6

Application of Adaptive Neuro Fuzzy Inference System in Supply Chain Management Evaluation

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1. Introduction

Each construction project has unique features that differentiate it from even resembling projects. Construction techniques, design, contract types, liabilities, weather, soil conditions, politic-economic environment and many other aspects may be different for every new commitment. Uncertainty is a reality of construction business. Leung et al. (2007) developed a model to deal with uncertain demand by considering a multi-site production planning problem. The inventory control problem and quantify the value of advanced demand information were examined (Ozer and Wei, 2004). Mula et al. (2010) proposed mathematical programming models to address supply chain production and transport planning problems. A model for making multi-criteria decision was developed for both the manufacturers and the distributors Dong et al. (2005). A stochastic planning model was constructed for a two-echelon supply chain of a petroleum company Al-Othman et al. (2008). Weng and McClurg (2003) and Ray et al. (2005) focused supply uncertainty along with demand uncertainty in supply chains. Bollapragada et al. (2004) examined uncertain lead time for random demand and supply capacity in assembly Systems.

A number of methods were developed by researches to solve problems associated with uncertainties, including scenario programming (Wullink et al., 2004; Chang et al., 2007), stochastic programming (Popescu, 2007; Santoso et al., 2005), fuzzy approach (Petrovic et al., 1999; Schultmann et al., 2006; Liang, 2008), and computer simulation and intelligent algorithms (Kalyanmoy, 2001; Coello, 2005). However, each method is suitable for particular situations. The decision makers have to select the appropriate method for solving a problem.

For a uncertain construction project, the fuzzy atmosphere has been represented with the terms 'uncertainty' or 'risk' by construction managers and researchers, and they tried to control this systematically through risk management and analysis methods since the early 1990s (Edwards L., 2004). Some researchers like Flanagan et al. Flanagan R, Norman G. (1993) and Pilcher R. (1985) put differentiation between these two terms. They have mentioned that uncertainty represents the situations in which there is no historical data; and risk, in contrast, can be used for situations where success or failure is determined in probabilistic quantities by benefiting from the previous data available. Since such a separation is regarded as meaningless in the construction literature, risk turns out to be the most consistent term to be used for construction projects because some probability values can be attached intuitively and judgmentally to even the most uncertain events (Flanagan R, Norman G., 1993). The uncertainty represented quantitatively at some level is not the uncertainty any more; rather it is the risk henceforth and needs to be managed.

Construction companies are trying to make their supply chain more effective, and more efficient. Supply chain management has the potential to make construction projects less fragmented, improve project quality, reduce project duration, and hence reduce total project cost, while creating more satisfied customers. Construction companies need to respond of uncertain environment by using the concept of flexibility. Construction companies have recognized that flexibility is crucial for their survival and competitiveness. Several definitions of flexibility have been proposed since the construct is still in its initial stage of application to organizational phenomenon. Flexibility is defined as "the agility of a supply chain to respond to market changes in demand in order to gain or maintain its competitive advantage" (Bolstorff, P., Rosenbaum, R., 2007). The combination of Supply Chain Management (SCM) and flexibility is a significant source of competitiveness which has come to be named Agile Supply Chain (ASC). This paper argues that it is important to establish the flexibility of the construction supply chain. After embracing ASC an important question must be asked: How construction companies can evaluate flexibility in supply chains? This evaluation is essential for construction managers as it assists in achieving flexibility effectively by performing gap analysis between existent flexibility level and the desired one and also provides more informative and reliable information for decision making. Therefore, this study attempts to answer this question with a particular focus on measuring flexibility.

An approach based on Adaptive Neuro Fuzzy Inference System (ANFIS) for measurement of agility in Supply Chain was developed (Seyedhoseini, S.M., et al., 2010). The researchers used ANFIS to deal with complexity and vagueness of agility in global markets. ANFIS was applied order to inject different and complicated agility capabilities (that is, flexibility, competency, cost, responsiveness and quickness) to the model in an ambiguous environment. In addition, this study developed different potential attributes of ANFIS. Membership functions for each agility capabilities were constructed. The collected data was trained by using the functions through an adaptive procedure, using fuzzy concepts in order to model objective attributes. The proposed approach was useful for surveying real life problems. The proposed procedure had efficiently been applied to a large scale automobile manufacturing company in Iran. Statistical analysis illustrated that there were no meaningful difference between experts' opinion and our proposed procedure for supply chain agility measurement.

A procedure with aforementioned functionality must be develop to cope with uncertain environment of construction projects and lack of efficient measuring tool for flexibility of supply chain system. This study is to apply fuzzy concepts and aggregate this powerful tool with Artificial Neural Network concepts in favor of gaining ANFIS to handle the imprecise nature of attributes for associated concepts of flexibility. ANFIS is considered as an efficient tool for development and surveying of the novel procedure. Due to our best knowledge this combination has never been reported in literature before. This paper is organized as follows.

Section 2 reviews the literature on construction supply chain, supply chain performance evaluation and Agile Supply Chain (ASC); Section 3 represents the conceptual model using the capabilities of construction supply chain such as reliability, flexibility, responsiveness, cost, and asset, Section four contains an adaptive neuro fuzzy inference system (ANFIS) model which is proposed to evaluate flexibility in construction supply chains and the applicability of the proposed model has been tested by using construction companies in Thailand. Finally, in section 5 the main conclusion of this study is discussed.

2. Construction supply chain

Considering the construction industry, the client represents a unique customer with unique requirements. Stakeholders in the supply chain will provide these requirements. They must have the required primary competencies to make possible the fulfilment of these requirements.

2.1 Construction supply chain

In reality, organisations within a supply network delivering an office development will differ from those required to deliver a residential project. It may be useful to consider the chain as a network of organisations or a network organisations operating within the same market or industry to satisfy a variety of clients. Stakeholders involved in the construction supply-chain were classified into five categories related to the construction stages (H. Ismail & Sharif., 2005). The contract is the predominant approach for managing the relationship between organisations that operate in a construction project to deliver the client's required project. Although contracts are a sufficient basis for the delivery of a completed project, they are not sufficient to deliver a construction efficiently, at minimum cost, and right first time'.

2.2 Flexibility supply chain

The definition of flexibility is still fuzzy, mainly because it largely deals with things already being addressed by industry and which are covered by existing research projects and programs. Many researchers provide conceptual over views, different reference and mature models of flexibility. For instance, Siemieniuch and Sinclair (2000) presented that to become a truly agile supply chain key enablers are classified into four categories: Collaborative relationship as the supply chain strategy, Process integration as the foundation of supply chain, Information integration as the infrastructure of supply chain and Customer /marketing sensitivity as the mechanism of supply chain. The aggregation of current approaches can be criticized as they haven't considered the impact of enablers in assessing supply chain flexibility and also the scale used to aggregate the flexibility capabilities has the limitations.

Several papers present application of theories of measurement systems for managing performance of supply chain. However, there is no measurement system for managing performance of the entire supply chain. The adoption of metrics that cross of the borders of organization considering dimensions of performance related to inter and intra organization processes (Lapide, L., 2000). The metrics developed by the SCOR model (Supply-Chain Council (SCC), 2011) were proposed to analyze a supply chain form three perspectives: process, metrics and best practice. The connections between the inter-organizational processes in each company in a supply chain are created based on the SCOR framework. The common and standardized language among the company within a supply chain is developed in order to compare supply chain performance as a whole.

There are five performance attributes in top level SCOR metric, namely reliability, responsiveness, flexibility, cost and asset management efficiency (Bolstorff, P., Rosenbaum, R., 2007). Reliability is defined as the performance related to the delivery, i.e., whether the correct product (according to specifications) is delivered to the correct place, it the correct quantity, at the correct time, with the correct documentation and the right customer. The definition of responsiveness is the speed at which a supply chain provides the products to customers. Flexibility is the agility of a supply chain to respond to market changes in demand in order to gain or maintain its competitive advantage. All the costs related to the operation of supply chain are included in the cost attribute. The asset management efficiency is the efficiency of an organization in managing its resources to meet demand. The management of all the resources (i.e., fixed and working capital) is considered.

The first limitation of supply chain flexibility evaluation is that the techniques do not consider the ambiguity and multi possibility associated with mapping of individual judgment to a number. The second limitation is the subjective judgment, selection and preference of evaluators having a significant influence on these methods. Because of the fact that the qualitative and ambiguous attributes are linked to flexibility assessment, most measures are described subjectively using linguistic terms, and cannot be handled effectively using conventional assessment approaches. The fuzzy logic provides an effective means of handling problems involving imprecise and vague phenomena. Fuzzy concepts enable assessors to use linguistic terms to assess indicators in natural language expressions, and each linguistic term can be associated with a membership function. In addition, fuzzy logic has generally found significant applications in management decisions. This study applies a fuzzy inference system for mapping input space (tangible and intangible) to output space in order to assist construction companies in better achieving an flexibility supply chain. The proposed Fuzzy Inference System (FIS) has been based on the experiences of experts to evaluate flexibility of construction supply chains.

3. Methodology

To evaluate flexibility of the construction supply chain two main steps are performed. At the first step, measurement criteria are identified. A conceptual model is developed based on literature review. Capabilities of supply chain are employed to define supply chain performance in three basic segments: sourcing, construction and delivery. In this study the conceptual model involves four attributes: reliability, flexibility, responsiveness, cost, and asset. Twenty seven sub-attributes are the basis of the conceptual model as shown in Table 1. At the Second step, the design of an ANFIS architecture is performed by constructing an input-output mapping based on both human knowledge in the form of fuzzy if-then rules with appropriate membership functions and stipulated input-output data based- for deriving performance in supply chains.

Reliability	Flexibility	Responsiveness	Cost	Asset
Perfect order fulfillment	Upside flexibility supply chain	Order fulfillment	Total cost supply chain management	Cash to cash
Orders in full	Upside source flexibility	Source cycle time	Finance and planning cost	Days sales outstanding
Delivery to commit day	Upside make flexibility	Make cycle time	Inventory carrying cost	Days payable outstanding
Delivery to commit day	Upside delivery flexibility	Delivery cycle time	IT cost for supply chain	Inventory days of supply
Perfect condition			Material acquisition cost	Return of asset
Accurate documentation			Order management cost	Asset turns
				Net profit

Table 1. Input/Output indicators

4. Neurofuzzy 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 (R.E. Spekman, J.W. Kamau! Jr., N. Myhr., 1998). 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. An ANFIS architecture is equivalent to a two-input first-order Sugeno fuzzy model with nine rules, where each input is assumed to have three associated membership functions (MFs) (Z.Zhang., D.Ding., L.Rao., and Z.Bi., 2006). Sub-attributes associated with reliability, flexibility, responsiveness, cost, and asset are used as input variables; simultaneously, construction supply chain performance is considered as output variables. These input variables were used in the measurement of the supply chain performance by (G.M.D. Ganga, L.C.R. Carpinetti., 2011). Fig 1 is an ANFIS architecture that is equivalent to a two-input first-order Sugeno fuzzy model with nine rules, where each input is assumed to have three associated membership functions (MFs) (J. Jassbi, S.M. Seyedhosseini, and N. Pilevari., 2010).

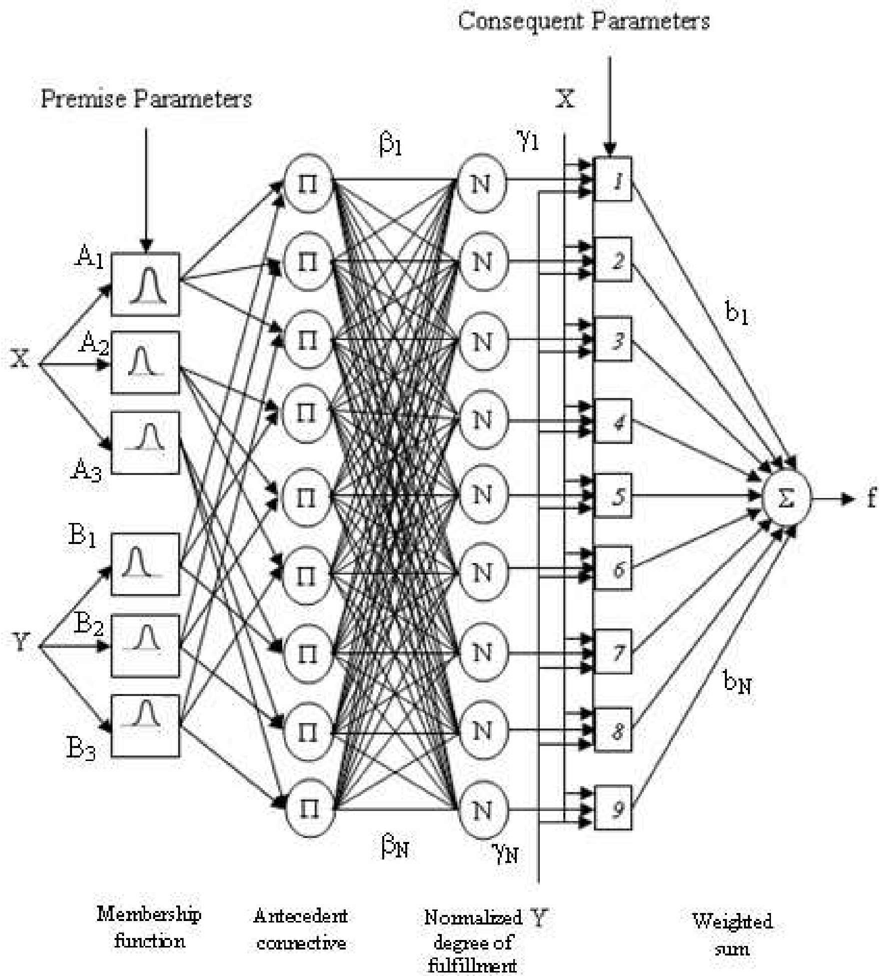

Fig. 1. The ANFIS architecture for two input variables

For proving the applicability of the model and illustration, the proposed model was applied in twenty-five of the construction companies in Thailand. The first step to apply the model was to construct the decision team. The stakeholders involved in the construction stage became the decision team including main contractor, domestic subcontractors, nominated subcontractors, project manager, material suppliers, plant/equipment suppliers, designers, financial institution, insurance agency, and regulatory bodies. For training the ANFIS, a questionnaire was designed including the identified criteria. The decision team was asked to give a score to them, based on their knowledge associated with the construction stage. 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 2 shows the structure of the ANFIS; a Sugeno fuzzy inference system was used in this investigation. Based on the collected data, 150 data sets were used to train the ANFIS and the rest (50) for checking and validation of the model. For rule generation, the subtractive clustering was employ 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. The trained fuzzy inference system includes 20 rules (clusters) as present in Fig 3. Because by using subtractive clustering, input space was categorized into 20 clusters. Each input has 20 Gaussian curve built-in membership functions. During training in ANFIS, sets of processed data were used to conduct 260 cycles of learning.

By inserting ANFIS output to the system the flexibility level of the supply chain management can be derived. In addition, the trend of training error and checking error has been shown in Fig 4. The researcher continued the training process to 500 epochs because the trend of checking error started to increase afterward and over fitting occurred. The value of checking error by 500 epochs was 1.45 which is acceptable. Then the value of supply chain flexibility is derived by a trained ANFIS. The ANFIS output in Thai construction companies is calculated.

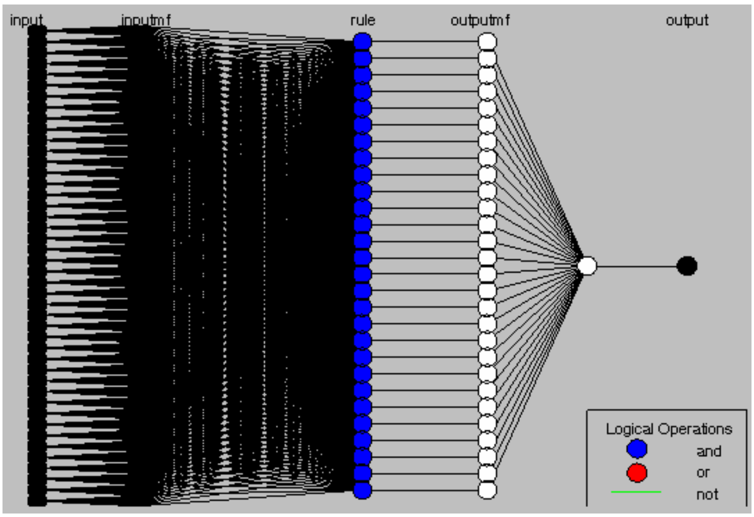

Fig. 2. Network of innovation performance by the ANFIS

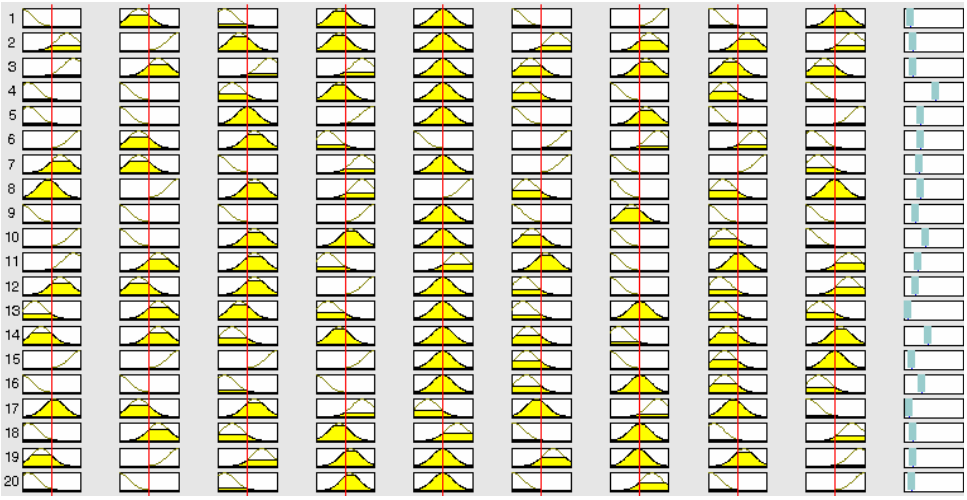

Fig. 3. Trained main ANFIS surface of supply chain performance

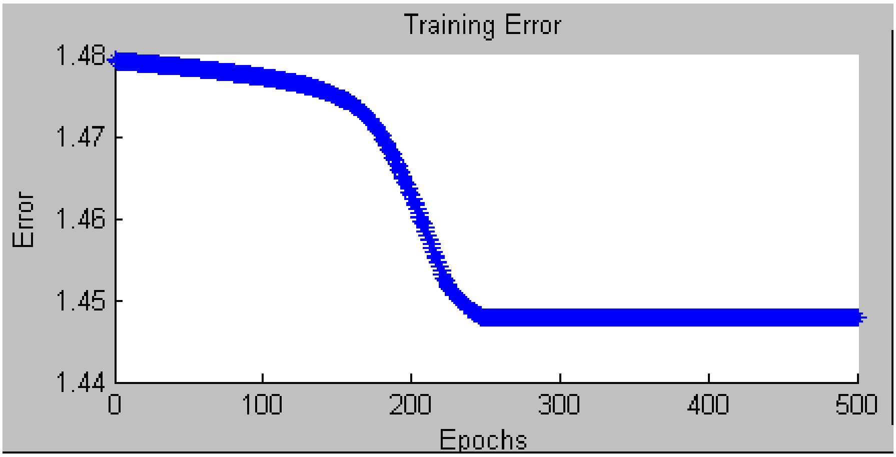

Fig. 4. Trend of errors of trained fuzzy system

Fig 5 depicts a three dimensional plot that represents the mapping from reliability (in1) and flexibility (in2) to supply chain performance (out1). As the reliability and flexibility increases, the predicted supply chain performance increases in a non-linear piecewise manner, this being largely due to non-linearity of the characteristic of the input vector matrix derived from the collected data. This assumes that the collected data are fully representative of the features of the data that the trained FIS is intended to model. However the data are inherently insufficient and training data cannot cover all the features of the data that should be presented to the trained model. The accuracy of the model, therefore, is affected under such circumstances.

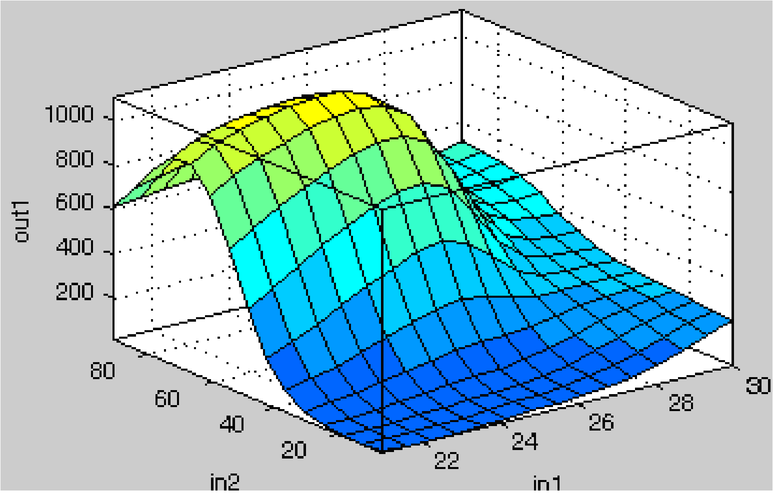

Fig. 5. Network of construction supply chain performance by the ANFIS

The rate of sub-attributes associated with flexibility, responsiveness & quickness, competency and cost and the output of ANFIS have been shown in Table 2 and 3, respectively. The twenty-five scenarios were used to test the performance the proposed method. The results indicate that the output values obtained from ANFIS are closer to the values given by experts in most scenarios being tested. The average and standard deviation of the differences between the estimated and the output values obtained from expert produced by ANFIS are calculated to be 12.6% and 8.75% respectively. As far as ANFIS is concerned, its biggest advantage is that there is no need to know the concrete functional relationship between outputs and inputs. Any relationship, linear or nonlinear, can be learned and approximated by an ANFIS such as a five-layer with sufficient large number of neurons in the hidden layer. In the case that the functional relationship between outputs and inputs is not known or cannot be determined, ANFIS definitely outperforms regression, which requires the relationship between output and inputs be known or specified. Another remarkable advantage of ANFIS is its capability of modelling the data of multiple inputs and multiple outputs. ANFIS has no restriction on the number of output. The relationships can be learned simultaneously by an ANFIS with multiple inputs and multiple outputs.

No.	Criteria				
	Reliability	Flexibility	Responsiveness	Cost	Asset
1	23	54	31	31	20
2	20	65	65	28	26
3	19	75	75	30	23
:	:	:	:	:	:
98	20	65	65	28	31
99	26	70	70	32	65
100	23	70	25	31	75

Table 2. Input values for the trained ANFIS

No	Value of output		
	Expert's	ANFIS	Percent Difference
1	11	72	15.4
2	20	75	15.08
3	19	75	19.67
:			
98	18	66	10.17
99	26	30	28.46
100	28	55	8.77

Table 3. Possible value obtained form ANFIS method

5. Conclusion

This paper has discussed the need for flexibility assessment of the construction supply chain. The particular features of construction supply chains highlighted. The need for and potential benefits of, construction supply chain flexibility assessment were then examined and the conceptual model of a flexibility assessment model for the supply chain presented. Case studies of the use of the model in assessing the construction organizations were also presented. The following conclusions can be drawn from the work presented in this paper: The way to improve the construction supply chain delivers projects is necessary to achieve client satisfaction, efficiency, effectiveness and profitability. It is important to perform the flexibility assessment of the construction supply chain in order to ensure that maximum benefit can be obtained. Since agile supply chain is considered as a dominant competitive advantage in recent years, evaluating supply chain flexibility can be useful and applicable for managers to make more informative and reliable decisions in anticipated changes of construction markets. The development of an appropriate flexibility assessment tool or model for the construction supply chain is necessary, as existing models are not appropriate in their present form. The results reveal that the ANFIS model improves flexibility assessment by using fuzzy rules to generate the adaptive neuro-fuzzy network, as well as a rotation method of training and testing data selection which is designed to enhance the reliability of the sampling process before constructing the training and testing model. The ANFIS model can explain the training procedure of outcome and how to simulate the rules for prediction. It can provide more accuracy on prediction.

Further research is necessary to compare efficiency of different models for measuring flexibility in supply chain. Although this study has been performed in the construction companies, the proposed methodology is applicable to other companies, e.g. consulting companies. Enablers in flexibility evaluation should be determined and the impact of them on capabilities must be studied in further researches. In addition, the relations between enablers should be considered in order to design a dynamic system for the supply chain management evaluation.

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