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Optimized artificial intelligence models for predicting project award price

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ABSTRACT

Bridges are essential components of transportation systems. The bidding process is the main determinant of whether a contractor is commissioned to complete a construction project. Therefore, contractors must rapidly and precisely estimate construction costs and the bid award amount. This study involved optimizing artificial intelligence models to forecast bid award amounts for bridge construction projects. A genetic algorithm is used in several forecasting models, including models based on multiple regression analysis, artificial neural networks (ANNs), and case-based reasoning (CBR). Data for public bridge construction projects were collected from the Taiwan government e-procurement system. The cross-validation results show that the mathematical model for the ANNs provides more reliable simulations and has a superior fit compared with the regression methods, CBR, and the conventional approach. This study provides an optimization process for estimating project award prices that improves construction and evaluations of AI-based models as well as an auxiliary tool that contractors can use to make bidding decisions.

1. Introduction

Bridges are major structures within transportation systems and serve as lifelines that connect people to economic activities. These structures enable the public to cross rivers, valleys, and terrains of all types. Taiwan is a country with many rivers and streams of all sizes. In particular, Taiwan has more than 9699 bridges constituting a total length of 502,021.8 m [33]. The bridges vary in their styles, spanning rivers and valleys or intersections of freeways, roads, and highways. Thus, bridges are essential transportation components in Taiwan.

The bidding process is a crucial determinant of whether construction firms receive project contracts. Because the main objective of construction companies is to expand their business volume by being commissioned to complete various projects, preparing realistic and accurate bids is essential [3]. The Government Procurement Law in Taiwan classifies project bidding invitations as open, selective, or restricted and divides the bidding invitation process into two or three stages. Bidding award methods include the lowest bid, most advantageous bid, and multiple-awards bid [38]. The government has jurisdiction over public construction in Taiwan, and contracts are generally awarded through open bidding, in which the lowest bid wins the contract.

Because general bidding prices depend on cost and profit, competitive bidding requires vendors to consider the bidding prices of other vendors and the base price acceptable to the client before proposing their own bid. However, bidding firms usually rely on subjective judgment for initial costs estimates. The subjective judgments of many people may produce estimation errors that do not provide a sound basis for setting actual bid amounts. Estimation errors may also distort the bid amount. Overestimation of costs can cause loss of the contract, whereas underestimation can cause a financial loss for the company. Therefore, construction firms must rapidly and precisely estimate construction costs and bid award amounts.

A limitation of bidding models used in the construction industry [7,27] is that they require sensitive information on competitors. Many models have been developed for estimating construction costs [11–13,26,44]. These methods are more suitable for use at the early stages of a construction project, such as at the conceptual and schematic design stages, rather than at the bidding stage.

Previous studies have asserted that, because the knowledge-based economy has major implications for the construction industry, construction firms should apply tools that can improve their performance and competitiveness [37]. Most approaches based on artificial intelligence (AI) have focused on developing algorithms for improving modeling accuracy or the speed of model building [15,28,34,46]. Therefore,

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AI-based models are potential tools for solving civil engineering and management problems.

This study applied techniques based on data mining and AI, namely genetic algorithm (GA), multiple regression, artificial neural network (ANN), and case-based reasoning (CBR) models, to forecast bid award amounts on the basis of limited available information and to provide a reference for vendors when making bid submission decisions. For validation, the proposed modeling system uses a k-fold cross-validation algorithm [31]. A case study method was used to analyze cases in the government e-procurement system involving bridge bidding for public roads within a budget range of NT$1 billion. The bridges were either beam or rigid-frame bridges.

The remainder of this paper is organized as follows: Section 2 summarizes the literature on this topic; Section 3 introduces the theories and research methodologies employed in the study; Section 4 elucidates the data prearrangement process and model construction (specifically, the combination of predictive models and a GA are performed to estimate the award bid amounts); finally, Section 5 draws conclusions and provides suggestions for future studies.

2. Literature review

For construction contracts, the conventional approach used by government agencies is competitive bidding. Many studies of strategies for bidding and identifying the most appropriate projects have addressed the determination of whether to submit a bid and the optimal bid value (or markup) [47]. The "lowest bidding price for a given base price" method is currently used in the bidding process for Taiwan construction projects. This study focuses only on the second decision (i.e., bid award method). Many studies have addressed bidding models, which can be classified into statistical models [7,20,39,41], multicriteria models [6,10], game theory [24], and AI models [9].

Conventional bidding models are based on statistical and probability theory. The Friedman model (1956) provides the optimal set of bids on contracts in a competitive bidding scenario [20]. The general bidding model developed by Carr (1982) estimates the probability distribution of contractor costs and bids by opponents [7]. Ahmad (1990) used a utility-value-based approach and developed a bidding methodology of decision analysis for solving the bidding problem [1]. The correlation analysis of the lowest bidding price and the final project completion price performed by Williams (2003) showed that a natural logarithm conversion increases the correlation between the lowest bidding price and final project completion price [49]. However, making a bidding decision is a complex process that involves many factors; the level of complexity may not be adequately reflected in these models.

Several bidding-related studies have focused on determining bid markups in relation to an estimated project cost [16,17]. Dozzi et al. (1996) applied a multicriteria utility theory to bid-markup decisions for construction projects [19]. Wang et al. (2007) integrated a simulation-based cost model and a multicriteria evaluation model to reflect bidder preferences regarding decision criteria [45]. Cheng et al. (2011) developed a multicriteria model for making bidding-related decisions to assist contractors in making bidding decisions and to determine the scale of markup for the submitted bid [10].

Another major line of research is estimating project costs during bidding [44]. Chou (2009a) used a generalized linear model for accurately and reliably estimating public road construction costs and for continually tracking construction expenses [13]. Several other studies have applied or evaluated AI-based models for estimating construction prices and costs [5,23,50]. Williams (2002) used bidding data in ANN and regression models to predict the completed cost of competitively bid highway projects and found that a natural log transformation of the data strengthened the linear relationship between a low bid and completed cost [48].

Another AI-based forecasting technique is CBR, which is a subbranch of AI. This computational method involves solving current problems on the basis of previous solutions. Chou (2009b) applied CBR in analyzing road-paving maintenance costs and forecasting maintenance costs at the initial project planning stages [14]. Yao and Yang (1998) employed CBR to forecast the work period and costs of a construction project [51]. Ji et al. (2010) developed a CBR revision model in which a "revise" phase is implemented in the CBR cycle to improve the accuracy of the predicted costs for multifamily housing projects [28].

Recently, a growing tendency is to enhance performance by using hybrid models. Křivý et al. (2000) used a randomized algorithm to identify parameter values in a nonlinear regression (NLR) [32]. Cheng et al. (2010) combined AI with fuzzy neural network concepts to enhance the precision of cost estimates at the early stages of a construction project [11]. To study early-planning practice and its relationship to final project outcomes in the Taiwan building construction industry, Wang et al. (2012) used ANN ensemble and support vector machine classification models to predict construction costs and scheduling successes [46].

Studies have proven that hybrid methods that combine AI and GA are powerful. A GA [21] is a stochastic search algorithm inspired by the mechanics of natural evolution, including survival of the fittest, reproduction, crossover, and mutation. To improve performance, GAs are often combined with other AI techniques. To optimize ANN parameters, Seo (2006) proposed a hybrid method in which product life cycle costs are estimated using a GA for simultaneous optimization of ANN parameters [42]. Hegazy and Ayed (1998) substituted a GA for neuron weighting in ANNs to establish a road item and project estimation model [23]. Evolving hybrid systems combining CBR and a GA have also been used in various fields [2,8,18,29].

However, for cost estimation in bridge projects, AI models have been used only in the maintenance and management phases; the forecasting techniques and accuracy rates remain inadequate. Although erecting a bridge is among the most vital construction projects in Taiwan, bridge projects are complex to classify, and a basis of calculation remains to be developed. Therefore, construction companies often experience difficulty in calculating times and costs when estimating bidding prices. Providing bidders with improved bid award estimation techniques would increase the accuracy of award price predictions for competitive bidding.

Generally, related studies have focused on estimating construction costs rather than bid award amounts. By contrast, this study focused on predicting bid prices in instances in which the bid has already been awarded (i.e., this study did not involve analyzing whether a bid amount should be accepted or rejected). This study used hybrid models in which AI techniques are integrated to enhance accuracy in predicting bid award prices.

3. Methodology

3.1. Statistical analysis

Many statistical methods for describing, testing, and forecasting data have been developed. Analysis of variance and curve evaluations are used for factor testing and verification, and regression analysis is used for forecasting. However, because the values used in regression analysis must conform to a normal distribution, models that do not meet this normality require a variable transformation [30,40] such as the Box–Cox transformation to convert original data into a normal distribution, as shown in Eq. (1):

$$y(\lambda) = \begin{cases} \dfrac{y^{\lambda}-1}{\lambda}; & \text{if } \lambda \neq 0 \\ \log(y); & \text{if } \lambda = 0 \end{cases} \quad (1)$$

where λ can use GA searching to ensure a normal distribution in the posttransformation data of the chi square test. After the variable transformation, the data can be subjected to regression analysis.