FORECASTING THE COST AND DURATION OF SCHOOL RECONSTRUCTION PROJECTS USING ARTIFICIAL NEURAL NETWORK

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ABSTRACT : This paper presents the development of Artificial Neural Network models for forecasting the cost and contract duration of school reconstruction projects to assist the planners' decision-making in the early stage of the projects. 132 schools reconstruction projects in central Taiwan, which received the most serious damage from the Chi-Chi Earthquake, were collected. The developed Artificial Neural Network prediction models demonstrate good prediction abilities with average error rates under 10% for school reconstruction projects. The analytical results indicate that the Artificial Neural Network model with back-propagation learning is a feasible method to produce accurate prediction results to assist planners' decision-making process.

Key words : Artificial Neural Network, Reconstruction Project, Cost and Duration

1. INTRODUCTION

Chi-Chi Earthquake struck the island of Taiwan in the early morning of September 21st, 1999. As the results of the Chi-Chi Earthquake, 2,455 lives were lost, 8,000 were injured and 38,935 homes were destructed. Reconstruction of damaged or destroyed infrastructure facilities, such as roads, bridges, and schools, in a short time and under the limited resources is the primary concern of the whole society. During the recovery period, one major difficulty is to estimate accurately the cost and contract duration of the reconstruction projects in the early planning phase without detailed information, particularly for those personnel without adequate engineering background or experience. Therefore, this study attempts to build a prediction model to forecast the reconstruction duration and cost to assist decision-making for any emergency situations.

Reconstruction projects have different characters with conduction projects; therefore, literature has been discussed about challenges and problems faced by the reconstruction projects [1][2][3], but few have concentrated on the relationship among reconstruction cost, project duration and other factors. This study established the forecasting models for the cost and duration of school-reconstruction projects using Artificial Neural Networks (ANN).

The Artificial Neural Networks model, information-processing paradigms inspired by the way the densely interconnected, parallel structure of the human brain processes information, has been introduced in civil engineering applications as an alternative to traditional approaches. ANNs have been employed to solve many civil engineering issues, as well as being implemented in cost prediction for construction projects. Attalla and Hegazy [4] proposed an artificial neural networks model to examine the cost performance of reconstruction projects. Williams [5] implemented a radial basis function neural network algorithm to predict the completed cost of competitively bid highway projects built by the New Jersey Department of Transportation in the USA. In this study, the multi-layer perceptron approximation with back propagation learning was adopted to develop the prediction model.

2. ARTIFICIAL NEURAL NETWORKS

Figure 1 illustrates the layout of a multi-layer network for the case of a single hidden layer. Generally, a multi-layer network with m source nodes, hn neurons in the n-th hidden layers, and q neurons in the output layers is referred to as an m-h1-h2-…-hn-q network. As shown in Figure 1, this network has 5 source nodes, 4 hidden neurons, and 2 output neurons and is referred to as a 5-4-2 network for brevity.

Among the proposed computational models of neural networks, the (error) back-propagation network, which are based on fully connected, layered networks, has been demonstrated to be theoretically sound [6][7] and the most widely used approach. Back-propagation learning technology is based on error-correction learning rules. It comprises two passes through different network layers, a forward pass and a backward pass. The forward pass presents a sample input to the network and lets activations flow until they reach the output layer. In the backward pass, by contrast, the synaptic weights are all modified according to an error-correction rule. During the learning process, the network "learns" incrementally from the input-output pair and reduces the difference (error) between the network's predicted output and the actual output.

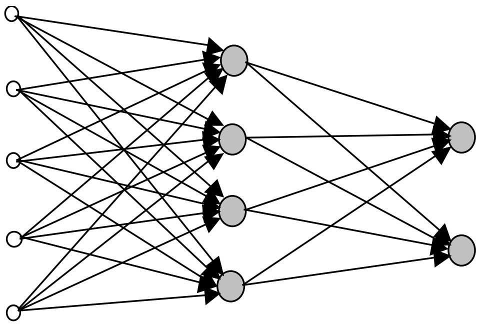

Figure 1. Fully connected network with one hidden layer

3. SCHOOL RECONSTRUCTION PROJECTS

After the Chi-Chi Earthquake's strike, 1,546 schools were quake-damaged, including 293 that were almost completely destroyed. To rebuild these schools as soon as possible, the school reconstruction projects were planned and contracted through both the public and private sectors. The public sector organizations include the central agency (Construction and Planning Agency, the Ministry of the Interior, entrusted by the Ministry of Education), and the local governments managing the damaged schools. The private organization putting efforts on reconstructions are charity groups mostly, such as Tzu Chi Foundation and the Lion Clubs International.

The contract-awarding approaches of the public sectors are either the Lowest Price Tendering approach (LPT) or the Most Advantageous Tendering approach (MAT) based on the Government Procurement Law (GPL) in Taiwan [8]. Based on the LPT approach, a qualified bidder with the lowest bid price within the client estimate is awarded the contract. Based on the MAT, the best-qualified contractor will be chosen without using the lowest cost tendering scheme. Within the MAT approach, the evaluation criteria presented in the tender documentation may include the technology, quality, function, commercial terms or price of the bids. If the bid price is among the evaluation criteria, the weight of the bid price must not exceed 50% of all criteria [9]. For the private organizations, the procurement procedures are not restricted by the GPL; thus, the contracts were awarded principally to the lowest bidder.

4. DATA COLLECTION AND ANALYSIS

132 reconstruction projects of the elementary and preliminary schools in Nantou County, which received the most serious damage from the Chi-Chi Earthquake, were collected. At least one building collapsed in each of those schools during the Chi-Chi Earthquake. Based on the planning and contracting agency, these reconstruction projects were classified into three categories: the central agency, the local government and the private sector, as mentioned above. Among these projects, 34 were contracted by the central agency, 44 by the local government, and 54 by the private sector. The data collected include contract duration, cost, and floor area of each project. The ranges of data collected are summarized in Table 1.

Table 1. Information of collected reconstruction projects

Category	Central Agency	Local Government	Private Sector
Sample Size	34	44	54
Duration (Day)	90~380	6 ~259	135~493
Cost (Thousands Dollar)	470~7,826	7~1,389	9 ~6,172
Floor Area (m^2)	512~19,930	21~4,499	1,419~20,053

The correlation coefficient for every linear relationship between each variable was computed by the software of Statistical Package for Social Science (SPSS). As shown in Table 2, the correlations between duration and cost, and between duration and floor area were found to be similar. For reconstruction projects contracted by the central agency, the correlation coefficients between duration and cost, and between duration and floor area, were found to be closed with the values of 0.809 and 0.849, respectively. Similar situations were found for reconstruction projects contracted by the local government or the private sectors. For the previous projects, the correlation coefficients between duration and cost, and between duration and floor area were found to be around 0.75. For the last projects, the correlation coefficients between duration and cost, and between duration and floor area are around 0.4. These analytical results also illustrated the relationships of high correlations between duration and cost, and between duration and floor area, for reconstruction projects contracted by the governments, the central agency and local government. For reconstruction projects contracted by the private sectors, the relationships between duration and cost, and between duration and floor area, are medium correlation with correlation coefficients around 0.4, indicating a possible nonlinear relationship between them.

The results also reveal that the correlation coefficients between cost and floor area are around or above 0.9 regardless of the project's category. This finding demonstrates a relationship of high correlation between cost and floor area.

Table 2. Correlations of variables for reconstruction projects

Category		Variables		
		Duration	Cost	Floor Area
Central Agency	Duration	1	0.809	0.849
	Cost	0.809	1	0.966
	Floor Area	0.849	0.966	1
Local Government	Duration	1	0.744	0.760
	Cost	0.744	1	0.910
	Floor Area	0.760	0.910	1
Private Sector	Duration	1	0.400	0.430
	Cost	0.400	1	0.893
	Floor Area	0.430	0.893	1

5. MODEL DEVELOPMENT AND VALIDATION

This study implemented the multi-layer perceptron approximation method with back-propagation learning to develop the neural network models for forecasting the cost and duration for the school reconstruction projects. Ten percent of collected sample projects for each category were selected randomly and set aside as the testing data set for validation, while the rest were employed as the training data set for model building.

The activation functions for the hidden layers and the output layer are log-sigmoid function and sigmoid function, respectively. The setting of the learning rate of the model determines how far to move in the direction of the gradient of the surface over weight space defined by an error function. The smaller learning rate, the smaller the changes to the weights in the network will be from one iteration to the next, and the smoother the trajectory in the weight space will be. The setting of the momentum factor allows a network to response not only to the local gradient, but also to recent trends in the error surface. It allows the network to skip over a shallow local minimum.

To determine the best prediction model configuration, the following settings were tested.

a) The number of hidden layers: 0, 1, and 2 hidden layer(s)
b) The number of hidden neurons: 3, 4, 5, 6 and 7 hidden neurons
c) The learning rate: 0.1, 0.3, 0.5, 0.7, 0.9
d) The momentum factor: 0.1, 0.3, 0.5, 0.7

The best configuration of each prediction model was determined by the root mean square of error (RMSE). A smaller RMSE implies a better configuration.

5.1 Cost Prediction Model

In the cost prediction model, the input is the floor area, and the output is the cost of the project. It was found, as shown in Table 3, for this study, multi-layer perception models with one hidden layer and with 5 hidden neurons in the hidden layer is the best configuration (1-5-1) for the cost prediction models for reconstruction projects contracted by the central agency or the private sector. For reconstruction projects contracted by the local government, multi-layer perception models with one hidden layer and with 4 hidden neurons in the hidden layer is the best configuration (1-4-1). The learning rates are 0.7 for reconstruction projects contracted by the public sectors, and 0.5 for ones contracted by the private sectors. The momentum factors are 0.3 for all categories.

5.2 Duration Prediction Model

In the duration prediction model, the inputs are the floor area and cost, and the output is the duration of the project. As shown in Table 4, for this study, multi-layer perception models with one hidden layer and with 5 hidden neurons in the hidden layer is the best configuration (2-5-1) for the duration prediction models for reconstruction projects contracted by the central agency or the private sector. For reconstruction projects contracted by the local government, multi-layer perception models with one hidden layer and with 4 hidden neurons in the hidden layer is the best configuration (2-4-1). It also found the best settings of learning rate and momentum factors are as the same results as the ones for cost prediction model.

Table 3. Best configuration of cost prediction model

Category	Training Sample Size	Configuration of Network	Hidden Layer(s)	Hidden Neuron(s)	Learning Rate	Momentum Factor	RMSE
Central Agency	30	1-5-1	1	5	0.7	0.3	11,029,034
Local Government	39	1-4-1	1	4	0.7	0.3	1,859,523
Private Sector	48	1-5-1	1	5	0.5	0.3	13,951,323

Table 4. Best configuration of duration prediction model

Category	Training Sample Size	Configuration of Network	Hidden Layer(s)	Hidden Neuron(s)	Learning Rate	Momentum Factor	RMSE
Central Agency	30	2-5-1	1	5	0.7	0.3	11.7052
Local Government	39	2-4-1	1	4	0.7	0.3	22.9371
Private Sector	48	2-5-1	1	5	0.5	0.3	60.4834

5.3 Model Validation

Testing data set were used to validate the trained models. Table 5 presents the average percentage error of the prediction results using neural network models for the testing data set. The results show that the duration prediction model presents better prediction ability than the cost duration model. It also shows that the neural network models reach better cost and duration prediction results for reconstruction projects contracted by the public sectors (central agency and local government) than for the projects contracted by the private sectors.

For all categories, the average percentage errors for both the cost and duration prediction models are all under 10%, and that neural network prediction model predicts well the cost or the duration of school reconstruction projects regardless of the organization which contracted the projects.

Table 5. Average percentage error for neural network prediction model

Category	Testing sample size	Average Percentage Error	
		Cost Prediction Model	Duration Prediction Model
Central Agency	4	7.29	5.25
Local Government	5	6.13	5.27
Private Sector	6	9.37	9.06

6. CONCLUSIONS

This study concentrates on school reconstruction projects in central Taiwan, which received the most serious damage from the Chi-Chi Earthquake. Artificial Neural Network models for forecasting the cost and contract duration of school reconstruction projects were developed to assist the planners' decision-making in the early stage of the projects. As the results, the neural network prediction models demonstrate good prediction results with average error rates under 10% for reconstruction projects contracted by either the central agency, local government or the private sector. The analytical results indicate that the Artificial Neural Network model with back-propagation learning is a feasible method to produce accurate prediction results to assist planners' decision-making process.

REFERENCES

[1] Kerr, W.C., Tamaro, G.J., and Hahn, D.M. (1992) Exchange place station subsurface reconstruction and improvements. Journal of Construction Engineering Management, 118(1), 166-178.

[2] Kritzek, D., and Lavon, B. (1996) Success or failure: A tale of two projects. Civil Engineering (N.Y.), 66(46), 62-63.

[3] Krug, T. (1997) Everything old is new again. Civil Engineering (N. Y.), 67(4), 58-60.

[4] Attalla, M. and Hegazy, T. (2003) Predicting cost deviation in reconstruction projects: artificial neural networks versus regression. Journal of Construction Engineering and Management, 129(4), 405-411.

[5] Williams, T.P. (2002) Predicting completed project cost using bidding data. Construction Management and Economics, 20, 225-235.

[6] Rumelhart, D. E., Hinton, G. E., and McClelland, J. L. (1986a). A general framework for parallel distributed processing. Parallel Distributed Processing, 45-76.

[7] Rumelhart, D. E., Hinton, G. E., and Williams, R. J. (1986b). Learning internal representations by error propagation. Parallel Distributed Processing, 318-362.

[8] Public Construction Commission, Executive Yuan, Taiwan, R.O.C., 1998. Government Procurement Law. (http://planpe.pcc.gov.tw/gplaw/egplaw/).

[9] Yang, J.B. and Wang, W.C. (2003) Contractor selection by the most advantageous tendering approach in Taiwan. Journal of the Chinese Institute of Engineers, 26(3), 381-387.