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Applications of electronically facilitated bidding model to preventing construction disputes

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Abstract

When a lump-sum public construction project is implemented, disputes often arise concerning issues around the accuracy of contracted quantities, the acceptability of unit prices of cost items, and whether an "equal (or equivalent)" for a product (equipment or material) can be used. In Taiwan, contracted quantities and unit prices are primarily based on owner's estimations, and the trademarks of a product specified in a tendering documentation are only for reference. A contractor has to struggle for profit when the amount of work completed differs from the contracted amount, when change orders are priced according to the owner's estimates, and when inexpensive equals may be used. This work comprehensively elaborates the background of the current practice, and presents experience of applying an electronically facilitated bidding model to evaluating the bidder's submitted quantities, unit prices and equals in several practical projects in Taiwan. Results of this study indicate that the aforementioned construction disputes can be prevented or at least mitigated.

Keywords: Project procurement; Bidding; Quantity; Unit price; Equal; Cost items; Construction dispute

1. Introduction

In Taiwan, when the contract for a lump-sum pubic construction project is awarded to the lowest bidder, the total contract price equals the total bid price; the contracted quantity of each cost item is basically that specified by the owner (or architect/engineer or A/E); and the unit price of each cost item is the owner's estimated unit price, multiplied by a discounting ratio. This discounting ratio equals the lowest bidder's total bid price divided by the owner's estimated cost of the project such that the total contract price will be the total bid price. This owner-based method is unfair in not giving the contractor (that is, the lowest bidder or winning bidder) the right to allocate the costs (unit prices multiplied by quantities) when executing the work, even though the contractor is primarily responsible for completing the project according to the contractual requirements.

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Since the contracted quantity is that provided by the owner, the contractor tends to claim cost compensation when the actual quantity for a given cost item is more than the contracted quantity, by arguing that the owner's original quantity take-off was too low. The owner typically rejects the contractor's arguments because the contractor has agreed to the owner's original estimates during the bidding process. Consequently, disputes occur.

Accordingly, since the estimation of contractual unit price is owner-based, the contractor tends to claim a higher unit price than the contracted one when a change order for an increased quantity of a cost item is issued, by arguing that the owner's original estimate was too low. When a change order that reduces a certain piece of work is issued, the contractor claims a lower unit price by arguing that the owner's original unit price (i.e., contacted unit price) was too high. Certainly, public owners tend to reject the contractor's claim as these contracted unit prices are part of the contract. Again, disputes are common.

With respect to equals (or equivalents), Taiwan Government Procurement Law stipulates that no requirements are made concerning a particular trademark or trade name, patent or supplier for a product (equipment or material) in a tendering document, unless no adequately precise way exists to describe the procurement of the product [1]. If a precise description of a product is included, then words such as "or equal" must be included. Directly specifying preferred trademarks of a product (such as Marley and Kuken for a cooling tower; Carrier and McQuay for a heat pump; HITACHI, IOY and ELITE for an air compressor) in the tendering document is prohibited, and only general performance-based specifications can be provided, to avoid favoring particular suppliers and to prevent discrimination. Accordingly, any product with a trademark (although not provided in the tendering document) can be used as long as such a product (called an equal or equivalent, herein) meets the given general specifications. Unfortunately, in practice, a contractor normally proposes an inferior product (which is less expensive than those wanted by the owner or A/E) by claming that it is an "equal". Meanwhile, the owner or A/E may force the contractor to use the products with the stated trademarks. Again, a dispute occurs.

Each of these disputes usually extends the project and disturbs the working atmosphere. Thus, the motivation for this study is the following question: can these disputes be mitigated or even resolved before the construction work begins? The rest of this paper is organized as follows. The practical aspects of related research problems are elaborated first. Existing research is reviewed. Next, an electronically facilitated bidding model is proposed to evaluate quantities, unit prices and equals in an integrated manner. The results and experiences of applying the model to real projects are discussed. Finally, conclusions and future research tasks are given.

2. Elaborating current practice

This section addresses problems concerning the accuracy of quantities, the reasonableness of unit price, and the use of equals.

Quantity related—In Taiwan, a bidder is actually permitted to propose his estimated quantity of each cost item. However, for the following two important reasons, most bidders will not work on quantity take-off. First, a rather short bidding period (that is, the time period between the announcement of the bid and the opening dates of the bid-only about 7 to 28 days) is available to prepare a bid. Second, the main criterion by which the contract is awarded for a lump-sum project is the total bid price, and the accuracy of the bidders' proposed quantities (and the reasonableness of the unit prices) are not considered in evaluating the bids. Although some bidders may try to make estimates, they are reluctant to submit their own estimates by using the following pricing strategies. For example, suppose that a bidder's original estimates of the quantity and unit price of a cost item j are b_j and $u_{(\text{regular})j}$, respectively. If he finds that the owner's provided quantity (o_j) exceeds his b_j, then he will probably use a low unit price (u_j) such that $u_j \times o_j = b_j \times u_{(\text{regular})j}$, in his total-bid-price calculations. Since $o_j > b_j$, then $u_j < u_{(\text{regular})j}$. Thus, the use of a low unit price makes his bid more competitive than (lower than) the bids of other bidders (especially when other bidders do not recognize that o_j is overestimated), yet he can still make a "reasonable" bid (with high o_j and low u_j). On the contrary, if o_j is underestimated ($o_j < b_j$), then the bidder will be likely to use the regular unit price of $u_{(\text{regular})j}$ (instead of the low unit price of u_j), because he can then remain competitive and can gain reasonable cost compensation (rather than a low cost compensation, based on the low unit price, u_j) when the change order for increased work is issued in the future.

Unit price related—The most commonly used method in bid pricing by bidders in Taiwan is a so-called "floor area method" (a conceptual estimation method), by which the total estimated project cost simply equals the unit price (such as cost per square meter or yard) multiplied by the total floor area of the project. Notably, the data on this unit price per area are derived chiefly from experience. The total bid price is merely this total estimated project cost multiplied by a ratio that is determined by the bidder's gut feeling (following subjective consideration of the competitiveness of the bids), or simply rounded down (removing lower-valued digits from the estimated cost is commonly seen as making the price appear tidy). Since this floor area method is not a detailed method of estimation, public owners doubt the reasonableness of the bidders' submitted unit prices. Adopting the bidder's submitted unit prices as the contracted ones is unwise because the A/E's estimated unit prices are prepared over a much longer time (for example, several months). Also, the advantage of this owner-based practice is to avoid the submission of unbalanced bids. An unbalanced bid may follow from the judicious increase of the unit prices of certain cost items and the simultaneous reduction in the unit prices of other items to inflate progress payments in the early phases of the project [2 3]. Such an unbalanced bid is unfavorable because the bidder may not execute the contract in good faith, since only a few project payments will be left in the late phases. An unbalanced bid may also be placed if the bidder feels that the amount associated with some item of work was underestimated, and therefore a high unit price on that item would increase profit [4].

Equal related—A/Es (or owners) and contractors commonly misapply concepts of "equal" and "substitution" for a product. As defined by Civitello [5], an equal is "the recognized equivalent in substance, form and function, considering quality, workmanship, economy of operation, durability and suitability for the purpose intended, and not constituting a change in the work"; and a substitution is "a replacement for the specified material, device, or equipment, which is sufficiently different in substance and function to be considered a change in the work". This study addresses the equals. Contractually, if the contractor's proposed equal meets the specifications, then the A/E must accept the proposal. Problems of equals are generally few in the civil/structure/architecture (CSA) part of a building project because the specifications of the CSA part are easy to define clearly. Also most CSA-related products are common in the market and can be supplied at fair prices. Thus, the contractor does not need to propose an equal when no significant price and/or construction advantage can be enjoyed.

However, problems of equals frequently occur in the mechanical/electrical (M/E) part because of difficulties in providing precise specifications that most products with various trademarks can satisfy, while simultaneously meeting the A/E's design needs. If the specifications of a product are too specific and thus favor a particular trademark, the A/E is very likely to be accused of discrimination. The prices of M/E-related products and the qualities of such products vary greatly across range of trademarks. For example, a cooling tower with a foreign trademark, which meets internationally accepted standards, is usually much more expensive than the one with a local trademark that meets only national standards. Thus, given the inevitably general specifications, a contractor would prefer to use the "equal" with a local trademark. However, the A/E argues that the original budget for the corresponding cost items warrants a product (with a foreign trademark) of higher quality. Thus, a dispute arises. In practice, such a dispute is usually resolved in many formal or informal negotiations between the A/E and the contractors. If the dispute over a particular product is not resolved before the delivery or scheduled erection of this product, then the schedule is likely to be delayed.

A proposed equal must be approved by the A/E, who designed the project and inspects the work to ensure that it proceeds according to the design. If both parties act in good faith, then problem of equals can often be resolved. However, many contractors who win the project contract with a rather low total bid price tend to fight for their proposed inexpensive equals as long as they have a chance of success. Even worse, the problem is sometimes caused by the A/E's subcontractors who are really doing the M/E design. (Most A/Es only specialize in the CSA part.) That is, some of the A/E's subcontractors actually act in bad faith by favoring particular suppliers who deliberately raise their selling prices to the contractors. While some contractors may reluctantly absorb the loss by accepting the specified trademarks to allow the work to continue smoothly, others will fight for their rights. Thus, in addition to technical considerations, personal bad faith makes problems of equals even more complex; consequently, problems of equals have greatly hindered construction in Taiwan.

3. Related research

Most previous research in this area has focused on the nature of bids or the evaluation of competitive bids for a lump sum project. For example, Crowley and Hancher [6] designed a statistical procedure for substantiating the risk of growing costs in projects that were competitively bid for. Their statistical findings demonstrated that projects awarded to bidders with extremely low bids were more likely to undergo excessive cost growth than a project awarded to bidders with more reasonable bids. Skitmore et al. [7] used seven data sets to perform a bid-spread analysis; he concluded that bids were entirely random, being drawn from a lognormal distribution. Crowley and Hancher [8] proposed a quantitative method for evaluating competitive bids, involving preparation and examination phases. The preparation phase used bid records of previous projects to develop an appropriate scale for separating inherent bid variation from variability that is related to the size of the project, and to define a discordance threshold for measuring differences among bids. The examination phase evaluated apparently low bids, based on the expected recurrence of scale deviations between the median (market value) and these low bids. According to the owner's preference regarding the expected recurrence, a decision to accept or reject the bid can be made. Some related work includes the proposal to award the project contract to the bidder with a bid closest to, but lower than the average [9], and other work considers the most effective procedures for evaluating bids accurately [10]. Liao et al. [11] proposed the framework of an electronic tendering system that supports procurement by government. Their work focused on system features for computerizing bidding functions (such as, for example, posting/receiving bids over the Internet, online bidding and online payment) rather than on the problems discussed herein. Other research was on the contractor's bid markup decision [12–14].

Unlike past studies, this work concerns the evaluation and adjustment of quantities, unit prices (excluding the evaluation of the total bid prices) and equals for a lump sum project that has already been awarded. That is, this work is not concerned with deciding whether to accept or reject the lowest bid. Based on an earlier study that was concerned with the assessment of unbalanced bids [3], this work extends to devise a bidder-based electronically facilitated bidding model to support quantity, unit price, and equal evaluations.

4. Prerequisites

Before the proposed model can be elucidated, the definitions of cost items and quantities, and the requirements for submitting an electronically facilitated bidding package, must be discussed.

4.1. Cost item and quantity

The estimation of the cost of a construction project is normally divided into three levels. The first is the project summary (or bid summary) level. This level summarizes various categories of costs. The second is the cost item level (also called the bill item, line item or pay item level, and referred to, herein, simply as the item level). Each cost category is subdivided into smaller cost items for particular construction processes. The cost of an item equals the product of its unit price and the quantity required. The third is the unit price level. A unit price is expressed as the cost of completing a unit of work associated with a cost item. The terms, "cost item" and "quantity", as used here, refer to the cost item and the quantity on the second level.

4.2. Bidding package

Bidders must submit bids of cost estimates electronically. A file (such as Excel), saved on a floppy diskette with the owner's estimated unit price of each cost item left blank, must be included in the bid package documents to support the bidding model. Notably, the owner's estimated quantities (and particular trademarks, if any) are also provided for reference. Each bidder must fill in a unit price and quantity (if his estimated quantity differs from the referenced one) for each cost item. A bidding package submitted without this completed file is disqualified.

5. Proposed model

The main idea that underlies the proposed model is to tackle the problems considered herein, during the contracting process rather than in the construction phase. Disputes may be prevented or at least mitigated by including the agreed quantity, unit price and equal for each cost item in the project contract. The proposed model includes three algorithms, summarized in Fig. 1. The following sections detail each algorithm. Notably, the owner or the entrusted construction management (CM) consultant (or the A/E if no CM consultant is involved in the project) controls the execution of the model.

Preparation step—After a project is awarded, a preparation step should be implemented. That is, the quantities and unit prices from all parties (including the owner and the qualified bidders) should be electronically integrated into a single spreadsheet to allow the proposed model to be executed. Table 1 gives an example of some of the data found in such an integrated spreadsheet file. The data include the item number, description, owner's and lowest bidder's

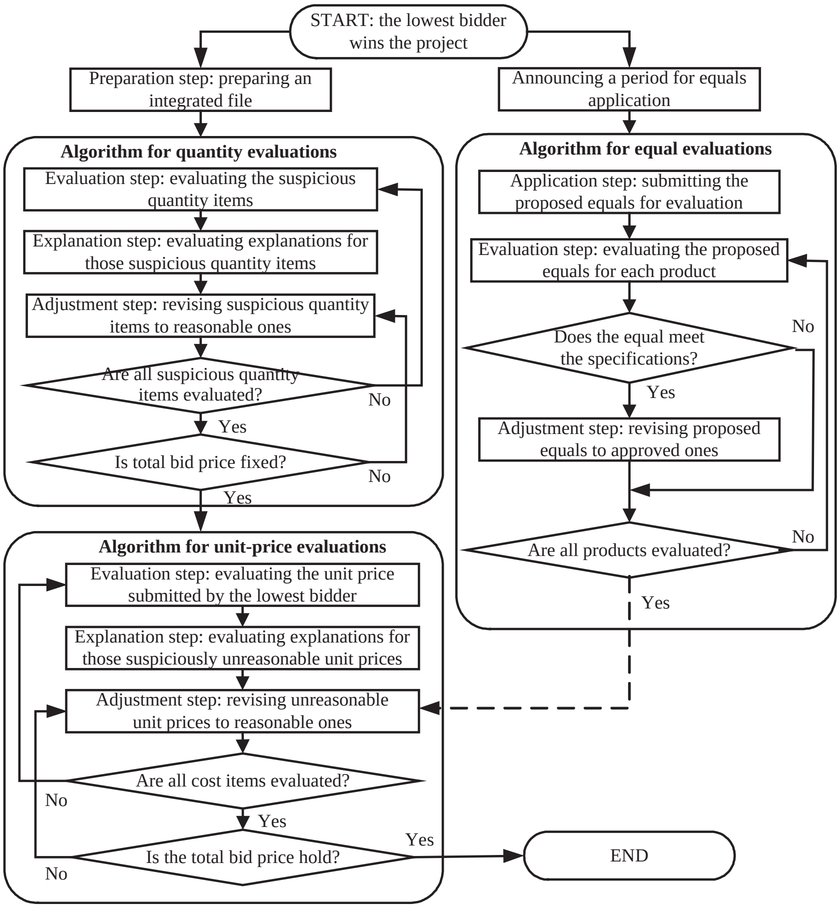

Fig. 1. The proposed model.

Table 1
Example of integrated cost estimate sheet for the cost items of excavation

Cost item no.	Item description	Unit	Quantity (owner) o	Quantity (lowest bid) b	Quantity differential ratio $d=(b-o)/o$	Unit price (owner) O	Unit price (lowest bid) B	Differential ratio $D=(B-O)/O$	Contractual quantity	Contractual unit price	Unit price (bidder 1)	–	Minimum unit price of bidders	–
1	Excavation													
1–1	Slurry wall	M^2	10,004	9000	−0.10%	160	167	4%			110	–	110	–
1–2	Piling 140 cmϕ(30.5 m depth)	Each	34	34	0%	10,396	8333	−20%			8500		7687	
⋮														
1–3	Piling 260 cmϕ(30.5 m depth)	Each	10	10	0%	33,224	21,333	−36%			22,033		19,267	
⋮														
1–21	Finish grading	M^3	345	345	0%	4	2	−50%			2.3		2	

quantities, owner's unit price, lowest bidder's unit price, and other unit prices, such as minimum, average and maximum unit prices, determined from the qualified bids for each cost item. In this integrated file, a quantity differential ratio, d_j, for cost item j is defined as d_j=($b_j - o_j$), where b_j and o_j are the quantities of cost item j, submitted by the lowest bidder and the owner, respectively. A positive d_j implies that the quantity submitted by the lowest bidder exceeds that assessed by the owner, and vice versa. A higher positive or lower negative value of d_j indicates a larger difference between b_j and o_j. Similarly, a unit-price differential ratio, D_j, for cost item j is defined as D_j=($B_j - O_j$)/O_j, where B_j and O_j are the unit prices of cost item j submitted by the lowest bidder and the owner, respectively. A positive D_j implies that the unit price submitted by the lowest bidder exceeds that assessed by the owner, and vice versa. A higher positive or lower negative value of D_j indicates a greater difference between B_j and O_j.

5.1. Algorithm for evaluating quantities

The quantity evaluation algorithm involves evaluation, explanation and adjustment steps.

Evaluation step—The evaluation step identifies suspicious quantities. If the value of d_j falls within a pre-determined "reasonable range" (for example, between −10% and +10%), then b_j is considered to be reasonable and should remain unchanged. Otherwise, b_j is treated as being suspicious, and the bidder should provide an explanation to defend the reasonableness of the submitted quantity.

Explanation step—The explanation step aims to clarify suspicious quantities. A suspicious quantity can be finally treated as reasonable (and eventually treated as the contracted quantity) if the A/E is convinced that the bidder's quantity take-off is more accurate than that of the owner's. Otherwise, the owner's quantity will be used as the contracted quantity.

Adjustment step—The adjustment step alters the unreasonable quantity to a reasonable one. Notably, when this quantity evaluation algorithm is applied, the final total project price should still be the total bid amount to ensure that regulations governing the awarding of contracts to the lowest bid are not violated. This fixing of the total bid price is performed as follows.

- Fix the determined quantity of each cost item.
- Use the determined quantities and the bidder's originally submitted unit prices to recalculate the total bid price ($Bid_{revised}$).
- Calculate the revised ratio=$Bid_{submitted}/Bid_{revised}$, where $Bid_{submitted}$ is the originally submitted total bid price.
- Multiply each unit price of the lowest bidder by this revised ratio. Then, the total contract price (with the determined contracted quantities) will be the original total bid price proposed by the lowest bidder.

5.2. Algorithm for evaluating unit prices

Since a lump-sum contract is awarded on the basis of low bid, the lowest bidder cannot easily be challenged on the validity of his unit prices, except in cases of flagrant violations [4]. Thus, the algorithm proposes to use all available unit prices (from both the owner and all other qualified bidders) to identify objectively the flagrant violations. Although the unit-price and equal evaluation algorithms are executed separately, they should be implemented closely because the unit price should change with the approval of equals. (See the dashed line in Fig. 1.) The unit price evaluation algorithm also includes evaluation, explanation and adjustment steps.

Evaluation step—The evaluation step is to identify suspicious unit prices. Firstly, if D_j falls within a pre-determined "reasonable range" (for example, between −30% and +30%), then B_j is considered to be reasonable and should remain unchanged. Otherwise, B_j is treated as being suspicious and the bidder should defend the reasonableness of his unit price. Notably, however, the unit prices originally identified as reasonable may still eventually be adjusted if both parties agree (especially to maintain the total bid price). Specific cost items may govern the quality of a given construction project or they may be of major concern to the owner. Accordingly, another approach for identifying suspicious unit prices is to select directly those important cost items (even if their unit prices lie within the reasonable range of D_j) for evaluation [3].

Explanation step—The explanation step aims to clarify suspicious unit prices. A suspicious unit price can be finally treated as reasonable if the evaluation committee (typically consisting of the owner, CM consultant, A/E and some cost-estimating experts) is convinced that the bidder will carry out the work according to the specifications at that unit price. Otherwise, this suspicious unit price should be viewed as unreasonable and be changed.

Adjustment step—This step alters the unit price to a reasonable one. Wang [3] used several heuristic rules (such as a negotiation rule, an owner-based rule, and the rule that the total bid amount must be maintained) for adjusting unit price. Again, the final total project price following this adjustment process should remain the total bid amount.

5.3. Algorithm for evaluating equals

Application step—Usually one to three equals with different trademarks will be provided for each of significant product in the tendering documentation. The proposed algorithm requires the contractor to submit his "equals" for any of the specified products within a specified number of days (for example, 7 days) after the contract is awarded. During the construction phase, the contractor can employ any of the pre-approved equals for a particular product. Because the equals do not have just one supplier, the contractor can purchase his preferred equal at a fair price (because price competition will exist between suppliers). Also, the A/E ensures the quality of the product. Disputes are thereby eliminated. Notably, each proposed equal must gain approval or disapproval before the unit-price adjustment step (in the unit-price evaluation algorithm), so the unit price can be suitably adjusted to that of the approved equal. The minimum, average and maximum unit prices of the unsuccessful bidders are good references for making unit-price adjustments. Notably, during the construction phase, a new equal, either proposed by the contractor or required by the A/E, will not be used unless all the pre-approved equals for the product are no longer available. If such is the case, the conventional process of reviewing that newly proposed equal goes.

Evaluation step—After the contractor submits his proposals, a formal evaluation meeting is scheduled. As well as the project owner, A/E, and CM consultant, one or two representatives of the corresponding unions (such as mechanical unions with respect to the mechanical subproject) should be present to ensure the objectivity of the evaluations. As for the unit-price evaluation meetings, auditing officers should be also formally invited to witness the evaluation meetings to protect the owner from any possible accusations, by clarifying the fairness and openness of the process.

Adjustment step—If the functions of a proposed equal meet the specifications, then it is an equal; otherwise, it is not. The documents associated with the approved equals will be incorporated into the contract.

6. Applications

The proposed model was applied to five subprojects (architectural, electrical, mechanical, furnishings and lighting) of the construction project of the Civil Service Development Institute (CSDI) in central Taipei, Taiwan. Since the results of applying the model to these subprojects were similar, most will be demonstrated by considering only the mechanical subcontract (associated with many proposed equals) of CSDI as an illustrative example. The total budget of the CSDI project was about US$42.6 million dollars (Dollar values hereafter are in US dollars; 1 US dollar ≅ 30 New Taiwan dollars). The cost estimate of the mechanical subcontract was US$3.63 million. This subproject attracted eight bidders. The lowest of the bids was $2.93 million, and the subcontract was tendered out accordingly. The bid ratio (the winning bid divided by the owner's project cost estimate) was 0.81 (=$2,933,333/$3,633,333). After the subproject contract was awarded, the three evaluation algorithms were implemented. (Refer to Fig. 1.)

6.1. Results of quantity evaluations

Unexpectedly, none of the bidders submitted their own estimated quantities, in any of the subprojects. In interviews with some of the successful bidders for these subprojects, the main reason for their waiving the right to propose different quantities was that the project was awarded based only on total bid price. However, the bidders appreciated being explicitly allowed to submit their own estimated quantities. During the implementation phase of these CSDI subprojects, several quantities of certain cost items were found to have been under-estimated by the A/E. However, no disputes related to the quantities occurred because the amount of work associated with each cost item was contractually and mutually agreed in advance. However, the contractors did regret not proposing their own estimated quantities during the bidding process.

6.2. Results for unit price evaluations

Tables 2 and 3 summarize the unit-price evaluation results, such as the numbers, before- and after-adjustment, of cost items within each differential ratio interval. The tables compare contracted unit prices with the bidder's price, and compare other statistical values, concerning the mechanical subproject. Fig. 2 presents the "before-adjustment" and "after-adjustment" distributions of the percentages (of all cost items) for various differential ratio intervals for the

Table 2
Before-adjustment and after-adjustment numbers of items within each differential ratio interval for mechanical subproject

	No. of items	Differential ratio interval								
		$D<-31\%$	$-30\%\le D<-1\%$	$D=0$	$1\%<D\le 30\%$	$31\%<D\le 200\%$	$201\%<D\le 1000\%$	$1001\%<D$	Minimum D	Maximum D
Before adjusted	829	231	237	3	140	185	28	5	−94%	5306%
After adjusted	829	182	311	3	182	138	11	2	−100%	1582%

Table 3
Comparisons of contractual unit prices, bidder's unit price and other statistic for mechanical subproject

Owner's cost estimate	Lowest bid	Bid ratio	No. of bids	No. of items	C=O (%)	C<B (%)	C=B (%)	C>B (%)	C<min (%)	C=min (%)	min<C<ave (%)	C=ave (%)	ave<C<max (%)	C=max (%)	max<C (%)
$3,633,333	$2,933,333	0.81	8	829	7.96	14.35	74.55	11.10	3.86	10.86	39.08	0	35.34	8.93	1.93

C: contractual unit price; O: owner's unit price; B: lowest bidder's unit price; min: minimum unit price; ave: average unit price; max: maximum unit price.

mechanical subproject. These two distributions generally peak in the middle, falling on both sides; however, the before-adjustment distribution is flatter. Restated, the model tends to decrease the difference between the owner's and the bidder's unit prices. (For each subproject, the mean differential ratios before and after the adjustment of unit prices were 24% and 3%, respectively. That is, the average differential value generally decreased after the unit prices were adjusted.) Some of the most important results for the subproject are described below.

- In Table 2, these two high differences in D_j (that is, 5306% and −94%) were caused by different interpretations of the specifications of the items. The contracted prices for these two items were determined from the average unit prices of all bidders, resulting in a smaller value of D_j (such that, 5306%→1197% and −94%→−54%).
- 74.55% (618 out of 829) of the contracted prices were those proposed by the bidder, while only 7.96% were those estimated by the owner. (See Table 3.) This result indicated that the proposed model was bidder-based and thus fairer.
- Intriguingly, the result shows that the winning a contract in a low-bid system does not necessarily depend on proposing the lowest unit prices for most cost items. For example, although around 52% (=16.65+35.34%) of the unit prices proposed by the lowest bidder were less than the average of all bidders, about 48% (=33.78+14.23%) of the unit prices exceeded the average of all bidders for the mechanical subproject. (See Table 4.)

Wang [3] discussed many of the aspects of the unit-price evaluation algorithm (such as the evaluation committee's decision on each bidder's explanation, the use of heuristic rules for adjusting the unit price, factors that influence successful applications and benefits of the unit-price evaluation model).

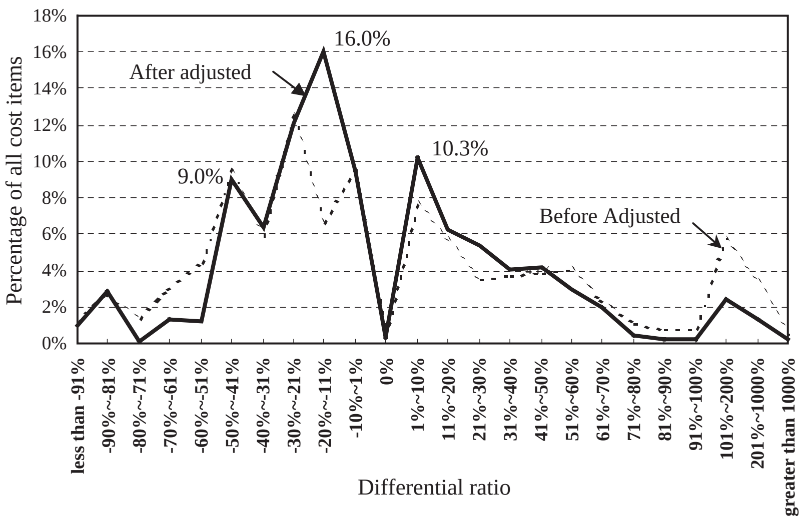

Fig. 2. Percentage of cost items for each differential ratio interval–mechanical subproject.

Table 4
Comparisons of bidder's unit prices with other statistic for mechanical subcontract

No. of items	B=min (%)	min<B< ave (%)	B=ave (%)	ave<B< max (%)	B=max (%)
829	16.65	35.34	0	33.78	14.23

B: Lowest bidder's unit price; min: minimum unit price; ave: average unit price; max: maximum unit price.

6.3. Results for equal evaluations

Consider the mechanical subproject for example: a total 41 equals (including those named by the A/E and those proposed by the contractor) were approved for 15 major products. Each product had two to three equals. Some of the equals were actually produced by the contractor who was also a manufacturer of some of the mechanical equipment. These 41 equals influenced the unit prices of 270 cost items (out of 829 for the whole subproject). Namely, the unit prices for these related cost items had to respond to the choice of equals during the unit-price adjustment process.

The results of applying the algorithm to other subprojects were also successful. While the contractors appreciated that the A/E did not unfaithfully profit from particular product suppliers, the A/E was also happy that the contractors did not sneakily propose cheaper and inferior products. The owner was positive that no disputes concerning equals of evaluated cost items arose. However, disputes did occur about equals for some less important products that were not evaluated in advance. However, because the costs of the involved cost items were comparatively small, the associated disputes were easily resolved.

7. Other lessons learned

Although the requirement to submit an electronic file was new to Taiwanese bidders, none complained or failed to meet this requirement. The bidders appreciated the fairness of the model and no litigation arose during the execution of these projects. Several governmental officers in Taiwan strongly praised the model's improvement of the current public procurement practice. The results presented herein may also help to establish a fully electronic government procurement system. Several other lessons were learned when the model was applied.

- This model helped double-check the A/E's estimates (including quantities and unit prices) and review the A/E's products with suggested trademarks. This advantage is especially important to some public owners who have too few engineers to review thoroughly the tendering document prepared by the A/E. This double-checking process helped to assess the performance of the A/E. High estimation errors, ambiguous documents, and discriminatory product specification discredit the A/E's professional service.
- The unit-price explanation step clarified some of the ambiguous specifications and drawings. The owner may need to pay close attention to controlling the quality of those cost items with relatively low unit prices as originally proposed by the bidder, because a low price may intentionally lead to poorer work.
- The cost items with comparatively high unit prices, as proposed by the bidder, may have to be reexamined, because a high price may indicate under-estimation of the amount of work. If the work has been underestimated, then the owner may revise the work in advance or simply to prepare extra budget for a future change order.
- The mutual agreements on quantities, unit prices and equals, increased the fairness of compensations or deductions from the contract price when issuing a change order.
- The proposed model can be considered to be bidder-based, allowing the bidder to realize the benefits of their accurate estimates, eventually improving their estimation skills.
- The outside experts and union representatives on the evaluation committee were crucial third parties when arguments between the A/E and contractor arose.
- Since the proposed model was new to Taiwan, some practitioners worried that the lowest bidder may unfaithfully refuse to agree to the adjusted unit prices or the evaluations of equals for certain cost items, such that a contract may eventually not be signed. The tendering documentation thus contained language legally to force the evaluation

process to return to conventional procedures for cost items (or even all items) not mutually agreed upon to prevent this worst-case scenario. The worst-case scenario did not arise since the proposed model gave the bidder fairer rights than the conventional procedure.

- From the owner's perspective, maintaining the unit prices of significant cost items that most strongly govern the quality of the project could limit the potentially adverse impact of a low bid. That is, the difference between the total bid amount and the owner's project cost estimate was absorbed by the low contracted unit prices for operating- (for example, labor related) and profit-related cost items.
- Future improvement of evaluations of bids for lump-sum projects may include the accuracy of the bidders' proposed quantities and unit price as evaluation criteria, improving the bidders' estimating skills. Future research on the model should address the development of a standard format of the electronic spreadsheet file, for a range of types of construction projects, to support more efficient evaluations.

8. Conclusions

This work has described the practical experience of using a regimented electronic-based bid evaluation model that considers how low bidder's and owner's quantities, unit prices, and equals deviate. In this model, suspicious deviations are reviewed and negotiated before the work begins, with those results included in the contracting documents. The entire process can be viewed as an electronically facilitated reshuffling of the reasonable allocation of costs (related to the quantities, unit prices, and equals) of bid items for the low bid initially offered. Additionally, what this paper is proposing can be the necessary inspection of a low bid by the contracting officers who have been under long-standing obligation to evaluate the low bid for reasonableness. However, without a systematic and justifiable model (as the one proposed herein) to support those evaluations, most contracting officers in Taiwan constantly adopt the above-mentioned problematically owner-based practice (which is unfair to the bidder) to avoid being accused of incompetence or corruption. Moreover, although the proposed model is not based on a complicated analysis, its practical implications have greatly contributed to the current public procurement practice in Taiwan. A nationwide operational procurement administrative order for governmental entities has been enacted in 1999 in Taiwan [15], following the pioneering success of the electronic-based bidding process proposed by the model. This administrative order has suggested that public owners apply this electronic-based bidding process to procuring all construction projects with a budget exceeding US$1.6 million, although the full use of the model is not presently mandatory.

References

[1] Taiwan Government Procurement Law (TGPL), Chapters II: Invitation to tender, Article 26, Public Construction Commission, Executive Yuan, Taiwan (1999).

[2] Y. Tong, Y. Lu, Unbalanced bidding on contracts with variation trends in client-provided quantities, Construction Management & Economics 10 (1992) 69–80.

[3] W.C. Wang, Electronic-based procedure for managing unbalanced bids, ASCE Journal of Construction Engineering and Management 130 (3) (2004) 455–460.

[4] C. Hendrickson, T. Au. Project management for construction, fundamental concepts for owners, engineers, architects and builders, http://www.ce.cmu.edu/(~cth/pmbook/, Chapter 8.3, Prentice-Hall, Inc., Englewood Cliffs, N.J (1998).

[5] A.M. Civitello, Construction operations manual of policies and procedures, second edition, McGraw-Hill, Inc., NY, 1994, Section 3.7.

[6] L.G. Crowley, D.E. Hancher, Risk assessment of competitive procurement, ASCE Journal of Construction Engineering and Management 121 (2) (1995) 230–237.

[7] M. Skitmore, D. Drew, S. Ngai, Bid-spread, ASCE Journal of Construction Engineering and Management 127 (2) (2001) 149–153.

[8] L.G. Crowley, D.E. Hancher, Evaluation of competitive bids, Journal of Construction Engineering and Management 121 (2) (1995) 238–245.

[9] P.G. Ioannou, S.S. Leu, Average-bid method-competitive bidding strategy, ASCE Journal of Construction Engineering and Management 119 (1) (1993) 131–147.

[10] L.G. Crowley, Robust statistical estimators for use within competitive bid data, ASCE Journal of Construction Engineering and Management 123 (1) (1997) 53–63.

[11] T.S. Liao, M.T. Wang, H.P. Tserng, A framework of electronic tendering for government procurement: a lesson learned in Taiwan, Automation in Construction 11 (6) (2002) 731–742.

[12] I. Ahmad, Decision-support system for modeling bid/no-bid decision problem, ASCE Journal of Construction Engineering and Management 116 (4) (1990) 595–608.
[13] S.P. Dozzi, S.M. AbouRizk, S.L. Schroeder, Utility-theory model for bid markup decisions, ASCE Journal of Construction Engineering and Management 122 (2) (1996) 119–124.
[14] D.K.H. Chua, D.Z. Li, W.T. Chan, Case-based reasoning approach in bid decision making, ASCE Journal of Construction Engineering and Management 127 (1) (2001) 35–45.
[15] Public Construction Commission (PCC), Operational regulations for adding electronic estimating file in bid documents for public construction projects, (in Chinese)Public Construction Commission, Executive Yuan, Taiwan, 1999.