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Time and Cost Analysis for Highway Road Construction Project Using Artificial Neural Networks

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Abstract: Success of the construction companies is based on the successful completion of projects within the agreed cost and time limits. Artificial neural networks (ANN) have recently attracted much attention because of their ability to solve the qualitative and quantitative problems faced in the construction industry. For the estimation of cost and duration different ANN models were developed. The database consists of data collected from completed projects. The same data is normalised and used as inputs and targets for developing ANN models. The models are trained, tested and validated using MATLAB R2013a Software. The results obtained are the ANN predicted outputs which are compared with the actual data, from which deviation is calculated. For this purpose, two successfully completed highway road projects are considered. The Nftool (Neural network fitting tool) and Nntool (Neural network/ Data Manager) approaches are used in this study. Using Nftool with trainlm as training function and Nntool with trainbr as the training function, both the Projects A and B have been carried out. Statistical analysis is carried out for the developed models. The application of neural networks when forming a preliminary estimate, would reduce the time and cost of data processing. It helps the contractor to take the decision much easier.

Keywords: Artificial neural networks, cost and duration, highway road Projects.

I. INTRODUCTION

Construction estimating is one of the most crucial functions in project management. Cost and time estimating need to be done in different manners at different stages of a project. Effective estimation is one of the main factors of the success of a construction project. Many factors negatively affect cost estimators and planners to make appropriate decisions. Contractors' experience on previous projects can undoubtedly be considered as an important asset that can help preventing mistakes and also increases the chances of success in similar future encounters. Construction cost data collected from past projects may be used to support cost and time estimation at different stages. The improvement of the future plan of any project represents a prior responsibility of each manager. Therefore, in the area of construction industry, many researchers attempted to develop the future projects costs and construction duration. There are several methods developed to predict the future cost and few researches attempting to forecast the future highway construction duration. The use of modern prediction methods is very valuable, a new class of tools, neural networks, has evolved which is based on artificial intelligence, and which offers an alternative approach to cost and time estimation.

II. ARTIFICAL NEURAL NETWORK

An Artificial Neural Network (ANN) is an information processing paradigm that is inspired by the way biological nervous systems, such as the brain, process information. The early model of an artificial neuron is introduced by Warren McCulloch and Walter Pitts in 1943. The McCulloch-Pitts neural model is also known as linear threshold gate. It is a neuron of a set of inputs I1, I2, I3….Ii and one output 'y'. The linear threshold gate simply classifies the set of inputs into two different classes. Thus the output 'y' is binary. Such a function can be described mathematically using the Eq. (1) and (2).

$$Sum = \sum_{i=1}^{i} Ii\, Wi \quad (1)$$

$$y = F(sum) \quad (2)$$

W1,W2…Wi are weight values normalized in the range of either (0,1) or (-1,1) and associated with each input line, sum is the weighted sum, and T is a threshold constant. The function F is a linear step function at threshold T. The symbolic representation of the linear threshold gate is shown in Fig .1.

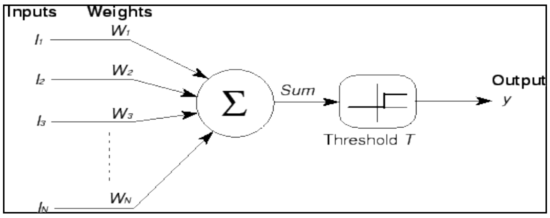

FIGURE I
SYMBOLIC ILLUSTRATION OF LINEAR THRESHOLD GATE

The McCulloch-Pitts model of a neuron is simple yet has substantial computing potential. It also has a precise mathematical definition. However, this model is so simplistic that it only generates a binary output and also the weight and threshold values are fixed. The neural computing algorithm has diverse features for various

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applications. Thus, we need to obtain the neural model with more flexible computational features. The main tasks associated with a processing unit are to receive input from its neighbours providing incoming activations, compute an output, and send that output to its neighbours receiving that output. Neurons in an ANN can be classified into one of three groups: input neurons, hidden neurons and output neurons. Igor Pesko et al., (2013) developed neural networks for the preliminary estimation of time and cost in urban road construction [1]. Pewdu et al., (2009) used an ANN model to forecast final budget and duration of a highway construction project during construction stage [2].

A neural network is a massively parallel distributed processor made up of simple processing units that have a natural tendency for storing experiential knowledge and making it available for us. Artificial neural network (ANN) is a type of Artificial Intelligence technique that mimics the behavior of the human brain. ANNs have the ability to model linear and non-linear systems without the need to make assumptions implicitly as in most traditional statistical approaches. They have been applied in various aspects of science and engineering.

Sodikov (2005) focused on the development of a more accurate estimation technique for highway projects using artificial neural networks [3]. Wilmot and Mei (2005) developed an artificial neural network model which relates overall highway construction costs to improve a procedure that estimates the escalation of highway construction costs over time [4]. Kim et al., (2004), by comparing the multiple regression model (MRM), neural network model (NNM) and case-based reasoning model, (CBR) came to the conclusion that ANNs provide the most accurate results regarding cost estimates [5]. Skitmore and Thomas (2003), developed different forms of regression models for forecasting the actual construction time and cost [6]. Hegazy and Ayed (1998) used Neural network approach to determine highway construction cost, project scope, year, construction season, location, duration, size, capacity, water body, and soil condition [7].

III. METHODOLOGY

The defined inputs and targets are fed into the network, once the network is created. The network is trained and the results are obtained. The below Fig. 2 shows the architecture of the network with 2 Layers 10 neurons in the first layer (2L-10N1) using trainlm as training function in Nftool approach. It has 10 hidden layers with one output layer. After defining the architecture (modelling), the remaining two phases of training and testing the network is carried out. The resultant output helps in defining the solution.

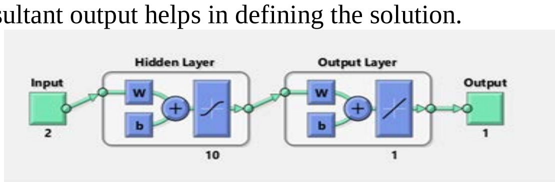

FIGURE II
NEURAL NETWORK DIAGRAM FOR TRAINED SET (TRAINLM FUNCTION)

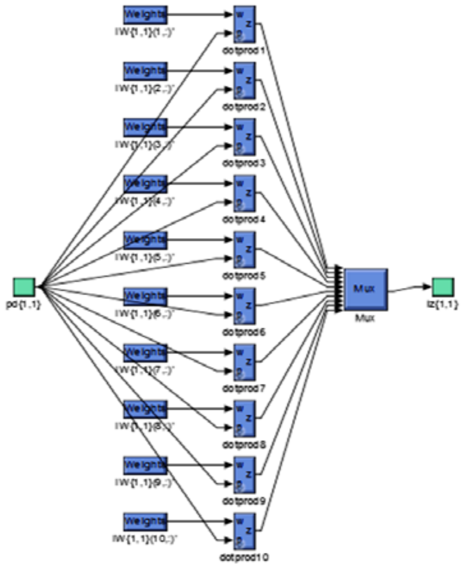

FIGURE III
WEIGHTS AND DOT PRODUCTS OF THE TRAINED DATA SET (2L-10N1 MODEL)

The output is computed as a result of a transfer function of the weighted input. The net input for this simple case is computed by multiplying the value of each individual input by its corresponding weight, or equivalently, taking the dot product of the input and weight vectors. The processing element then takes this input value and applies the transfer function to it to compute the resulting output. The weights can also be changed manually by setting the parameters of weights after opening the weights pane. The Fig. 3 shows the weights and dot products of the 2L-10N1 model. Similarly, for the remaining models results are obtained for the first training. The architecture of weights and dot products for the remaining models developed in Nntool approaches are similar, but differs in weights, dot products, number of layers and neurons present in the models.

In Nntool approach, three models developed are 1L-1N1 (one layer), 2L-3N1 (2 layers, 3Neurons in first layer) and 3L-3N1 (3 layers 3 Neurons in first layer). The Fig. 4, 5, 6 shows the architecture of the models developed.

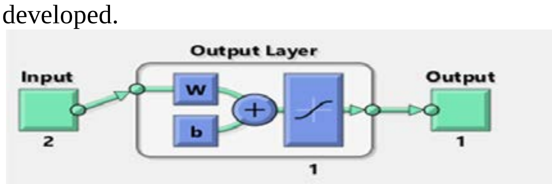

FIGURE IV
NEURAL NETWORK DIAGRAM FOR 1L-1N1 MODEL (TRAINBR FUNCTION)

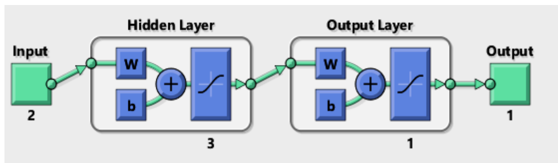

FIGURE V
NEURAL NETWORK DIAGRAM FOR 2L-3N1 MODEL
(TRAINBR FUNCTION)

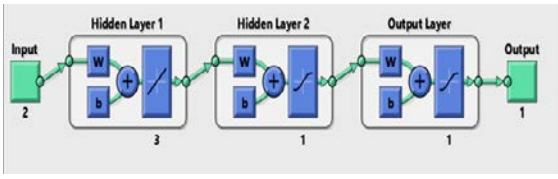

FIGURE VI
NEURAL NETWORK DIAGRAM FOR 3L-3N1 MODEL (TRAINBR FUNCTION)

A. Database Preparation

The data of completed highway projects was collected for the preparation of database. It should be noted that every project consists of same resources. The model 2L-10N1 developed, is used in the entire process. The database consists of two successfully completed highway projects. The bill of quantities considered is shown below Table.1.

TABLE I
BILL OF QUANTITIES AND DESCRIPTION

Bill of Quantities	Description
A	Preliminaries
B	Site Clearance
C	Earth Work
D	Sub Base Works
E	Bituminous Works
F	Culverts
G	Major and Minor Bridges
H	Drainage Works
I	Junctions and Kerbs
J	Traffic Signs
K	Miscellaneous Items
L	Vup's, Pup's and Return Walls
M	Flyovers, Robs and Over Pass
N	Toll Plaza
O	Street Lighting in Urban Areas

B. Normalization of Data

Normalization of the data using Z-scores, leads to an increase in performance of the trained ANN. It brings all the variables in proportion to one another. The dataset is transformed to have zero mean and unit variance using the Eq. (3)

$$S = \frac{X - \mu}{\sigma} \qquad (3)$$

Where:
S – Normalized value
X – Actual value
μ – Mean distribution
σ – Standard deviation

C. Training and Testing of ANN Models

MATLAB is a numerical computing environment and also a programming language. It allows easy matrix manipulation, plotting of functions and data, implementation of algorithms, creating user interfaces and interfacing with programs in other languages. The Neural Network Toolbox contains the MATLAB tools for designing, implementing, visualizing and simulating neural networks. It also provides comprehensive support for many proven network paradigms, as well as graphical user interfaces (GUIs) that enable the user to design and manage neural networks in a very simple way.

In modelling phase, the network architecture is defined considering the number of input parameters, the number of layers, the number of neurons in them, the amount of output data, the type of training function and whether the network is oriented forwards or backwards. After defining the architecture of the ANN the training phase of the ANN begins. ANN training was carried out with supervision of feed forward back propagation network. It has the widest application, particularly when it comes to cost prediction. In Nftool approach, the training function used is trainlm. A model with 2L-10N1 (2 layers and 10 neurons in first layer) is created using training function trainlm. The other three models developed are 1L-1N1 (one layer), 2L-3N1 (2 layers, 3Neurons in first layer) and 3L-3N1 (3 layers 3 Neurons in first layer) using trainbr as the training function in Nntool approach. ANN Outputs are generated from the trained sets.

Percentage errors are calculated for every activity. The performance of the ANN is evaluated on the basis of MAPE (Mean Absolute Percent Error). Comparison of the output values from the ANN with the actual values. Percentage errors are calculated for each bill of quantity from the actual and ANN predicted values using the Eq. (4).

$$\text{Percentage Error} = \left[\frac{|\text{ACTUAL} - \text{ANN PREDICTED}|}{\text{ACTUAL}}\right] \text{x } 100 \quad (4)$$

Testing the neural network is done on the basis of MAPE (Mean Absolute Percent Error), using the Eq. (5). Later Sensitivity analysis for the ANN model is done for the projects.

$$\text{MAPE} = \frac{\Sigma\left[\frac{|\text{ACTUAL} - \text{ANN PREDICTED}|}{\text{ACTUAL}}\right] \text{x } 100}{\text{n}} \qquad (5)$$

The ANNs with training function *trainbr (Nntool approach),* with all the three models has a greater MAPE proved themselves to be unstable. The best results are given by the ANN with training function *trainlm (Nftool approach)* with 2 layers and a hidden layer of 10 neurons. Hence the ANN model with 2L-10N1 is chosen. The Percentage error graphs and sensitivity plots are plotted for the 2L-10N1 model. The Fig. 7 and 8 shows the percentage error graph drawn for Project A and B.

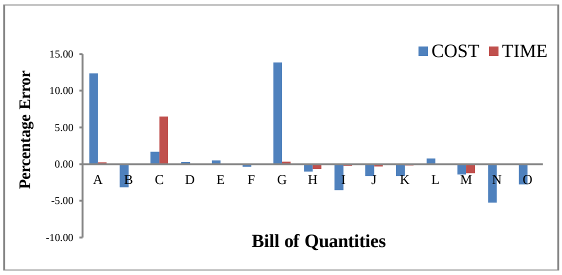

FIGURE VII
THE GRAPHIC PERCENTAGE ERROR OF EACH BILL OF QUANTITY USING TRAINLM FOR PROJECT A

From the Fig. 7, the percentage errors of the activities Preliminaries (A), Major and minor bridges (G) are relatively higher compared to other activities in Project A.

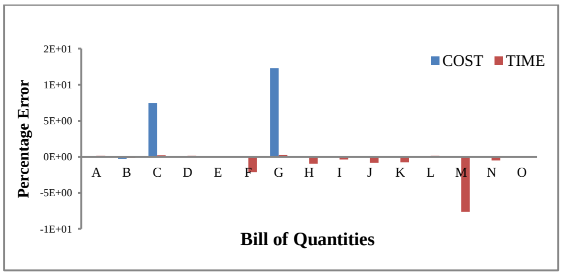

FIGURE VIII
THE GRAPHIC PERCENTAGE ERROR OF EACH BILL OF QUANTITY USING TRAINLM FOR PROJECT B

From the Fig- 8, the percentage errors for earth work (C), major and minor bridges (G) have shown the most deviation among all the other activities in Project B.

Sensitivity analysis compels the decision maker to identify the variables which affect the cash flow forecasts. This helps in understanding the investment project in totality. The decision maker can consider actions which may help in strengthening the "weak spots" in the project.

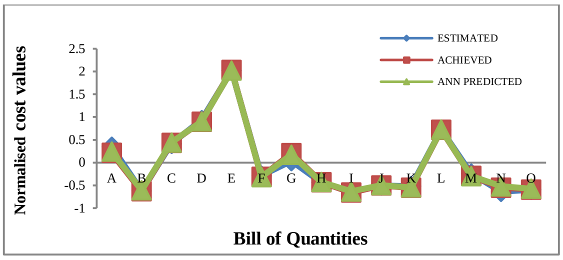

FIGURE IX
SENSITIVITY ANALYSIS OF NORMALISED COST VALUES VERSUS BILL OF QUANTITIES FOR PROJECT A

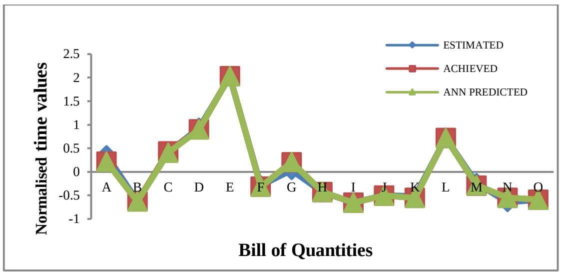

FIGURE X
SENSITIVITY ANALYSIS OF NORMALISED TIME VALUES VERSUS BILL OF QUANTITIES FOR PROJECT A

From the Fig. 9 and 10, the bill of quantities A, G and N are the weak spots observed in Project A. This helps the decision maker to identify the weak spots and strengthen them.

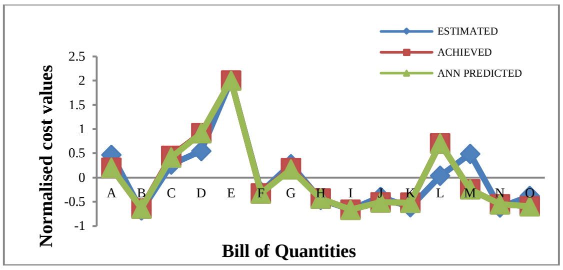

FIGURE XI
SENSITIVITY ANALYSIS OF NORMALISED COST VALUES VERSUS BILL OF QUANTITIES FOR PROJECT B

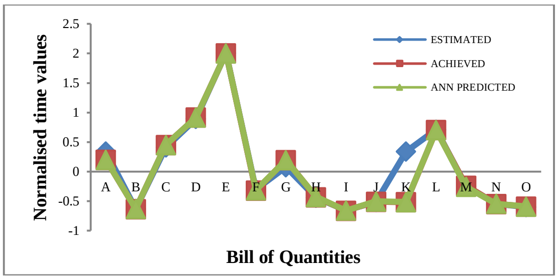

FIGURE XII
SENSITIVITY ANALYSIS OF NORMALISED TIME VALUES VERSUS BILL OF QUANTITIES FOR PROJECT B

From the Fig- 11 and 12, the bill of quantities A, C, D, G, J, L, M and O are the weak spots observed in Project B.

TABLE II
COMPARISON BETWEEN NORMALISED ACTUAL COST AND TIME VALUES WITH THEIR RESPECTIVE ANN OUTPUTS (PROJECT A AND B)

Bill of Quantities	Project A				Project B			
	Cost		Time		Cost		Time	
	Actual	ANN outputs	Actual	ANN outputs	Actual	ANN outputs	Actual	ANN outputs
A	0.215	0.242	0.215	0.216	0.201	0.201	0.201	0.201
B	-0.629	-0.609	-0.629	-0.629	-0.636	-0.634	-0.636	-0.634
C	0.435	0.442	0.435	0.407	0.450	0.416	0.450	0.449
D	0.901	0.903	0.901	0.901	0.915	0.915	0.915	0.914
E	2.033	2.023	2.033	2.033	2.004	2.004	2.004	2.004
F	-0.314	-0.315	-0.314	-0.314	-0.323	-0.323	-0.323	-0.316
G	0.206	0.177	0.206	0.206	0.194	0.170	0.194	0.194
H	-0.428	-0.424	-0.428	-0.426	-0.434	-0.434	-0.434	-0.430
I	-0.656	-0.632	-0.656	-0.654	-0.662	-0.662	-0.662	-0.660
J	-0.503	-0.495	-0.503	-0.501	-0.511	-0.510	-0.511	-0.507
K	-0.552	-0.543	-0.552	-0.553	-0.519	-0.519	-0.519	-0.515
L	0.721	0.727	0.721	0.721	0.703	0.703	0.703	0.702
M	-0.290	-0.294	-0.290	-0.286	-0.240	-0.240	-0.240	-0.259
N	-0.548	-0.519	-0.548	-0.548	-0.550	-0.550	-0.550	-0.547
O	-0.591	-0.574	-0.591	-0.591	-0.593	-0.593	-0.593	-0.593

D. Comparisons of Actual and Predicted Values

The actual data and the artificial neural networks outputs of two Projects A and B are compared to check the whether the actual data is optimum or not. The comparison of the outputs and actual values of the bill of quantities is shown in Table.2 for Project A and Project B. The normalised values of cost and time are compared. From the Table 2, it can be analyzed that the actual data and ANN outputs have the lowest difference between them. For the purpose, MAPE values are calculated to highlight the deviation for cost and time.

IV. CONCLUSIONS

The percentage error graph shows the activities that mostly affected the cost and duration of the Projects. The sensitivity analysis plotted shows the deviations between the estimated, actual and ANN predicted values for both time and cost. The errors between the actual and ANN outputs are very low when compared. This shows that the projects estimated data and ANN predicted data has no greater deviation. The average MAPE for total cost and construction period are 0.57% and 0.27 % respectively. The deviation of the output data in comparison with the actual values is less than ±8 % which is acceptable for the estimation of the cost and duration of works. This approach significantly increases the quality of decisions made regarding the involvement in potential projects and it reduces the risk of going over the budget and time envisaged for construction. This approach is useful for the estimation of time and cost for highway road constructions and building projects.

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