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Application of Neuro-Fuzzy System to Evaluate Sustainability in Highway Design

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ABSTRACT: *In this paper, adaptive neuro-fuzzy inference systems (ANFIS), using Sugeno ANFIS is used to evaluate the construction sustainability of highway design projects in Thailand. Input variables include factors associated with geometrics and alignments, earthworks, pavement, drainage, retaining walls, slope protection, landscape and ecology, transportation facilities, transportation maintenance, bridges, sound insulation, tunnels, electrical and mechanical work, and lighting. Finally, on the basis of our analysis, our results hold an important lesson for decision makers who may clearly picture the rules and use the fuzzy neural network approach to promote effective environmental protection to meet the highway district's goals.*

Keywords: *Sustainability, Highway design, Neuro-fuzzy system, Uncertainty, Evaluation*

I. INTRODUCTION

Public awareness of global environmental problems such as global warming and ozone depletion has increased, to become one of the biggest issues for the new millennium, since the concept of sustainable development has attracted public attention as the greatest concern of the late twentieth century. Sustainable development in the construction industry is now an important issue [1]. However, it is lagging behind other sectors because, by its very nature, construction involves manipulation and use of large quantities of natural and man-made materials. Also, the construction and operations of infrastructure are large users of energy. A construction project generates a large amount of pollutants, including noise, air, solid waste and water [2-3]. There are suggestions that the environmental effects of the construction project can be studied under the following headings: (i) energy consumption; (ii) dust and gas emission; (iii) noise distribution; (iv) waste generation; (v) water discharge; (vi) use of water resources; (vii) unnecessary building consumption; (viii) pollution by building materials; (ix) land use; and (x) use of natural resources (Ball, 2002).Environmental impacts of buildings over their entire life cycle process have been recognized as a serious problem [4]. Nevertheless, the construction industry has not been showing very much concern about the environmental issues [5].

The sustainable concepts can be effectively integrated into construction project in the design stage [6]. One of the most importance stage of the life cycle in most green building guidelines and evaluation methods is the design stage [7]. It is important to focus on planning and design services provided by engineering consultants in the initial stages of the life cycle of infrastructure. The sustainable planning and design lead to the good management of the energy and materials required constructing highway, and waste produced by construction. Considering sustainability early in planning and design will result in high potential reductions in operations' sustainable impacts could be generated [8-10].

As a result, the planning and design stage is a critical stage for the study of ecology, the systematic analysis of resource and energy flows within the anthroposphere, and the realm of man-made or managed resources. The wide variety of materials used in construction work, as well as fuel and electricity used for construction machinery and recycling plants has a significant environmental impact. The risk score is an overall aggregation of construction risks that are usually assessed against different criteria such as safety, functionality, sustainability and environment and characterized by risk ratings such as High, Medium, Low or None. The aggregation process involves a large number of subjective judgments of construction experts, but there is no explicit functional relationship between risk score and risk ratings.

The AASHTO (American Association of State Highway and Transportation Officials) conducted a compendium of practices, procedures, and policies for integrating environmental stewardship into highway construction and maintenance activities for Departments of Transportation (DOT) in many states [11]. It is one of the standards and improvements in environmental processes, practices, and significant environmental items.

Currently, several studies have been done on development of the forecasting models. However, a model used to predict the sustainability of highway design is rarely concerned. The research focus is to investigate the factors affecting sustainability in highway design in Thailand.

The ability of hybrid ANN models in predicting country risk rating was determined [12]. The hybrid ANN models were compared with traditional statistical techniques such as discriminate analysis (DA), logit model, probit model and ordinary neural networks. Their results indicated that hybrid neural networks outperformed all the other models. In order to determine the construction sustainability, mathematical models need to be developed to predict the risk scores of construction project. Adaptive neuro-fuzzy inference systems (ANFIS), using Sugeno ANFIS and logistic regression analysis are two alternative approaches for modelling construction sustainability data. This study compares the modelling mechanisms and performances in modelling construction sustainability data.

This study firstly identified the performance measurement indicator for construction sustainability assessment associated with a construction project. Then the impact of regulatory compliance, auditing activities and resources consumption on construction sustainability were investigated. The study framework is a simple linear model of the relationship between the independent and dependent variables. Sustainability items as the independent variables consists of 14 groups, namely geometrics and alignments, earthworks, pavement, drainage, retaining walls, slope protection, landscape and ecology, transportation facilities, transportation maintenance, bridges, sound insulation, tunnels, electrical and mechanical work, and lighting. There are 60 input variables. . These input variables used in the measurement of the sustainability are proposed by [13]. Table 1 shows sustainable items for highway design.

Table 1 Sustainable items for highway design (Tsai and Chang, 2012)

Activities	Sustainable items
1. Geometrics and alignments	1.1 Reduction in volume or weight 1.2 Mild curves 1.3 Mild slopes
2. Earthworks	2.1 Earthwork balance 2.2 Minimum excavation and fills 2.3 Topsoil recycling 2.4 Waste reuse
3. Pavement	3.1 Reduction in volume or weight 3.2 Permeable materials 3.3 Recycled materials 3.4 Noise reduction materials 3.5 Fiber materials

Table 1 Sustainable items for highway design (Tsai and Chang, 2012) (con't)

Activities	Sustainable items
4. Drainage	4.1 Runoff reduction 4.2 Vegetated or gravel ditches 4.3 Rainwater catchments 4.4 Infiltration trenches or catch basins 4.5 Sediment ponds 4.6 Regional materials
5. Retaining walls	5.1 Reduction in volume or weight 5.2 Vegetation 5.3 Grinding stones or soft reinforcing
6. Slope protection	6.1 Vegetation 6.2 Reinforced slopes 6.3 Waste reuse
7. Landscape and ecology	7.1 Avoidance of natural preservation sites 7.2 Embankments or cutting replaced by bridges or tunnels 7.3 Native trees 7.4 Tree transplanting 7.5 Vegetation 7.6 Topsoil recycling 7.7 Culverts for wildlife crossings 7.8 Ecological ponds 7.9 Habitat connectivity 7.10 Biological porous environment 7.11 Reduction in landscaping facilities 7.12 High bridges

Table 1 Sustainable items for highway design (Tsai and Chang, 2012) (con't)

Activities	Sustainable items
8. Transportation facilities	8.1 Reduction in volume or weight 8.2 Multi-function poles
9. Transportation maintenance	9.1 Reduction in path changes
10. Bridges	10.1 Reduction in volume or weight 10.2 Long-span bridges 10.3 Pre-casting techniques 10.4 Temporary bridges for construction 10.5 Hollow railings

	10.6 Reinforced materials 10.7 High strength concrete 10.8 Self-compacting concrete 10.9 Lightweight concrete 10.10 Steel
11. Sound insulation	11.1 Reduction in volume or weight 11.2 Landscaping
12. Tunnels	12.1 Reduction in volume or weight 12.2 Vegetation 12.3 Reduction in ventilation facilities 12.4 Waste reuse 12.5 Fiber materials
13. Electrical and mechanical work	13.1 Reduction in transportation controlling facilities
14. Lighting	14.1 Reduction in lighting equipment 14.2 Renewable energy 14.3 Shading board

II. NEURO-FUZZY MODEL

The neuro-fuzzy system attempts to model the uncertainty in the factor assessments, accounting for their qualitative nature. A combination of classic stochastic simulations and fuzzy logic operations on the ANN inputs as a supplement to artificial neural network is employed. Artificial Neural Networks (ANN) has the capability of self-learning, while fuzzy logic inference system (FLIS) is capable of dealing with fuzzy language information and simulating judgment and decision making of the human brain. It is currently the research focus to combine ANN with FLIS to produce fuzzy network system. ANFIS is an example of such a readily available system, which uses ANN to accomplish fuzzification, fuzzy inference and defuzzification of a fuzzy system. ANFIS utilizes ANN's learning mechanisms to draw rules from input and output data pairs. The system possesses not only the function of adaptive learning but also the function of fuzzy information describing and processing, and judgment and decision making. ANFIS is different from ANN in that ANN uses the connection weights to describe a system while ANFIS uses fuzzy language rules from fuzzy inference to describe a system.

The ANFIS approach adopts Gaussian functions (or other membership functions) for fuzzy sets, linear functions for the rule outputs, and Sugeno's inference mechanism [14]. The parameters of the network are the mean and standard deviation of the membership functions (antecedent parameters) and the coefficients of the output linear functions as well (consequent parameters). The ANFIS learning algorithm is then used to obtain these parameters. This learning algorithm is a hybrid algorithm consisting of the gradient descent and the least-squares estimate. Using this hybrid algorithm, the rule parameters are recursively updated until an acceptable level of error is reached. Each iteration includes two passes, forward and backward. In the forward pass, the antecedent parameters are fixed and the consequent parameters are obtained using the linear least-squares estimation. In the backward pass, the consequent parameters are fixed and the error signals propagate backward as well as the antecedent parameters are updated by the gradient descent method. Based on the original ANFIS study [15]; the learning mechanisms should not be applied to determine membership functions in the Sugeno ANFIS, since they convey linguistic and subjective descriptions of possibly ill-defined concepts. Hence, the choice of membership function should depend on the specific types of data.

III. TRAINING ANFIS FOR SUSTAINABLILITY EVALUATION

For proving the applicability of the model and illustration, the proposed model was applied in a highway district in Thailand. The first step to apply the model was to construct the decision team. The decision team included head and staffs of highway district, construction consultants, contractors with capital of more than hundred million baht, contractors with capital of less than hundred million baht, and sub-contractors. For training the ANFIS, a questionnaire was designed including 14 activities (60 variables). Fig 2 presents an input-output model for earthworks. The decision team was asked to give a score to them, based on their knowledge about the highway projects in a case study highway district. Then, they rated the highway projects with respect to each criterion in the range of [0, 10] with triangular or trapezoidal membership functions describing the linguistic variables such as the impact of reduction in volume or weight on sustainability, for example: "low", "medium" or "high" (Fig 3). The system was built in the Matlab Fuzzy Toolbox and Simulink environment. A Matlab programme was generated and compiled. The pre-processed input/output matrix which contained all the necessary representative features, was used to train the fuzzy inference system. Fig 4 show membership functions describing the linguistic variables such as the operation performance, for example: "low", "medium" or "high" after training the network. Fig 5 shows the structure of the ANFIS; a Sugeno fuzzy inference system was used in this investigation. From 60 attributes generated by the proposed approach, the decision makers derived 60 completed questions. We used 50 of them for training the ANFIS and the rest (15) for checking and validation of the model. For rule generation, we used subtractive clustering where the range of influence, squash factor, acceptance ratio, and rejection ratio were set at 0.5, 1.25, 0.5 and 0.15, respectively during the process of subtractive clustering. Rules (clusters) of the trained FIS for earthworks are presented in Fig 6. Because by using subtractive clustering, input space was categorized into 18 clusters. Each input has Gaussian curve built-in membership functions. Fig 7 shows the surface of ANFIS after training. The training error of the ANFIS was ranged from 0.32 to 0.75 after 50 epochs as present in Fig 8. The rate of highway projects with respect to criteria and the output of ANFIS (sustainability level of highway design) have been shown in Table 2.

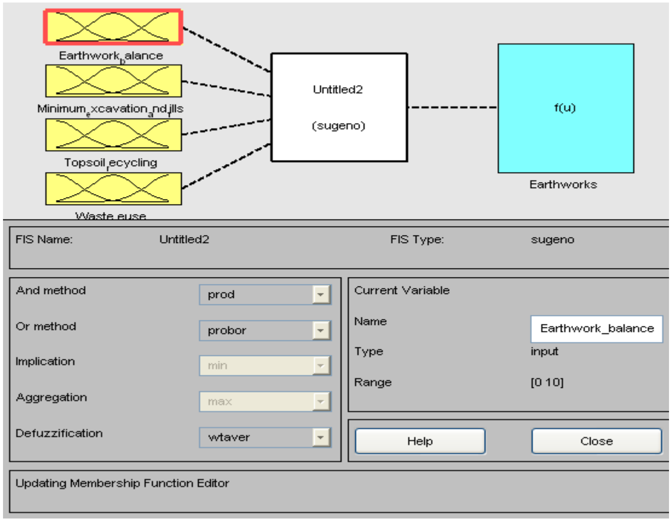

Figure 2 Input-output model for earthworks

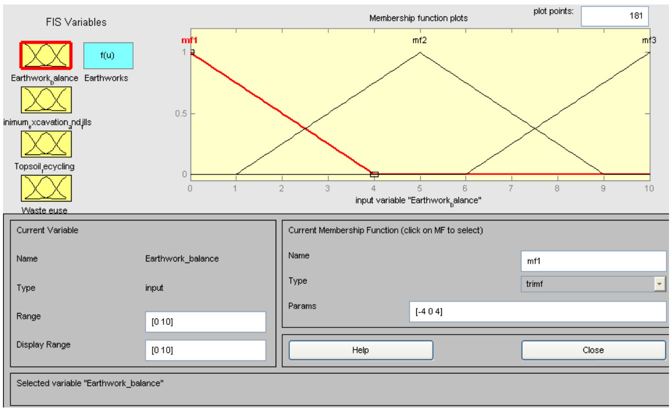

Figure 3 Membership functions of the operation performance (before Training)

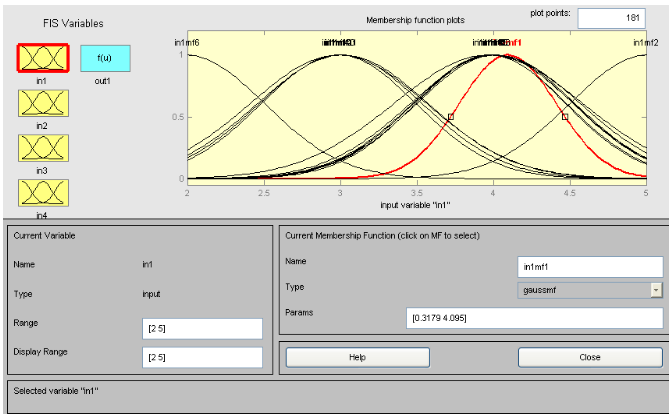

Figure 4 Membership functions of the operation performance (after Training)

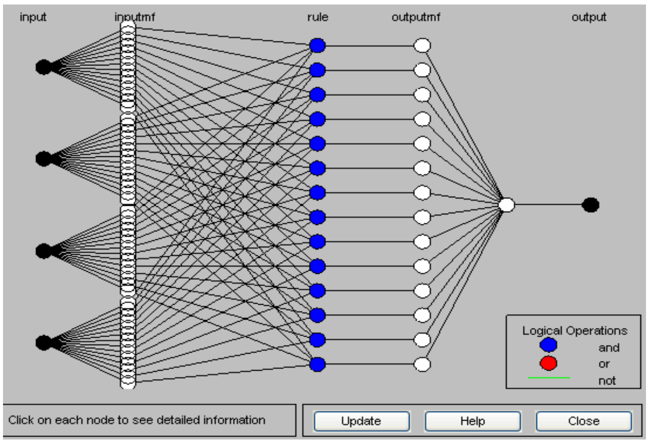

Figure 5 Network of sustainability evaluation by the ANFIS

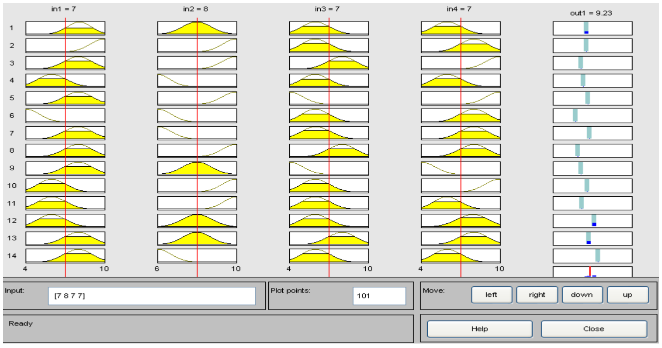

Figure 6 Rules (clusters) of the trained FIS

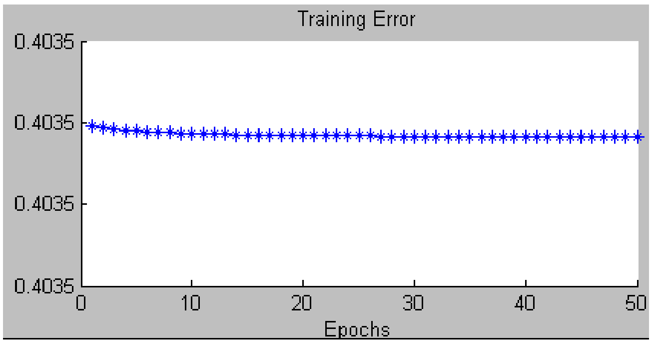

Figure 7 Trained main ANFIS surface: construction sustainability

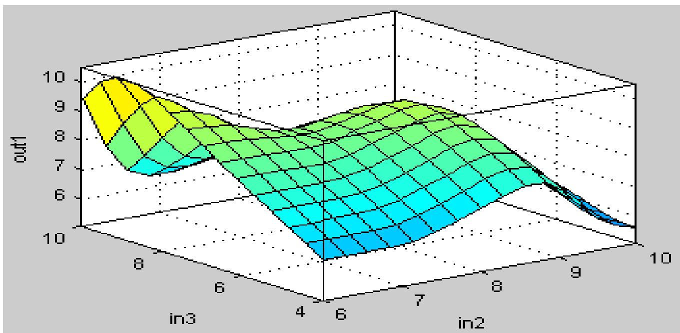

Figure 8 Training error of the ANFIS

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Table 2. Inputs (rates of a case study) and output of ANFIS

Activities	Sustainable items	Head and staff of highway district (a case study)	Construction consultants,	Contractors with capital of more than hundred million baht,	Contractors with capital of less than hundred million baht	Sub-contractors
1. Geometrics and alignments	1.1 Reduction in volume or weight	8	10	6	8	6
	1.2 Mild curves	8	10	6	10	6
	1.3 Mild slopes	8	10	8	8	6
2. Earthworks	2.1 Earthwork balance	10	10	8	10	6
	2.2 Minimum excavation and fills	10	10	8	8	4
	2.3 Topsoil recycling	10	10	8	10	8
	2.4 Waste reuse	6	6	4	6	4
3. Pavement	3.1 Reduction in volume or weight	8	8	4	10	8
	3.2 Permeable materials	8	8	6	10	6
	3.3 Recycled materials	8	8	10	10	8
	3.4 Noise reduction materials	8	8	8	10	6
	3.5 Fiber materials	8	8	6	8	8
4. Drainage	4.1 Runoff reduction	10	8	8	10	8
	4.2 Vegetated or gravel ditches	10	8	10	10	8
	4.3 Rainwater catchments	10	10	6	8	8
	4.4 Infiltration trenches or catch basins	10	10	6	10	8
	4.5 Sediment ponds	10	10	4	8	8
	4.6 Regional materials	10	10	8	10	8
5. Retaining walls	5.1 Reduction in volume or weight	10	10	8	8	8
	5.2 Vegetation	10	10	10	10	8
	5.3 Grinding stones or soft reinforcing	8	8	8	8	8
6. Slope protection	6.1 Vegetation	8	8	6	10	8
	6.2 Reinforced slopes	8	8	10	6	6
	6.3 Waste reuse	8	8	10	8	6
7. Landscape and ecology	7.1 Avoidance of natural preservation sites	8	10	10	6	6
	7.2 Embankments or cutting replaced by bridges or tunnels	8	10	10	8	8
	7.3 Native trees	6	10	4	8	6
	7.4 Tree transplanting	8	10	8	8	8
	7.5 Vegetation	8	10	6	8	6
	7.6 Topsoil recycling	10	10	6	10	10
	7.7 Culverts for wildlife crossings	8	10	8	10	6
	7.8 Ecological ponds	8	10	8	8	8
	7.9 Habitat connectivity	6	10	6	8	6
	7.10 Biological porous environment	8	10	6	8	8

Table 2. Inputs (rates of a case study) and output of ANFIS (con't)

Activities	Sustainable items	Head and staff of highway district (a case study)	Construction consultants,	Contractors with capital of more than hundred million baht,	Contractors with capital of less than hundred million baht	Sub-contractors
7. Landscape and ecology	7.11 Reduction in landscaping facilities	6	8	4	6	4
	7.12 High bridges	8	8	8	8	8
8. Transportation facilities	8.1 Reduction in volume or weight	6	10	4	6	4
	8.2 Multi-function poles	8	10	8	8	8
9. Transportation maintenance	9.1 Reduction in path changes	6	8	4	4	4
10. Bridges	10.1 Reduction in volume or weight	8	8	6	8	8
	10.2 Long-span bridges	6	10	6	8	4
	10.3 Pre-casting techniques	8	10	8	10	10
	10.4 Temporary bridges for construction					
	10.5 Hollow railings	8	10	8	10	10
	10.6 Reinforced materials	6	10	4	4	4
	10.7 High strength concrete	8	10	4	8	6
	10.8 Self-compacting concrete	8	10	8	8	6
	10.9 Light-weight concrete	8	10	8	10	8
	10.10 Steel	8	10	8	8	6
11. Sound insulation	11.1 Reduction in volume or weight	8	10	8	10	8
	11.2 Landscaping	10	10	8	8	6
12. Tunnels	12.1 Reduction in volume or weight	10	10	8	10	8
	12.2 Vegetation	10	10	8	10	6
	12.3 Reduction in ventilation facilities	10	10	8	10	8
	12.4 Waste reuse	10	10	8	10	8
	12.5 Fiber materials	8	10	8	10	8
13. Electrical and mechanical work	13.1 Reduction in transportation controlling facilities	8	10	8	10	8
14. Lighting	14.1 Reduction in lighting equipment	10	10	8	8	10
	14.2 Renewable energy	10	10	8	10	8
	14.3 Shading board	10	10	8	10	8
Sustainability level	Expert's opinions	112	105	119	98	84
	ANFIS Model	109	97	113	76	73

IV. CONCLUSION

A major objective of this paper was to present an application of ANFIS, and its performances in modeling a set of construction sustainability data. Considering data obtained from experts based on eighty scenarios, the sustainability level is calculated. Scenarios No. 1 to 50 were used as training cases for both methods. Scenarios No. 51 to 80 were used as test cases to compare performance of the Logistic regression and ANFIS methods. The five scenarios were used to compare the performance of the proposed approach by comparing with the values given by experts in scenarios being tested. The average and standard deviation of the differences between the estimated and the possibility obtained from expert produced by ANFIS are calculated to be 9.91 and 7.89 respectively. The performance of the models developed by ANFIS is summarized in Table 2.

Since it is an important lesson for decision makers aiming to promote effective environmental protection to meet the highway district's goals, the findings present a model of how sustainability for highway design was predicted regarding factors associated with 14 activities. Results present that the ANFIS model enhances sustainability forecasting by using fuzzy rules, which are easy for communication. The ANFIS model can explain the training procedure of outcome and how to simulate the rules for prediction.

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