</td>
<td>2</td>
<td>68</td>
<td>3</td>
<td>0.13</td>
<td>1.09</td>
</tr>
<tr>
<td>13</td>
<td>10</td>
<td>1</td>
<td>68</td>
<td>3</td>
<td>0.13</td>
<td>1.09</td>
</tr>
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<td>14</td>
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<td>3</td>
<td>45</td>
<td>1</td>
<td>0.15</td>
<td>0.86</td>
</tr>
<tr>
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<td>5</td>
<td>3</td>
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<td>15.03</td>
</tr>
<tr>
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<td>15.03</td>
</tr>
<tr>
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<td>1.56</td>
<td>15.99</td>
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<td>18</td>
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<td>12</td>
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<td>3</td>
<td>1.56</td>
<td>15.99</td>
</tr>
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<td>16.95</td>
</tr>
<tr>
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<td>3</td>
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<td>10</td>
<td>1</td>
<td>0.71</td>
<td>4.73</td>
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<tr>
<td>21</td>
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<td>13</td>
<td>10</td>
<td>1</td>
<td>0.75</td>
<td>5.01</td>
</tr>
<tr>
<td>22</td>
<td>8</td>
<td>10</td>
<td>50</td>
<td>4</td>
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<td>2.26</td>
</tr>
<tr>
<td>23</td>
<td>8</td>
<td>8</td>
<td>50</td>
<td>4</td>
<td>0.34</td>
<td>2.12</td>
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<tr>
<td>24</td>
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<td>13</td>
<td>50</td>
<td>3</td>
<td>0.38</td>
<td>2.06</td>
</tr>
<tr>
<td>25</td>
<td>8</td>
<td>14</td>
<td>77</td>
<td>3</td>
<td>0.38</td>
<td>1.49</td>
</tr>
<tr>
<td>26</td>
<td>10</td>
<td>14</td>
<td>77</td>
<td>3</td>
<td>0.32</td>
<td>1.44</td>
</tr>
<tr>
<td>27</td>
<td>10</td>
<td>10</td>
<td>77</td>
<td>3</td>
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<td>28</td>
<td>10</td>
<td>5</td>
<td>77</td>
<td>3</td>
<td>0.28</td>
<td>1.28</td>
</tr>
</tbody>
</table>
In figure 2, the abscissa represents the number of iterations, the ordinate represents the error accuracy. As we can see from the figure, the network begin to converge at the time of iteration to 2000th, and the error accuracy can meet the requirements, the network training is completed.

Put the five groups of data at the end of table 1 into the trained network, the output of the network shown in the table below:

### TABLE 2. The Network Output and the Expected Output

<table>
<thead>
<tr>
<th>Serial number</th>
<th>Network output</th>
<th>Expected output</th>
<th>Error accuracy (%)</th>
<th>Network output</th>
<th>Expected output</th>
<th>Error accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>29</td>
<td>0.2162</td>
<td>0.2</td>
<td>8.1</td>
<td>1.6743</td>
<td>1.69</td>
<td>-0.93</td>
</tr>
<tr>
<td>30</td>
<td>0.2224</td>
<td>0.23</td>
<td>-3.3</td>
<td>1.3216</td>
<td>1.31</td>
<td>0.89</td>
</tr>
<tr>
<td>31</td>
<td>0.5810</td>
<td>0.55</td>
<td>5.6</td>
<td>3.0667</td>
<td>2.82</td>
<td>8.7</td>
</tr>
<tr>
<td>32</td>
<td>0.4602</td>
<td>0.44</td>
<td>4.5</td>
<td>2.0302</td>
<td>1.6</td>
<td>26.8</td>
</tr>
<tr>
<td>33</td>
<td>0.2828</td>
<td>0.32</td>
<td>-11.6</td>
<td>1.4220</td>
<td>1.07</td>
<td>32.9</td>
</tr>
</tbody>
</table>

As we can see from Table 2, the network output and the expected output are similar as a whole, error accuracy can be controlled within 10%, only a few data error accuracy is bigger, and these data occurred in the samples that the earth-rock category is more than 5(i.e., belongs to the category of rocks), the analysis found that the main cause is: the rating of rock is divided into 12 levels from 5 to 16 class, the number of sample which is belong to rock category in the training samples is only 16, the sample quantity is too little, so it cannot fully reflect the internal rule of the data. Therefore, if increasing the number of sample which is belong to rock category in the training samples, we will get better training effect.

### V. CONCLUSIONS

From the above, we can know that the application of neural network technology to hydropower projects quota establishment work is very applicable, we can predict the consumption through the limited sample size that is known, it can effectively reduce the workload at the construction site, and greatly improving the efficiency of compiling quota work.

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