OPTIMAL BID MODEL FOR PRICE-TIME BIPARAMETER CONSTRUCTION CONTRACTS

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ABSTRACT: Construction clients are increasingly calling for bids that require competing contractors to submit both the bid price and contract time. In such situations contractors are faced with the problem of deciding which combination of bid price and contract time to submit. An important consideration is the cost of time to the client. This varies from contract to contract and is usually expressed in terms of a unit time value such as liquidated damages rate or, for highway contracts, a daily road user cost. The unit time value is normally set out in the contract appendix and often used by the client as a basis for determining the contractor's total combined bid. This kind of procurement method is commonly referred to as the A + B method. To illustrate the mechanism of price-time biparameter procurement, a total combined bid Iso-map is developed in this study. The contractor's price-time performance curve is then incorporated into the map to determine the contractor's optimal bid parameters: tender price and contract time. Also, based on this mechanism, a mathematical optimization bid model is developed for calculating the optimal bid parameters.

INTRODUCTION

Traditionally, the vast majority of construction contracts are procured under the low bid system (Park and Chapin 1992). In the low bid system, as construction time is usually specified in the tender documents, tender price appears to be the main criterion used by the client in awarding the contract. However, construction time has become increasingly important to all parties involved in the construction business. For clients, early completion of a project can have a profound contribution to the return of their investment, and the delayed delivery of a project will normally cause loss of business opportunities and potential profits, or, for public projects, even create social/public problems. For example, the delay of urban infrastructure projects can create serious disruption and inconvenience including traffic congestion, communication delay, and prolonged air and noise pollution.

In an attempt to reduce contract duration, more clients are turning to fast track contracting methods (Franks 1998). An increasing number of clients are also developing innovative procurement procedures including bidding on cost and time (Herbsman et al. 1995). The principle of such a bidding procedure is that a certain monetary value is given to each unit of construction time, and this time value will be incorporated with the bid price in evaluating contractors' total combined bid (TCB). If a contractor includes a lower TCB value, his overall competitiveness will be perceived higher by the client.

Herbsman et al. (1995) reported that bidding on both cost and time has been successfully applied by American state highway agencies and that time reductions have been achieved in almost every case in which it has been used. Such a development has a significant impact on contractors' bidding strategies. Instead of determining the most competitive bid price according to the time given in the tender documents, contractors will need to look more closely at their construction project scheduling methods and to see how time impacts on their competitiveness. On the other hand, clients will need to determine to which contractor to award the contract by considering both contract time and tender price. To increase the chance of winning a price-time biparameter construction contract, the contractor then needs to relate the bid strategy to the relative importance that the client places on time and cost. In other words, the contractor should take into consideration the time value specified in the contract in formulating the bid strategy. The objective of this paper is to offer an optimal price-time bid model based on the client's unit time value (UTV).

UTV

TCB incorporates both tender price and contract time. A TCB from a particular contractor shows the overall competitiveness in the competition. In determining the total combined bid, time is usually related to cost in terms of a UTV. Herbsman et al. (1995) considered the UTV as representing the cost of delays to the owner and suggested that this is made up of both direct costs (e.g., increased use of temporary facilities and increased moving costs) and indirect costs (e.g., losses to the business opportunity and reduction of potential profits). They then identified that the highway construction industry refers to UTV as the ''daily road-user cost'' and pointed out that no standard computational procedures have been developed for determining the value of UTV.

An alternative measure that may be used in general construction contracts to represent the relevance of time value is the liquidated damages rate. Murdoch and Hughes (1996) defined liquidated damages rate as ''a (predetermined) fixed rate of money that is entered into the appendix to the contract . . . which becomes payable by a party to a contract if certain specified breaches occur.'' They also pointed out that, in legal terms, the amount for liquidated damages should not be a penalty but a genuine preestimate of the employer's likely loss.

TCB

In reviewing innovative contracting methods in highway construction, Herbsman et al. (1995) commented that in attempting to reduce project duration for highway contracts, bidding on both cost and time is one of the four most popular methods being utilized by various state highway agencies. They also pointed out that the successful bidder is the contractor who submits the lowest TCB according to the following formula:

$$\mathrm{TCB} = \mathrm{ECC} + (\mathrm{DRUC} \times \mathrm{EPD}) \tag{1}$$

where TCB = total combined bid; ECC = estimated construction cost for the project; DRUC = daily road user cost; and EPD = estimated project duration.

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By applying (1), the contractor who submits the lowest TCB will be considered as having the highest overall competitiveness and will be awarded the contract. This formula is written from the client's viewpoint for awarding road contracts. To encompass general construction contracts where price-time bidding is used, the foregoing equation can be rewritten as follows:

$$\mathrm{TCB} = p + (\mathrm{UTV} \times t) \tag{2}$$

where TCB = total combined bid; p = contractor's tender price; UTV = unit time value specified by client; and t = construction time (contract time).

For example, assume that a contractor, denoted as BEN, is tendering for a construction contract to which the UTV of $12,500/day is applied. The contractor considers two bidding strategies: (1) bidding strategy *x*: submit the tender comprising a 210-day contract with a bid price of $1,900,000; and (2) bidding strategy *y*: submit the tender comprising a 180-day contract with a bid price of $2,100,000. By applying (2), it can be seen that the TCB from strategies *x* and *y* are as follows:

$$\mathrm{TCB}(x) = \$1{,}900{,}000 + (210 \text{ days} \times \$12{,}500/\text{day}) = \$4{,}525{,}000$$

$$\mathrm{TCB}(y) = \$2{,}100{,}000 + (180 \text{ days} \times \$12{,}500/\text{day}) = \$4{,}350{,}000$$

In this case, strategy *y* has a better overall competitiveness value of $175,000 even if it has a higher bid price.

TCB ISO-MAP

In the previous example where the UTV of $12,500/day is applied, by trading-off between contract time and bid price, contractor BEN could have other bidding strategies that could also offer the same TCB of $4,350,000. For example, contractor BEN could have another bidding strategy *z* comprising a 170-day contract with a bid price of $2,225,000. The TCB from strategy *z* would be

$$\mathrm{TCB}(z) = \$2{,}225{,}000 + (170 \text{ days} \times \$12{,}5000/\text{day}) = \$4{,}350{,}000$$

Thus strategy *z* offers the same TCB value as that offered by strategy *y*. This implies that the client considers BEN's bid strategies *y* and *z* as being of the same competitiveness. It depends on the contractor to decide which price-time combination to submit. The contractor is likely to compare the two options by considering company practice and the availability of resources and by examining which strategy can be of greater benefit before making the choice between strategies *y* and *z*.

In fact, with a given UTV, (2) suggests that there are infinite combinations of tender price *p* and contract time *t*, and they give the same TCB. When these combinations are plotted in a price-time right-angled coordinate diagram, they form a linear line, called Iso-line, as shown in Fig. 1. The slope of the Iso-line is determined by UTV. As all points on this line give the same TCB value, this line is referred to as TCB Iso-line. Each individual point on the TCB Iso-line represents a particular bidding strategy but has the same competitiveness value (TCB). In theory, these infinite points on the TCB Iso-line indicate that a contractor could have many bidding strategies offering the same TCB. In the previous example, contractor BEN's strategies *y* and *z* offer the same TCB value ($4,350,000). The contractor could have one other strategy by offering the price of $1,975,000 with a contract time of 190 days, which also gives a TCB of $4,350,000. The TCB Iso-line also indicates that there could be more than one contractor who have the same competitiveness value but with different tender price and contract time.

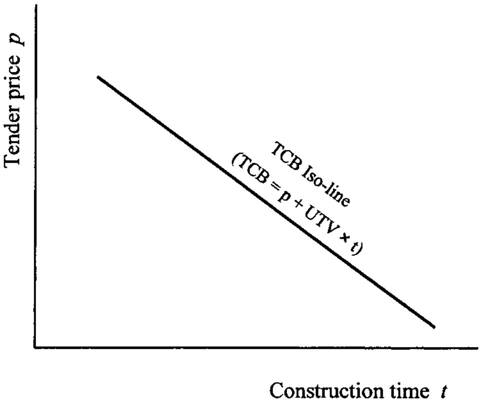

FIG. 1. Contractors' Overall Competitiveness: TCB Iso-Line

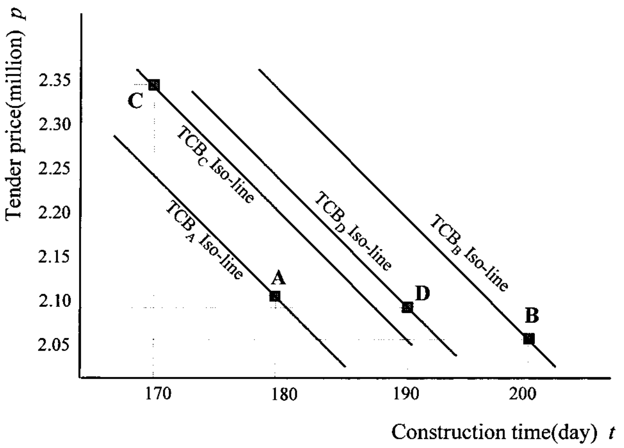

FIG. 2. Contractors' Overall Competitiveness: TCB Iso-Map

With a specified UTV, when different TCB values are given, a set of TCB Iso-lines can be plotted on the diagram, forming a TCB Iso-map, as shown in Fig. 2. This figure shows that there are four TCB values: TCB$_A$, TCB$_B$, TCB$_C$, and TCB$_D$ from Contractors A, B, C, and D. By applying the UTV of $12,500/day, the client would give the contract to contractor A who offers a 180-day contract with a bid price of $2,100,000 and has a TCB$_A$ value of $4,350,000. Contractor B obtains a TCB$_B$ value of $4,550,000 by offering a 200-day contract with a bid price of $2,050,000. Contractor C offers a 170-day contract with a bid price of $2,350,000 and obtains a TCB$_C$ of $4,445,000. Contractor D offers a 190-day contract with a bid price of $2,080,000 and a corresponding TCB$_D$ value of $4,455,000. Thus, the following relationship is obtained:

$$\mathrm{TCB}_A < \mathrm{TCB}_C < \mathrm{TCB}_D < \mathrm{TCB}_B$$

By referring to the layout of the TCB Iso-map in Fig. 2, it can be seen that the TCB Iso-map has an ascending gradient from low-left to high-right. As the TCB value represents the client's price-time evaluation on contractor's competitiveness, the contractor whose offer falls on the lowest TCB line is the most competitive and will, therefore, win the contract. Fig. 2 shows Contractor A having the highest competitiveness.

The client can construct the TCB Iso-map, as shown in Fig. 2, by applying a set of TCB values and using the UTV as their slope. All contractors' bids can then be plotted on the TCB Iso-map. The client can simply select the contractor whose TCB value falls on the lowest TCB Iso-line. To competing contractors, to improve their winning chance, it is important for them to know in which position their TCB will fall on the TCB Iso-map.

INTERRELATIONSHIP OF CONSTRUCTION COST, TENDER PRICE, AND CONSTRUCTION TIME

Construction cost and time for undertaking a particular construction project are interrelated. Standard literatures on construction project scheduling [e.g., Callahan et al. (1994)] show that, to a particular construction company, for every construction contract there is an optimum cost-time point. At this point the contractor would have the lowest construction cost. In general, the interrelationship between cost and time for a construction project is expressed in a curve as shown in Fig. 3 (Cusack 1991). On this curve, the ''normal point'' represents the construction plan where construction cost (normal cost) is the lowest with a specific construction time (normal time). Any variation in time from the normal point will result in a corresponding increase in construction cost. For example, to shorten construction time will increase project direct cost due to the use of multiple shifts, overtime work, or other costly measures. Crowded work crews or excessive plant on site will make job supervision more difficult and is likely to result in lower work productivity. Material delivery in a shorter time is normally more expensive. On the other hand, an increase in the construction duration from the normal point will obviously incur the increase in general indirect cost.

Clough and Sears (1991) pointed out that the degree of cost increase toward the left side of the normal time point is much higher than that toward the right side. In other words, taking the normal point as reference, the impact of time reduction on cost increase is much larger than that of time extension. To expedite a project is often called ''crashing.'' The minimum time to which the construction of a project can be reduced is called ''project crash time'' and the construction cost corresponding to the project crash time can be called ''project crash cost'' (Clough and Sears 1991). However, as the relationship between construction cost and time is determined by many factors such as the contractors' management skills and construction techniques, the shape of the cost-time curve will be different to the various contractors for a specific project. Therefore, for a particular project, different contractors will have their own ''normal points'' by which they can have their own lowest construction costs and ''normal time.''

Furthermore, a contractor's tender price for a contract is actually closely related to his construction cost, and such a relation can be written in the following formula:

$$p = c(1 + \alpha) \tag{3}$$

where p = tender price; c = estimation of construction cost that has the relation with construction time shown in Fig. 3; and α = mark-up coefficient applied by the contractor. The parameter α reflects the contractor's demand on profit and premiums on uncertainties. Therefore, the contractor's tender price is also closely related to construction time, and such a relation can be denoted with the following equation:

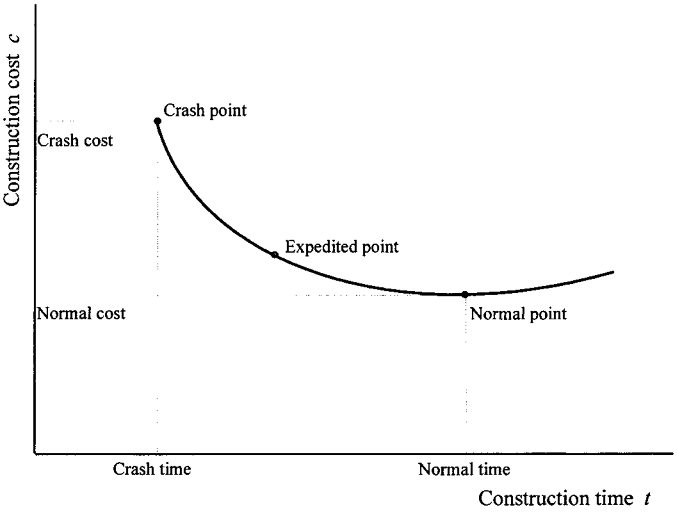

FIG. 3. Interrelationship of Construction Time and Cost

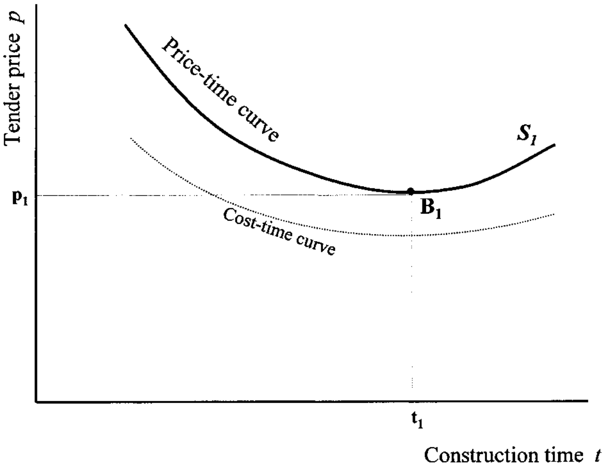

FIG. 4. Interrelationship of Construction Time and Tender Price

$$p = f(t) \tag{4}$$

where p = tender price; t = construction time; and f represents a certain function relation between p and t. Eq. (4) can be demonstrated by curve S_1 shown in Fig. 4. The shape of the price-time curve is similar to the cost-time curve shown in Fig. 3. As there is a constant coefficient $(1 + \alpha)$ in (3) between construction cost and tender price, the price curve S_1 in Fig. 4 is produced by proportionally shifting the cost curve upward.

It can be seen from the price-time curve S_1 in Fig. 4 that point B_1 indicates a contractor's lowest tender price p_1 that could be offered with construction time t_1. Under the traditional low bid system, in which the price is the major determinator, the contractor's most competitive strategy is to offer price p_1 with contract time t_1 in the case shown in Fig. 4, provided that t_1 is shorter than the time specified in the contract.

IMPACT OF UTV ON CONTRACTORS' MOST COMPETITIVE TENDER PLAN

A contractor's most competitive tendering strategy (point B_1), previously presented in Fig. 4, assumes that the tender price is the dominant determinator for clients to choose the successful contractor. In the situation where the client cares more about the significance of construction time, he will apply a UTV rather than specify a fixed period in the contract, and the time implication on the contractors' most competitive tender plan becomes more significant. The application of UTV enables the client to evaluate the contractors' overall competitiveness by considering the contractors' tender price and contract time collectively. Such an application also attracts contractors to shorten the construction period to a certain extent by considering both the practice and business situation within their organizations and the impact of UTV to produce their most competitive TCB.

The impact of UTV on the contractors' most competitive tender plan can be analyzed as shown in Fig. 5. Curve S_1 represents a contractor's price-time curve. Curve S_2 is the time-value line (straight line) reflecting the client's time value determined by UTV. When the client evaluates the contractor's overall competitiveness, the client will calculate the contractor's total TCB by using the model introduced in (2). Curve

S represents the contractor's TCB values. In applying the price-time biparameter procurement approach, the TCB curve *S* becomes the contractor's competitiveness curve, and the lowest point on the TCB curve represents the contractors' most competitive bidding strategy. Thus the contractor's most competitive strategy in Fig. 5 is determined by point b_0.

In Fig. 5, if the contractor assumes that the client would only consider tender price, the most competitive tender strategy would be at point B_1 on price-time curve S_1, where the contractor would offer tender price p_1 and contract period t_1. However, in the price-time competition, the contractor has to consider the client's application of UTV. This forces the contractor to change his tender strategy from point B_1 to B_0 if he wants to offer his own most competitive strategy. Point B_0 on the price-time curve S_1 corresponds to the lowest point b_0 on the competitiveness curve *S*. The strategy at point B_0 is more competitive than the contractor's original tender plan at point B_1 as the new strategy brings the reduction in the TCB value from TCB_1 to TCB_0 and thus increases the contractor's total combined competitiveness. While the new strategy increases slightly the tender price from p_1 to p_0, it shortens the contract period from t_1 to t_0, which gains more competitiveness. This shows that the value of time has a significant influence on the contractor's tendering strategy.

Under the traditional low bid system, the client does not normally consider the UTV measure at the time of awarding the contract, and contractors will usually not shorten the construction time from that defined in the contract. However, under a price-time contractual arrangement, the client is, in effect, increasingly willing to reimburse the contractor for time reduction with a specified rate. This provides a motive for the contractor to compress the project contract duration to some extent to submit a more competitive tender by considering the minimum TCB value.

CONTRACTOR'S OPTIMIZATION BID MODEL

The impact of UTV on the contractors' most competitive tender can also be analyzed on the TCB Iso-map introduced previously. If we introduce the contractors' price-time curve to a TCB Iso-map, we can get the graph as shown in Fig. 6. In this figure, S_1 is a contractor's price-time curve. Point B_1,

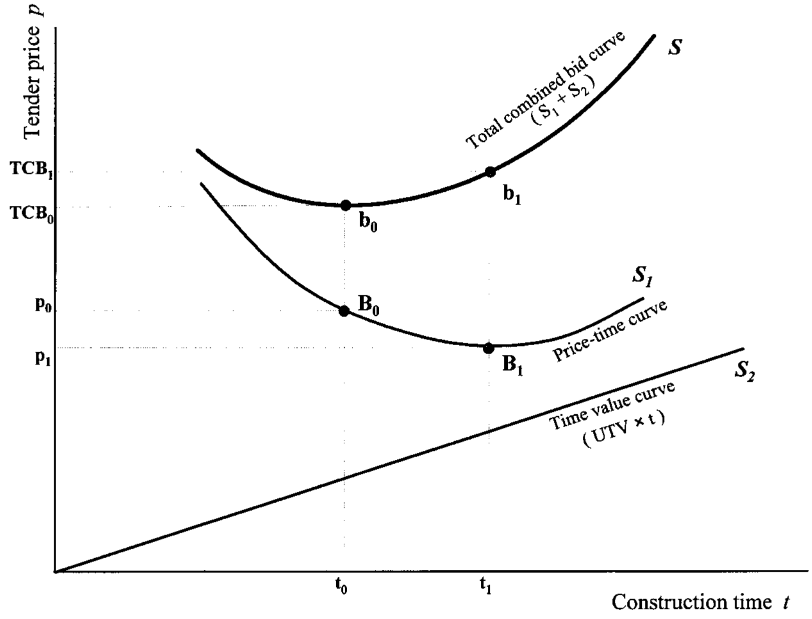

FIG. 5. Impact of UTV on Contractors' Competitive Tender Plan

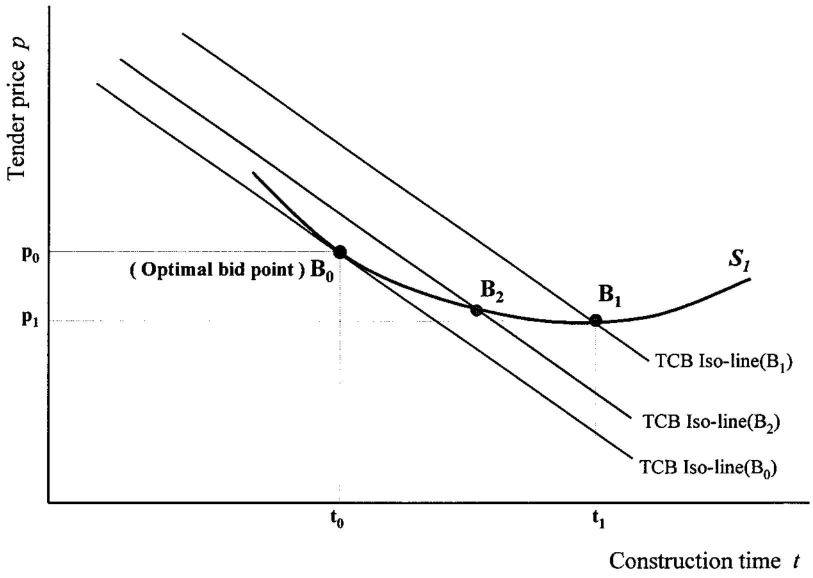

FIG. 6. Optimal Bid Point on TCB Iso-Map

which is the lowest point on the curve that falls on the TCB Iso-line(B_1), would be the contractor's most competitive tender without considering the value of time imposed by the client. By submitting this tender, the contractor's TCB value assessed by the client would be TCB(B_1). For example, when considering another bid strategy at point B_2, the contractor can get a TCB value of TCB(B_2), which is on the TCB Iso-line(B_2). As previously discussed, the TCB Iso-map has an ascending gradient from low-left to high-right. Thus, the value TCB(B_2) is smaller than TCB(B_1) as the Iso-line(B_2) is in a lower position than the Iso-line$(B)_1$. Thus, tender strategy at point B_2 is more competitive than the strategy at point B_1.

By examining other points on the curve S_1 in Fig. 6 we will be able to find a particular point B_0, where S_1 is in tangent with a particular TCB Iso-line [i.e., Iso-line(B_0)]. In other words, point B_0 does exit on the curve S_1, at which the TCB (Iso-line(B_0)is curve S_1's tangential line. On the other hand, it can be seen on the diagram that the Iso-line(B_0) is in the lowest position among all possible Iso-lines crossing curve S_1. This means that the contractor's TCB value at point B_0, TCB(B_0), is the minimum TCB that the contractor can offer. Therefore, the contractor's tendering strategy at the tangent point B_0 is the most competitive strategy, in which price p_0 and construction time t_0 are offered.

The value of p_0 and t_0 can be further analyzed through developing a mathematical model. By referring to the shape of the price-time curve S_1 given in Figs. 4–6, the relationship between tender price and time is assumed as a quadratic equation with one unknown quantity; thus (4) can be written as

$$p = a + b_1 t + b_2 t^2 \tag{5}$$

where p = tender price; t = construction time; and a, b_1, and b_2 = constants. Eq. (5) is considered as the quantitative presentation for the price-time curve S_1. Therefore, from (5), the slope of the price-time curve S_1 can be obtained as follows:

$$p'(t) = b_1 + 2b_2 t$$

and the slope of the price-time curve S_1 at the point B_0 will be

$$p'(t_0) = b_1 + 2b_2 t_0 \tag{6}$$

On the other hand, the tangent point B_0 also falls on the TCB Iso-line(B_0). By referring to (2), the TCB Iso-line(B_0) can be given by

$$\text{TCB}(B_0) = p + \text{UTV} \times t$$

or

$$p = \text{TCB}(B_0) - \text{UTV} \times t \tag{7}$$

From (7), the slope of the TCB Iso-line(B_0) at point B_0 can be obtained as

$$p'(t_0) = -\text{UTV} \tag{8}$$

Because the straight line TCB Iso-line(B_0) is the price-time curve S_1's tangential line at point B_0, according to the principle of tangent line, the curve S_1's slope at the tangent point B_0 will be equal to the slope of the Iso-line(B_0). Therefore, by referring to (6) and (8), the following relationship is obtained:

$$b_1 + 2b_2 t_0 = -\text{UTV}$$

so that

$$t_0 = -(b_1 + \text{UTV})/2b_2 \tag{9}$$

On the other hand, according to (5), the tender price at the point B_0 will be

$$p_0 = a + b_1 t_0 + b_2 t_0^2 \tag{10}$$

Then by applying (9) to (10), the value of p_0 can be obtained as

$$p_0 = a + (\text{UTV}^2 - b_1^2)/4b_2 \tag{11}$$

Eqs. (9) and (11) form a mathematical optimization bid model for contractors to calculate their most competitive bidding parameters: tender price p_0 and construction time t_0.

This model suggests that, under the price-time procurement arrangement, contractors can obtain their maximum total combined competitiveness if they offer the price p_0 and contract period t_0 calculated from the model. In the model, UTV is the UTV specified by the project client, and a, b_1, and b_2 are constants determining the shape of the contractors' price-time relation curve. It can be seen that the computational procedures for the constants a, b_1, and b_2 will be very difficult. An alternative is to apply polynomial regression analysis for obtaining the values of the constants. In applying polynomial regression analysis, at least three pairs of t and p values are required in (5). Then, the polynomial regression analysis suggests that the values for a, b_1, and b_2 are calculated from the following equations (Bland 1985):

$$na + b_1 \sum t_i + b_2 \sum t_i^2 = \sum p_i \tag{12}$$

$$a \sum t_i + b_1 \sum t_i^2 + b_2 \sum t_i^3 = \sum t_i p_i \tag{13}$$

$$a \sum t_i^2 + b_1 \sum t_i^3 + b_2 \sum t_i^4 = \sum t_i^2 p_i \tag{14}$$

where n = number of pair values. Assume that, by considering its company background and previous experience, a contractor can give three feasible tender plans for a construction contract to be tendered. These three estimates are suggested as shortest time tender plan (I), most likely tender plan (II), and lowest construction cost tender plan (III). Their estimates are denoted as follows:

- Tender I: (t_1, p_1)
- Tender II: (t_2, p_2)
- Tender III: (t_3, p_3)

In these three bidding plans, t_1 is the crashing time or shortest possible construction time, by which the contractor intends to offer p_1 as tender price. Time t_2 is the most likely time needed for the construction of the project, by which the contractor tends to offer p_2 as tender price. Time t_3 is the contractor's normal time needed for the construction of the project, by which the contractor can have the lowest construction cost and thus offers the lowest price p_3.

By applying the three estimates to the polynomial regression analysis of (12)–(14), we can get the values for the constants a, b_1, and b_2 from the following equations:

$$3a + b_1(t_1 + t_2 + t_3) + b_2(t_1^2 + t_2^2 + t_3^2) = p_1 + p_2 + p_3 \tag{15}$$

$$a(t_1 + t_2 + t_3) + b_1(t_1^2 + t_2^2 + t_3^2) + b_2(t_1^3 + t_2^3 + t_3^3) = t_1 p_1 + t_2 p_2 + t_3 p_3 \tag{16}$$

$$a(t_1^2 + t_2^2 + t_3^2) + b_1(t_1^3 + t_2^3 + t_3^3) + b_2(t_1^4 + t_2^4 + t_3^4) = t_1^2 p_1 + t_2^2 p_2 + t_3^2 p_3 \tag{17}$$

Eqs. (9), (11), and (15)–(17) form the optimization bid model with the contractor's three estimates or plans of tender strategies.

APPLICATION OF OPTIMIZATION BID MODEL

The following discussion uses a hypothetical case to show the application of the suggested optimization bid model consisting of (9), (11), and (15)–(17). Assume that Contractor ABC is tendering for a housing project. The project client applies a liquidated damage rate at $10,000/day. The contractor's estimating department provides three feasible tender plans based on the company's own experience and resources. The three plans are as follows:

- Tender I: $t_1 = 170$ days and $p_1 = \$5,100,000$
- Tender II: $t_2 = 190$ days and $p_2 = \$4,900,000$
- Tender III: $t_3 = 210$ days and $p_3 = \$4,800,000$

In adopting the most competitive bidding strategy, the contractor needs to decide what tender price and construction time can be offered that will produce maximum competitiveness. The optimization bid model can be used to assist the contractor in deciding his optimal bidding parameters: tender price p_0 and construction time t_0. In applying the model, the given three pairs of values of price and time are applied to (15)–(17), and the values for the constants a, b_1, and b_2 are consequently obtained as follows:

$$a = 10.8375; \quad b_1 = -0.055; \quad b_2 = 0.000125$$

Therefore, the price-time relation to contractor ABC can be given with a specific equation as follows:

$$p = 10.8375 - 0.055t + 0.000125t^2 \tag{18}$$

By applying the values of the constants $a = 10.8375$, $b_1 = -0.055$, and $b_2 = 0.000125$ to (9) and (11), along with considering the UTV of \$10,000/day, the optimal contract time and tender price are calculated as follows:

$$t_0 = -(b_1 + \mathrm{UTV})/(2b_2) = -(-0.055 + 0.01)/(2 \times 0.000125)$$

$$= 180 \text{ (days)}$$

$$p_0 = a + (\mathrm{UTV}^2 - b_1^2)/(4b_2)$$

$$= 10.8375 + (0.01^2 - 0.055^2)/(4 \times 0.000125) = 4.9875 \text{ (million)}$$

Thus, Contractor ABC's best competitive tender strategy is to offer a bid price of \$4,987,500 and to include construction time of 180 days. This strategy gives the contractor the highest winning chance because this combination produces the lowest TCB value.

To further demonstrate the foregoing example, seven bid price and contract time alternatives shown in Table 1 are now considered. The calculations of these alternatives are obtained from the contractor's price-time relation equation (18). It can be seen from Table 1 that Strategy 5 offers the lowest TCB value [TCB(5) = \$6,787,500], and this is the contractor's most competitive bidding strategy, which offers the price of \$4,987,500 and construction time of 180 days. It also can be seen that while Strategy 2 offers the lowest price of \$4,800,000, the total combined competitiveness is less than that offered by Strategy 5 as TCB(2) is \$6,900,000. The reason for Strategy 2 losing competitiveness is that it extends construction time to 210 days, which is much longer than that offered by strategy 5. Although Strategy 5 offers a higher price, it gains the competitiveness by shortening the construction time. This again shows how the value of time could affect the contractor's bidding strategy. Of course, the benefit for competition from the reduction of construction time has limitation. In this example, any further reduction in construction time from Strategy 5 will in fact decrease the contractor's overall competitiveness. For example, consider Strategy 6, which offers the tender price of \$4,997,625 with a contract time of 179 days. It gains the TCB value with TCB(6) of \$6,787,625, which is higher than that given by Strategy 5; thus it is less competitive than Strategy 5 by \$125. Therefore, Strategy 5 is the most competitive bid strategy for the contractor to be able to offer.

TABLE 1. Calculations of Contractor's Optimal Tender Strategy

Bid strategy (1)	Construction time (day) (2)	Tender price (\$) (3)	TCB value (\$) (4)
1	220	4,823,500	7,023,500
2	210	4,800,000	6,900,000
3	190	4,900,000	6,800,000
4	181	4,977,625	6,787,625
5	180	4,987,500	6,787,500
6	179	4,997,625	6,787,625
7	170	5,100,000	6,800,000

Note: UTV = \$10,000/day.

CONCLUSIONS

Construction contracts have traditionally been awarded to contractors on the basis of bid price with the contract time stated in the bid documents. However, it appears that an increasing number of contracts are now being awarded on the basis of bid price and contract time. Such a development has a significant impact on contractors' bidding strategies. Instead of determining the most competitive bid price according to the time given in the tender documents, contractors now need to look more closely at their project scheduling methods and to consider the impact of time on their competitiveness. Cost of time to the client, which is usually expressed in terms of a UTV, will influence the client's evaluation on contractor's competitiveness.

Using the client's UTV value, this paper offers contractors a bid optimization model. The model provides a quantitative tool to assist contractors in finding out their own most competitive bidding strategies for submission, and therefore the contractors will have a higher chance to win a price-time biparameter procurement contract. The three estimates for price and time requested for applying the model provide contractors an easy and effective approach to input data into the model. The model provides a systematic basis for determining the contractor's most competitive bidding strategy, and this is considered an improvement on the traditional ad hoc approach.

The TCB Iso-map developed in the study also provides clients with an alternative and more systematic method in evaluating contractors' overall competitiveness, by considering tender price and construction time collectively, and enable the client to easily identify the most competitive tender on the map.

It would seem that the most appropriate use of the optimal bid model would be for those construction contracts where (1) a high degree of confidence exists for the completeness of design as expressed in the plans and specifications, as demonstrated by a review of the ''bidding contractor community''; (2) the potential for geotechnical or environmental unknowns that could impact progress is low; and (3) the potential for third party interference that could impact progress is low.

APPENDIX. REFERENCES

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