Optimizing Bidding Strategy of the Roadway Projects – An Application of Utility Function Theory

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Abstract. The "A+B" bid method is determined by the lowest combined bid. Contractors must greatly shorten construction time to be able to win bidding competitions. However, the risk under the shortened duration of construction increased rapidly. For this reason, it is important to propose a bidding strategy to acquire the best composition of construction cost and time. This research targeted contractors with a questionnaire regarding A+B bidding in Taiwan by applied "Utility Function Theory" to construct a decision model of the best construction cost and time. It was found that the optimal profit regressed from the modified utility function differs from contractors’ preliminary bids. In the situation that the difference in basic profits is not large, contractors can set up a decision maker’s utility function based on their ability to take a risk and simulate the major competitors based on experience to judge the potential success and risk from shortening the construction time.

1. Introduction

Roadway construction projects at present are still mostly based on the project cost as the final bid, and the construction duration is decided by the owners. Project owners are often worried about the commitment bounced of completion deadline or to avoid unnecessary troubles. To decrease the loss of social costs caused by the roadway construction projects and reduce the inconvenience of road users, advanced countries in Europe and the United States have already incorporated the ‘construction duration’ which represents the social cost into the final bid consideration and obtained quite good results.

Under this mechanism, the setting right of construction duration is transferred from the project owners to the contractors bidding. The contractors participating in the bidding according to their resources and construction capacity, estimate and deliver the construction duration of the bidding project. The shorter the setting of the construction duration, the contractors have the relative advantages of winning the bid. Most participating bidders estimate the optimal combination of project bid amounts and durations, due to the lack of systematic evaluation criteria, which often heavily depend upon previous bidding experience. Therefore, this study uses the Utility Function Theory (UFT) to build the
optimization model of the cost and duration for participating bidders, to assist them to set the best total bid price to increase the chances of winning the project.

2. Literature review

2.1. The Application of Bidding Theory

The probability model is the earliest bidding theory applied to construction projects. Friedman applied probability theory to bidding [1], which explore the probability distribution of the bid price and estimated cost ratio, the relationship between the number of participants and estimated cost, the choice of multiple contracts, etc., then a relatively complete set of theories was proposed by Gates [2,3] and followed by Griffis [4] and Carr [5]. Jaśkowski [6] also use the way of probabilistic theory in determining the Contractor's bid pricing strategy with applications in numerical form. Although these bidding models, which are constructed based on construction cost, bid price, and contract risk, have no problems in the mathematical derivation process but are less applicable in practices.

The decision analysis model takes different hypothesis scenarios, uses their attributes as the basis for analysis and comparison, to evaluate the merits of each scheme. Ahmad [7] used the Simple Additive Weighting Method to quantify various considerations to decide whether to bid; Seydel & Olson [8] used Analytic Hierarchy Process (AHP) to calculate the best bid price and profit rate. Aznar [9] proposed a logistic regression model in deciding whether or not to bid on the infrastructure project. A model has also been developed by Issa et al. [10] namely the Multi-Criteria Decision-Making Model (MCDMM), in which the AHP and Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (Fuzzy TOPSIS) are combined, intended for the selection of the best alternatives by decision-makers. These methods of analysis are more suitable for realistic bidding and easier to understand than mathematical models, but will not result in new schemes and spend a lot of time.

In recent years, due to the rapid development of artificial intelligence, there is correlative research on the use of expert systems, neural networks, and fuzzy mathematics to construct bidding decision models. Hatefi [11] proposes that the dematel-fuzzy ANP model be integrated for construction projects to address project risk gaps affecting each other, and Polat et al. [12] proposes an integrated fuzzy MCGDM that uses AHP and TOPSIS together to select material suppliers in a project. Also, Lee [13] developed and proposed linear programming in the FAHP process based on fuzzy number values that are expected to determine alternative criteria and weights. Based on fuzzy set theory, Lesniak [14] devised a decision model to help contractors decide whether or not to bid on a construction project.

2.2. Utility Function Theory (UFT)

Utility theory provides the basis for examining mathematical limitations concerning efforts to find optimal solutions for portfolio selection [15]. Utility Function (UF) is mostly used in financial management (e.g. security investment) and risk management (e.g. insurance theory). The application of UF in construction projects is mainly decision analysis. Meanwhile, Levy [16] said that one of the foundations of the world economy and finance is expected utility theory (EUT). The cost/time (A+B) bidding method has been implemented in several countries for many years, which has a considerable effect on shortening the construction duration [17]. This study adopted UF to quantify the risk tolerance of decision-makers, used a decision tree to construct the bid winning probability and expected utility value with different proportions of shortening the construction duration, compare the actual bidding decision with the expected utility decision accordingly to explore the feasibility of UFT applied to “A+B” bidding method.

3. Results and discussions

The study was conducted on two roadway intersection projects of the exit Highway-II (Project-1 and Project-2) which awarded the projects based on the Most Advantageous Tender. Before the project
bidding, the owner has announced the project base price and the maximum construction duration and carried out qualification screening for the financial status, project performance, and vendor credit.

3.1. Establish the UF Process of Contractor

The steps of building the contractor's UF process are as follows: 1) understand the behaviour of contractor decision-makers and analysis of potential competitors; 2) establish the decision tree model of project cost, probability of scheme feasibility, crash cost, and the probability of winning bid for different shortening the construction duration; 3) conduct the dialogue and inquiry with the contractor decision-makers of the bidding, obtain the expected utility value and profit value, to understand the degree of risk tolerance of contractor under the case of the shortened construction period; and 4) fitting each point of dialogue, to construct the UF of the contractor bidding method for cost and construction schedule.

3.2. Statistical data analysis

The contractor subjects interviewed in this study, are mainly with Project-1 and Project-2 bidders as the decision directors (there are 6 and 5 bidders, respectively). For utility curves mounted by different function patterns, table 1 shows that the best result is polynomial fitting, especially in the curves fitted by the 'utility expectation' and 'profit/cost' variables, the coefficient of determination values ($R^2$) of the two bidding cases are the highest (0.6205 and 0.9515 respectively) by excluding data from one bidder for each irrational project. Meanwhile, the $R^2$ of both bidding projects exceeded 0.5, which is obvious that the acceptableness of the bidder’s dialogue and inquiry about each point is extremely high.

Furthermore, Anova verification was performed with Excel 2000, to determine whether there is a significant regression relationship between the dependent variable (expected utility value) and the independent variable (profit value). At 95% confidence level ($\alpha = 0.05$), the significant level of F verification in both bidding cases are 3.72 E-05 and 6.08 E-11 which both less than 0.05, so the null hypothesis that there is no regression relationship between the dependent variable and the independent variable can be abandoned. Finally, in the T verification results, the significant level (P-value) of the constant (intercept) term (0.007, 0), profit value (0.003, 0.002) and squared profit value (0.026, 0.043) are all less than $\alpha = 0.05$, so the null hypothesis of 0 is discarded, thus it cannot be omitted.

| Variables       | Project-1              | Project-2              |
|-----------------|------------------------|------------------------|
|                 | Y                      | X                      | R²      | Pattern     | Equation                | R²      |
| Expected utility value | Polythnic Y=−5.039x²+7.320x-1.669 | 0.6043 | Polythnic Y=−2.625x²+6.048x²-2.266 | 0.9372 |
|                 | Logarithmic Y=1.058 ln(x)+1.406 | 0.5700 | Logarithmic Y=1.651 ln(x)+1.254 | 0.9330 |
|                 | Linear Y=2.070x-0.469 | 0.5017 | Linear Y=2.526x-1.135 | 0.9195 |
| Expected utility value | Polythnic Y=−0.018x²+0.441x-1.701 | 0.6104 | Polythnic Y=−0.013x²+0.421x²-2.118 | 0.9515 |
|                 | Logarithmic Y=1.100 ln(x)-1.663 | 0.5837 | Logarithmic Y=1.679 ln(x)-3.063 | 0.9492 |
|                 | Linear Y=0.132x-0.470 | 0.5238 | Linear Y=0.197x-1.175 | 0.9404 |
| Expected Profit/utility value | Polythnic Y=−0.042x²+0.666x-1.669 | 0.6044 | Polythnic Y=−0.033x²+0.675x²-2.267 | 0.9372 |
|                 | Logarithmic Y=1.058 ln(x)-1.131 | 0.5700 | Logarithmic Y=1.651 ln(x)-2.365 | 0.9330 |
|                 | Linear Y=0.188x-0.409 | 0.5017 | Linear Y=0.282x-1.134 | 0.9195 |

Due to shortening of the construction duration requires an additional increase of various equipment and manpower input, errors in any segment will affect the overall project progress. Therefore, the shorter the construction period plan, the worse the constructability. In terms of 'proportion of shortening the construction schedule' and 'crash cost', the correlation coefficients of the two bid projects are highly positive correlation, whereas there is a highly positive correlation between the 'proportion of shortening the construction schedule' and 'probability of winning the bid'.

3.3. UF Discussion of Bidders

About numerical analysis theory, the UF analysis method in this paper adopts quadratic polynomial, the main reason is that the utility curve between the 'expected utility value' and the various variables, with
the curve $R^2$ fitted with the quadratic polynomial, is the highest, thus use the 'expected utility value' and 'profit value', combining with a quadratic polynomial to perform conversion and analysis of the bidder UF fitting. After fitting the bidder UF, the decision tree models of different shortening construction period schemes are further constructed. Decision-makers can generally use two methods of 'net income' and 'expected value' for evaluation and selection of decision-making.

Taking figure 1 as an example, the contractor considering the project risk associated with shortening the construction duration, proposed a scheme to shorten the construction period by 90 days to participate in the bidding. Before the tender the contractor conducted the scheme evaluation and selection based on the range of net income, even if the scheme is evaluated and selected with the highest utility value, the result will be the same as the highest net income scheme.

![Figure 1. Different decision tree models that shorten the duration](image)

### 3.4. Discussion on UF with the optimal profit value

It is assumed that the contractors are already known who the competitors are when participating in the project bidding. Since the bidders of the first bidding project are all proposed the schemes with the shortest construction period for bidding, and based on the UF of the bid winner, perform the function transformation to obtain the updated modified UF. This is intended to determine the profit value of the shortest construction schedule bid scheme and to revise the bid profit value of the original setting, then evaluate whether to participate in the bidding.

### 4. Conclusions

The scheme with a higher expected utility value does not necessarily mean that winning the bid, but the UF conversion can be used to know the situation of the opponent function, to moderately modify its UF to understand the maximum profit value represented by the modified curve, whether which is acceptable by the bidders. In the case of the most proportion of shortening the construction schedule, properly reducing the management profit will help to strengthen the competitive advantage of the bidders. However, shortening the construction duration is likely to cause the occurrence of potential risks, even delay the construction period, and be punished. In the future implementation of the “A+B” bidding method, the bidders can select the best-shortened duration scheme to bid, based on the established UF.
and decision tree model. When the bidding opponents are known, the bidder can judge the possible scheme of shortening the construction schedule proposed by the opponents, based on the experience of past fights simulate the utility function curve of the bidding opponent. In addition to modifying its own UF can also reconstruct the initial decision tree model.

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