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Research Paper

Application of artificial neural networks to predict the quality of road construction. A Case Study

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ABSTRACT: *The quality of construction is one of the factors determining the success of construction projects in road construction and other objects in the field of civil engineering. The degree of success of a project depends greatly on the efficiency and quality of construction. This study aims to carefully consider the factors that adversely affect the construction quality of road projects during construction. The team used the ANN artificial neural network model to forecast road construction quality. The results show that using the artificial neural network model ANN has high accuracy R = 0.95855.*

KEYWORDS: *Road construction quality, ANN, AI, R*

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I. INTRODUCTION

The construction sector makes a significant contribution to the economic growth and social development of developing countries. Maintaining the quality of work is one of the very important factors to achieve competitiveness in the production and business strategy of enterprises. Different quality management techniques such as Total Quality Management (TQM) and others are applied to analyze the quality of any project. TQM is a quality management technique aimed at long-term success through customer satisfaction [18]; [23]. The main obstacles to the implementation of TQM in developing countries include jobs without the commitment of the Company's management, insufficient expertise, low participation in competitive bidding, undervalued education and training, lack of worker participation, lack of employee empowerment, strict operating regime, the approach of executives to the quality management system (QMS) is still rigid [17].

Quality is the perfection or excellence of any process, product, or system and is measured against the tools, standards, processes, norms, and standards prescribed for each of those product areas and the needs of [11]. TQM is the result of the revolution in quality management techniques [5]. The concept of TQM in the construction sector has not been widely applied and has not been widely implemented. However, it is necessary to have a holistic concept or model to solve TQM problems in the construction sector. Table 1 summarizes several current studies on TQM.

Table 1. Synthesis of studies on TQM

No.	TQM Concept	References
1	The Effects of Total Quality Management Practices on Performance and the Reasons and the Barriers to TQM Practices in Turkey	[19]
2	Evaluation of Total Quality Management Implementation as Engineering Practices in Jordanian Construction Projects	[2]
3	Impact of Total Quality Management on Innovation in Service Organizations: Literature review and New Conceptual Framework	[3]
4	Mediating effect of TQM on the relationship between organizational culture and performance: evidence from Indian SMEs	[21]
5	The relationship between total quality management practices and their effects on firm performance	[14]

During the construction of road works, there are many factors affecting the quality of work such as design, materials, machinery, topography, engineering geology, hydrogeology, meteorology, construction technology, operation methods, technical measures, and management systems. According to [15], quality is the symbol of human civilization and with the progress of human civilization, quality control will play an incomparable role in business and other objects. It can be said that without quality control there is no economic

benefit. He also emphasized that quality control is a process used to ensure a certain level of quality in a product or service. The basic objective of quality control is to ensure that the products, services, or processes offered meet specific and reliable requirements.

Quality is one of the key factors for the success of construction works. The quality of the construction project is also the success of the project, which can be considered as the expected completion (satisfaction) of the project participants. Quality, cost, and time have been recognized as key factors related to customers. However, for many projects, the cost and time parameters are important factors before the construction of the project. Here the authors emphasize more attention to quality. Quality in the construction industry is generally associated with customer satisfaction and the implementation of a quality management system (QMS) is an important tool to manage the goal of customer satisfaction consistently and reliably. The QMS can be implemented at the organizational level or the project level.

For the implementation of QMS in construction projects, the concepts of quality planning (defining quality standards), quality assurance (evaluating the overall results of the project), and quality control (monitoring the specific results of the project) are in the QMS process.

The construction phase is a major stage of the construction investment process to transform the "paper-based" works into existing works, the construction process has a direct and decisive impact on the quality of construction works. The quality management of construction contractors during construction is very important to ensure and improve the quality of the work. Establishing a comprehensive quality management system model applied to the construction process proves to be an effective and sustainable solution to help contractors improve construction quality management, contributing to improving the quality of construction works.

In recent years, the application of the artificial neural network (ANN) has been used in many projects. Besides, its use in the construction industry is still limited and not widely applied. ANN is the abbreviation of Artificial Neural Network which is a mathematical model or computational model simulating the structure and function of biological neural networks [23]. The most used algorithm of the neural network is Back Propagation (BP), which consists of an input layer, a hidden layer, and an output layer (Figure 1). Its main idea is:

1) Since the output of ANN has an error with the actual result, the error between the estimated value and the actual value is calculated and the error is passed back from the output layer to the hidden layer until it is transmitted to the input layer.

2) During the back-transmission, the values of the different parameters are adjusted according to the error.

3). Continuously repeat the above process until convergence occurs. Multilayer neural networks can also be implemented by the least squares method in the learning process.

The objective research is to use artificial neural networks to forecast the quality of road construction. This forecast plays an extremely important role, a reliable basis for the investor to serve as a basis for acceptance of the project. In many forecasting models. In this study are selected the model of ANN, ANN that is an advanced technology being widely applied in the world. ANN is an artificial intelligence (AI) technology platform. ANN's structure and its reasoning process can dynamically self-adapt (autofit) in response to a correlation signal from the data set. Based on various experimental works, ANN demonstrated the ability to deliver highly accurate prediction results. ANN is widely used to solve nonlinear regression analysis problems.

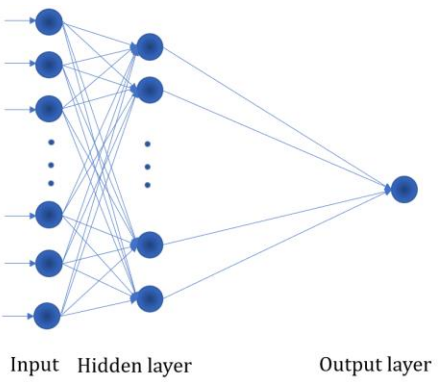

Figure 1. Multilayer neural network

II. RESEARCH METHOD

1. Overview of the ANN Model

An artificial neural network is a set of data analysis algorithms that allows for defining a complex mathematical relationship between an input variable and a target variable. ANN is an application based on

artificial intelligence, ANN's structure, and the learning, reasoning, and reconstruction process of Autofit with various types of data.

ANN processes simulated information in a way that processes the information of the biological neuron systems in the human brain. ANN is made up of many neurons connected through weighted links, forming a unitary body, intended to process, and analyze information, a problem. An artificial neural network is structured for a specific application (pattern recognition, data classification, …) through a training process from a set of training patterns. Inputs will run through the entire neural network, which will be processed, searched for relationships, and reconstructed as output. These Outputs will be compared to the Target data previously learned by the system. If there is still a significant difference between the Output and Target, then the training process is repeated, and the link weights between the neurons are calibrated to give a better output. This process is repeated repeatedly until the smallest possible deviation (Bias) between Output and Target is achieved. Thus, in essence, the training process is the process of correcting the link weights between the neurons until an optimal result is achieved, which is to reproduce the similar Target Output and can be used to forecast off-sample for the Target.

2. Structure of artificial neurons

The typical ANN structure has the components described in Figure 2.

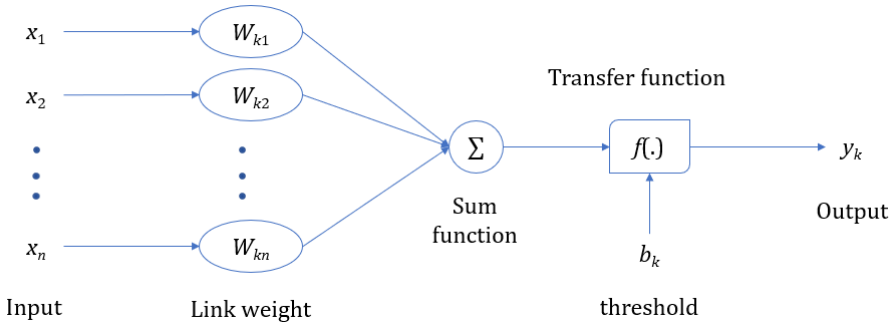

Figure 2. Structure of artificial neurons [16]

The input provides the input signals of the neurons, which signals are typically introduced as an N - dimensional vector.

Links: Each link is represented by a weight (called a link weight - Synaptic weight). The link weight between the j-th input signal and the neuron k is usually denoted as w_{kj}. Typically, these weights are randomly generated at the time of network initialization and continuously updated during network training.

Summing function: This field is used to calculate the sum of the inputs with their associated weights.

$$\sum_{i=1}^{m}\left(w_i x_i\right)+bias\,. \qquad (1)$$

Threshold (also known as a Bias): This threshold is usually included as a component of the transfer function.

Transfer function: This function is used to limit the output range of each neuron. It receives the input because of the sum function and the given threshold. Typically, the output range of each neuron is limited to [0.1] or [-1.1]. The transfer functions are very diverse, be they linear or nonlinear functions. Some of the transfer functions commonly used in neural network models include Symmetrical Hard Limit (Hardlims), Linear (Purelin), Saturating Linear (Satlin), and Log-Sigmoid (Logsig).

$$f\left(x\right)=\begin{cases}1\ if\ \sum wx+b\geq 0\\ 0\ if\ \sum wx+b<0\end{cases}. \qquad (2)$$

Output: The output signal of a neuron, with each neuron having a maximum of one output.

Thus, like a biological neuron, an artificial neuron also receives input signals, processes (multiplies these input signals by the link weight, calculates the sum of the obtained ticks, and then sends the result to the transfer function), reproduces the output signal (the result of the transfer function).

A neural network may include one or more neurons. Each neuron is an information processing unit, and the interconnections between the neurons form a network structure. Although every single neuron can perform certain information processing functions, the power of neuron computation is primarily obtained by combining neurons in a unified architecture. A neural network is a computational model that is defined through parameters: the type of neuron (such as nodes if we consider both neural networks as a graph), the connection

architecture (the organization of connections between neurons), and the learning algorithm (the algorithm used to learn for the network). The neurons are connected by a weighting matrix. The way neurons are connected in the network determines the Topology of the network, so there are many different network structures. The typical structure of a neural network consists of three layers: the input layer, the hidden layer, and the output layer.

- The input layer consists of one or more input variables, providing information to the artificial network.
- The output layer may include one or more output variables.
- The association between input and output factors is calculated through the intermediate hidden layer with a system of transfer functions and thresholds.

Based on the connection properties between the output neurons to the input neurons, the network is divided into two structures:

Feedforward architecture: is the type of network architecture that does not have back-to-back connections from the output neurons to the input neurons; the network does not save the previous Output values and activation states of the neurons. Straightforward transmission neural networks allow signals to travel in a single path; from input to output, the output of any layer will not affect that layer. Perceptron-type networks are straight-line networks.

Feedback Architecture: is the type of network architecture with connections from the output neuron to the input neuron. The network stores the previous states, and the next state depends not only on the input signals but also on the previous states of the network. Hopfield networks are of this type.

An artificial neural network can have a single hidden layer or multiple hidden layers (Figure 3). The most widely used is the MLP (Multi-Layer Perceptron) network structure. A generalized MLP network is a network with n ($n \geq 2$) tiers (normally the input tier is not taken into account): which includes an output tier (nth tier) and (n - 1) hidden tier. Each neuron of the following tier is associated with all neurons of the layer preceding it. The output of the front cascade neuron is the input of the neuron of the back cascade behind it.

The hidden multilayer neural network allows deep information and data processing (Deep Learning), however, many studies have demonstrated that with only one hidden layer, the artificial neural network can still simulate very complex nonlinear functions with high accuracy (Cybenko, 1989; Hornik, 1991; Hornik et al., 1989; Zhang et al., 1998; Caputo et al., 2011; Demir et al., 2015).

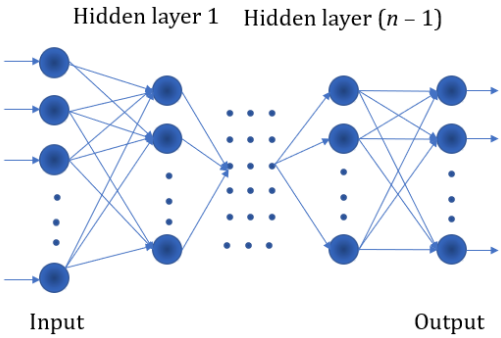

Figure 3. Multi-hidden layer [16]

3. Data Analysis Process with ANN

Select variables: When creating a template, you need to select the variables used in the model. There are two issues of concern:

- It is necessary to learn how to transform information and data so that it is more beneficial for the network: information before being introduced into the network needs to be transformed in the most appropriate form so that the network achieves the highest performance.
- Choose from the transformed variables which would be most beneficial for the network to include in the model. Not all the information about the sample is good for the network.

Data preparation: Data is usually divided into 3 sub-samples, as follows:

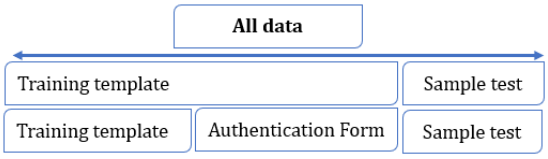

Figure 4. Data Preparation

In Figure 4:

- Training Set provides information for the learning process of artificial intelligence.
- Testing Set is used to test the model.
- Validation set is used to revalidate training results.

There is no formula for the ratio between the sample sizes. In many studies, the data sample is divided into the following proportions: 70% for the training sample, 15% for the test sample, and 15% for the validation sample. Some other studies use 100% of the sample for coaching, which is consistent with data with short time series, volatile, and consistent with the objective of off-sample forecasting.

Define parameters for artificial neural networks

- Determine the number of neurons
- Identify the number of hidden floors
- Select the transfer function

There is no formula for defining parameters for artificial neural networks, it depends on the specific problem and experience of the network designer.

The end of the process is the step of network training and automatic weighting initialization.

4. Overview of research works

Project: Construction of Le Cong Thanh Road - Ha Nam Province [25]

Capacity

- Vertical axis D1 (Figure 5):

Starting point: Km0 intersects with NH38 (Km83+622-QL38) next to the 110 kV power station in TT. Dong Van, Ha Nam, Vietnam

End point: Km7 + 566.28 intersects with the new National Road 21b (Km56 + 919.81 - National Road 21b) in the hamlet of North, Tien Hiep commune, Duy Tien district.

Length of line 1: 7.57 km.

Length of line 2: 2.1 km.

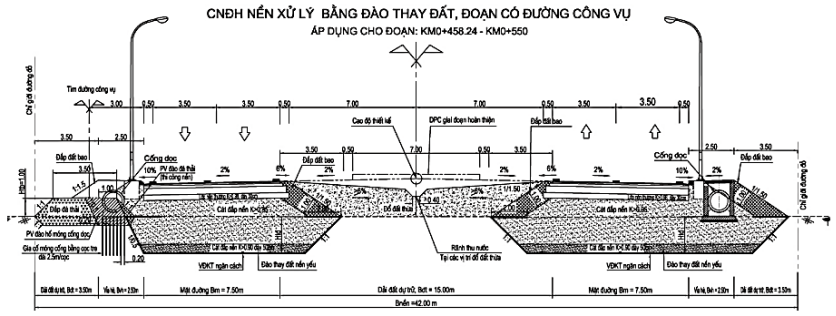

Figure 5. Typical cross-section of soil replacement excavation

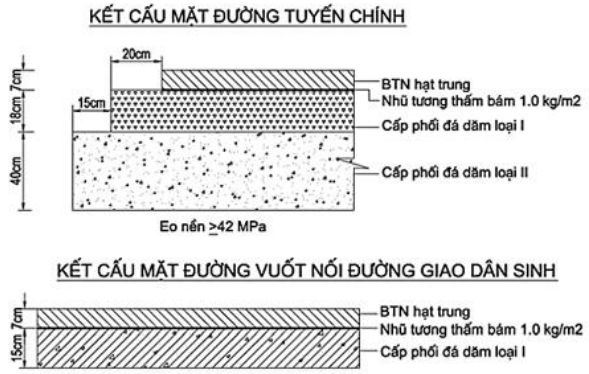

Figure 6. Typical Structure of Pavement

5. Data and structure ANN forecast quality of road construction

The road construction quality assessment indicator used in the construction project of Le Cong Thanh, Phu Ly, Ha Nam, Vietnam streets is based on the evaluation criteria of experts, here the research team has preliminary surveyed and presented 5 main groups of criteria and 15 sub-criteria groups as Table 2.

Table 2. Criteria for assessing the quality of road construction

Rating Index	Top index	Number	Second index
C	C_1 Labour index	1	C_{11} Level of manager compliance qualification
		2	C_{12} Level of operator qualification standards
	C_2 Material index	3	C_{21} Material standards
		4	C_{22} Material Attribute Status
	C_3 Machinery and equipment index	5	C_{31} Degree of quality compliance of machinery and equipment.
		6	C_{32} Reasonableness of the choice of machinery and equipment
		7	C_{33} Standard for Machinery Operators
	C_4 Construction method indicators	8	C_{41} Reasonableness of construction technology diagrams
		9	C_{42} Advanced and rational construction technologies and methods
		10	C_{43} Reasonableness of construction methods and development of technical measures
	C_5 Environmental indicators	11	C_{51} Natural environment of the construction site
		12	C_{52} Quality assurance index of construction contractors
		13	C_{53} Quality management system of construction contractors
		14	C_{54} Technical and economic conditions
		15	C_{55} Working environment of the construction site

In Table 2, the level of influence of the factors was assessed at 5 levels from 1 to 5 corresponding to 1 (Very Good); 2 (Good); 3 (Medium); 4 (Poor); 5 (Very Poor). Based on the evaluation survey, we have the evaluation value in Table 3.

Table 3. Evaluation results from experts

Sample	C_1		C_2		C_3			C_4			C_5				
	C_{11}	C_{12}	C_{21}	C_{22}	C_{31}	C_{32}	C_{33}	C_{41}	C_{42}	C_{43}	C_{51}	C_{52}	C_{53}	C_{54}	C_{55}
1	2	1	1	3	2	3	2	1	2	2	2	2	2	1	3
2	3	4	2	3	1	3	3	2	2	1	1	4	5	2	1
3	2	2	2	2	2	3	3	2	1	2	2	2	3	3	3
4	1	2	2	2	3	3	3	3	2	2	3	2	2	2	4
5	3	3	3	3	2	3	3	2	1	2	3	4	3	3	3
6	2	4	2	3	3	2	1	1	2	2	2	3	3	3	2
7	2	3	2	2	3	3	1	2	2	2	3	2	2	3	3
8	2	3	2	3	2	2	2	3	3	2	2	2	3	2	2
9	1	2	2	2	2	3	2	2	3	3	2	2	1	3	2
10	2	1	3	3	2	2	2	2	1	2	3	2	2	2	3
11	2	3	3	3	1	2	2	1	1	2	2	2	3	2	1
12	1	2	3	3	3	3	3	2	2	2	4	2	2	3	4
13	2	4	3	3	2	3	3	2	2	2	1	2	2	2	1
14	1	2	2	2	3	3	3	3	2	2	2	4	2	1	2
15	3	3	3	3	1	2	2	1	2	2	2	2	1	2	1

Input data is normalized to be in the [-1;1] segment and used Matlab for training.

Step 1. Selection of input variables

In this study, 15 input parameters were used including: C_{11}; C_{12}; C_{21}; C_{22}; C_{31}; C_{32}; C_{33}; C_{41}; C_{42}; C_{43}; C_{51}; C_{52}; C_{53}; C_{54}; C_{55} and normalized data as in Table 4.

Table 4. Normalization of ANN model input parameter data

Sample	C_1		C_2		C_3			C_4			C_5				
	C_{11}	C_{12}	C_{21}	C_{22}	C_{31}	C_{32}	C_{33}	C_{41}	C_{42}	C_{43}	C_{51}	C_{52}	C_{53}	C_{54}	C_{55}
1	0.0	-1.0	-1.0	1.0	0.0	1.0	0.0	-1.0	0.0	0.0	0.0	0.0	0.0	-1.0	1.0
2	0.0	0.5	-0.5	0.0	-1.0	0.0	0.0	-0.5	-0.5	-1.0	-1.0	0.5	1.0	-0.5	-1.0
3	0.0	0.0	0.0	0.0	0.0	1.0	1.0	0.0	-1.0	0.0	0.0	0.0	1.0	1.0	1.0
4	-1.0	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	1.0

Sample	C_1		C_2		C_3			C_4			C_5				
	C_{11}	C_{12}	C_{21}	C_{22}	C_{31}	C_{32}	C_{33}	C_{41}	C_{42}	C_{43}	C_{51}	C_{52}	C_{53}	C_{54}	C_{55}
5	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	-1.0	0.3	0.3	1.0	0.3	0.3	0.3
6	0.3	1.0	0.3	0.3	0.3	0.3	-1.0	-1.0	0.3	0.3	0.3	0.3	0.3	0.3	0.3
7	0.0	1.0	0.0	0.0	1.0	1.0	-1.0	0.0	0.0	0.0	1.0	0.0	0.0	1.0	1.0
8	-1.0	1.0	-1.0	1.0	-1.0	-1.0	-1.0	1.0	1.0	-1.0	-1.0	-1.0	1.0	-1.0	-1.0
9	-1.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	1.0	1.0	0.0	0.0	-1.0	1.0	0.0
10	0.0	-1.0	1.0	1.0	0.0	0.0	0.0	0.0	-1.0	0.0	1.0	0.0	0.0	0.0	1.0
11	0.0	1.0	1.0	1.0	-1.0	0.0	0.0	-1.0	-1.0	0.0	0.0	0.0	1.0	0.0	-1.0
12	-1.0	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	1.0	0.3	0.3	0.3	1.0
13	0.3	1.0	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	-1.0	0.3	0.3	0.3	-1.0
14	-1.0	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	1.0	0.3	-1.0	0.3
15	1.0	1.0	1.0	1.0	-1.0	0.0	0.0	-1.0	0.0	0.0	0.0	0.0	-1.0	0.0	-1.0

Step 2. Selection of coaching and testing forms

Matlab is a powerful mathematical tool that has many applications, and it has a dedicated neural network module.

- Input layer: According to [1] most project managers rely on intuition and experience to judge and evaluate the quality and risk of the construction process. In addition, [10] investigated and reached the same conclusion that in the assessment of quality as well as the risk of construction works, intuition, judgment and experience are the most frequently used methods. Therefore, the survey of experts, and obtaining the evaluation of experts on the value of the indicators of quality are different.

- Hidden layer: Based on the experience as well as the research of [7] to determine the number of neuron nodes used is $m = 0.5\ n \times 1$ (m for hidden layer nodes, n for input layer nodes, 1 for an output node).

- Output layer: Represents the results of quality or risk assessment during the road construction phase. The higher the score, the higher the level of risk or the poorer the quality of construction.

Step 3. Selection of the number of hidden layer neurons

According to research by [8], [13], [24], our ANN model is structured with some hidden layer neurons sufficient for ANN to estimate any complex non-linear function with the desired accuracy. The team constructed ANN with 14 hidden layer neurons due to the following reasons: (1) the network with the number of hidden layer neurons is equal to the number of input layer neurons minus one showing better forecast results in some studies [6]; [20]. In our case, it is 15 - 1 = 14 hidden layer neurons (2) by running the test (test and test), the number of hidden layer neurons of 14 gives the best result (also consistent with the recommendation of [7].

The following nonlinear regression model was formed:

$$y_t = f\left(y_{t-1},...,y_{t-d},...,x_{t-d}\right). \qquad (3)$$

With y as the function of the quality of road construction works, x as the value of the construction quality assessment, and d as the number of assessment indexes 15 as determined above.

A relay network is created with 15 input nodes for each variable, and 14 hidden layers with 14 nodes for each output node. The ANN structure of the model proposed in this study is illustrated in Figure 7.

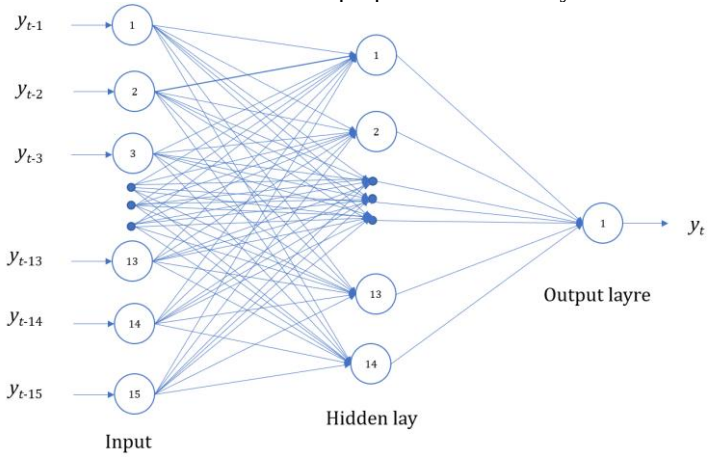

Figure 7. Suggested multi-chain model

III. RESULTS AND DISCUSSIONS

The proposed model uses the Levenberg-Marquest algorithm, the training results are depicted in Figure 8, and the training, validation, and test curves are similar. The best confirmation performance with a mean square error index (MSE) of 0.179 was found in Epoch 4 and training continued for five more iterations before it stopped. More importantly, training performance noted no Overfitting phenomenon.

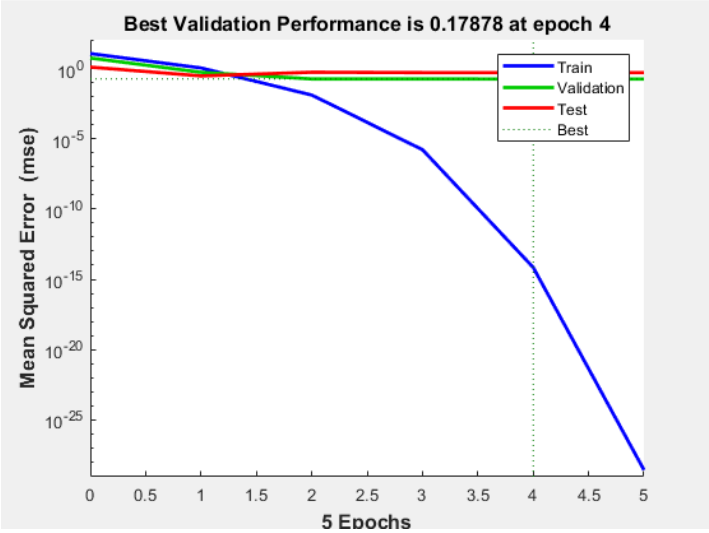

Figure 8. Results of ANN's network training

The next step of ANN network validation consists of creating a regression chart that shows the relationship between the network's output (the observed work quality rate from ANN) and the objectives (the predicted work quality rate) in training, validation, testing, and all data. Theoretically, the network output and goals will be the same if the training is perfect. However, this relationship rarely occurs in practice. As shown in Figure 8, the three axes respectively represent training, validation, and testing data. The dashed line in each axis indicates the optimal result which means the output is equal to the target. Meanwhile, the solid line represents the linear regression line that best fits the output and the goal. In addition, the value of R indicates the relationship between the output and the goal. Accordingly, $R = 1$ proposes a correct linear relationship between output and target while R is close to zero, assuming that there is no linear relationship between them [22]. The algorithm is terminated according to the early-stop procedure.

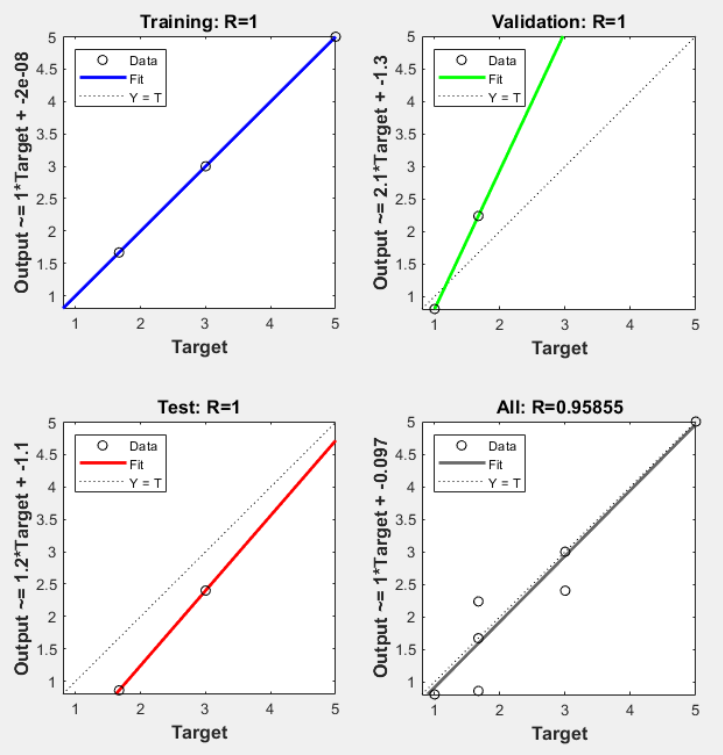

Figure 9. Regression model training

Figure 9 shows: the training sample shows that the network output and the target are almost identical because the *R*-value is close to 1. This shows that the proposed model is reliable and effective. Furthermore, the research team continued to perform automatic model error correction as shown in Figure 10. This also provides cross-checking of network performance. Except for zero latency, the correlation is around zero with 95% confidence. In other words, the ANN model studied is appropriate.

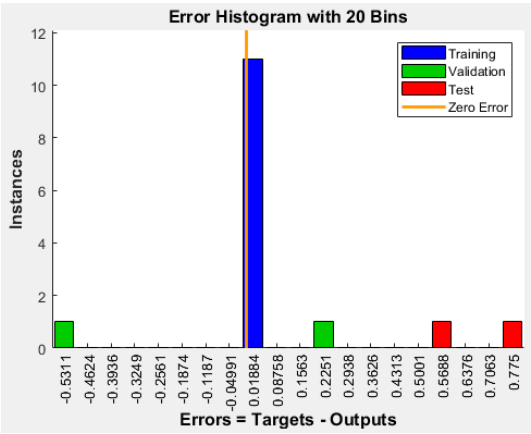

Figure 10. Correlation of the proposed model

Figure 11 presents the results of the outputs, goals, and deviations between the Target and Output. Accordingly, the time points that have been selected for training, testing, and validation can be determined. It is important to note that these points are chosen at random in the first step. Once the data is updated, the proposed ANN model can automatically match the new data set. That's one of the strengths of using ANN models. However, this error is acceptable.

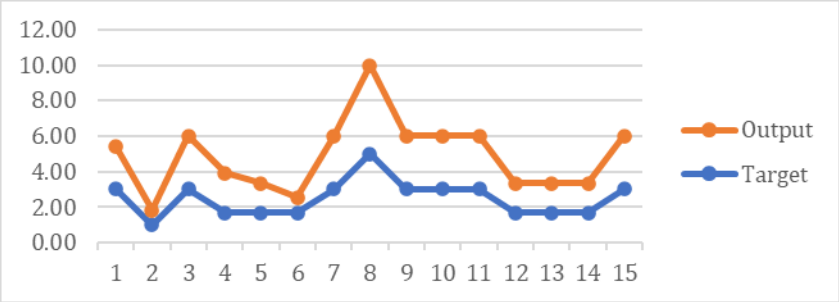

Figure 11. Output of the ANN model compared to the target

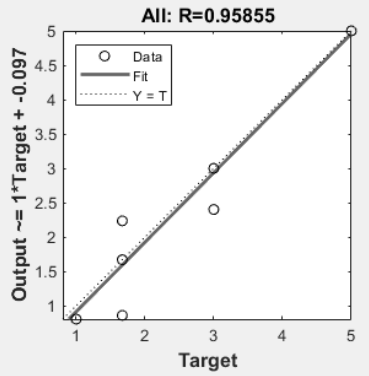

Figure 12. Research results of the ANN Model

Figure 12 shows the results of the model here for the value R = 0.95855 which has the reliability value of the high-precision output. Thus, the ANN model of the research team is perfectly suitable for the input data set.

Table 5. Results of forecasting the parameters affecting the quality of road construction

No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Target	3.000	1,000	3.000	1,670	1,670	1,670	3.000	5.000
Ouput	2,401	0.806	3.000	2,236	1,670	0.861	3.000	5.000
Error	0.599	-0.194	0.000	-0.566	0.000	0.809	0.000	0.000
No.	**9**	**10**	**11**	**12**	**13**	**14**	**15**	
Target	3.000	3.000	3.000	1,670	1,670	1,670	3.000	
Ouput	3.000	3.000	3.000	1,670	1,670	1,670	3.000	
Error	0.000	0.000	0.000	0.000	0.000	0.000	0.000	

The results of Table 5 show that the second and sixth values for the minimum output value show that the importance of the second and sixth criteria of Table 1 will greatly affect the quality of road construction: The level of operator qualification standards (Indicator C_{12}) and the reasonableness of selecting machinery and equipment (Indicator C_{32}), which is also fully consistent with the current reality in Vietnam's road construction works.

IV. CONCLUSION

The study shows that improving the quality of road construction now depends on many factors. The research team based on the survey and evaluation of statistical experts analyzed and developed an ANN model to predict indicators affecting the quality of road construction. The ANN neural network was used as the basic research tool for this study. The analysis results show high accuracy and reduced time in the calculation process. As a basis for investors, supervision consultants as well as state management agencies to initially coordinate with construction contractors to set criteria to improve the quality of road construction.

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