ELSEVIER

Automation in Construction 17 (2008) 623 – 632

AUTOMATION IN CONSTRUCTION

www.elsevier.com/locate/autcon

AHP- and simulation-based budget determination procedure for public building construction projects

Yu-Ting Lai, Wei-Chih Wang *, Han-Hsiang Wang

Department of Civil Engineering, National Chiao Tung University, 1001, Ta-Hsueh Road, Hsinchu, 300 Taiwan

Accepted 29 October 2007

Abstract

Public construction project budgets account for a high percentage of annual government budgets. Thus, objectively determining project budgets is of priority concern for effectively allocating these budgets by government officers. However, Taiwanese regulations for setting construction project budgets only qualitatively describe the governmental administration process. Without a systematic quantitative method, government officers typically determine project budgets based on their personal experience; thus, budgeting results can be unreliable. This study presents a novel procedure for determining construction project budgets. The proposed procedure integrates an analytical hierarchy process (AHP)-based multi-criteria evaluation model with a simulation-based cost model. The AHP reflects officer evaluations with respect to budget determination criteria. Cost items are variables. The cost model generates a cumulative cost distribution for establishing project budget boundaries. The merits of the proposed procedure are demonstrated through its application to a Taiwanese project.

Keywords: Budget; Cost; Simulation; Analytical hierarchy process; Public building construction project

---

1. Introduction

Public construction project budgets often account for a high proportion of annual budgets in many countries. For example, the public construction budget in Taiwan amounted to roughly US $1.33 billion in year 2002, which was approximately 25% of total central government budget. The Public Construction Commission (PCC), the highest construction- related governmental agency in Taiwan, has the authority to determine budgets of public construction projects that exceed US $1,515,152. (1 US dollar ≅ 33 New Taiwan dollars. The US dollar is used hereinafter.) A low budget creates a risk that project may run over budget. Conversely, a high budget is in conflict with taxpayer interest in minimizing costs. The dilemma for PCC officers (i.e., budget reviewers) is to set a budget that is sufficiently low to reduce costs, and sufficiently high such that a project can be completed successfully.

However, regulations for determining construction project budgets in Taiwan only outline the governmental administration process qualitatively [1]. The PCC officers decide project budgets principally based on their own experience. As a result, PCC officers are constantly faced with complaints regarding their budgeting decisions. Two issues have been identified by PCC officers for enhancing the performance of this experience-based practice. First, what criteria are used for evaluating a construction project budget? Without using explicit evaluation criteria, project budgets cannot be assessed using a consistent decision-making process. Second, a quantitative method should be utilized for systematic determination of construction budgets.

This work identifies an appropriate list of evaluation criteria and proposes a quantitative procedure for determining budgets of public building construction projects. The Analytical Hierarchy Process (AHP) [2] is utilized to weight the various evaluation criteria. Additionally, simulation is used with project costs (budgets) as variables and derives a range of possible project budgets. Finally, an AHP-based multi-criteria evaluation model and a simulation-based cost model are integrated to determine project

---

* Corresponding author. Tel.: +886 3 5712121x54952; fax: +886 3 5716257.
E-mail address: weichih@mail.nctu.edu.tw (W.-C. Wang).

0926-5805/$ - see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.autcon.2007.10.007

budgets. The remainder of this paper is organized as follows. Current practices and past research are reviewed first. Next, the proposed procedure is elucidated, and its detailed procedure is demonstrated using one Taiwanese construction project. Finally, the strengths of the procedure and future research directions are identified.

2. Budget determination practices in Taiwan

A public construction project in Taiwan that exceeds US $1,515,152 is evaluated via two stages: the conceptual planning stage and preliminary planning stage. During the first stage, the needs of a construction project are verified. Restated, this stage determines whether a proposed project meets public interests. Notably, a screening estimation method (e.g., unit pricing method) is often used to examine the approximate size of the required budget. Once project needs are approved by the Executive Yuan, the project proceeds to the second stage.

In the second stage, the owner (i.e., a government entity) of the project typically entrusts a consulting company to help develop a project proposal (including preliminary plans and required budget) and then submits the proposal to the PCC for further review. The proposed budget should explicitly list required item costs, including engineering costs, direct construction costs, indirect construction costs, and others costs. (The budget determined by the PCC is then sent to lawmakers for final approval. However, lawmaker evaluations are usually political and not profession-based decisions.) Notably, the project owner usually proposes a budget exactly the same as, or close to, the initial budget established in the first stage because a budget exceeding an initial budget is not desired by the PCC and a low budget is not preferred by the project owner. Consequently, most proposed budgets are likely overestimated. During budget reviews, project owners may be asked to provide additional information that justifies their cost estimations.

This investigation focuses on budget evaluation in the second stage. When a project proposal is sent to the PCC for review, a PCC officer will be assigned to review the project primarily according to certain budgeting regulations [1] and his experience. Over the past few years, proposed budgets have been decreased by PCC officers by approximately 5–8%. However, certain questions remain. What criteria are utilized for evaluating a construction project budget? Can the decisions of PCC officers regarding project budgets be justified?

3. Pertinent research

3.1. Cost estimation methods

Many screening cost estimation methods have been developed for meeting budgeting needs in the early stages of a construction project. These cost estimation methods include cost indices, cost-capacity factors, unit-based estimates (e.g., units of gross floor area), factored estimation, and parameter cost estimation [3–5]. Although these methods are suitable for determining initial budgets during the conceptual planning stage, they are inappropriate for use in the preliminary planning stage as these approaches do not explicitly represent cost-item budgets, which are required for PCC budget reviews.

3.2. Bidding and tendering research

Bidding and tendering research is also related to estimations of construction project costs. Considerable bidding research addresses the determination of bid markup [6–10]. Tendering research related to the perspective of project owners includes assessment of bidder capability to complete a contract [11,12], tests that minimize subjective bias in best-value procurement [13], selection of an approach for awarding contracts [14,15], setting a cost threshold or ceiling price (under a given budget) as a reference point for evaluating a low bid [16,17], application of an electronically facilitated bidding model to prevent construction disputes [18], and evaluation of low bids [19–21]. To date, no existing research has considered appraisal of public construction project budgets.

3.3. Research on cost uncertainty

Numerous models have been developed to account uncertainties in cost estimation. These recently presented cost models are based on neural networks [22], simulation [23,24], experiential learning theory [25] and other systematic approaches [26,27]. In summary, the project cost or budget is variable or probabilistic since future events are always uncertain.

3.4. AHP for determining criteria weightings

The AHP approach has recently become popular in assessing criteria weightings in various multi-criteria decision-making (MCDM) problems. For instance, several decision criteria assist bidders in pricing their work in relation to estimated construction costs. Dozzi et al. [7] applied an AHP-based multi-criteria utility theory for construction project bid markup decisions. Based on the AHP, Cagno et al. [28] proposed a simulation model for assessing the probability of winning in a competitive bidding process in which competing bids were examined based on multiple criteria. Additionally, Marzouk and Moselhi [29] designed a model for estimating markup and evaluating bid proposal using multi-attribute utility theory and AHP. Furthermore, Lin et al. [30] applied an adaptive AHP approach to determine the weightings of multiple criteria for solving a best-value-bid problem. Overall, a multi-criteria evaluation scheme has been employed for real-life situations. The AHP method is an efficient tool for use in solving an MCDM problems such as the determination of the construction projects budgets, considered herein.

4. Criteria for reviewing budgets

Although project budgeting practices are mainly experience based, criteria implicitly influence budgeting decisions made by PCC officers. To identify those criteria, a questionnaire was filled out by five officers responsible for reviewing building construction project budgets. Based on their experience, 20 criteria (called second-level criteria) were identified. These second-level criteria can be grouped into the following five first-level criteria: project conditions (R1), environmental conditions (R2), regulation conditions (R3), planning conditions (R4), and estimation conditions (R5). Criteria R1, R2 and R3 generally represent project constraints, while criterion R4 concerns how well a project owner has prepared a project proposal and criterion R5 concerns the quality of the cost estimates. Fig. 1 displays the hierarchical structure of these budget-review criteria. Table 1 presents a description of each second-level criterion.

Project conditions (R1) have the following four second-level criteria: project complexity (r1), government level (r2), project duration (r3), and project owner experience (r4). High project complexity (r1) indicates high risk. Structural and mechanical material costs are often high for complex buildings. Hospitals, museums, theaters, and experimental buildings are considered to have the highest complexity, whereas residence, office, and classroom buildings have the lowest complexity. Criterion r2 (government level) represents whether a project is owned by a local or central government entity. A central government entity generally has a higher priority during budget competition than does a local government entity. Regarding criterion r3, a project with a tight timeline should have a high budget. Criterion r4 indicates that a relatively smaller budget may be needed for experienced project owners who should be capable of reducing costs by making appropriate decisions.

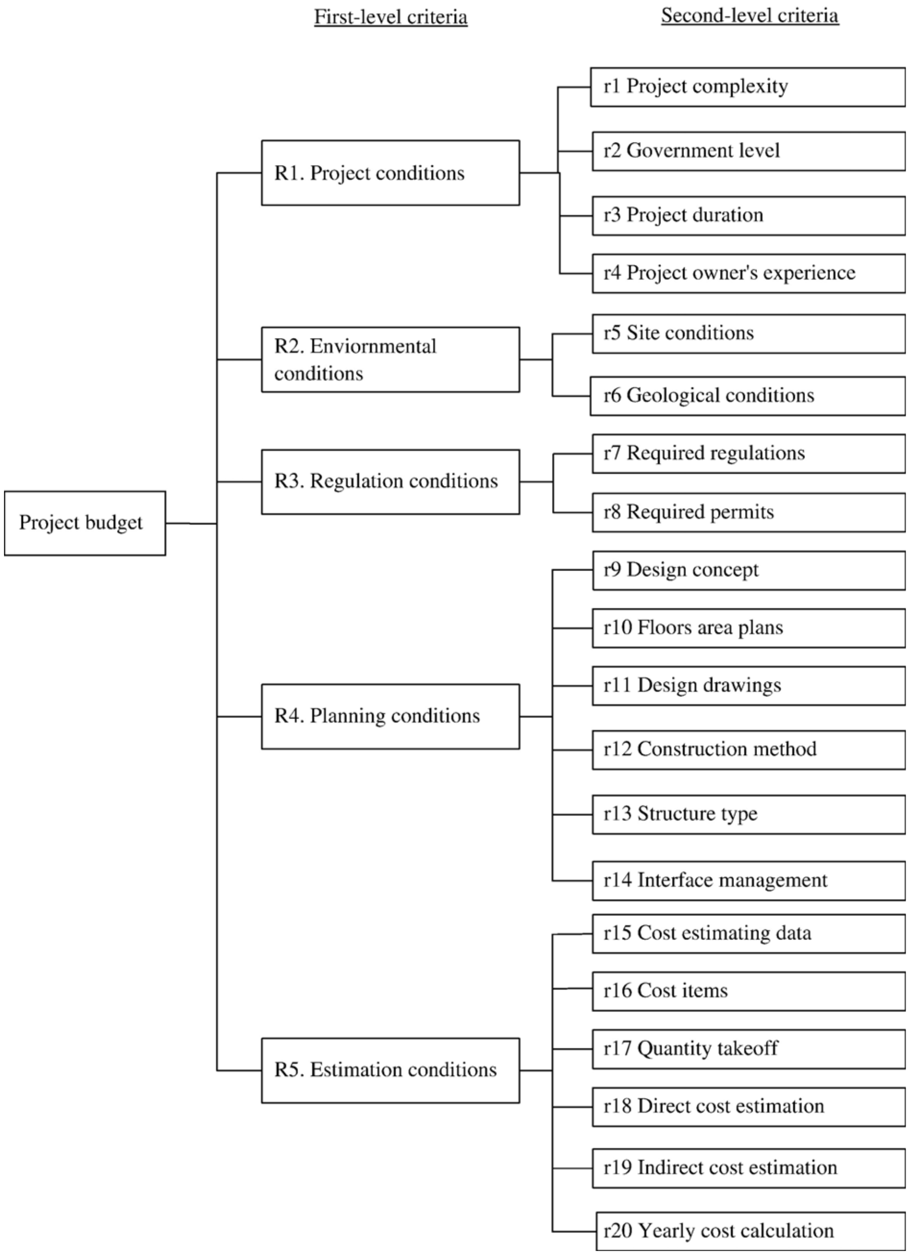

Fig. 1. Hierarchical structure of budget-review criteria.

Table 1
Description and range of scores for budget-reviewing criteria

Criteria	Description	Range of scores
R1. Project conditions		
r1. Project complexity	Is the project complexity high? High complexity ➔ high risk ➔ high cost ➔ high score	Low=0, High=1
r2. Government level	Is the project owner a local or central government entity? Central government entity ➔ high budget ➔ high score	Low=0, High=1
r3. Project duration	Is the project duration tight? Tight duration ➔ high risk ➔ high cost ➔ high score	Low=0, High=1
r4. Project owner's experience	Is project owner experienced in similar projects? Good experience ➔ save costs ➔ low score	Low=1, High=0
R2. Environmental conditions		
r5. Site conditions	Is the density of underground utilities high? High density ➔ high cost to move ➔ high score	Low=0, High=1
r.6. Geological condition	Are geological conditions good? Poor conditions ➔ high cost to improve soil conditions ➔ high score	Low=0, High=1
R3. Regulation conditions		
r7. Required regulations	Does the project need additional regulations? Yes ➔ high risk ➔ high score	Low=0, High=1
r8. Required permits	Number of permits required for a project. Many permits required ➔ high uncertainties ➔ high risk ➔ high score	Few=0, Many=1
R4. Planning conditions		
r9. Design concept	Is the design concept clearly described? Clear ➔ good basis for review ➔ high score	Poor=0, Good=1
r10. Floor area plans	Do floor area plans meet government standards? Over-estimation ➔ incorrect data ➔ low score	Poor=0, Good=1
r11. Design drawings	Are design drawings clearly presented? Clear drawings ➔ few errors ➔ good basis for review ➔ high score	Poor=0, Good=1
r12. Construction method	Is the method clearly explained? Clear explanation ➔ good basis for review ➔ high score	Poor=0, Good=1
r13. Structure type	Are reasons for selecting a specific structure type explained? Poor explanation ➔ poor basis for review ➔ low score	Poor=0, Good=1
r14. Interface management	Are the coordination and drawing composite plans considered? Good plan ➔ good basis for review ➔ high score	Poor=0, Good=1
R5. Estimation conditions		
r15. Cost estimating data	Are cost estimates based on government data? Yes ➔ good basis for review ➔ high score	No=0, Yes=1
r16. Cost items	Are important cost items included in the estimation? Included ➔ few errors ➔ good basis for review ➔ high score	No=0, Yes=1
r17. Quantity takeoffs	Are the details of quantity takeoffs included? Yes ➔ good basis for review ➔ high score	No=0, Yes=1
r18. Direct cost estimation	Are the required direct cost items clearly presented? Clear ➔ good basis for reviewing ➔ high score	Poor=0, Good=1
r19. Indirect cost estimation	Are the percentages of indirect cost items used in line with the governmental estimating manual? Yes ➔ good basis for review ➔ high score	No=0, Yes=1
r20. Yearly cost calculation	Is total cost well distributed to each year? Good description ➔ good basis for review ➔ high score	Poor=0, Good=1

Environmental conditions (R2) are site conditions (r5) and geological conditions (r6). For a project with poor site conditions (e.g., numerous public underground pipelines and cultural heritage items that must be removed in advance of construction), a high budget may be necessary. Similarly, a project with poor geological conditions (e.g., high underground water level, fragmented earth, or ground prone to slides) will have a high probability of overspending, resulting in the need for a large budget.

In R3, if a project located in a region with additional regulations (r7; environmental impact assessment, soil and water conservation, and green building codes) or requiring numerous permits (r8), intensive coordination with governmental authorities is needed. Typically, design changes are needed that meet regulations; thus, cost increases.

Criterion R4 demonstrates the amount of effort a project owner and consulting company have put into the project proposal. Criteria r9–14 are applied to evaluate these efforts. Briefly, if a proposal is prepared in great detail and logically presented such that plans and estimations are easily justified, then the budget is frequently granted without deductions. For example, a good planning proposal includes floor area plans that meet government standards (r10).

Criterion R5 relates to the performance of the estimation by an owner, and it consists of six second-level criteria (r15–20). For instance, the costs should be estimated from published government data (r15). Additionally, the percentages associated with indirect cost items should be taken from the appropriate government estimating manual (r19). Table 1 presents examples for other criteria.

5. Proposed procedure

The proposed procedure enhances the quality of budget determination processes for public building construction projects by incorporating assessments of various decision criteria and by treating project costs as variables that fit real-world situations. Fig. 2 shows the proposed hybrid procedure by modifying the models developed by Wang [16] and Wang et al. [10]. The right side of the figure illustrates an integrated

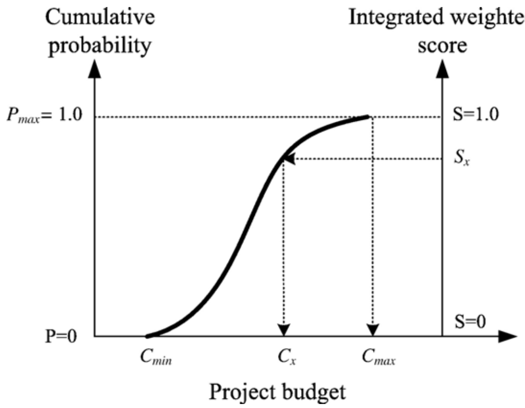

Fig. 2. Proposed procedure.

weighted score generated based on criteria evaluations, whereas the left side presents a cumulative probability distribution of project budget. Additionally, the AHP is adopted to evaluate the criteria weightings and a simulation is conducted to derive a range of possible project budgets. The modeling steps of the proposed procedure are described in the following section.

5.1. Modeling steps

The proposed procedure consists of six steps.

- The AHP-based multi-criteria evaluation model
  1. Assess the weights of second-level criteria via the AHP approach.
  2. Assign a score for each second-level criterion, and then calculate the integrated weighted score of the project. The integrated weighted score S_x ranges from 0–1.
- Simulation-based cost evaluation model
  3. Generate a project budget that includes four principal parts: construction costs (i.e., direct and indirect costs), engineering costs, owner overhead costs, and other costs.
  4. Conduct simulation analysis that includes cost uncertainties, and then generate a cumulative distribution of the project budget.
  5. Identify the maximum budget ($C_{\max}$) and minimum budget ($C_{\min}$) for the project (namely, the upper and lower boundaries of the project budget).
- Integration the two models
  6. Based on the value of S_x, find a recommended project budget C_x from the cumulative distribution of the project budget. A high S_x suggests a high score for criteria evaluations, resulting in a high budget, and vice versa.

5.2. The AHP-based multi-criteria evaluation model

5.2.1. Criteria weights

The 20 criteria are assumed independent, and the importance of criteria is pairwisely compared by the same five PCC officers to derive criteria weights according to AHP algorithms. The scale utilized to derive the relative importance from matrices of pairwise comparisons ranges from 1–9 [2], where 1 represents equally important, 3 represents slightly more important, 5 represents strongly more important, 7 represents demonstratedly more important, and, 9 represents absolutely more important, whereas 2, 4, 6, 8 denote the degree of importance lying between 1 and 3, 3 and 5, 5 and 7, and 7 and 9, respectively. The matrix of preferences is generated via a method that determines the eigenvector corresponding to the maximum eigenvalue of a matrix [2]. The sum of all criteria weights equals 1.

Comparisons are then organized in a pairwise weighting matrix (PWM) [30]. Fig. 3 displays an example of PWM of the first-level criteria. Due to the limitation of Saaty's discrete 9-value scale and the inconsistency inherent in human judgment while weights are assessed during the pairwise comparison process, the aggregation weight vector might be invalid. Saaty [2] developed an approach for measuring inconsistency by first estimating the consistency index (CI). The CI is defined in Eq. (2).

$$\mathrm{CI} = \frac{\lambda_{\max} - n}{n - 1} \tag{2}$$

where n denotes the number of criteria, and $\lambda_{\max}$ is the maximum eigenvalue. Then, the CI is divided by the random CI to acquire the consistency ratio (CR) [30]. When CR is >0.1, pairwise comparison results should be rejected. Another cycle of reassessment for the relative importance weights of criteria is required until CR is <0.1.

After the consistency test, the weights of the 5 PWMs obtained from the five PCC officers are averaged to get the weights of building construction projects. Notably, the results of CRH of 2 PWMs are >0.1. After reassessment, all CRH results of the 5 PWMs are acceptable. Table 2 lists the weights of the first- and second-level criteria. The preference matrix is analyzed to determine the eigenvector that corresponds to the maximum matrix eigenvalue. For instance, the matrix eigenvectors (Table 2) (preferences according to first-level criteria) are 0.3224, 0.1328, 0.1338, 0.1432 and 0.2678, with a

	R_1	R_2	R_3	R_4	R_5
R_1	—	5	3	5	1
R_2	$\frac{1}{5}$	—	1	3	$\frac{1}{3}$
R_3	$\frac{1}{3}$	1	—	3	$\frac{1}{3}$
R_4	$\frac{1}{5}$	$\frac{1}{3}$	$\frac{1}{3}$	—	$\frac{1}{5}$
R_5	1	3	3	5	—

Fig. 3. Example of pairwise weighting matrix of the first-level criteria.

Table 2
Criteria weights

First-level criteria	Second-level criteria	Weight of first-level criteria ($W_{i(\text{1st-level})}$)	Weight of second-level criteria ($W_{i(\text{2nd-level})}$)	Adjusted weight ($W_i = W_{i(\text{1st-level})} \times W_{i(\text{2nd-level})}$)
R1	r1	0.3224	0.3884	0.1252
	r2		0.3279	0.1057
	r3		0.0913	0.0294
	r4		0.1924	0.0620
R2	r5	0.1328	0.7164	0.0951
	r6		0.2832	0.0376
R3	r7	0.1338	0.3666	0.0486
	r8		0.6333	0.0847
R4	r9	0.1432	0.2791	0.0400
	r10		0.2256	0.0323
	r11		0.2149	0.0308
	r12		0.1065	0.0153
	r13		0.1061	0.0152
	r14		0.0678	0.0097
R5	r15	0.2678	0.2588	0.0693
	r16		0.1133	0.0304
	r17		0.0939	0.0252
	r18		0.2977	0.0800
	r19		0.0660	0.0178
	r20		0.1703	0.0457

maximum eigenvalue of 5.0837. Restated, the weights of project conditions, environmental conditions, regulation conditions, planning conditions, and estimation conditions are 0.3224, 0.1328, 0.1338, 0.1432 and 0.2678, respectively. These weights are then adjusted within the hierarchical structure. The adjusted weight of criterion *i* is thus obtained from Eq. (3), where, $W_{i(\text{1st-level})}$ is the weight of first-level criterion *i*, and $W_{i(\text{2nd-level})}$ is the weight of second-level criterion *i*. Table 2 lists the calculated weights ($W_{i(\text{1st-level})}$ and $W_{i(\text{2nd-level})}$) and adjusted weights (W_i) of all criteria for building constructions projects.

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

The first-level criteria R1 (project conditions) and R5 (estimation conditions) receive high weights. Furthermore, the PCC officers indicate that second-level criteria r1 (project complexity), r2 (government level), r5 (site conditions), r8 (required permits), r15 (cost estimating data), and r18 (direct cost estimation) affect project budgets most, with adjusted weights (W_i) equal to 0.1252, 0.1057, 0.0951, 0.0847, 0.0693 and 0.0800, respectively.

5.2.2. Assigning criteria scores

According to the 20 second-level criteria, PCC officers should assess project budget by scoring (Y_i) each criterion. The range of scores for each criterion is 0–1. Hence, multiplying a score and its weight generates a weighted score for each criterion. Finally, the sum of weighted scores for all criteria is the project integrated weighted score (S_x).

5.3. Simulation-based cost evaluation model

5.3.1. Project costs

Most cost models include only estimates of construction costs to suit bidding or tendering purposes. However, for budgeting purposes, the total cost (or budget) of a building construction project (C_{proj}) comprises construction costs (C_{con}), engineering costs/owner overhead costs (C_k) and other costs (C_{om}). In this investigation, construction costs, C_{con}, are derived by

$$\begin{aligned} C_{\text{con}} &= \left[(C_1 \ldots + C_i) \times \left(1 + D_1 + \ldots + D_j\right)\right] \times (1+t) \\ &= \left[\left(\sum_{i=1}^{I} C_i\right) \times \left(1 + \sum_{j=1}^{J} D_j\right)\right] \times (1+t) \\ &= \left[\sum_{i=1}^{I} C_i + \sum_{i=1}^{I} C_i \times \sum_{j=1}^{J} D_j\right] \times (1+t) \end{aligned} \tag{4}$$

where C_i is the cost of direct construction cost component *i*, and *I* is the number of direct construction cost components. Thus, $\sum_{i=I}^{I} C_i$ represents total direct construction costs. Direct construction costs, measured in dollar terms, include the costs for excavation, the structure, exterior and interior finishes, doors, windows, painting, and furnishings. The cost of each C_i (e.g., site work) in Eq. (4) is the sum of costs of several detailed cost items (e.g., clearing, excavation, compaction). Moreover, D_j is the cost of indirect construction cost component *j*, and *J* is the number of indirect construction cost components. Indirect construction costs include contractor markup, insurance, quality control, site safety management cost, environment monitoring cost, contingency cost and inflation cost. Each indirect construction cost is a percentage of total direct construction costs. Thus, $\sum_{i=1}^{I} C_i \times \sum_{j=1}^{J} D_j$ represents total indirect construction costs. Value *t* represents tax as a percentage (a constant value, typically 5% in Taiwan) of the sum of total direct and indirect construction costs.

The cost for a component of engineering costs and owner overhead costs (E_k) is also represented by a percentage of total direct and indirect construction costs. Thus, total engineering costs and owner overhead costs (C_k) is represented as

$$\begin{aligned} C_k &= \left[(C_1 + \ldots + C_i) \times \left(1 + D_1 + \ldots + D_j\right)\right] \times (E_1 + \ldots + E_k) \\ &= \left[\left(\sum_{i=1}^{I} C_i\right) \times \left(1 + \sum_{j=1}^{J} D_j\right)\right] \times \sum_{k=1}^{K} E_k \\ &= \left[\sum_{i=1}^{I} C_i + \sum_{i=1}^{I} C_i \times \sum_{j=1}^{J} D_j\right] \times \sum_{k=1}^{K} E_k \end{aligned} \tag{5}$$

where *K* is the number of engineering and owner overhead cost components. Notably, engineering costs are fees paid to architects, project managers, and other consultants. Owner overhead costs include office rent, overhead and costs of public art.

Variable O_m, measured in dollar terms, is the cost of any other cost item *m*, such as geological drill fee and costs associated with applying for various permits, and *M* is the number of other cost items. Hence, total other costs (C_{om}) is derived by

$$C_{om} = O_1 + \ldots + O_m = \sum_{m=1}^{M} O_m \tag{6}$$

Thus, the total cost of a building construction project (C_{proj}) can be rewritten as

$$\begin{aligned} C_{\text{proj}} &= C_{\text{con}} + C_k + C_{om} \\ &= \left[\left(\sum_{i=1}^{I} C_i + \sum_{i=1}^{I} C_i \times \sum_{j=1}^{J} D_j\right) \times (1+t)\right] \\ &\quad + \left[\left(\sum_{i=1}^{I} C_i + \sum_{i=1}^{I} C_i \times \sum_{j=1}^{J} D_j\right) \times \sum_{k=1}^{K} E_k\right] + \left(\sum_{m=1}^{M} O_m\right) \\ &= \left[\left(\sum_{i=1}^{I} C_i + \sum_{i=1}^{I} C_i \times \sum_{j=1}^{J} D_j\right) \times \left(1 + t + \sum_{k=1}^{K} E_k\right)\right] + \left(\sum_{m=1}^{M} O_m\right) \end{aligned} \tag{7}$$

5.3.2. *Cost uncertainty*

The cost model assumes that costs of direct construction cost components (C_i), indirect construction cost components (D_j), engineering costs or owner overhead costs (E_k), and other cost components (O_m) are variables presented as dollars or percentages. Additionally, since the three-point estimation method is widely applied in modeling construction uncertainties [31], this work employs optimistic, most likely and pessimistic costs to specify a Beta distribution for each cost component. For instance, optimistic cost for C_i is the cost that is lowest when the cost component is repeated 20 times under the same conditions. Similar definitions are applied to pessimistic cost. Each indirect construction cost component is evaluated in terms of optimistic, most likely, and pessimistic percentages. The PCC officers must specify the three-point cost estimations for each cost component when generating a cost model.

5.3.3. *Simulation and computer implementation*

Simulation involves the generation of random values (i.e., costs or percentages) according to C_i,D_j, E_k, and O_m distributions in each iteration. The project budget (C_{Proj}) is then computed using Eq. (7). This process is repeated several hundred times, with C_{Proj} calculated each time. A cumulative probability distribution of the project budget can then be constructed based on the C_{Proj} values. Simulated maximum and minimum project budgets are assumed maximum and minimum project budgets, respectively.

Table 3
Scenarios of possible outcomes after evaluations

Scenario of possible outcomes	Determined budget	Increase or decrease of owner-proposed budget
(1) $C>C_{\max}$	Need further explanations	–
(2) $C_x<C\leq C_{\max}$	C_x	Decreased by $C-C_x$
(3) $C=C_x$	C_x	0
(4) $C_{\min}\leq C<C_x$	C_x	Increased by C_x-C
(5) $C<C_{\min}$	Need further explanations	–

C: owner-proposed budget; C_x: modeling result (recommended project budget); $C_{\max}$: upper boundary of project budget; $C_{\min}$: lower boundary of project budget.

Table 4
Integrated weighted score for the application project

Criterion	Score (Y_i)	Adjusted weight (W_i)	Weighted score (Y_iW_i)	Performance score (Y_iW_i/W_i)
R1		0.3224	0.2726	85
r1	1.0	0.1252	0.1252	
r2	0.7	0.1057	0.0740	
r3	0.6	0.0294	0.0176	
r4	0.9	0.0620	0.0558	
R2		0.1328	0.0974	89
r5	1.0	0.0951	0.0951	
r6	0.6	0.0376	0.0226	
R3		0.1338	0.1005	75
r7	0.5	0.0486	0.0243	
r8	0.9	0.0847	0.0762	
R4		0.1432	0.0817	57
r9	0.5	0.0400	0.0200	
r10	0.5	0.0323	0.0162	
r11	0.6	0.0308	0.0185	
r12	0.6	0.0153	0.0092	
r13	0.6	0.0152	0.0091	
r14	0.9	0.0097	0.0087	
R5		0.2678	0.1442	54
r15	0.4	0.0693	0.0277	
r16	0.4	0.0304	0.0122	
r17	0.6	0.0252	0.0151	
r18	0.5	0.0800	0.0400	
r19	0.4	0.0178	0.0172	
r20	0.7	0.0457	0.0320	
Integrated weighted score (S_x) =			0.6964	

The cost model is implemented in the simulation language Stroboscope [32]. Stroboscope can define probabilistic cost data for each cost component, and generates a cumulative distribution for a project budget. The cost model is implemented on a Pentium III PC with 768 MB of RAM in a Windows XP environment. Analyzing the example project 5000 times took approximately two minutes. Simulation details can be found in Wang [33].

5.4. *Integration of two models*

The project budget is assumed to exist between $C_{\min}$ and $C_{\max}$ (Fig. 2). Comparison of the project owner's proposed budget (C) and modeling result (C_x) identifies five possible scenarios: (1) $C>C_{\max}$, (2) $C_x<C\leqq C_{\max}$, (3) $C\leqq C_x$, (4) $C_{\min}\leqq C<C_x$ and (5) $C<C_{\min}$.

In scenarios (1) and (5), the owner's proposed budget (C) is beyond the upper or lower boundaries ($C_{\max}$ and $C_{\min}$) for project budget, respectively. In such scenarios, the PCC officer should request detailed explanations from the project owner to justify their cost estimations before determining the project budget. In scenarios (2), (3) and (4), project owner's proposed budget (C) is within $C_{\min}$ and $C_{\max}$, and C_x is suggested. Table 3 summarizes the scenarios of possible outcomes after evaluations.

6. Application

A building construction project located in central Taiwan is used to demonstrate the proposed procedure. The project owner proposed a budget of US$28,026,406. Notably, the decided project budget was US$26,023,477. A PCC officer fully responsible for reviewing this project is asked to help execute the proposed procedure. The following subsections describe the modeling steps.

6.1. Assessments of multi-criteria evaluation model

The 20 criteria weights (Table 2) are utilized for this project. Then, the PCC officer assigns a score (between 0 and 1) for each criterion. For example, project complexity (r1) is considered high, thus, a value of 1.0 is assigned. Moreover, a weighted score is then derived by multiplying the score and weight for each criterion. Table 4 summarizes the scores and weighted scores of each criterion. By summing all weighted criterion scores, the integrated weighted score (S_x) of this multi-criteria project evaluation is 0.6964. Notably, this project proposal receives high performance scores (i.e., Y_iW_i/W_i) of evaluations for criteria R1 (project conditions) and R2 (environmental conditions), which were 85 and 89 points out of 100 points, respectively.

6.2. Evaluations of the cost model

The left side of Table 5 lists the 22 cost components in this project. These cost components are construction costs (C_{con}; components 1–11 and 14–19 in Table 5), engineering costs and owner overhead costs (C_k; components 20–22), and other costs (C_{om}; components 12 and 13). The PCC officer then gives the three-point cost estimation (optimistic, most likely and pessimistic costs or percentages) to each cost component. Table 5 presents these estimates. Notably, the PCC officer applies the same cost item quantities calculated in the project proposal and unit prices published in the government estimation manual to generate the three-point cost estimations for assessing direct construction costs. Additionally, data used in past projects are applied to calculate percentage-based cost components. See Wang [33] for details.

Table 5
Three-point estimates for each cost component in the application project

Cost components	Most optimistic cost ($US)	Most likely cost ($US)	Most pessimistic cost ($US)
1. Structure	7,460,900	7,895,519	8,010,847
2. Finishes	6,263,885	6,294,865	6,314,152
3. Doors, windows, glass	3,460,941	3,736,487	4,012,032
4. Miscellaneous items	1,084,396	1,143,790	1,196,821
5. Furniture	211,187	263,983	290,382
6. Neighborhood inspection fees	48,485	60,606	66,667
7. Steel	572,568	715,711	787,282
8. Temporary facilities	1,187,407	1,201,362	1,211,664
9. Landscaping	858,410	888,963	912,535
10. Parking facilities	361,697	452,121	497,333
11. Water disposal system	19,433	20,188	20,442
12. Geological drill fee	23,630	23,630	23,630
13. Air pollution control	15,648	15,648	15,648
	Most optimistic %	Most likely %	Most pessimistic %
14. Site safety management	0.32	0.48	0.94
15. Insurance	0.17	0.30	0.60
16. Quality control	0.41	0.52	0.57
17. Waste and pollution control	0.20	1.22	1.82
18. Markup	3.00	5.00	7.00
19. Tax	5.00	5.00	5.00
20. Engineering costs	4.12	4.16	4.27
21. Owner overhead	0.68	0.69	0.70
22. Public art	1.00	1.00	1.00

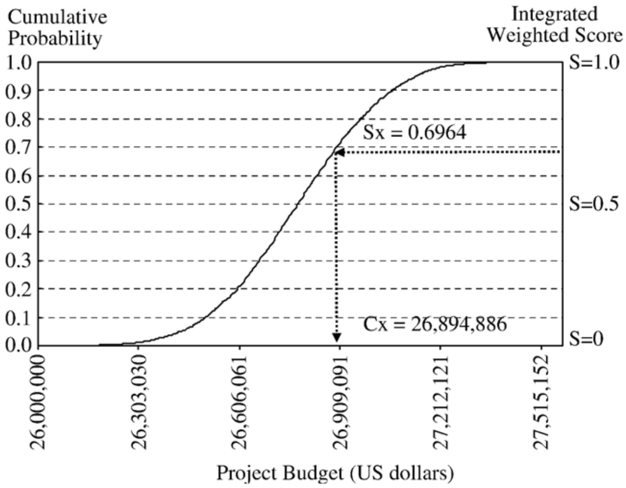

Fig. 4. Modeling results for the application project.

Following 5000 simulations, the maximum and minimum project budget ($C_{\max}$ and $C_{\min}$) are $27,548,266 and $26,023,464, respectively. The left-hand side of Fig. 4 plots the cumulative probability distribution of the project budget.

6.3. Results

According to the proposed procedure, the PCC officer should ask the project owner to provide explanations before determining the project budget as the proposed budget (C, $28,026,406) exceeds the maximum project budget ($C_{\max}$, $27,548,266). Restated, scenario (1) (Table 3) is the result for this project.

Notably, in the proposed procedure, based on the integrated weighted score (S_x=0.6964), probabilities of 0.6954 (project budget of $26,893,939) and 0.6996 (project budget of $26,896,969) are identified to calculate the value C_x. When a linear relationship is assumed, the recommended project budget (C_x), corresponding to S_x, can be determined; it is $26,894,886.

6.4. Discussion

Evaluation results for this application project were presented to the five PCC officers for feedback. The discussion results are summarized as follows.

- In current practices, over-estimation (similar to this application project with a C exceeding $C_{\max}$) is usual because budget reviewers typically discount proposed budgets to save government capital. In the proposed procedure, proposing a reasonable project budget is encouraged since increasing the proposed budget is possible.

- A PCC officer said: "The process is more important than the result for the budget evaluations." Since scenario (1) ($C > C_{\max}$) is the result for the application project, the project owner must provide further explanations. According to multi-criteria evaluations (Table 4), the project owner did not perform well in preparing the proposal and the cost estimates, resulting in poor performance scores in criterion R4 (only 57 out of 100 points) and criterion R5 (54 out of 100 points). Particularly, criteria r15 (cost estimating data), r16 (cost items) and r19 (indirect cost estimation) are assessed as the poorest (i.e., only 0.4 point out of 1.0 for each criterion). These areas require substantial improvement.
- In the proposed procedure, some criteria evaluation scores (Y_i) can be revised after reviewing the additional explanations provided by the project owner. Consequently, integrated weighted score (S_x) and suggested project budget (C_x) will change.
- The proposed procedure suggested that the budget was about 95.96% (=26,894,886/28,026,406) of the proposed budget. The PCC officer's previous decision was 92.85% (=26,023,477/28,026,406) of the proposed budget. That is, budget obtained using the proposed procedure was approximately 3.11% (95.96%–92.85%) or $871,409 (=26,894,886 − 26,023,477) higher than the previous result obtained by the PCC officer. The PCC officer in this application project admitted that he and other PCC officers typically cut project budgets as much as possible to demonstrating their ability to save taxpayer's money. Therefore, such a difference is expected.
- The proposed procedure does not constrain the number of applied criteria. Furthermore, when additional PCC officers participate in budgeting, the criteria weights can be reevaluated if the consistency ratios of the pairwise comparisons are less than 0.1.
- The practical meanings corresponding to each score scale (Y_i, between 0 and 1) for each criterion should be explored to improve evaluation consistency among different budgeting reviewers.

7. Conclusion

Determining budgets of public construction projects are critical tasks for government officers when attempting to utilize effectively the government budget. This study contributes to this budget decision-making process in two major areas. First, a set of budget evaluation criteria and their associated weights for public building construction projects were established via a questionnaire and execution of AHP, respectively. Using the same criteria and weights should facilitate evaluation of budgets for different projects consistently, thus enhancing the quality of decision making. Second, the novel procedure combines an AHP-based model for evaluating numerous decision criteria and a simulation-based cost model for assessing cost uncertainties for determining the budgets of construction projects. The case study presented the merits of the proposed procedure.

During the course of this work, several other research directions arose that may improve the proposed procedure. First, a cost database of completed projects can be established to help derive the cumulative probability distribution of the cost model herein. Second, this study evaluates the budget of a single project. Research regarding project priorities for allocating limited budgets for multiple projects should be investigated. Third, the proposed procedure can be applied to other construction projects using different sets of evaluation criteria and weights. Fourth, a user-friendly computerized system should be developed to automate the proposed procedure to ease the budget evaluation process.

Acknowledgements

The authors would like to thank the National Science Council of Taiwan (Contract No. NSC94-2211-E-009-038) and the Ministry of Education of Taiwan via the Aim for the Top University (MOU-ATU) program for financially supporting this research. Dr. John Chien-Chung Li and several other colleagues from the PCC are also appreciated for sharing their valuable knowledge and supporting the application of the proposed procedure to a case project. Mr. Jang-Jeng Liu is commended for performing the simulation algorithms in the application project. Finally, Dr. Wen-Der Yu, Mr. Chun-Chang Lin and Dr. Hen-Yi Jen are also appreciated for their thoughtful comments.

References

[1] Public Construction Commission, Budget Reviewing Procedure for Public Construction Project, 2002 (in Chinese), Taiwan.
[2] T.L. Saaty, Exploring the interface between the hierarchies, multiple objectives and fuzzy sets, Fuzzy Sets and Systems 1 (1978) 57–68.
[3] S.D. Schuette, R.W. Liska, Building Construction Estimating, McGraw-Hill, NY 1994.
[4] C. Hendrickson, T. Au, Project Management for Construction, Fundamental Concepts for Owners, Engineers, Architects and Builders, Prentice-Hall, NJ 1998 web version (http://www.ce.cmu.edu/~cth/ pmbook/), Chapter 8.3.
[5] R.H. Clough, G.A. Sears, S.K. Sears, Construction Project Management, 4th Edition, John Wiley & Sons, NY 2000.
[6] O. Moselhi, T. Hegazy, P. Fazio, DBID: analogy-based DSS for bidding in construction, ASCE Journal of Construction Engineering and Management 119 (3) (1993) 466–470.
[7] 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.
[8] D.K.H. Chua, D. Li, Key factors in bid reasoning models, ASCE Journal of Construction Engineering and Management 126 (5) (2000) 349–357.
[9] M.F. Dulaima, H.G. Shan, The factors influencing bid markup decisions of large- and medium-size contractors in Singapore, Construction Management and Economics 20 (2002) 601–610.
[10] W.C. Wang, R.J. Dzeng, Y.H. Lu, Integration of simulation-based cost model and multi-criteria evaluation model for bid price decisions, Journal of Computer-Aided Civil and Infrastructure Engineering 22 (2007) 223–235.
[11] J.S. Russell, M.J. Skibniewski, Decision criteria in contractor prequalification, ASCE Journal of Management in Engineering 4 (2) (1988) 148–164.
[12] W. Lo, R.J. Krizek, A. Hadavi, Effects of high prequalification requirements, Construction Management and Economics 17 (5) (1999) 603–612.
[13] D. Kashiwagi, R. Byfield, Testing of minimization of subjectivity in best value procurement by using artificial intelligence systems in state of Utah procurement, ASCE Journal of Construction Engineering and Management 128 (6) (2002) 496–505.

[14] Z.J. Herbsman, R.D. Ellis, Multiparameter bidding system — innovation in contract administration, ASCE Journal of Construction Engineering and Management 118 (1) (1992) 142–150.

[15] P.G. Ioannou, S.S. Leu, Average-bid method 3/4 competitive bidding strategy, ASCE Journal of Construction Engineering and Management 119 (1) (1993) 131–147.

[16] W.C. Wang, SIM-UTILITY: model for project ceiling price determination, ASCE Journal of Construction Engineering and Management 128 (1) (2002) 76–84.

[17] W.C. Wang, Supporting project cost threshold decisions via a mathematical cost model, International Journal of Project Management 22 (2) (2004) 99–108.

[18] W.C. Wang, J.B. Yang, Applications of electronically facilitated bidding model to preventing construction disputes, Automation in Construction 14 (5) (2005) 599–610.

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

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

[21] W.C. Wang, H.H. Wang, Y.T. Lai, J.C. Li, Unit-price-based model for evaluating competitive bids, International Journal of Project Management 24 (2) (2006) 156–166.

[22] H. Adeli, M. Wu, Regularization neural network for construction cost estimation, ASCE Journal of Construction Engineering and Management 124 (1) (1998) 18–24.

[23] K.W. Chau, Monte Carlo simulation of construction costs using subjective data, Construction Management and Economics 13 (1995) 369–383.

[24] W.C. Wang, Simulation-facilitated model for assessing cost correlations, Journal of Computer-Aided Civil and Infrastructure Engineering 17 (2002) 368–380.

[25] D. Lowe, M. Skitmore, Experiential learning in cost estimating, Construction Management and Economics 12 (1994) 423–431.

[26] J.E. Diekmann, Probabilistic estimating: mathematics and applications, ASCE Journal of Construction Engineering and Management 109 (3) (1983) 297–308.

[27] G.D. Oberlender, S.M. Trost, Predicting accuracy of early cost estimates based on estimate quality, ASCE Journal of Construction Engineering and Management 127 (3) (2001) 173–182.

[28] E. Cagno, F. Caron, A. Perego, Multi-criteria assessment of the probability of winning in the competitive bidding process, International Journal of Project Management 19 (6) (2001) 313–324.

[29] M. Marzouk, O. Moselhi, A decision support tool for construction bidding, Construction Innovation 3 (2003) 111–124.

[30] C.C. Lin, W.C. Wang, W.D. Yu, Improving AHP for construction with an adaptive AHP approach (A^3), Automation in Construction 17 (2) (2008) 180–187.

[31] J.J. Moder, C.R. Philips, E.W. Davis, Project Management with CPM, PERT and Precedence Diagramming, 3rd Edition, Van Nostrand Reinhold, NY 1983.

[32] J.C. Martinez, STROBOSCOPE: State and Resource based Simulation of Construction Processes, Ph.D. Dissertation, University of Michigan, Ann Arbor, MI, 1996.

[33] H.H. Wang, Reviewing model for new public building construction projects (in Chinese), MS thesis, Department of Civil Engineering, National Chiao Tung Univ., Taiwan, 2003.