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Predicting the Impact Size of Uncertainty Events on Construction Cost And Time of Highway Projects Using ANFIS Technique

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Abstract. This study examines the ability and performance of Adaptive Neuro-Fuzzy Inference System (ANFIS) as an intelligent machine learning technique in the prediction of the impact size of uncertainty events on construction cost and time of highway projects. The rationale for the study stems from widespread reports of cost and time overruns on highway construction projects and the knowledge that the cost and time of projects are affected significantly by uncertainty events. Thus, the prediction of the impact size of uncertainty events during the design phase will enable project managers in preparing a proper plan with sufficient contingencies to deal with these uncertainty events. The success or failure of prediction depends on the credibility of the prediction method. In this study, the impact size of 76 uncertain events on the construction cost and time of highway projects were predicted using ANFIS technique, and the accuracy and reliability of ANFIS prediction were assessed. The results of R-Squared and four error tests proved that ANFIS is an accurate and reliable technique for predicting the impact size of uncertainty events on the cost and time of construction projects. Based on these findings, the study concludes that the use of intelligent machine learning methods such as ANFIS will minimise the potential inconsistency of correlations in construction cost and time prediction, improved accuracy in estimated project cost and time and reduced overruns.

Keywords: Accuracy, ANFIS, Construction cost and time, Impact size, Reliability, Uncertainty events.

1 Introduction

Construction of transportation infrastructure and particularly highway construction projects are one of the most unreliable projects in terms of estimating construction cost and time [1]. According to Abdullah, Rahman, et al. [2] 90% of the People's Trust Council highway construction projects experienced cost and time underestimation. Providing accurate estimates of cost and time on the construction of highway projects is a difficult task because construction projects are subject to risks and uncertainties, especially in the planning phase of the project when insufficient data and information about the project is available [3]. Typically, in the estimation of construction project resources, several variables are not known since uncertainties populate construction projects.

There are many common uncertainty events (also known as risk events) that influence the cost and time of construction activities of construction projects that affect construction performance differently [4]. According to Flyvbjerg [5], the occurrence of uncertainty events in the construction of infrastructure projects, particularly in highway projects, is higher than other construction projects, due to unique features of highway projects, which include complexity between major construction activities, long duration of construction, dynamic processes, repetitive linear projects, and mobile construction sites. The project is regarded as successful if adequate allowance is made for uncertainty events and a proper response is provided for their impacts on cost and time of project which may or may not occur [6].

Estimating construction cost and time at the early stage of project development represents a prediction provided by the estimator based on available information and data. Estimating in construction is defined as that area of construction practice where the estimator's experience and judgment are utilised in the application of scientific principles and techniques to the problem of predicting and controlling cost and time of projects [7]. The ability to accurately predict the impact size of uncertainty events on construction time has always been one of the most critical challenges of estimators [8]. The success or failure of prediction depends on the credibility of the prediction technique.

The impacts of risk and uncertainty events on cost and time of construction projects have been approached in two major ways: qualitative techniques and quantitative techniques. A qualitative technique such as contingency application and fault tree analysis are more basic techniques, and the subjective judgment could not determine the exact impacts of events [4]. Quantitative techniques such as regression modelling, neural networks and Monte Carlo simulation are more common and preferable than the qualitative techniques because of the capability of quantifying the impacts of such events [9]. However, quantification techniques are complex and hard and furthermore require exact data, and such data either do not exist at all or are hard to obtain in the realisation of construction projects [10]. Furthermore, the applicability of these techniques in predicting the impact size of uncertainty events in real construction projects is limited due to the unpredictable nature of construction projects and their dependence on the estimator's thinking prototype in the process of uncertainty analysis [10].

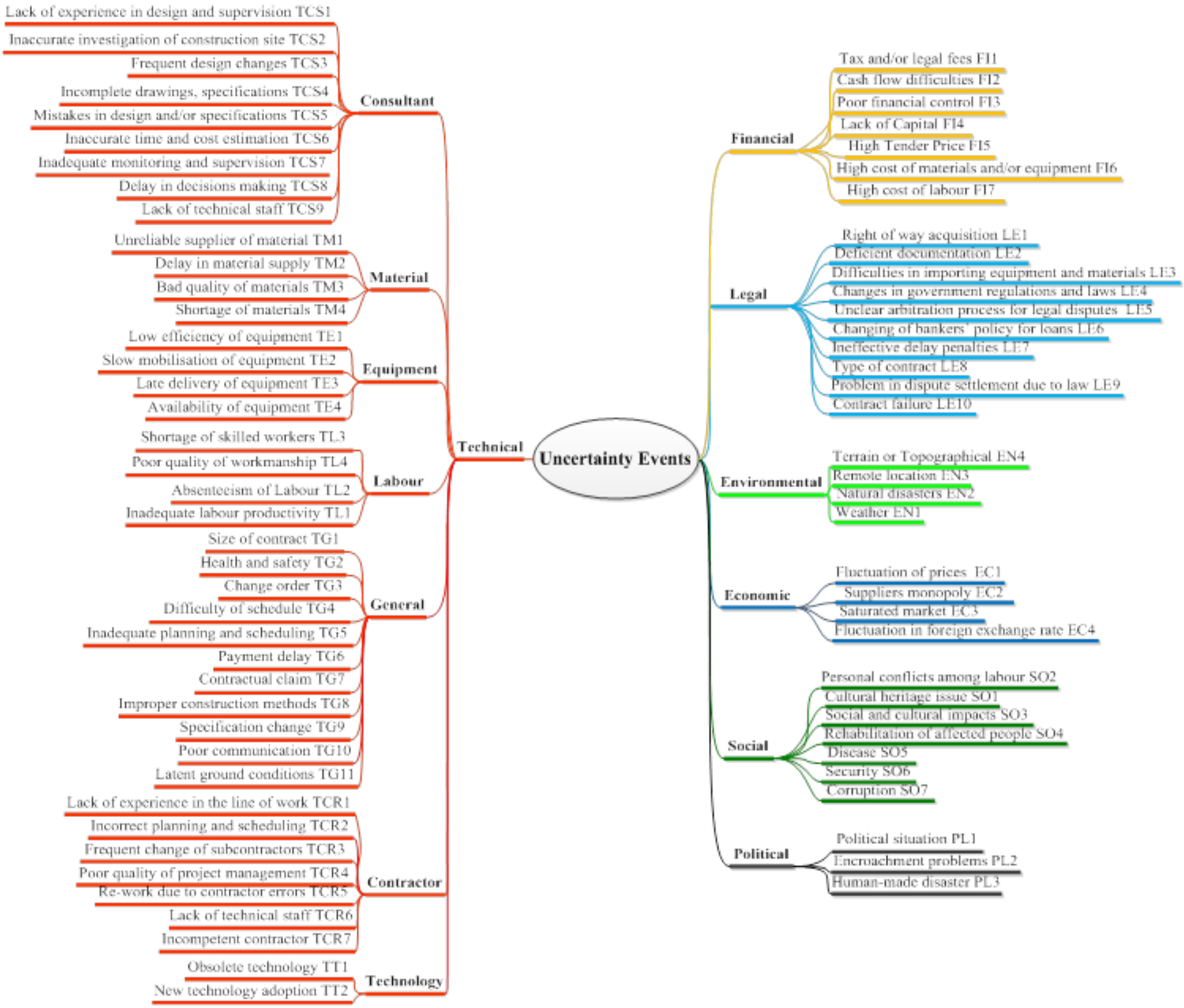
On the other hand, hybrid intelligence machine learning methods based on Fuzzy Inference System (FIS) is used in modelling the qualitative aspects without employing precise quantitative analyses, it provides standard practical methods for transformation into rule-based as well as effective methods for turning Membership Functions (MF) for better performance index [11]. The Adaptive Neuro-Fuzzy Inference System (ANFIS) combines the strengths of Artificial Neural Network (ANN) with Fuzzy Inference Systems (FIS) to create an efficient method for analysing the complex problems. Also, neural network fuzzy systems interpret human knowledge and deduce it into a mathematical model. These two tools were combined to achieve readability and learning ability at the same time. ANFIS, trained to develop fuzzy rules and determine Membership Functions (MF) for input and output variables of the system is an intelligent system which can estimate the variables and fuzzy rules intelligently and does not require a systematic method for design of fuzzy systems. ANFIS can handle nonlinearity, uncertainty, and complex problems which are involved in predicting the impact size of uncertainty events on construction cost and time [12]. Generally, Neuro-Fuzzy has two major categories namely: fuzzy linguistic modelling which is focused on interpretability (Mamdani), and precise fuzzy modelling which is focused on accuracy (Takagi-Sugeno) [13].

ANFIS has been used in various fields of engineering. For instance, Ugur [14] has developed ANFIS to estimate the costs of the residential building. While Fragiadakis, Tsoukalas, et al. [15] assessed the occupational risk in the shipbuilding industry; Ebrat and Ghodsi [10] applied ANFIS to evaluate the risk in construction projects; Li, Su, et al. [16] forecasted building energy consumption using hybrid ANFIS; GüNeri, Ertay, et al. [17] used ANFIS to overcome supplier selection problem in construction projects; Shahhosseini and Sebt [18] used ANFIS to establish a fuzzy adaptive decision-making model for selection and assignment of human resources to construction projects based on competency; and Wang and Elhag [19] developed an ANFIS based risk assessment model for bridge maintenance projects.

However, there are limited researches undertaken using ANFIS in the field of construction management and limited studies have evaluated the performance of ANFIS as a technique for predicting the impact size of uncertainty events on construction cost and time of highway projects. Therefore, this study examines the predicted impact size of uncertainty events on the construction cost and time of highway projects using ANFIS as an intelligence method, and after that assessed the ability and accuracy of prediction of ANFIS.

2 Uncertainty Events on highway projects

An uncertainty event (also known as risk or unforeseen event) is an event with a substantial impact on the construction activities and process and occurs with some probability of occurrence, and severely disrupt the construction process if it occurs [20]. Uncertainty events are associated with the project characteristics and location and has no root causes that can be generalised [21]. Therefore, there is an obvious need to effectively anticipate, identify and classify the uncertainty events on different locations and projects to assess their influence on the objectives of construction projects. Moghayedi and Windapo [22] identified 76 uncertainty events as affecting the construction of South African highway projects under seven major groups namely Economic, Environmental, Financial, Legal, Political, Social and Technical as presented in Figure 1. The 76 uncertainty events identified by Moghayedi and Windapo [22] was used in the current study to evaluate the performance of proposed techniques for predicting the uncertainty events.



123 **Fig. 1.** Uncertainty events on South African highway construction projects
124 distributed according to causative factors

3 Methodology

This paper developed An ANFIS model and evaluated its performance in predicting the impact size of uncertainty events on construction cost and time of highway projects. The hierarchy structure of the model developed for predicting the impact size of uncertainty events consists of four main steps; determination of uncertainty event attributes, data collection, developing the predicting models, evaluating the performance of the developed model and recommendations.

The process begins with a determination of criteria for uncertainty assessment. The impact size of uncertainty is assessed by two parameters, probability of occurrence and severity [23]. To model, the impact of uncertainty events on construction time, the ISO 31000 (International Standard Organization) impact matrix was used [23]. Figure 2 shows the probability of occurrence and severity as two input variables and relevant impact size as the output of the predicting model.

		Severity				
		Insignificant (1)	Minor (3)	Moderate (5)	Major (7)	Catastrophic (9)
Probability of Occurrence	Rare (.1)	Minimal (1)	Minimal (1)	Low (2)	Low (2)	Moderate (3)
	Unlikely (.3)	Minimal (1)	Low (2)	Moderate (3)	Moderate (3)	High (4)
	Possible (.5)	Low (2)	Moderate (3)	Moderate (3)	High (4)	High (4)
	Likely (.7)	Low (2)	Moderate (3)	High (4)	High (4)	Extreme (5)
	Almost Certain (.9)	Moderate (3)	High (4)	High (4)	Extreme (5)	Extreme (5)

Fig. 2. Uncertainty impact matrix

In the second step, the uncertainty event attributes (probability of occurrence and severity) were obtained from 32 project managers with a minimum of 20 years of work experience in South African highway construction projects recommended by The South African National Roads Agency SOC Ltd (SANRAL) using the five-point linguistic Likert scale questionnaires.

In the third step, an ANFIS model is developed in MATLAB based on the impact matrix to predict the impact size of uncertainty events on construction cost and time of highway projects to assess the impact size of uncertainty events in construction cost and time of highway projects. In the last step, the fitness of predicted impact sizes to the real data are evaluated by R-Square, and the reliability of ANFIS on predicting impact size are evaluated using Root Mean Square Error (RMSE) and Mean Absolute Percentage Error (MAPE). The predicted impact size and the performance values of ANFIS on construction cost and time of highway projects are presented in the next section.

The RMSE, MAPE and of predicted impact size of uncertainty events are calculated to evaluate the performance of ANFIS. The result of the selected 20 events is presented in Table 1.

4 Results

The study developed a first-order Takagi-Sugeno fuzzy inference system to accurately assess the impact size of uncertainty events on construction cost and time of highway projects. In this inference system, the output of each rule is a linear combination of two input variables added by a linear term of "AND" logic. The final output is the weighted average of each rule's output [24]. Figure 3 illustrates the Takagi-Sugeno ANFIS structure which was developed for this study. To model this ANFIS following 25 fuzzy rules "If-Then" are considered.

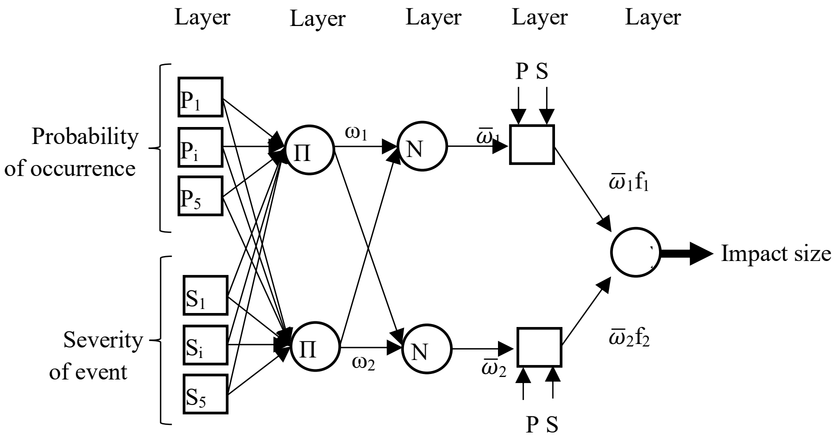


Fig. 3. Developed Takagi-Sugeno ANFIS structure

Eighty per cent (80%) of the data collected from the research participants was used for training of the FIS, while the twenty per cent (20%) was used for checking and testing the neural network which set the system parameters. The RMSE, MAPE and R-Square value of predicted impact size of uncertainty events are calculated to evaluate the ANFIS performance and the result for the selected 20 events are presented in Table 1.