INTEGRATED MODEL OF WEIGHTING AND EVALUATING DECISION CRITERIA FOR SUPPORTING BEST-VALUE CONTRACTOR SELECTION

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ABSTRACT

This study proposes an integrated model to facilitate the weightings and evaluations of tenders involved in the best-value contractor selection process. In the criteria weighting, an adaptive AHP approach (A^3) is applied. A^3 uses a soft computing scheme, genetic algorithms, to recover the weights of the various criteria based on the derived pairwise weighting matrix (PWM) of criteria. In the evaluations of tenders, two sub-models are proposed. The first sub-model is a bid price evaluation model (PRICE), and it is developed to deal with the quantitative criterion, i.e., bid price criterion. The second sub-model is a performance-based evaluation model (PERFORM), and it is employed to quantify the expected performances of other qualitative criteria for each bidder. The proposed model integrates with A^3, PRICE and PERFORM to support the best-value contractor selection. The benefits of this proposed model are demonstrated by applying it a real-world case project. Lessons learned from this case project are also summarized to provide future applications.

KEY WORDS

contractor selection, analytic hierarchy process, adaptive AHP approach, performance, utility function.

INTRODUCTION

Contractor selection is one of the most important decisions made by the construction project owner because selecting a suitable contractor plays a key role in successful execution of a construction project. The best-value (BV) approach (also called most advantageous tendering approach in Taiwan) is a multi-criteria decision making (MCDM) problem, and has been receiving much attention recently by considering that the bid price is not the only decision criterion (PCC 2000, Yang and Wang 2003). The BV method not only attempts to select a best-qualified contractor whose proposal is most favorable to the project owner by evaluating the bidder's proposed plans, but also the selected contractor can improve the ability of contract performance during preparing the bid materials. Contractor selection methods usually involves several tendering tasks, including identifying criteria, weighting criteria, evaluation of tenders such as scoring (or ranking) bidders with respect to criteria, and determining the

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winning bidder (Lin 2008, Lin et al. 2008). However, there are numerous methods have been proposed to support contractor selection, including utility theory (Hatush and Skitmore 1998, Pongpeng and Liston 2003), fuzzy theory (Hsieh et al. 2004, Singh and Tiong 2005, Li et al. 2007), performance-based model (Kumaraswamy 1996; Alarcón and Mourgues 2002), analytical hierarchy process (AHP) or AHP-based approach (Saaty 1978, Fong and Choi 2000, Al-Harbi 2001, Shiau et al. 2002, Kahraman et al. 2003, Bertolini et al. 2006, Anagnostopoulos and Vavatsikos 2006, El-Sawalhi et al. 2007). Besides, Maturana et al. (2007) developed an on-site evaluation method based on lean principles and partnering practices to select the subcontractors. The method allows main contractors to help subcontractors improve their performance by providing them with periodic feedback (Maturana et al. 2007).

This study proposes an integrated model to facilitate the weightings of criteria and evaluations of tenders involved in the BV contractor selection process. In the criteria weighting, adaptive AHP approach (A^3) is applied (Lin 2008, Lin et al. 2008). In the evaluations of tenders, two sub-models are proposed, PRICE sub-model that is applied to calculate the bid price scores (Lin 2008, Lin et al. 2007) and PERFORM sub-model that is applied to assess the expected performances of qualitative criteria (called performance criteria) for each bidder. The remainder of this paper is organized as follows. First, the BV contractor selection process in Taiwan is described. Second, the A^3, PRICE sub-model and PERFORM sub-model are reviewed. Third, the research methodology is discussed. Fourth, details of the demonstrated case study are presented. Fifth, findings and lessons learned are documented to provide prospect users a useful guideline. Finally, a summary and recommendations for future research are concluded.

BV CONTRACTOR SELECTION PROCESS IN TAIWAN

As required by the Taiwanese Government Procurement Law, if a government entity (called project owner or client hereafter) intends to adopt the BV approach in tender selection, obtaining the approval of his superior entity is necessary at first (PCC 1998, PCC 2000, Yang and Wang 2003, Wang et al. 2006). Then, the procedure described in Figure 1 must be followed. In step 2 of Fig. 1, the project client must prepare a draft of selection methodology, including the evaluation criteria, the criteria weightings, scoring method, and other relevant documents. Then, a selection committee must be established to review the draft and should at least hold one official meeting to confirm the evaluation criteria and selection methodology (step 3). Based on the published tendering documentation and contractor selection methodology, interested bidders can prepare bidding documentation and then submit bids (step 5). After bidder amount is legal, the final selection procedure proceeds. Following pre-qualification that will eliminate unqualified bidders (step 6), there will be a selection meeting that shortlist bidders are invited to present their proposals and the committee will do the evaluations and determine the BV contractor (steps 7~8). In step 7.3, three types of scoring methods can be utilized to choose the contract winner: the weighted score method, the unit-price method, and the ranking method. Further details concerning these three scoring methods can be found in PCC (2000).

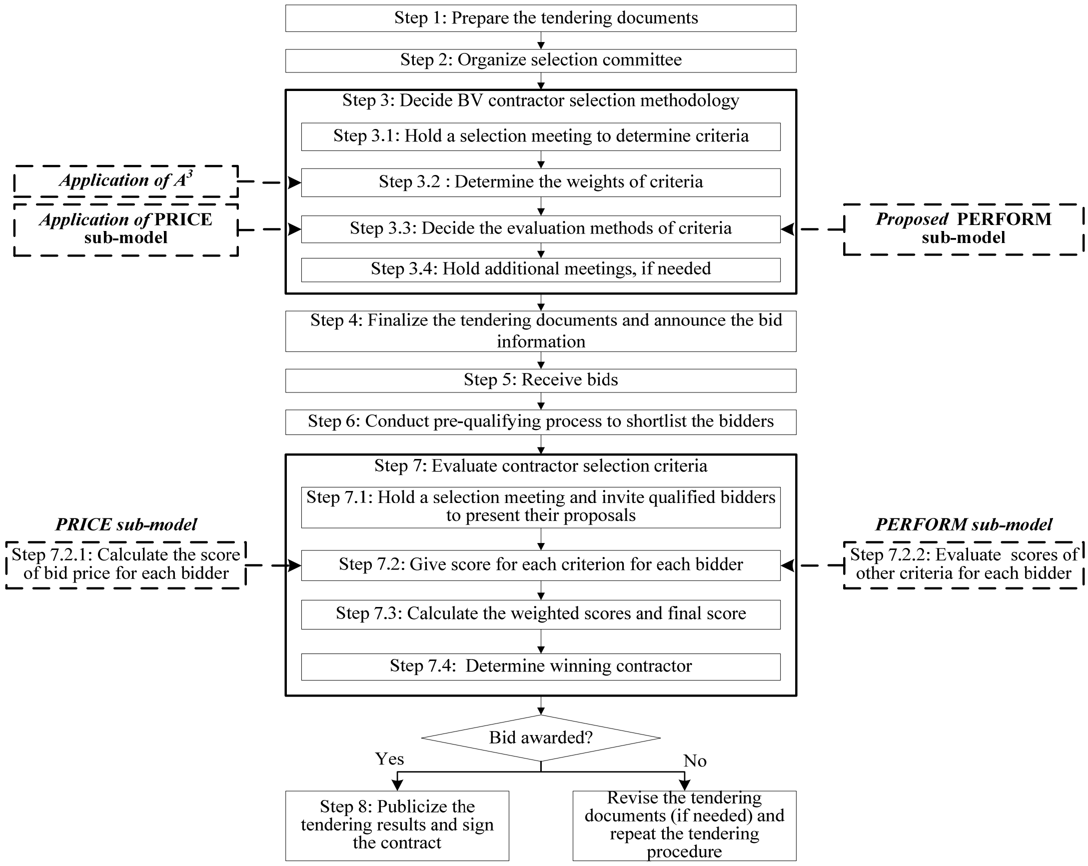

Figure 1: Best-Value Contractor Selection Procedure in Taiwan

REVIEW OF METHODS

The A^3, PRICE and PERFORM methods for contractor selection are reviewed hereafter to provide the research background.

ADAPTIVE AHP APPROACH (A^3)

The A^3 method was proposed by Lin et al. (2008) to resolve the difficulty encountered by the AHP users in obtaining consistent PWMs. The required execution procedure of A^3 is identical to AHP except that no iterative reassessments are required to obtain the consistent PWM. Figure 2 designs the implementation steps to incorporate A^3 into the step 3.2 of Figure 1 for BV contractor selection procedure. Sub-steps 3.2.1 to 3.2.6 describe the procedure to calculate weights of criteria based on AHP. As shown in Figure 2, instead of reassessing the relative weightings of the committee members, A^3 assumes that the original PWM generated can best reflect the belief of the member and use it as a guide to adapt the PWM toward the direction to achieve a lower CR. That is, an adaptive algorithm (e.g., Genetic Algorithms) is adopted to modify the elements in PWM so that it maintains the original PWM as much as possible and results in a lower CR. Further details concerning the A^3 please refer to articles by Lin et al. (2008).

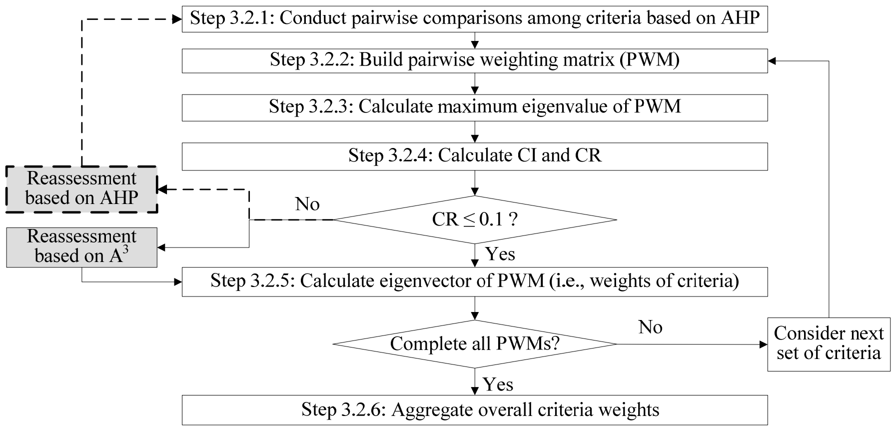

Figure 2: Implementation Steps Based on AHP and Using A^3 to Calculate Weights of Criteria

PRICE SUB-MODEL

The PRICE sub-model is dependent upon the use of an electronic-facilitated bidding procedure that requires bidders to submit bids electronically (Wang 2004; Wang et al., 2006, Lin et al. 2007). An electronic spreadsheet file for project cost estimates (with a blank cost cell for each cost category) is included in bid package documents. Each bidder must fill in a cost for each cost category. A bidding package submitted without this completed file is disqualified. This electronic file helps establish an integrated spreadsheet that combines the costs submitted by all parties, including the owner and the qualified bidders, into a single spreadsheet. This sub-model evaluates the bids in terms of the levels of total bid price and cost category. Evaluation proceeds in four steps: weighting of the total price and category-level costs; establishing reasonable prices; scoring the submitted prices; and, integrating the overall scores. Figure 3 designs the implementation steps to incorporate PRICE sub-model into the step 7.2 of Figure 1 for BV contractor selection procedure. Figure 3 represents the evaluation steps in the model, and further details can be found in articles by Lin et al. (2007).

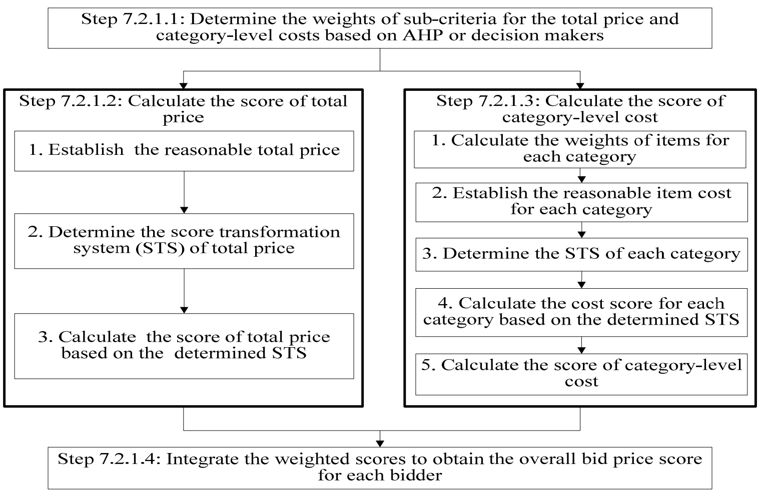

Figure 3: Evaluation Steps in the PRICE Sub-Model

PERFORM SUB-MODEL

The PERFORM sub-model is adopted to evaluate and quantify the expected performances based on bidder submission and oral presentations on the selection meeting for each bidder. Holt et al. (1994) employed the concept of relative index ranking in the multi-attribute analysis to assess the anticipated performance of bidders on cost, schedule and quality as the foundation for contractor selection. Hong Kong Housing Authority (1994) developed a performance assessment scoring system (PASS) to carry out the performance estimation. Alarcón and Mourgues (2002) proposed a general performance model for contractor selection using criterion items determined according to characteristics of project, client, and contractors. Therefore, referring to the concept of utility risk from Hatush and Skitmore (1998), Pongpeng and Liston (2003) and Georgy et al. (2005), we suggest a performance evaluation model for the application of utility function. First, performance level scale (PLS) is defined as shown in Table 1. Then through the utility function established according to the risk preference of selection committee, each evaluation criterion can be translated into performance utility value (PUV) as the performance scoring basis for each bidder.

Left of the Figure 4 shows the utility risk attitudes, where $u_i(y_L)$ is the utility corresponding to the lowest PLS and $u_i(y_H)$ is the utility corresponding to the highest PLS. The shape of the utility function, u(y), depicts the risk attitude of decision-maker. In this study, the straight-line function, used for risk-neutral attitude, is commonly employed in practical application. The evaluation steps included in this PERFORM sub-model are the following:

1. Determine the performance level scale (PLS). A ten-point Liker scale ranging from 1 to 9 is used to assess the performance criteria (Table 1).
2. Define the utility function of performance assessment (right of the Figure 4).

   $$u_i(y_i) = c_i y_i + d_i \quad (1)$$

   where c_i and d_i are constants equal to 10.

   y_L (i.e. the lowest PLS) is 1 and $u_i(y_L)$ is 20

   y_H (i.e. the highest PLS) is 9 and $u_i(y_H)$ is 100
3. Measure the PLS of each performance criterion for each bidder.
4. Calculate the expected utility value for each bidder.

Table 1: Performance Level Scale for PERFORM Sub-Model

Performance (Meaning)	level scale (Numerical rating)*
Very Negative	1
Negative	3
Neutral	5
Very positive	7
Extremely positive	9

＊ 2, 4, 6, 8 are intermediate values.

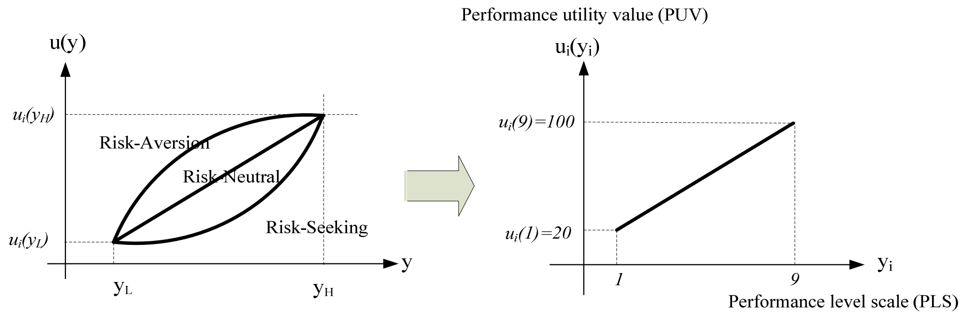

Figure 4: Utility Risk Attitudes and Single-Attitude Utility Function for the Measure of Contractor performance

RESEARCH METHODOLOGY

In this study, A^3, PRICE sub-model and PERFORM sub-model establish an integrated model to facilitate the weightings of criteria and evaluations of tenders involved in the BV contractor selection process (dotted lines in Figure 1). The research methodology are defined and presented thereinafter. First, the A^3 method is used to determine the weightings of criteria as presented by step 3.2 in Figure 1 and sub-steps 3.2.1 to 3.2.6 in Figure 2 (Lin et al. 2008). A real world example to determine the weightings of the multiple criteria for a best value bid is described in the next section to demonstrate the applicability of the proposed A3. Secondary, considering the evaluations of tenders, the PRICE sub-model had been developed by Lin et al. (2007) to deal with the quantitative criterion, that is, the bid price assessment. This sub-model scores both the total bid price and the costs of cost categories (or bid items) submitted by each bidder shown as step 7.2.1 in Figure 1 and corresponding sub-steps in Figure 3. The PERFORM sub-model is proposed in this study and employed to quantify the expected performances of qualitative criteria (such as technology, quality, schedule and safety) for each bidder (Step 7.2.2 of Figure 1). Thirdly, the integrated model is applied in a real world public construction project in Taiwan to demonstrate the applicability of the proposed method in BV contractor selection procedure. Finally, lessons learned from this demonstrated case study were formulated as guidelines to support future applications.

DEMONSTRATED CASE STUDY

PROJECT BACKGROUND

The case project, National Laboratory Animal Center construction project, is located in Southern Taiwan and it is to construct a high-tech laboratory facility to raise laboratory animals. The facility is a five-floor reinforcement concrete (RC) building plus two underground floors. Total floor area is about 15,992 m^2. The construction budget is about USD $18 million. The project duration is 450 calendar days. The project consists of three main construction components, including: (1) civil and building (C&B) construction; mechanical, electrical, and plumbing (MEP) works; and (3) specific pathogen free (SPF) construction. Because of such high project complexity, the BV tendering method was adopted for contractor selection.

MEMBERS OF SELECTION COMMITTEE

To alleviate the influence of individual members, the project owner accepted the task force's suggestion to set a largest committee of 17 members who possessed the C&B, MEP, or SPF expertise required by this project. Notably, only 14 members were involved in selection evaluations because three members were unable to attend those selection meetings due to their tight schedule. Among these 14 members, three members were from C&B domain (specific background: architectural design and construction management), five members were from MEP domain (specific background: HVAC, electrical engineering, and industrial safety), and six members were from SPF domain (specific background: animal laboratory researchers) were involved in selection evaluations. All of these members were either from academia or government agencies.

EVALUATION CRITERIA

The hierarchy determined by the committee is shown as Figure 5, consisted of one level-one criterion: overall score; and four level-two criteria: bid price (criterion 1), technical (criterion 2), organization (criterion 3), and question and answer (Q&A; criterion 4). Besides, three level-two criteria (i.e., bid price, technical, and organization) were further broken down into sub-criteria. The *bid price* criterion included two level-three criteria: total bid price (criterion 1.1) and item bid prices (criterion 1.2). The *technical* criterion included three level-three criteria, namely: *C&B*, *MEP*, and *SPF*. The *organization* criterion consists of three level-three criteria, including integration ability (*integration*), joint contract experience (*experience*), and team member reputation (*reputation*). Moreover, the *C&B* (criterion 2.1) and *MEP* (criterion 2.2) consist of six level-four criteria, namely: quality assurance (*QA*), schedule planning and control capabilities (*schedule*), product specification (*SPEC*), construction management capability (*CM*), safety and environmental protection (*S&E*), and past feat (*Feat*). And the *SPF* (criterion 2.3) includes seven level-three criteria: QA, schedule, SPEC, S&E, perform, subcontractor management capability (*S. C.*), and service post installation (*service*). Subsequently, the committee determined the weightings of these criteria for each level of the hierarchy as shown in Table 2.

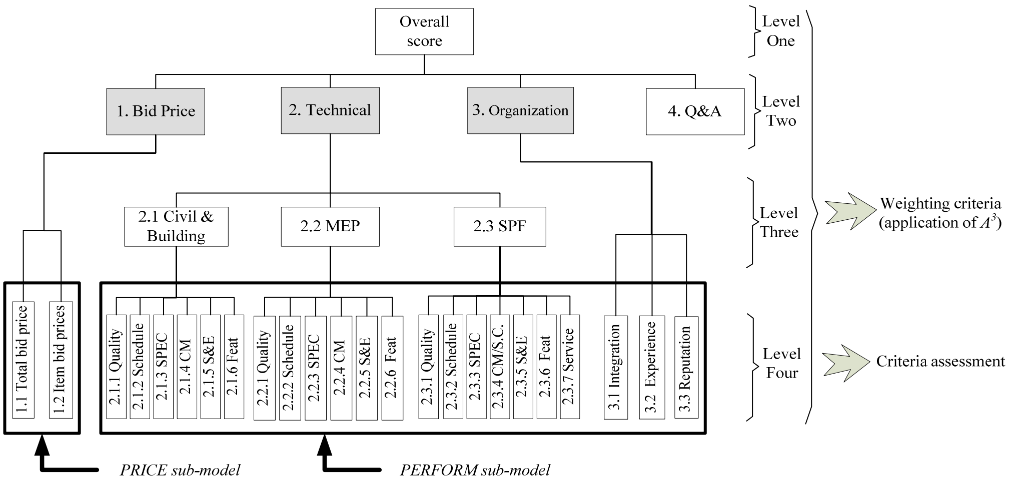

Figure 5: Hierarchy of Criteria Applied in AHP and A^3

RESULTS OF CONTRACTOR SELECTION

Only two bidders, namely bidders A and B, bid for this case project. After reviewing the bidder submissions, auditing their oral presentations, and clarifying questions via Q&A, except the bid price criterion, the committee is assumed to execute performance evaluation for the 22 criteria at the bottom level (i.e., level-four criteria) of the decision hierarchy for each bidder. The overall score of a bidder is calculated by aggregating the weighted score of each criterion at the bottom level. Table 2 illustrates the demonstrated scoring outcome including the average weightings of each level-criterion, average and weighted scores of criteria at the bottom level and overall score for each bidder when applying the A^3, PRICE and PERFORM model. This approach suggests the same result with the actual practice, namely, bidder B is identified as the best value bidder. Further details can be found in articles by Lin et al. (2008).

Table 2: The Scoring Outcome of Case Study when Applying the A3, PRICE and PERFORM Model

Criteria	Average weightings of criteria			Average scores of criteria				Weighted scores	
	A^3 method			PRICE sub-model		PERFORM sub-model		(Finial scores)	
	Level 2	Level 3	Level 4	bidder A	bidder B	bidder A	bidder B	bidder A	bidder B
1. Bid price	0.113								
1.1 Total bid price			0.078	96.356	96.554			7.516	7.531
1.2 Item bid prices			0.035	85.804	86.687			3.003	3.034
2. Technical	0.547								
2.1 C&B		0.109							
2.1.1 Quality			0.023			75.00	80.00	1.725	1.840
2.1.2 Schedule			0.026			80.00	81.67	2.080	2.123
2.1.3 SPEC			0.022			80.00	78.33	1.760	1.723
2.1.4 CM			0.018			81.67	83.33	1.470	1.500
2.1.5 S&E			0.007			81.67	81.67	0.572	0.572
2.1.6 Feat			0.013			80.00	86.67	1.040	1.127
2.2 MEP		0.206							
2.2.1 Quality			0.047			76.67	78.33	3.603	3.682
2.2.2 Schedule			0.042			83.33	83.33	3.500	3.500
2.2.3 SPEC			0.056			75.00	80.00	4.200	4.480
2.2.4 CM			0.025			75.00	76.67	1.875	1.917
2.2.5 S&E			0.015			75.00	83.33	1.125	1.250
2.2.6 Feat			0.021			83.33	83.33	1.750	1.750
2.3 SPF		0.232							
2.3.1 Quality			0.043			78.33	83.33	3.368	3.583
2.3.2 Schedule			0.032			83.33	81.67	2.667	2.613
2.3.3 SPEC			0.068			75.00	80.00	5.100	5.440
2.3.4 CM /S.C.			0.014			85.00	81.67	1.190	1.143
2.3.5 S&E			0.022			75.00	80.00	1.650	1.760
2.3.6 Feat			0.027			81.67	81.67	2.205	2.205
2.3.7 Service			0.026			81.67	80.00	2.123	2.080
3. Organization	0.281								
3.1 Integration			0.120			85.00	83.33	10.200	10.000
3.2 Experience			0.041			83.33	83.33	3.417	3.417
3.3 Reputation			0.120			80.00	81.67	9.600	9.800
4. Q&A	0.059					88.33	86.67	5.212	5.113
Overall score	1.000							81.951	83.184

LESSONS LEARNED

After conducting the demonstrated case study, several lessons corresponding to practitioners' major concerns of using the integrated approach by A^3, PRICE and PERFORM are presented in two aspects:

- The legality of A^3, PRICE and PERFORM implementation procedure: Implementing the A^3 to weight the criteria and using the PRICE and PERFORM to evaluate the criteria can meet the legal requirements of Taiwan's government procurement law (GPL). However, the following three tasks should be carefully performed: (1) the determined criteria weights and the evaluation procedure for PRICE and PERFORM must be enclosed in the publicized tendering documents (step 4 in Figure 1) for ensuring the tendering procedure to be fair and transparent to all potential bidders. (2) If A^3, PRICE and PERFORM are applied, required data, parameters and formula should be collected in the formal meeting(s), again for claiming the openness and fairness of the tendering procedure. (3) All A^3 implementation materials should be formally documented.
- Implementation time for A^3 procedure: For A^3 approach, the initial PWMs obtained from the first assessment of the AHP is automatically reassessed when *CR* exceeds 0.10. Therefore, to ensure the legality and fairness of A^3 procedure it must be accomplished before finishing the tendering documents. Furthermore, during the course of this study, it is also identified that implementation time for A^3 should be kept as short as possible to avoid too many selection meetings required.

CONCLUSION

This paper has accomplished a demonstrated case study of applying the integrated model to facilitate the weightings and evaluations of the criteria involved in the BV contractor selection process in a real-world public construction project in Taiwan. This empirical study has showed that the practitioners' concerns of selecting appropriate contractor can be resolved. That is, first, an operation-level AHP-based procedure (i.e., A^3) has been developed to determine the criteria weightings and to meet Taiwan's legal requirements. Second, the direct quantitative evaluation method (i.e., PRICE) that rather than only focuses on the total bid price level also assesses the reasonability of the bid price allocated to each cost category has been successfully applied to four real-world projects. And third, the proposed performance-utility model (i.e., PERFORM) has been employed to quantify the expected performances of qualitative criteria. Moreover, we also observed from the demonstrated case study that members from technical domain are very importance for the selection committee because they are usually the main decision maker for the BV contractor selection process. Therefore, a strategy to include experts from as many domains with different background conforming to project characteristics in the selection committee is suggested. However, the lessons learned from this demonstrated case study provide a useful guideline of applying this integrated model to future projects applications. The advantages of our proposed method include: (1) be able to quantify the expected performances; (2) be verified applicable to real-world public contraction projects in Taiwan. Finally, our future research tasks will be emphasized to develop a Multiple Criteria Decision Support System (MCDSS) for the BV contractor selection process with the modified performance utility function.

ACKNOWLEDGEMENTS

The authors would like to thank the Ministry of Education of Taiwan via the Aim for the Top University (MOU-ATU) program for financially supporting this research. The

National Laboratory Animal Center (NLAC) and the committee members of the case project are also appreciated for their collaboration.

REFERENCE

Alarcón, L. F. and Mourgues, C. (2002). Performance modeling for contractor selection, *Journal of Management in Engineering*, *ASCE*, 18 (2), pp.52-60.

Al-Harbi, K. A. S., Application of the AHP in project management, *International Journal of Project Management,* 19, pp.19-27 (2001).

Anagnostopoulos, K. P. and Vavatsikos, A. P. (2006). An AHP model for construction contractor prequalification, *Operational Research an International Journal*, 6 (3), pp.218-229.

Bertolini, M., Braglia, M. and Carmignani, G. (2006). Application of the AHP methodology in making a proposal for a public work contract, *International Journal of Project Management*, 24, pp.422-430.

El-Sawalhi, N., Eaton, D. and Rustom, R., Contractor pre-qualification model: State-of-the-art, *International Journal of Project Management*, 25 (5), pp. 465-474 (2007).

Fong, S. W. and Choi, K. Y. (2000). Final contractor selection using the analytical hierarchy process, *Construction Management and Economics*, 18, pp.547-557.

Georgy, M. E., Chang, L. M. and Zhang, L. (2005). Utility-function model for engineering performance assessment, *Journal of Construction Engineering and Management*, *ASCE*, 131 (5), pp.558-568.

Hatush, Z. and Skitmore M. (1998). Contractor selection using multicriteria utility theory: an additive model, *Building and Environment*, 33 (2), pp.105-115.

Hsieh, T. Y., Lu, S. T. and Tzeng, G. H., Fuzzy MCDM approach for planning and design tender selection in public office buildings, *International Journal of Project Management*, 22, pp.573-584 (2004).

Holt, G. D., Olomolaiye, P. O. and Harris, F. C., Evaluating performance potential in the selection of construction contractors, *Engineering, Construction and Architectural Management* , 1(1), 29-50 (1994).

Hong Kong Housing Authority, *PASS. Performance Assessment Scoring System*, Housing Department, Hong Kong Housing Authority (1994).

Kahraman, C., Cbeci, U. and Ulukan, Z., Multi-criteria supplier selection using fuzzy AHP, *Logistics Information Management*, 16 (6), pp.382-394 (2003).

Kumaraswamy, M. M. (1996). Contractor evaluation and selection: a Hong Kong perspective, *Building and Environment*, 31 (3), pp.273-282.

Lin, C. C., Wang, W. C., and Yu, W. D. (2008). "Improving Multiple Criteria Decision-Making in Construction via an Adaptive AHP Approach (A^3)," Automation in Construction, 17 (2), pp. 180-187.

Lin, C. C. (2008). Models of contractor selection and bid price evaluation for most advantageous tendering method, PhD dissertation, Department of Civil Engineering, National Chiao Tung University, Taiwan.

Lin, C. C., Wang, W. C. and Yang, J. B., Evaluating bid item prices to support contractor selection – a case study, *Journal of the Chinese Institute of Engineers,* 30 (4), pp. 765-771 (2007).

Li, Y., Nie, X. and Chen, S. (2007). Fuzzy approach to prequalifying construction contractors, *Journal of Construction Engineering and Management*, *ASCE*, 133

(1), pp.40-49.

Maturana, S., Alarcón, L. F., Gazmuri, P. and Vrsalovic, M. (2007). On-Site Subcontractor Evaluation Method Based on Lean Principles and Partnering Practices, *Journal of Management in Engineering*, *ASCE*, 23 (2), pp.67-74.

PCC, 1998, Government Procurement Law. Public Construction Commission, Executive Yuan, Taiwan. (http://www.pcc.gov.tw/; 2006/10/21)

PCC, 2000, Regulations for evaluation of the most advantageous tender (in Chinese), Public Construction Commission, Executive Yuan, Taiwan. (http://www.pcc.gov.tw/; 2006/10/21).

Pongpeng, J. and Liston, J. (2003). TenSeM: a multicriteria and multidecision-makers model in tender evaluation, *Construction Management and Economics*, 21, pp. 21-30.

Singh, D. and Tiong, R. L. K. (2005). A fuzzy decision framework for contractor selection, *Journal of Construction Engineering and Management*, *ASCE*, 131 (1), pp.62-70.

Wang, W. C., 2004, "Electronic-based procedure for managing unbalanced bids," *Journal of Construction Engineering and Management*, 130 (3), pp. 455-460.

Wang, W. C., Wang, H. H., Lai, Y. T., and Li, J. C., 2006, "Unit-price-based model for evaluating competitive bids, *International Journal of Project Managemen*t, 24 (2), pp. 156-166.

Yang, J. B. and Wang, W. C. (2003), "Contractor selection by the most advantageous tendering approach in Taiwan," *Journal of the Chinese Institute of Engineers*, 26 (3), 381-387.