SIM-UTILITY: Model for Project Ceiling Price Determination

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Abstract: Before considering bids submitted by competing contractors for a public procurement project, the owner should determine a project ceiling price or cost estimate to use as a reference point for evaluating the bids. A high ceiling price conflicts with the owner's interests in minimizing costs. Meanwhile, a low ceiling price can jeopardize the project if all bids exceed the ceiling price. This paper proposes a model for determining a reasonable project ceiling price. The model, called SIM-UTILITY, is based on a utility theory and facilitated by a cost simulation approach. The utility theory is applied to reflect the owner's preferences regarding the determination criteria, while the simulation approach is used to generate more objective project cost data to support execution of the utility theory. The advantages of SIM-UTILITY are proven by its successful application to three construction projects in Taiwan. A computerized SIM-UTILITY is expected to be broadly applicable to public construction projects in Taiwan.

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Introduction

Before allowing bidding to open among competing contractors for a public procurement project, the owner should determine a project ceiling price or cost estimate to use as a threshold or reference point for accepting or rejecting bids (GPL 1999). A high ceiling price conflicts with the owner's interest in minimizing costs since it potentially allows the successful bidder to earn excessive profit. When the difference between the price and most bids is large, a high ceiling price may also imply that the owner or a retained architect/engineer (A/E) has not estimated the costs accurately (i.e., the price does not reflect market conditions). However, a high ceiling price eases the process of tendering out the project because it becomes easier to find a bid that is lower than the price.

On the other hand, a low ceiling price creates a risk that all bids will be rejected and the project withdrawn for redesign or reconsideration, since all bids may exceed the ceiling price. Beginning project tendering afresh is time-consuming and increases the owner's liability for potential delays in the project completion date. The low ceiling price may also pressure bidders to make unrealistically low bids, meaning that the winner may then cut corners during construction to increase its operating margins. Despite these disadvantages, however, a low price is politically desirable because it indicates that the project owner is conscious of saving taxpayers' money.

The dilemma for the project owner is to set a ceiling price that is sufficiently low to satisfy the owner's interests in cost saving, yet sufficiently high to successfully tender out the project. In Taiwan, the ceiling price for a public project is determined based on a cost estimate prepared by the A/E. This cost estimate is then treated as the project budget. While some owners fix a ceiling price by multiplying the A/E's cost estimate by the average bidding ratio (winning bid divided by ceiling price) of past projects (frequently an unjustified bidding ratio becomes a multiplier of the A/E's cost estimate), most owners merely make a decision based on gut feeling. Despite its popularity, the historical average bidding ratio is inferior to more systematic evaluation methods. The major problem is that the ratio tends to be unrealistically low, especially in a slow construction economy when bidders tend to propose unsustainably low bids simply to get a contract. A further drawback is that the unique characteristics of the project are ignored.

The lack of a systematic evaluation model to help determine project ceiling prices has weakened confidence in pricing decisions among the owners of public construction projects in Taiwan. Project owners are constantly concerned by accusations of incapability or corruption. A model for fixing project ceiling prices would provide project owners with strong evidence to serve as an easily justifiable basis for their professional decisions, regardless of how the tendering results.

Current research has focused either on the development of bidding models to assist bidders in winning contracts (Carr 1987; Ioannou 1988; Moselhi et al. 1993; Dozzi et al. 1996; Fayek 1998) or on the evaluation of competitive bids (Crowley and Hancher 1995; Crowley 1997). To the writer's knowledge, no previous work has investigated the problem of determining the project ceiling price.

This study proposes a model, called SIM-UTILITY, that is built on a utility theory and facilitated by a cost-simulation approach. The utility theory is applied to find the preferences of the decision-makers in determining the ceiling price. Meanwhile, the simulation approach is employed to increase the objectivity of the project cost data and thus support the execution of the utility theory. The proposed model has been successfully applied to three real construction projects in Taiwan. The proposed model is described below, and its detailed workings are demonstrated using one of the application projects. Finally, the results of all three application projects are presented, discussed, and validated.

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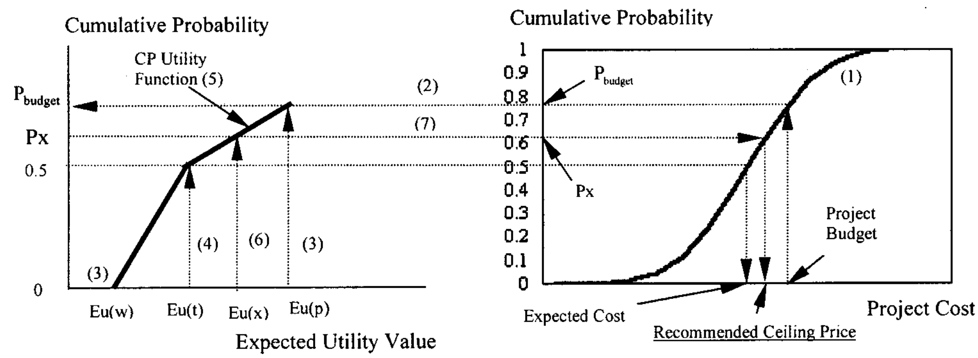

Fig. 1. Modeling procedure of SIM-UTILITY

Proposed Model

The key to developing SIM-UTILITY is first to identify various criteria that the owner will consider in discounting the A/E's cost estimate to come up with a ceiling price. Next, provided the upper and lower boundaries of the project ceiling price are found with respect to a best- and worst-case evaluation of these criteria, a recommended ceiling price should be obtained with respect to particular evaluation results. While the criteria are evaluated using the utility theory, the boundaries of the project ceiling price are identified via simulation.

Fig. 1 illustrates the detailed modeling procedure of SIM-UTILITY. The left of the figure presents an expected utility function generated based on the user's preferences regarding the identified criteria, while the right part displays a cumulative probability distribution of the simulated project cost. The procedure consists of the following seven steps:

1. Perform simulation analysis and then generate a cumulative probability distribution of project cost.
2. According to the distribution, find a cumulative probability with respect to the project budget (namely, the upper boundary of the project ceiling price), P_{budget}.
3. If high values or scores are assigned to favorable criteria evaluations, this probability, P_{budget}, can be considered the highest probability with respect to the user's highest utility value, $Eu(p)$. Meanwhile, a probability of 0, which is correspondent with the minimum project cost (i.e., lower boundary), has a minimum utility value, $Eu(w)$, at which the evaluation result will be least favorable. Both $Eu(p)$ and $Eu(w)$ are obtained through a series of evaluation steps of utility theory.
4. Set the probability of the expected utility value for the threshold points of criteria, $Eu(t)$, at 0.5 or 50% (the threshold point for each criterion represents the point of neutral desirability). This value implies that the owner wishes the winning bidder to have a 50/50 chance of overrun or underrun when completing the project under the threshold conditions. The 50/50 probability implies that the ceiling price will closely approximate the expected project cost. Notably, however, SIM-UTILITY allows the flexibility to choose a different value of probability with respect to $Eu(t)$.
5. Assuming a linear relationship, develop the ceiling price (CP) utility function based on the three points identified $[Eu(w),0]$, $[Eu(t),0.5]$, and $[Eu(p),P_{\text{budget}}]$. Other relationships can be used for describing the CP utility function based on the owner's perception of how the probability may vary for a change of utility function, as long as such a relationship can be defined. Examples of potential candidate relationships include exponential, parabolic, or s-curve like (e.g., combining with concave and convex) curves. Our use of a linear relationship herein represents the perception of CP utility function for the owner of the application projects.
6. After evaluating the utility value of each criterion of the project, compute the expected utility value of project $x,Eu(x)$. According to the straight-line utility functions developed above, find a probability, *Px*, with respect to $Eu(x)$.
7. Based on the value of *Px*, find a recommended ceiling price based on the cumulative distribution of the project cost.

In SIM-UTILITY, the procedure of applying utility theory resembles that developed by Dozzi et al. (1996). The similarities include identifying the criteria for determining the ceiling price, specifying the range of scale (namely, lower limit, threshold point, most preferred point, and upper limit) for each criterion, developing a straight-line utility function for each criterion, weighting the relative importance of each criterion over pairwise-compared criteria, producing a common-scale utility for each criterion, and establishing the straight-line ceiling-price utility function.

Instead of directly obtaining the value of the ceiling price, a normalized or dimensionless value of measure (that is, probability) between 0 and 1 is first derived. This normalization approach is practical since it resembles the markup decision process, in which the markup is decided in percentage rather than in absolute terms. Another benefit of this normalization approach is that the probability value reveals practical implications. That is, the value of probability for a particular ceiling price can be interpreted as "the maximum chance that the owner is willing to give the bidders of not losing money at such a ceiling price." Similarly, after awarding the contract to a bidder, the value of probability with respect to the bid can be used to represent the chance of the bidder completing the project profitably. Assume that the higher the chance of making a profit, the higher the project quality will be (that is, the contractor will have more money to spend on quality control). If a bid with a low probability emerges as the winner, SIM-UTILITY gives the owner an early warning to pay particular attention to quality control because the contractor may use devious means to minimize possible losses. Accordingly, it is unwise to fix a ceiling price with a probability of 0, since it will leave the winning bidder with no chance of making a profit.

The simulation approach is a feasible means of implementing the above normalization approach and supports execution of the utility theory. As shown in Fig. 1, the simulation approach provides a cumulative probability of between 0 and 1, and its simulated distribution of project cost can be used to identify the

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project cost (that is, recommended ceiling price) given a particular probability value.

Application to Practical Project

The SIM-UTILITY model has been applied to three subprojects (architectural, electrical, and mechanical) of a recent construction project, the Civil Service Development Institute (CSDI) project. Using the architectural project as an example, this section illustrates the detailed algorithms of both simulation approach and utility theory for SIM-UTILITY and presents the application results.

Project Description

The CSDI project is located in central Taipei, Taiwan. Besides three underground floors, the project includes a 14-story hotel-like dormitory, a 6-story educational building, a 6-story building containing an 800-seat capacity meeting hall, and a 200-person capacity convention hall, and a 3-story office building. The project uses a mixture of reinforced concrete and steel structures. The total budget of the project is approximately U.S. $42.6 million, and the budget of the architectural portion is approximately U.S. $30,166,667 (905,000,000/30) (1 U.S. dollar ≅ 30 New Taiwan dollars). To meet the objective of completion by mid-2000, the project is being fast-tracked. The project team includes an owner, a construction management group, an A/E, a prime contractor (architectural), seven contractors (including electrical, mechanical, and others), and several subcontractors.

Cost Simulation Approach

In a probabilistic estimation of project cost, each cost component is represented by a suitable statistical distribution (Touran and Wiser 1992). The total project cost, displayed in Eq. (1), is thus a random variable that is the sum of several random numbers:

$$C_{\mathrm{Tot}}=\sum_{j=1}^{n} C_j \tag{1}$$

in which C_{Tot} denotes the total project cost, C_j represents cost component j, and n is the number of cost components.

In the simulation-relevant algorithms of SIM-UTILITY, three-point estimates (optimistic cost, mode, and pessimistic cost) are used to produce a beta statistical distribution of each cost component. The three-point estimate approach is attractive because it is familiar to most construction practitioners, being widely applied in probabilistic network-based scheduling (for example, in the program evaluation and review technique). However, other methods (such as the direct assignment of a particular distribution to a cost component) can also be used, provided the cumulative distribution of project cost can be generated.

As suggested by Touran and Wiser (1992), it is impractical to consider every single variable that goes into a detailed estimate. Thus, the cost items considered are those that appear on the estimate summary sheets of the project, namely the C_js in SIM-UTILITY. While most C_js are measured in dollar terms, some are expressed in percentage terms because of their supportive or indirect characteristics. For example, the costs of installing temporary water and electricity supplies, treating construction wastes and environmental pollution, and paying construction insurance are conventionally estimated as percentages of the total direct costs of the project (such as excavation, structure, finishes, doors, windows, painting, and furnishing). Furthermore, by focusing only on the costs required to complete the project, the project cost C_{Tot} excludes profits or markups. Thus the probability value given a particular project cost indicates the probability of the contractor not losing money at that cost.

Since the execution of SIM-UTILITY does not rely on precisely computing C_{Tot}, and since solving Eq. (1) can be time-consuming, a simulation approach is adopted herein. Simulation involves a procedure for generating random costs according to C_j distributions that then sums these costs to obtain the total project

Table 1. Three-Point Estimates for Each Cost Component (in U.S. Dollars)

Cost components	Optimistic cost	Most likely cost	Pessimistic cost
1. Excavation	5,033,519	5,210,134	6,887,974
2. Structure	9,885,523	10,232,384	13,527,558
3. Finishes	4,074,271	4,217,228	5,575,318
4. Doors, windows, glass	3,054,753	3,161,937	4,180,188
5. Miscellanies	2,089,097	2,162,399	2,858,765
6. Furniture	45,086	46,668	61,697
7. Planting	152,255	157,598	208,349
8. Kitchen equipment	194,452	201,275	266,093
9. Swimming pool	287,193	297,270	393,001
10. Shop drawing composition	152,950	158,317	209,300
	Optimistic (%)	Most likely (%)	Pessimistic (%)
11. Temporary water and electricity	0.285	0.295	0.39
12. Temporary dewatering	0.475	0.492	0.65
13. Temporary power systems	0.095	0.098	0.13
14. Waste, pollution management	0.285	0.295	0.39
15. Site safety management	0.095	0.098	0.13
16. Quality control	0.475	0.492	0.65
17. Temporary facilities	0.475	0.492	0.65
18. Construction insurance	0.114	0.118	0.156
19. Tax	5	5	5

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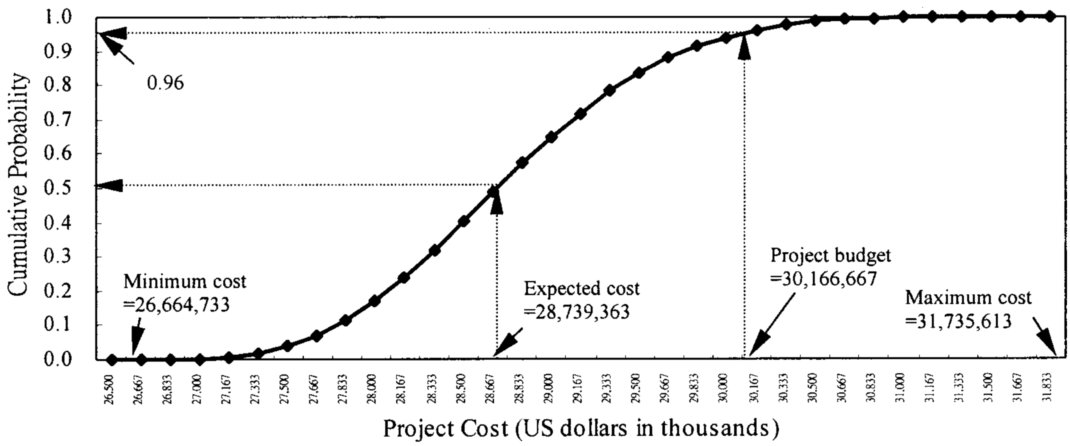

Fig. 2. Cumulative probability distribution of project cost

cost. This procedure is repeated several hundred times, with C_{Tot} being computed each time. A cumulative probability distribution of total project cost can then be constructed from the values of C_{Tot}. This distribution is used to estimate the probability of completing a project at or below a particular cost.

A newly developed simulation language, STROBOSCOPE (Martinez 1996), is used to execute the simulation-relevant procedure described in SIM-UTILITY. This procedure, based on STROBOSCOPE, was implemented on a 586 PC with 64 Megs of RAM under a 32-bit Windows environment (namely, Windows 97). Analyzing 21 cost components of the application project 10,000 times took approximately 45 min. The run time should be significantly reduced by using faster PCs and refining the source code of the model.

Simulation Inputs

For this application project, the specific statistical distribution for each cost component was derived from the values of the three-point cost estimates by assuming a beta distribution with shape parameters α and β. Table 1 presents these simulation inputs.

Simulation Outputs

The simulation analysis found that the minimum, expected, and maximum cost of the application project are U.S.$26,664,733, U.S.$28,739,363, and U.S.$31,735,613 with respect to the cumulative probabilities of 0, 0.49, and 1, respectively. Fig. 2 displays the generated cumulative probability distribution of the total project cost. (During the construction phase, the results illustrated in Fig. 2 were presented to the jobsite superintendent and were

Table 2. Definitions, Range of Scales, and Utility Functions of Criteria

Criterion i	Description of utility	Range (y_L, y_U)	y_T	y_M	A_i	B_i
1. Environment						
1.1 Estimator's accuracy	High accuracy of estimate→high ceiling price (little need to further discount A/E's estimate)	(0, 100); high=100; Low=0	30	100	0.0143	−0.4286
1.2 Historical bidding ratio	High bidding ratio→high ceiling price	(0.3, 1.0); average bidding ratio	0.6	1	2.5	−1.5
1.3 Market conditions	Good construction economy→bidders have more opportunities→loser can still seek other opportunities →high ceiling price for more likely tendering out of the project	(0, 100); good=100; poor=0	30	100	0.0143	−0.4286
2. Owner						
2.1 Tendering urgency	High urgency→high ceiling price for more likely tendering out of the project	(0, 100); high=100; low=0	30	100	0.0143	−0.4286
2.2 Budget tightness	Project budget is tight→high ceiling price for more likely tendering out of the project	(0, 100); tight=100; loose=0	50	100	0.02	−1
2.3 Avoiding controversy	High bidding ratio→being easily accused of poor estimation→low ceiling price	(0, 100); low=100; high=0	50	100	0.02	−1
3. Project						
3.1 Bidder's qualifications	High qualification→better bidders→low possibility of unrealistically low bids→high ceiling price	(0, 100); high=100; low=0	50	100	0.02	−1
3.2 Project duration	Tight duration→high risk→high bidding price→high ceiling price for contractor to meet project deadline	(0, 100); tight=100; loose=0	30	100	0.0143	−0.4286
3.3 Project complexity	High complexity of project→high risk→high bidding price→high ceiling price for contractor to meet specifications	(0, 100); high=100; low=0	30	100	0.0143	−0.4286

Note: y_L=lower limit; y_U=upper limit; y_T=threshold point; y_M=most preferred point; and A_i, B_i=constant of $U(y_i)=A_i xy+B_i$.

Table 3. Preferences of 1st-Level Criteria

Criteria	1. Environment factors	2. Owner factors	3. Project factors
1. Environment factors	1	1/7	1/5
2. Owner factors	7	1	1/3
3. Project factors	5	3	1

considered reasonable.) By interpolating the distribution, the probability of successfully completing the project within budget (U.S.$30,166,667), P_{budget}, equals 0.96.

Utility Theory

The application of utility theory requires that each criterion influencing the ceiling price be defined and represented by a utility function. Pair-wise and hierarchical comparison of the importance of each criterion allows a weighting factor to be assigned to each one. The weight is further adjusted for the classification within the hierarchical structure. Multiplying the utility value by a corresponding adjusted weight obtains a common scale utility value for each criterion. The sum of all common scale utility values is the expected utility value for a particular project scenario.

Identification of Determination Criteria

The nine major criteria considered in determining the ceiling price were identified through interviews with two senior Taiwanese government officials with experience in this area. These criteria can be divided into three 1st-level categories, namely environment-related factors, owner-related factors, and project-related factors. Each of these three 1st-level criteria is then further divided into three 2nd-level criteria, which are described below and summarized at the left of Table 2.

The environment-related factors include the accuracy of the A/E's estimate, the historical bidding ratio, and market conditions. For most public building projects, A/Es normally neglect their estimates to focus on their designing job. This environment of poor estimation has markedly influenced ceiling-price judgments in Taiwan. Since the A/E's fee is related to project cost, the A/E's estimate tends to be too high, and the owner generally discounts it. Additionally, despite the unique characteristics for each construction project, the historical bidding ratio of similar past projects may be used as a reference for the current project. Regarding market conditions, most practitioners agree that bidders tend to offer low bids during a slow market to keep their business running, and tend to bid high to compensate for their losses when the economy improves. Thus, the ceiling price should respond to market conditions, being lower when the economy is slow, and vice versa.

Table 5. Preferences of 2nd-Level Owner-Related Criteria

Criteria	2.1 Tendering urgency	2.2 Budget tightness	2.3 Avoiding controversy
2.1 Tendering urgency	1	5	9
2.2 Budget tightness	1/5	1	3
2.3 Avoiding controversy	1/9	1/3	1

Project owners in Taiwan must consider the criteria of tendering urgency, budget tightness, and avoiding controversy. Since most public construction projects must be completed rapidly to demonstrate government efficiency, owners are eager to tender the projects out as soon as possible. A higher ceiling price is more likely to achieve tendering rapidly. Most public projects in Taiwan have a budget that is insufficient to meet the desired project needs. The tight budget motivates the owner to set a higher ceiling price (that is, not to discount the A/E's cost estimate) to maximize the chance of finding a bid that falls below the price. However, the higher ceiling price encourages a lower bidding ratio (winning bid/higher ceiling price), which can lead to the owners being accused of either producing a substandard estimate or squandering public money. Thus it is also important to prevent the ceiling price from becoming too high.

Project-related factors include the qualifications of competing bidders, project contract length, and project complexity. Most owners believe that highly qualified bidders submit reasonable bids and thus feel little pressure to discount the A/E's cost estimate. Meanwhile, projects with a shorter duration and higher complexity should have a higher ceiling price to provide bidders with a greater chance of obtaining a profit.

Utility Functions of Individual Criteria

The utility functions for each criterion represent the owner's preferences over a range of options and are measured on a scale. Similar to the utility theory model proposed by Dozzi et al. (1996), the steps used to develop a utility function in SIMUTILITY are summarized as follows:

1. Specify the upper limit (y_U) and lower limit (y_L) for each criterion i.
2. Identify the threshold point (y_T) and most preferred point (y_M) for each criterion i. The utilities of y_T and y_M are set at 0 and 1, respectively; that is, $u(y_T)=0$, and $u(y_M)=1$.
3. Use a straight-line function to express the utility function for each criterion i. That is, the utility value of a particular y_i can be obtained by

$$U(y_i)=A_i\times y_i+B_i \tag{2}$$

where A_i and B_i are constants.

Table 4. Preferences of 2nd-Level Environment-Related Criteria

Criteria	1.1 Estimator's accuracy	1.2 Historical bidding ratio	1.3 Market conditions
1.1 Estimator's accuracy	1	7	9
1.2 Historical bidding ratio	1/7	1	3
1.3 Market conditions	1/9	1/3	1

Table 6. Preferences of 2nd-Level Project-Related Criteria

Criteria	3.1 Bidder's qualification	3.2 Project duration	3.3 Project complexity
3.1 Bidder's qualification	1	4	7
3.2 Project duration	1/4	1	3
3.3 Project complexity	1/7	1/3	1

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Table 7. Weights and Adjusted Weights for All Criteria

1st-Level criteria	2nd-Level criteria	$W_{i(\text{1st-level})}$	$W_{i(\text{2nd-level})}$	$S_i = W_{i(\text{1st-level})} \times W_{i(\text{2nd-level})}$
1. Environment		0.0746[a]		
	1.1		0.7854[b]	0.0586
	1.2		0.1488[b]	0.0111
	1.3		0.0658[b]	0.0049
2. Owner		0.3236[a]		
	2.1		0.7514[c]	0.2432
	2.2		0.1782[c]	0.0577
	2.3		0.0704[c]	0.0228
3. Project		0.6018[a]		
	3.1		0.7049[d]	0.4242
	3.2		0.2109[d]	0.1269
	3.3		0.0842[d]	0.0507

[a]maximum eigenvalue = 3.2332.

[b]maximum eigenvalue = 3.0803.

[c]maximum eigenvalue = 3.0291.

[d]maximum eigenvalue = 3.0324.

The sum of scales for each class or subclass equals 1.

4. Solve the constants A_i and B_i of each function for each criterion i.

By conducting the aforementioned steps, the values of y_U, y_L, y_T, y_M, A_i, and B_i of the nine determination criteria for this application project can be obtained and are illustrated in the right part of Table 2. Note that the scale for each criterion is a numerical value.

Weightings of Determination Criteria

Each criterion is assigned a weight to distinguish the preferences among the preferences of criteria from the same classification level (namely, 1st or 2nd level) of the hierarchical structure. The sum of the weights for each classification level equals 1. The weight of each criterion i is denoted by W_i. The scale used to derive the relative importance from matrices of pairwise comparisons ranges from 1 to 9 (Saaty 1978), as follows: 1 = equally important; 3 = slightly more important; 5 = strongly more important; 7 = demonstratedly more important; 9 = absolutely more important; 2, 4, 6, and 8 are values denoting a degree of importance lying between 1 and 3, 3 and 5, 5 and 7, and 7 and 9, respectively.

In this application project, the preferences of the 1st-level criteria (that is, environmental-, owner-, and project-related factors) are evaluated and listed in Table 3. The preferences of the 2nd-level criteria under each of the 1st-level criterion categories are evaluated and presented in Tables 4, 5, and 6, respectively.

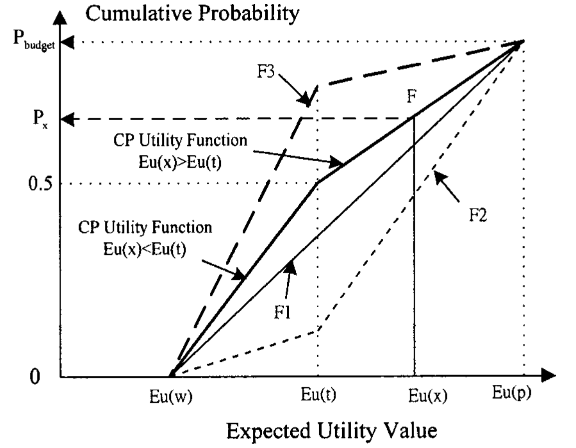

Fig. 3. Possible types of ceiling price utility function

The matrix of preferences is manipulated via a method that determines the eigenvector corresponding to the maximum eigenvalue of a matrix. For example, the eigenvector for the matrix of Table 2 (preferences of 1st-level criteria) is (0.0746, 0.3236, 0.6018) using the maximum eigenvalue of 3.2332. That is, the weights for environment-, owner-, and project-related criteria are 0.0746, 0.3236, and 0.6018, respectively. These weights are then adjusted for classification within the hierarchical structure. The adjusted weight for criterion i is thus obtained by the following equation:

$$S_i = W_{i(\text{1st-level})} \times W_{i(\text{2nd-level})} \tag{3}$$

where $W_{\text{i(1st-level)}}$ denotes the weight of the 1st-level criterion i, and $W_{\text{i(2nd-level)}}$ represents the weight of the 2nd-level criterion i.

For the application project, the weights ($W_{i(\text{1st-level})}$ and $W_{i(\text{2nd-level})}$) and adjusted weights (S_i) for all criteria are calculated and listed in Table 7. For example, in Table 7 the adjusted weight for the criterion of the estimate's accuracy is equal to 0.0586, which is obtained by multiplying 0.0746 by 0.7854. The sum of the adjusted weights of all criteria should equal 1 as a check to ensure there have been no errors in adjusting weights.

Transformation of Utility Values

By multiplying $U(y_i)$ by the S_i corresponding to each criterion i, a common scale utility value is calculated. The common scale utility values of all criteria are summed to produce an expected

Table 8. Expected Utility for Worst-Case Selections

Criterion	Criterion selection	Interpreted scale (y)	A_i	B_i	$U(y_i)$	S_i	Common scale utility
1.1	Low	0	0.0143	−0.4286	−0.4286	0.0586	−0.0251
1.2	0.3	0.3	2.5	−1.5	−0.75	0.0111	−0.0083
1.3	Poor	0	0.0143	−0.4286	−0.4286	0.0049	−0.0021
2.1	Low	0	0.0143	−0.4286	−0.4286	0.2432	−0.1042
2.2	Loose	0	0.02	−1	−1	0.0577	−0.0577
2.3	High	0	0.02	−1	−1	0.0228	−0.0228
3.1	Low	0	0.02	−1	−1	0.4242	−0.4242
3.2	Loose	0	0.0143	−0.4286	−0.4286	0.1269	−0.0544
3.3	Low	0	0.0143	−0.4286	−0.4286	0.0507	−0.0217
							Total score = −0.7206

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Table 9. Expected Utility for Most-Preferred Selections

Criterion	Criterion selection	Interpreted scale (y)	A_i	B_i	$U(y_i)$	S_i	Common scale utility
1.1	High	100	0.0143	−0.4286	1	0.0586	0.0586
1.2	1	1	2.5	−1.5	1	0.0111	0.0111
1.3	Good	100	0.0143	−0.4286	1	0.0049	0.0049
2.1	High	100	0.0143	−0.4286	1	0.2432	0.2432
2.2	Tight	100	0.02	−1	1	0.0577	0.0577
2.3	Low	100	0.02	−1	1	0.0228	0.0228
3.1	High	100	0.02	−1	1	0.4242	0.4242
3.2	Tight	100	0.0143	−0.4286	1	0.1269	0.1269
3.3	High	100	0.0143	−0.4286	1	0.0507	0.0507
							Total Score=1

utility value (total relative score) for a given project scenario. A developed ceiling price (CP) utility function is then used to transform the expected utility value, $Eu(x)$, for a project scenario x into a recommended probability value, denoted as Px. This CP utility function is constructed based on the values of the worst-case $[Eu(w)]$, threshold-point $[Eu(t)]$, and most-preferred $[Eu(p)]$ scenarios. As Fig. 3 illustrates, if $Eu(x)$ exceeds the expected utility of the threshold point with a probability of 0.5, then the CP utility function can be derived as follows:

$$\frac{P_x-0.5}{P_{\text{budget}}-0.5}=\frac{Eu(x)-Eu(t)}{Eu(p)-Eu(t)} \tag{4}$$

Since the expected utility of threshold point $Eu(t)=0$, Eq. (4) can be modified as

$$P_x=0.5+\frac{Eu(x)}{Eu(p)}(P_{\text{budget}}-0.5);\quad Eu(x)>0 \tag{5}$$

Alternatively, if $Eu(x)$ is less than $Eu(t)$, then the CP utility function can be derived by

$$\frac{P_x-0}{0.5-0}=\frac{Eu(x)-Eu(w)}{Eu(t)-Eu(w)} \tag{6}$$

Once again $Eu(t)=0$, and Eq. (6) can be modified as

$$P_x=0.5-0.5\left(\frac{Eu(x)}{Eu(w)}\right);\quad Eu(x)<0 \tag{7}$$

Using a probability of 0.5 with respect to $Eu(t)=0$ as a transition point is not essential to establishing the two-straight-line CP utility function. Users may choose values other than 0.5 while still following the transformation procedure described previously. For example, when a user has no preference regarding the value of probability at $Eu(t)=0$, the CP utility function $F1$, displayed in Fig. 3, may be selected. The straight-line $F1$ can actually be derived from just two points, $[Eu(w),0]$ and $[Eu(p),P_{\text{budget}}]$. In other situations, the user may favor the $F2$ or $F3$ functions illustrated in the same figure, depending on the probability of making a profit that the user (the ceiling price decision-maker) is willing to give to the contractor.

The F function is used for this application project. Table 8 lists the selections of the worst-case scenario for criteria with the value of $Eu(w)$ calculated to be −0.7206. Meanwhile, Table 9 lists the selections of most-preferred scenario, with $Eu(p)$ calculated as 1. The value of the $Eu(x)$ based on the inputs displayed in Table 10 is 0.6313. Notably, the value of P_{budget} is 0.96 for this application project. Since $Eu(x)>0$, Eq. (5) is applied, and the value of Px is computed as 0.7910.

Results

Determination of Project Ceiling Price

Given the value of Px, the corresponding cost (that is, suggested project ceiling price) can be obtained from the cumulative probability distribution of the project cost by using a straight-line interpolating method. For this project, the two simulated probabilities closest to Px (=0.7910) are 0.7819 and 0.8380, and they have corresponding project costs of $29,333,333 (NT$880,000,000/30) and $29,500,000 (NT$885,000,000/30), respectively. The ceiling price for the project suggested by SIM-UTILITY is thus approximately $29,360,367 (NT$880,811,000/30).

During the opening of bidding for the project, the final ceiling price set by the project owner was $29,333,333

Table 10. Expected Utility for Example Project Selections

Criterion	Criterion selection	Interpreted scale (y)	A_i	B_i	$U(y_i)$	S_i	Common scale utility
1.1	Average	50	0.0143	−0.4286	0.2864	0.0586	0.0168
1.2	0.79	0.79	2.5	−1.5	0.4750	0.0111	0.0053
1.3	Fair	50	0.0143	−0.4286	0.2864	0.0049	0.0014
2.1	Moderately high	75	0.0143	−0.4286	0.6439	0.2432	0.1566
2.2	Moderately tight	75	0.02	−1	0.5	0.0577	0.0289
2.3	Average	60	0.02	−1	0.2	0.0228	0.0046
3.1	Moderately high	80	0.02	−1	0.6	0.4242	0.2545
3.2	Tight	100	0.0143	−0.4286	1	0.1269	0.1269
3.3	Moderately high	80	0.0143	−0.4286	0.7154	0.0507	0.0363
							Total score=0.6313

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Table 11. Results for Electrical and Mechanical Subprojects

Subproject	Project budget	Simulated minimum cost	Simulated expected cost	Simulated maximum cost	Px	Suggested ceiling price	Eventually determined ceiling price	Lowest bid	Bid ratio	Probability of bid
Electrical	5,332,939	5,101,317	6,281,420	7,375,889	0.02	5,332,939 (159,988,184NT)	5,330,000 (159,900,000NT)	4,050,333 (121,510,000NT)	0.7599	0
Mechanical	3,666,599	3,724,867	4,246,561	4,846,261	0	3,666,599 (109,997,970NT)	3,633,333 (109,000,000NT)	2,933,333 (88,000,000NT)	0.8073	0

(=NT$880,000,000/30). The New Taiwan dollar ceiling price has been rounded down from the suggested NT$880,811,000 to NT$880,000,000. Removing additional numbers from the suggested price is common practice in Taiwan and is seen as making the price look tidy. For this project, the results generated by SIM-UTILITY provide valuable information to support the process of determining the ceiling price.

Tendering Outcomes

After opening the submitted bids for this project, the lowest bid was found to be U.S.$27,666,667 (=NT$830,000,000/30) and the project was successfully tendered out. The difference between the ceiling price and the bid was about $1,666,666 ($29,333,333−$27,666,667). Meanwhile, the bid ratio was 0.94 (=$27,666,667/$29,333,333), which was satisfactory from the perspective of avoiding accusations of mismanagement. Notably, the probability of profitably completing the project at this bid is only 0.0698, by interpolating from the cost distribution. This low probability is the result of the relatively small range of simulated project costs, between $26,664,733 and $31,735,613. Nevertheless, as suggested by SIM-UTILITY, this low probability indicates that the owner should pay careful attention to quality management during project construction.

Applications to Other Projects

The SIM-UTILITY model was also applied to the electrical and mechanical subprojects of the same building project. Following procedures similar to those used in the architectural project, the results for these two subprojects are also reliable. Table 11 summarizes the results of the budget, *Px*, suggested ceiling price provided by SIM-UTILITY, eventually determined ceiling price, lowest bid, bid ratio, and probability of profitability at the lowest bid for the two projects. Some of the data are presented in NT dollars for ease of interpretation.

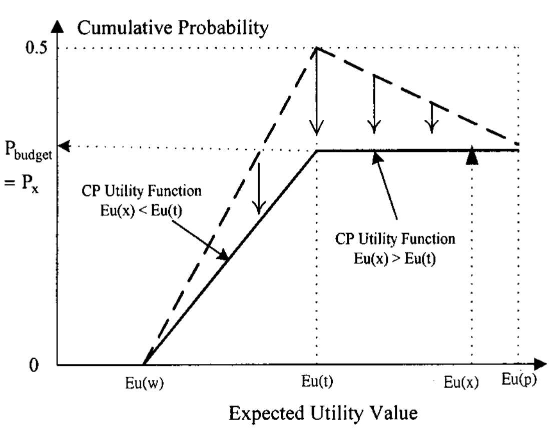

Fig. 4. Ceiling price utility function with $P_{budget}<0.5$

Table 11 reveals that in both subprojects, the owner simply removed the superfluous numbers from the price suggested by SIM-UTILITY and took this as the final ceiling price. Meanwhile, both subprojects were successfully tendered. However, the suggested ceiling price in each subproject equals the original project budget. This phenomenon is mainly owing to the project budget being too low, leading to a low P_{budget}. This phenomenon can be best illustrated graphically. According to Fig. 4, since a probability value of 0.5 with regard to $Eu(t)$ is higher than P_{budget}, any value of *Px* with regard to $Eu(x)$ that exceeds $Eu(t)$ will be higher than P_{budget}. Under the constraint of a fixed project budget, the value of *Px* must be smaller than or equal to P_{budget}. Thus, the CP utility function must be decreased to reflect reality, as shown in this figure. For a project scenario *x* with a $Eu(x)$ greater than $Eu(t)$, the value of *Px* should thus be P_{budget}. (Again, during construction, the simulated cost distributions of the two projects were also presented to the contractors and were considered reasonable.)

A low P_{budget} (0.02 and 0 for electrical and mechanical subprojects, respectively) due to the low project budget implies a low ceiling price (which cannot exceed the project budget) with respect to a low *Px*, subsequently leading to a low probability (0 for both electrical and mechanical subprojects) of profitability at the lowest bid. Thus, suggesting a project budget as the ceiling price with respect to a *Px* of 0.02 and 0 for electrical and mechanical subprojects, respectively, is what SIM-UTILITY can do best in this case. This lesson highlights the significance of initially providing a reasonable project budget for procuring public projects. The contractors also confirmed that the final costs for both subprojects were greatly overrun after completion, which corresponded to the profitable probabilities of 0 predicted by SIM-UTILITY.

Conclusions

This study has presented a simulation-facilitated utility theory model, SIM-UTILITY. The use of a more objective cost simulation approach to support the definition of the utility value boundaries, and the use of a systematic procedure for evaluating user utility over criteria, provide a systematic model for determining the project ceiling price and thus assisting the project tendering process. The modeling results have displayed their strengths by successfully applying the model to three practical construction projects. Future computerization of SIM-UTILITY is expected to significantly boost practices for determining project ceiling prices in Taiwan.

A subsequent paper will present an integrated procedure for comprehensively supporting the owner of public construction projects in dealing with three major owner-side, cost-related tasks

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involved in project tendering. SIM-UTILITY handles the task of determining the project ceiling price, and an electronic unit-price spreadsheet supports the evaluation of competitive bids and helps the negotiation of unbalanced bids under a fixed bid price. Future research on SIM-UTILITY may include exploring ways to incorporate historical cost data to provide more objective statistical distributions of cost components, considering the risk tolerance of the user (which may affect the straight-line assumption of utility functions), and applying SIM-UTILITY to additional construction projects.

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