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ANALYZING PROCUREMENT ROUTE SELECTION FOR ELECTRIC POWER PLANTS PROJECTS USING SMART

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Abstract. The decision of selecting the appropriate procurement/delivery system for large investment construction projects is a critical and challenging task for clients, and therefore a significant factor for the project's success. Complex projects as electric power plants can involve managing multiple contracts or subcontracts simultaneously or in sequence. The aim of this paper is to develop, and analyze a decision support tool to select the most efficient procurement/delivery system for multiple contracts Combined Cycle Power Plants (CCPP) constructed in Egypt and funded by the public-sector. This process involved the identification of various procurement routes, followed by the utilization of quantitative values developed in accordance with the requirements of the multi-criteria decision analysis technique known as simple multi-attribute rating technique (SMART). Results revealed that the procurement/delivery system with the highest score, for all contractual packages, is the integrated project delivery method (IPD) under which other procurement/delivery methods could be utilized such as performance-based contracting (PBC), and construction management (CM). Further in this research, a sensitivity analysis approach was adopted to validate the IPD selection, and to determine the most critical criterion and the most critical measure of performance for each contractual package.

Keywords: procurement/delivery, selection criteria, IPD, procurement routes, SMART, sensitivity, CCPP, performance/effectiveness.

Introduction

Selection of appropriate procurement/delivery method for electric power plants projects is a crucial task for government agencies that run such class of projects. Procurement is an integral part of a construction project which includes sourcing, purchasing, and all activities related to providing knowledge, manpower, equipment, materials, supplies, supervision, and management services necessary to accomplish the project objectives (Martins 2009; Clough *et al.* 2000).

Clients usually tend to select a procurement method because they are used to it not because of its appropriateness and suitability with the project conditions (Pishdad, Beliveau 2010). For this reason various selection tools and models have been developed by researchers to serve as decision support tools for clients. Oyetunji and Anderson (2006) developed a decision support tool identifying the optimal delivery solution for capital industrial and general building projects. Their approach utilized a multi-criteria decision analysis known as simple multi-attribute rating technique with swing weights (SMARTS) for evaluating project delivery alternatives. Kenig (2007) discussed different components of project delivery and contracting strategy (PDCS) such as the delivery method, management options (CMA, PM, Turnkey), selection method (low bid, best value, qualification), and contract type (fixed price, GMP, Cost Plus Fee, T&M). He presented the characteristics of the delivery methods (DBB, DB, CMR). He further argued that these components and their different alternatives would create various hybrids of delivery contracting methods.

Bausman *et al.* (2013) examined previous studies to develop 12 best practices for the procurement and contract administration of professional services consultants. They 12 best practices are identified in the following areas: strategic planning; quality management; professional services management structure; standardization; operations manual, training and certification; automation; contract-specific procurement plans; indefinite delivery contracts; lump sum contracting; and performance metrics. Arain *et al.* (2014) assessed the future of traditional procurement and evaluated the current popularity of traditional procurement against alternative approaches to construction procurement in Canada. It was concluded that traditional procurement alone cannot support the unique needs of each and every project.

Selection factors/criteria are usually determined based on client's requirements and project objectives. Luu *et al.* (2003) conducted a survey on 34 procure-

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ment selection criteria (PSC) using a principle component analysis. They identified eight significant factors in procurement system selection: 'external factors', 'client's long-term objectives', 'project's physical-characteristics', 'client's involvement and risk allocation', and 'building's aesthetics and complexity'. Later, Luu *et al.* (2005) suggested that in reality, a combination of procurement selection criteria (PSC), such as speed, time certainly, quality, risk allocation, flexibility, etc., might have to be considered to encapsulate the distinctive characteristics of a project and client.

This paper presents a decision support tool developed to select the most efficient procurement/delivery system for multiple contracts Combined Cycle Power Plants (CCPP) constructed in Egypt. Upon identifying the various possible procurement routes, SMART was employed in the process of evaluating the procurement/delivery alternatives, and a sensitivity analysis was conducted.

1. Combined Cycle Power Plants (CCPP)

CCPP are large investment construction projects of high complexity and uncertainty. Therefore, Clients, especially public-sector clients, tend to adopt a multi-package contracting plan as it optimizes the client's control over the project. The following 15 work packages constitute the CCPP project. Every work package is considered a separate contract with specific terms and conditions. These contractual packages under study are determined from real on-going CCPP projects:

- Combustion Turbine Generator (W1);
- Civil Works (W2);
- Environmental Monitoring (W3);
- Switchyard (W4);
- Heat Recovery Steam Generator (W5);
- Steam Turbine Generator (W6);
- Yard Tanks (W7);
- Water & Waste Water Treatment (W8);
- Electrical Equipment Installation (W9);
- Mechanical Equipment Installation (W10);
- Pumps & Drives (W11);
- Critical Piping & Valves (W12);
- Power Transformers (W13);
- Distributed Control System (W14);
- Medium & Low Voltage Switchgear (W15).

2. Procurement routes

There are a number of different types of procurement routes available for clients to choose from. Selection of optimal procurement systems is difficult, because even experienced clients cannot know all the potential benefits or risks for each system (Tookey *et al.* 2001). Laedre *et al.* (2006) emphasized that the combination of procurement procedure, contract model, and compensation format constitutes the procurement route (Laedre *et al.* 2006). This research considered procurement routes which consists of five elements: 1) selection method, 2) evaluation strategy, 3) awarding procedure, 4) procurement/delivery system (contract model), and 5) compensation format (see Fig. 1).

Unstructured interviews were conducted with three client's construction managers with more than 15 years of experience in power plants projects. They were given the procurement routes diagram (see Fig. 1) and were requested to select the most efficient route for a CCPP project. It was concluded that public-sector clients prefer best-value procurement, and would arrange for a bidding competition and select a two-step method in evaluating contractors. Furthermore, the three respondents recommended a Lump-Sum Unit Price compensation format which allows the use of unit prices for those contractual items of which the scope is not clearly defined. For the procurement/delivery system element, respondents discarded the BOT, BOOT, PPP and PFI methods for their unsuitability to a multi-package contracting plan. However for the remaining 7 methods, no definite clear re-

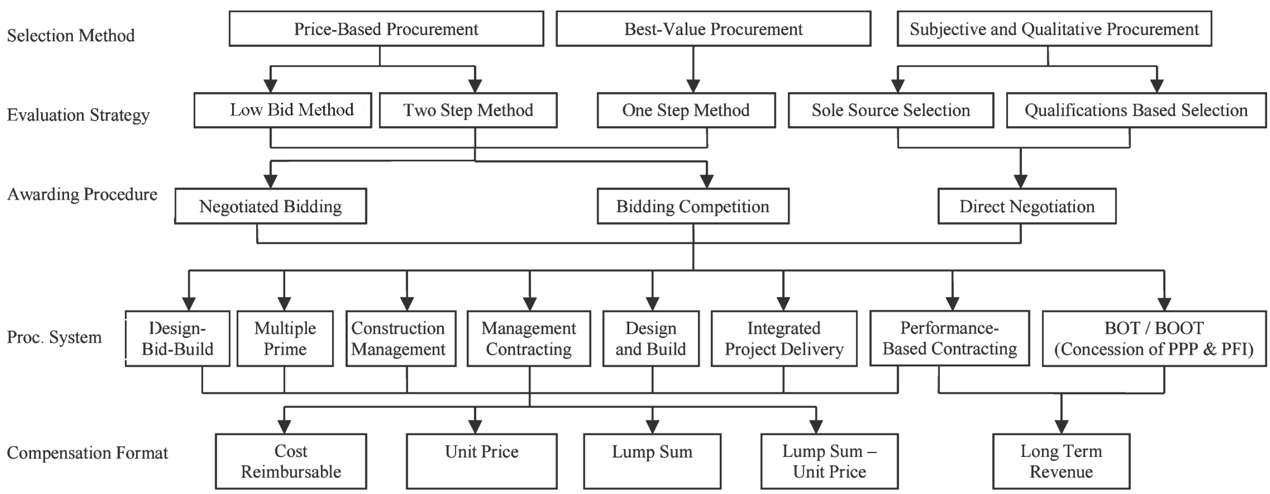

Fig. 1. Procurement routes elements

Fig. 2. Simple Multi-Attribute Rating Technique (SMART)

sponses were given. Accordingly, the main purpose of this research was determined to be the development of a decision support tool that would assist decision makers in their selection for the most efficient procurement/delivery system(s) for a multiple contracts CCPP project.

3. Simple multi-attribute rating technique

Simple Multi-Attribute Rating Technique (SMART) is utilized in this study (see Fig. 2), conducting the following main five steps.

3.1. Identification of alternatives

In their research, Ruparathna and Hewage (2013) presented a comprehensive review of traditional and emerging procurement practices in the construction industry, and concluded that the ultimate objective of a construction procurement method should be to satisfy the project owner through realizing the project objectives.

As a result of earlier discussion, the following seven alternative procurement/delivery systems have been studied with depth throughout this research.

Design Bid Build (DBB): A separate contract is entered into between the client and the structural/civil engineer. Later, a separate contract is entered into by the client and the contractor/supplier.

Multiple Prime (MP): Commonly utilized within a design-bid-build process. However, in a multi-prime delivery method, the client contracts directly with multiple contractors, and thus client acts as the general contractor on its own project (AIA 2007).

Design and Build (DB): One organization takes full responsibility and carries the sole liability for both design and construction. This process has several limitations. For example, the design which forms the basis of tenders inhibits ingenuity and creativity of the tendering consortia by limiting them to the initial consultant's vision of the desired facility (Ngowi 1998).

Construction Management (CM): Client engages a construction manager as an agent. Contracts are entered into directly between the client and the various works contractors (Donohoe, Brooks 2007). The construction manager, while managing information flow, has limited legal liability, and consequently earns profits at much less risk (Donohoe, Brooks 2007).

Management Contracting (MC): Contractors of various works enter into contracts with the management contractor, i.e. they do not contract directly with the client (Donohoe, Brooks 2007). The management contractor assumes all the liabilities and responsibilities of a general contractor, which is why this delivery system is also known as Construction Manager at Risk; CMc (AIA 2007).

Performance-Based Contracting (PBC): Under the performance-based contract, most of the payments to be paid to the contractor are not based on quantities of works measured by unit prices for works inputs, but on measured outputs reflecting the target conditions of the project under contract, expressed through "Service Levels". These levels are defined in the contract (World Bank 2006). PBC is beneficial for clients who prefer to shift project risks to contractors. PBC is also theoretically better for recipients, assuming the required outcomes are the ones that make a difference to them. Payments from the public sector could be forthcoming after completion. Payments for the use of the structure would be spread over a long period (Gruneberg 2007). Contractors would then have an incentive to provide quality in their built solutions to ensure payments in the long run.

Integrated Project Delivery (IPD): IPD is a delivery approach that integrates people, systems, business structures, and practices into a process that collaboratively harnesses the talents and insights of all participants to optimize project results, increase value to the client, reduce waste, and maximize efficiency through all phases of design, fabrication, and construction. IPD is distinguished by early contributions of knowledge and expertise through utilization of new technologies allowing all team members to better realize their highest potentials while expanding the value they provide throughout the project life cycle (AIA 2007).

In IPD procurement/delivery system, Multi-Party Agreements (MPA) take place where the primary project participants execute a single contract specifying their roles, rights, obligations, and liabilities. Under IPD, other procurement/delivery methods are adopted to constitute the project contractual model. Opportunities for integration are increased with delivery methods where the constructor can be brought early into the project, such as Design-Build that is very well suited for increasing collaboration among the design and construction team members. On the contrary, the Design-Bid-Build method offers very few opportunities for true integration. While for Construction Manager at Risk (CMc) method, it is particularly well suited to IPD. Also, a PBC model could be utilized under IPD process.

3.2. Identification of selection criteria

Six decision selection criteria, divided into 32 sub-criteria, have been identified and collected from literature and unstructured interviews with experts in power plants projects (see Table 1). A questionnaire survey in the form of face-to-face interview has been conducted with thirty-five practitioners, who are domain experts in the industry of power plants, however, only 27 responses were obtained. Respondents were classified into four categories: Client (5), Local Client Representative (10), International Client Representative (6), and International Contractors (6). Every respondent was requested to assign, on a five point scale, an importance value for each of the 32 selection sub-criteria with respect to the decision of selecting the best alternative procurement system for a power plant project.

Table 1. Selection criteria and sub-criteria

Selection criteria	Sub-criteria	Description
External Environment	Regulatory Feasibility	Existence of rules and regulations that have impact on the project delivery
	Materials Availability	Availability of materials as required in project specifications
	Technology Feasibility	Availability of technology to carry out certain construction techniques required
	Labour Productivity	Availability of experienced labour, capable of carrying out certain construction activities
	Market Competitiveness	Level of competition in market with respect to this project
	Contractors' Availability	Availability of contractors and/or subcontractors who have expertise to fulfil project requirements
	Natural Disasters	Probability of occurrence of natural disasters that might hinder the project activities
Project Characteristics	Complexity	Need for a highly specialized, technologically advanced, or highly serviced project
	Project Size	Project size measured by its estimated value
	Flexibility	Ability to effect changes
	Quality	The quality level required of the completed project
	Time Certainty	Availability of early and reliable schedule to ensure on-time completion
	Cost Certainty	Availability of early and reliable cost figures to facilitate financial planning and business decisions
	Project Culture & Location	Objection from neighbour or local lobby group to construct the project
Project Risks	Industrial Actions	Existence of industrial actions that might affect the project delivery
	Political Constraints	Existence of political activities that might have an impact on the project delivery
	Site Risk Factors	Existence of various site risk factors (known and unknown) that can impact the project delivery
	Usage of Pioneering Technology	The risk of using / providing pioneering technology that client's personnel are not used to
Client's Objectives	Within-Budget Completion	Client wishes that project is completed in budget
	On-Time Completion	Client wishes that project is completed on time
	Value for Money (VFM)	Client's desire to achieving better quality at same cost, or same quality at lower cost
	Life-Cycle Efficiency	Client's requirement for building to have low operational and maintenance costs
	Minimize Dispute	Client's desire to avoid adversarial relationships among the contracting parties
	Safety and Security	Client's requirement for the safety of people, and confidentiality of project documents and technology
	Sustainability	Client's requirement to achieve the anticipated results of the green revolution manifested in reductions in energy consumption, better health and higher productivity for occupants
Client's Characteristics	In-House Capability	Client's capability to use their own resources (financial and technical) in this particular project
	Experience	Experience of client and their organization in this construction domain
	Type	Nature of client's organization in this particular project
	Point of Responsibility	Client's choice on the number of contracting parties (single vs. multiple)
Client's Involvement & Risk Allocation	Willingness to be Involved	Client's wishes to be directly involved in this project
	Willingness to Take Risks	Client's willingness to take certain risks in order tom improve project performance

The coefficient of reliability was calculated for each category of respondents using Eqn (1) (Iacobucci, Duhachek 2003):

$$\alpha = \frac{p}{p-1}\left[1-\frac{\sum_{i=1}^{p}\sigma_i^2}{\sigma_T^2}\right], \quad (1)$$

where: α is Cronbach's coefficient alpha, p is the number of items in the scale, σ_i^2 is the variance of the i^{th} item, and $\sigma^2{}_T$ is the variance of the entire test.

Based on reliability values, each category of respondents was given a weight. Coefficients of reliability for the Client, Local Client Representative, International Client Representative, and International Contractors categories were computed to be 0.43, 0.78, 0.79, and 0.8 respectively. Accordingly, the weights assigned to Client, Local Client Representative, International Client Representative, and International Contractors categories are 0.1, 0.35, 0.35, and 0.2 respectively.

Weighted mean values were then calculated for each sub-criterion with respect to each of the four respondents' categories. Then the total mean value of each sub-criterion was determined by adding up the weighted mean values of the four respondents' categories. As a result, only four sub-criteria had a total mean value that is less than 3.0: Natural Disasters, Project Culture and Location, Industrial Actions, and Type of Client. These four sub-criteria were not considered further in this paper, only the remaining 28 sub-criteria.

3.3. Determination of relative weights for sub-criteria

A questionnaire survey has been designed for the purpose of determining relative weights for the 28 selection sub-criteria with respect to each of the 15 main work packages which constitute the CCPP project under study. For each package, the survey was distributed to three domain experts with technical, procurement, and site backgrounds. Targeted respondents to this survey have been working for more than 15 years in CCPP projects and are all in senior, supervisory, and managerial levels. Respondents were requested to assign relative importance for sub-criteria under each of the six main criteria, and also to assign relative importance for the six main criteria. Using Simo's procedure (Marzouk *et al.* 2013), weights for the 28 selection sub-criteria were determined. Since there is more than one cluster of criteria, the calculated weights had to be converted from local weights within each cluster to global weights among all sub-criteria of all clusters. Only the local weights for the main clusters of criteria are considered global as well. The top ten sub-criteria, i.e. the most important ten sub-criteria, based upon calculated weights, with respect to all 15 packages are listed under Table 2.

Several implications have been drawn from the weights obtained for sub-criteria, and accordingly their ranking with respect to each work package. For example, the most important criteria for the Combustion Turbine Generator package (W1) is Quality (C10) which indicates that quality is the most critical evaluation factor upon choosing the delivery method and the contractor for this package in specific. While for the Civil Works package (W2), Market Competitiveness (C5) is the most critical evaluation factor since the level of competition in market with respect to this package is relatively high, i.e. the components of this package have high market competitiveness. Moreover, the criteria of Regulatory Feasibility (C1) is the most critical for the Environmental Monitoring (W3) package as the existing environmental rules and regulations have a great impact on this package delivery.

Table 2. Top ten sub-criteria with respect to all 15 work packages

Ranks of Sub-Criteria	Top 10 Sub-Criteria for Each Work Package														
	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15
1*	C10	C5	C1	C13	C15	C25	C17	C14	C14	C14	C25	C13	C14	C15	C5
2	C28	C11	C23	C14	C11	C24	C25	C17	C17	C17	C24	C5	C15	C24	C15
3	C24	C14	C6	C1	C10	C17	C23	C6	C18	C13	C14	C17	C13	C17	C6
4	C15	C13	C10	C17	C19	C19	C4	C16	C2	C16	C11	C15	C16	C10	C10
5	C11	C2	C17	C2	C14	C11	C6	C18	C15	C3	C17	C3	C2	C14	C9
6	C6	C1	C15	C15	C13	C14	C18	C4	C13	C21	C10	C2	C17	C11	C17
7	C3	C17	C5	C26	C17	C10	C16	C2	C24	C6	C19	C18	C5	C20	C2
8	C7	C12	C3	C16	C24	C22	C14	C24	C6/ C4	C11	C23	C16	C20	C19	C24
9	C26	C18	C22	C11	C8	C18	C10	C10	C20/ C19	C5	C9	C11	C10	C23	C16
10	C23/ C13	C16	C11/ C7	C6/ C4	C6	C16/ C7	C21	C15/ C13	C16/ C11	C24/ C25	C8	C10	C24/ C25	C7	C3

* Most important sub-criterion, i.e. sub-criterion with highest weight.

3.4. Determination of performance/effectiveness values of alternative procurement/delivery systems

Unlike the classical MAUT process that provides for both linear and curvilinear value functions, the SMART approach is based on linear value functions only (Oyetunji, Anderson 2006). With qualitative selection factors like those in this study, the relative performance/effectiveness values of the alternative procurement systems are obtained directly based on judgment of experienced practitioners. A questionnaire survey was given to five domain experts in the field of procurement management of power plants projects. All experts have been managing CCPP projects for the past 5–10 years. Respondents were requested to assign performance/effectiveness values, on a 0–100 scale, for each of the 7 procurement/delivery systems with respect to every selection sub-criteria. Calculated means of performance/effectiveness values of the alternative procurement/delivery systems given by respondents are shown in Table 3.

Figure 3 compares the performance/effectiveness of the seven alternative procurement/delivery systems with respect to the 28 selection sub-criteria. It has been observed that the performance/effectiveness of IPD is the highest among other alternatives with respect to most sub-criteria except C1, C2, C5, C6, C20, C21, and C28.

For C2, C5, and C6, MP is the most effective alternative procurement/delivery method, while for C1, CM is the most effective alternative, and for C20, C21, and C28, DB is the most effective method. Furthermore, it has been noted that the performance/effectiveness values of alternatives are very close with respect to some sub-criteria such as C13. On the other hand, for certain sub-criteria such as C20, there are a high discrepancy in alternatives' performance/effectiveness values.

Furthermore and in order to validate the performance/effectiveness values obtained from experts, an index of qualitative variation, i.e. Coefficient of Variation (C_v), is computed in accordance with Eqn (2) (Freund 2004) to measure the statistical dispersion of performance/effectiveness responses with respect to every sub-criteria and every alternative. According to Abdi (2010), in a finite sample of N non-negative numbers with a real zero, the coefficient of variation can take value between 0 and $\sqrt{N}-1$.

In this research, it has been determined that performance/effectiveness values with a relative high coefficient of variation (i.e. $C_v \geq 1.0$) are less valid/reliable than those with a low coefficient of variation, and consequently need to be re-examined in future research. High coefficients of variation indicate that experts' responses vary with a great extent, and therefore their mean values could be misleading:

$$C_v = \frac{S}{M}, \tag{2}$$

where: S and M are the standard deviation and mean values for the responses for every sub-criteria.

3.5. Optimal alternative selection

The overall aggregate score, i.e. preference, for each alternative procurement/delivery system has been calculated. The most widely used aggregation rule follows the additive model, represented in Eqn (3) (Oyetunji, Anderson 2006):

$$U_i(x_1, x_2, ..x_n) = \sum_{i=1}^{n} w_i \cdot u_i(x_{ij}), \tag{3}$$

where: U_j represents the aggregate value score of alternative j, $u_i(x_{ij})$ represents the relative value of performance/effectiveness level of alternative j for the selection factor i, and w_i represents the relative weight of selection factor i ($\sum w_{i \text{ for all } i} = 1.0$). For the combustion turbine generator work package (W1), the aggregate scores/preferences (P) of the seven alternative procurement/delivery systems

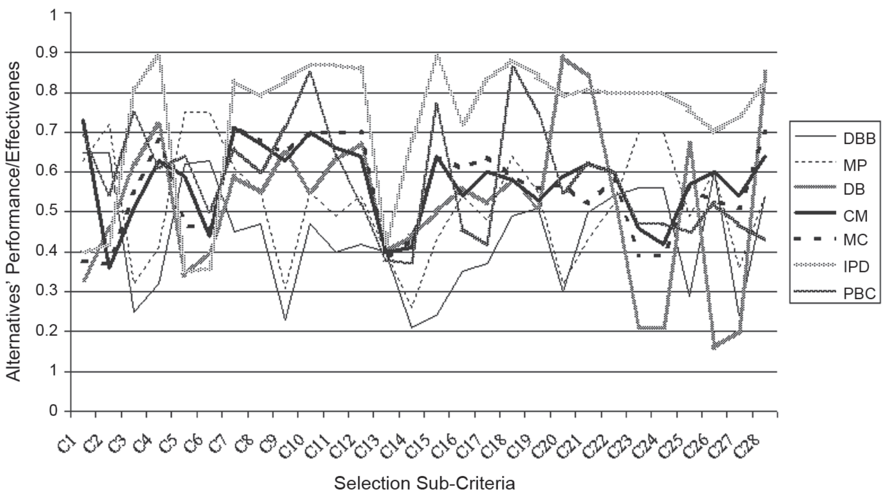

Fig. 3. Performance/effectiveness of procurement/delivery alternatives with respect to selection sub-criteria

Table 3. Metrics of aggregate scores/preferences of alternative procurement/delivery systems with respect to W1

C_i	Selection Sub-Criteria	Weight	Performance/Effectiveness						
			DBB	MP	DB	CM	MC	IPD	PBC
C1	Regulatory Feasibility	**0.034**	0.65	0.63	0.33	0.73	0.38	0.40	0.69
C2	Materials Availability	**0.017**	0.65	0.72	0.46	0.36	0.37	0.42	0.54
C3	Technology Feasibility	**0.057**	0.25	0.32	0.62	0.51	0.55	0.81	0.75
C4	Labor Productivity	**0.017**	0.32	0.41	0.72	0.63	0.68	0.89	0.61
C5	Market Competitiveness	**0.045**	0.62	0.75	0.34	0.59	0.47	0.35	0.64
C6	Contractors' Availability	**0.068**	0.63	0.75	0.40	0.44	0.46	0.36	0.50
C7	Complexity	**0.054**	0.45	0.61	0.59	0.71	0.72	0.83	0.66
C8	Project Size	**0.014**	0.47	0.55	0.55	0.67	0.68	0.79	0.60
C9	Flexibility	**0.040**	0.23	0.31	0.65	0.63	0.65	0.83	0.71
C10	Quality	**0.082**	0.47	0.55	0.55	0.70	0.70	0.87	0.85
C11	Time Certainty	**0.068**	0.40	0.49	0.63	0.66	0.70	0.87	0.64
C12	Cost Certainty	**0.027**	0.42	0.54	0.67	0.64	0.70	0.86	0.52
C13	Political Constraints	**0.048**	0.40	0.40	0.40	0.40	0.38	0.42	0.38
C14	Site Risk Factors	**0.024**	0.21	0.26	0.44	0.41	0.43	0.68	0.37
C15	Usage of Pioneering Technology	**0.071**	0.24	0.43	0.50	0.64	0.64	0.89	0.77
C16	Within-Budget Completion	**0.009**	0.35	0.54	0.56	0.54	0.61	0.72	0.46
C17	On-Time Completion	**0.012**	0.37	0.48	0.52	0.60	0.64	0.83	0.42
C18	Value for Money (VFM)	**0.010**	0.49	0.64	0.58	0.58	0.59	0.88	0.86
C19	Life-Cycle Efficiency	**0.007**	0.51	0.55	0.51	0.53	0.56	0.84	0.75
C20	Minimize Dispute	**0.002**	0.30	0.32	0.89	0.59	0.57	0.79	0.55
C21	Safety and Security	**0.005**	0.50	0.43	0.84	0.62	0.52	0.81	0.62
C22	Sustainability	**0.003**	0.54	0.52	0.54	0.60	0.58	0.80	0.60
C23	In-House Capability	**0.048**	0.56	0.70	0.21	0.46	0.39	0.80	0.47
C24	Experience	**0.071**	0.56	0.70	0.21	0.42	0.39	0.80	0.47
C25	Point of Responsibility	**0.024**	0.29	0.49	0.67	0.57	0.56	0.76	0.45
C26	Willingness to be Involved	**0.048**	0.60	0.60	0.16	0.60	0.53	0.70	0.52
C27	Willingness to Take Risks	**0.024**	0.24	0.36	0.20	0.54	0.51	0.74	0.47
C28	Trust towards Other Parties	**0.071**	0.54	0.54	0.85	0.64	0.70	0.82	0.43
Total		$\sum w_i$ **=1.00**							
Preferences (P)			0.45	0.54	0.49	0.57	0.56	0.73	0.59

with respect to the 28 selection sub-criteria are shown in Table 3. Similar quantitative metrics have been computed for the remaining 14 packages.

4. Sensitivity analysis

Data in multi-criteria decision making (MCDM) problems are often imprecise and changeable (Triantaphyllou, Sanchez 1997). Thus an important step in many applications of MCDM is to perform a sensitivity analysis on the input data.

4.1. Determining the most critical criterion

The most critical criterion is not necessarily the most important criterion, i.e. does not necessarily correspond to the criterion with the highest weight. Critical here is the smallest change that might occur to a certain criterion in order to affect the ranking of alternatives. The term "smallest change" can be defined in two different ways. The first way is to define smallest change in *absolute terms*, and the second way is to define smallest change in *relative terms* (Triantaphyllou, Sanchez 1997). Monitoring the behavior of alternatives is essential, and this can occur by observing the changes that occur in weights of criteria and its effect on the ranking of alternatives, considering two different points of views (Marzouk *et al.* 2013). The first one is of those who are concerned with the change within any two alternatives to reverse their existing rankings, while others might be interested only in the best (top) alternative changes. Accordingly, four definitions can be considered: Absolute Any (AA), Absolute Top (AT), Percent Any (PA), and Percent Top (PT) (Marzouk *et al.* 2013).

Let $\delta_{k,i,j}$ ($1 \leq i < j \leq M$ and $N \geq k \geq 1$) denote the minimum absolute change in the current weight W_k of criterion C_k such that the ranking of alternatives A_i and A_j will be reversed, while $\delta'_{k,i,j}$ expresses changes in relative terms (Triantaphyllou, Sanchez 1997). Absolute and relative changes in weights of sub-criteria have been computed by applying Eqns (4) or (5), and (6):

$$\delta_{k,i,j} < \left[\frac{P_j - P_i}{a_{jk} - a_{ik}}\right], \; if\,(a_{jk} > a_{ik}), \text{ or} \tag{4}$$

$$\delta_{k,i,j} > \left[\frac{P_j - P_i}{a_{jk} - a_{ik}}\right], \; if\,(a_{jk} < a_{ik}), \tag{5}$$

$$\delta'_{k,i,j} = \delta_{k,i,j} \times \left(\frac{100}{W_k}\right), \tag{6}$$

where: P is the final preference of alternatives and a is performance/effectiveness of alternatives.

The following condition should be satisfied for the values to be feasible (Triantaphyllou, Sanchez 1997):

$$\frac{P_j - P_i}{a_{jk} - a_{ik}} \leq W_k\,. \tag{7}$$

Table 4 illustrates the above-mentioned four definitions of AA, AT, PA, and PT for the 15 work packages under study. PA and PT can be found respectively by looking for the smallest relative $\delta'_{k,i,j}$, and the smallest relative $\delta'_{k,i,j}$ only of those related to the best alternative procurement/delivery system (Triantaphyllou, Sanchez 1997). The AA and AT have been similarly determined, upon calculating all possible absolute changes in the current weights of sub-criteria.

Criticality degrees and sensitivity coefficients of all sub-criteria, with respect to the 15 work packages, have been computed. The criticality degree of criterion C_k, denoted as D'_k, is the smallest percent amount by which the current value of the alternatives will change, such that the existing ranking of alternatives will change. The sensitivity coefficient of criterion C_k is the reciprocal of its criticality degree (Triantaphyllou, Sanchez 1997). Sensitivity coefficients are given the value zero for infeasible criticality degrees:

$$D'_k = \min_{1 \leq i < j \leq M} \left\{\left|\delta'_{k,i,j}\right|\right\}, \; for \text{ all } \; N \geq k \geq 1. \tag{8}$$

Table 4. Absolute any, absolute top, percent any, and percent top critical criteria

Work Packages	AA	AT	PA	PT
W1	C1	C5	C1	C6
W2	C2	C1 & C5	C5	C5
W3	C9	C1 & C5	C23	C1
W4	C1	C1	C1	C1
W5	C3	C1 & C5	C15	C6
W6	C18	C5	C17	C6
W7	C20	C5	C23	C6
W8	C20	C5	C6	C6
W9	C20	C5	C24	C2
W10	C23 & C24	C1	C21	C6
W11	C20	C5	C24	C6
W12	C2	C1 & C5	C5	C5
W13	C1	C1	C17	C5
W14	C28	C1	C17	C6
W15	C2 & C9	C1 & C5	C5	C5

The most important sub-criterion, i.e. sub-criterion with the highest weight, versus the most sensitive sub-criterion for the 15 work packages are shown in Table 5.

4.2. Determining the most critical measure of performance

The second stage of sensitivity analysis is determining the most critical measure of performance (a_{ij}). Let $_{i,j,k}$ ($1 \leq i < k \leq M$ and $N \geq j \geq 1$) denote the threshold value of $a_{ij,}$ which is the minimum change which has to occur on the current value of a_{ij} such that the current ranking between alternatives A_i and A_k will change. Since there are M alternatives, then each a_{ij} performance measure is associated with (M–1) such threshold values. It could also be considered here to express threshold values, denoted as $^{/}_{i,j,k}$, in relative terms (Triantaphyllou, Sanchez

Table 5. Most important vs. most sensitive sub-criteria for all 15 work packages

Work Package	Most Important Sub-Criterion	Most Sensitive Sub-Criterion
W1	Quality (C10)	Regulatory Feasibility (C1)
W2	Market Competitiveness (C5)	Market Competitiveness (C5)
W3	Regulatory Feasibility (C1)	In-House Capability (stakeholder integration) (C23)
W4	Political Constraints (C13)	Regulatory Feasibility (C1)
W5	Usage of Pioneering Technology (C15)	Usage of Pioneering Technology (C15)
W6	Experience (C24) / Point of Responsibility (C25)	On-Time Completion (C17)
W7	On-Time Completion (C17)	In-House Capability (stakeholder integration) (C23)
W8	Site Risk Factors (C14)	Contractors' Availability (C6)
W9	Site Risk Factors (C14)	Experience (C24)
W10	Site Risk Factors (C14)	Safety and Security (C21)
W11	Experience (C24) / Point of Responsibility (C25)	Experience (C24)
W12	Political Constraints (C13)	Market Competitiveness (C5)
W13	Site Risk Factors (C14)	On-Time Completion (C17)
W14	Usage of Pioneering Technology (C15)	On-Time Completion (C17)
W15	Market Competitiveness (C5)	Market Competitiveness (C5)

1997). Absolute and relative threshold values are computed as shown in Eqns (9) and (10). The most sensitive alternative is the one which is associated with the smallest threshold value:

$$_{i,j,k} = \frac{P_i - P_k}{W_i}; \quad (9)$$

$$'_{i,j,k} = _{i,j,k} \times \frac{100}{a_{ij}}. \quad (10)$$

The following condition should be satisfied for the values to be feasible:

$$'_{i,j,k} \leq 100. \quad (11)$$

Table 6. Most sensitive alternative procurement/delivery system(s) with respect to all 15 work packages

Work Package	Most Sensitive Alternative(s) Procurement/ Delivery System
W1	Construction Management (CM) & Management Contracting (MC)
W2	Multiple Prime (MP)
W3	Multiple Prime (MP)
W4	Construction Management (CM)
W5	Performance-Based Contracting (PBC)
W6	Construction Management (CM)
W7	Design and Build (DB)
W8	Multiple Prime (MP)
W9	Design and Build (DB)
W10	Design and Build (DB)
W11	Multiple Prime (MP)
W12	Construction Management (CM)
W13	Management Contracting (MC)
W14	Performance-Based Contracting (PBC)
W15	Multiple Prime (MP)

According to Eqns (12) and (13), criticality degrees ($'_{i,j}$) and sensitivity coefficients [*Sens* (a_{ij})] of A_i with respect to each a_{ij} performance measure have been computed for the seven alternative procurement/delivery systems with respect to the 15 work packages. It is noted that the smaller the criticality degree is, the easier the ranking of alternative A_i can change. However, the ranking of alternative A_i can change easier as the sensitivity coefficient is higher. Thus, the most sensitive alternative is the one with the highest sensitivity coefficient:

$$'_{i,j} = \min_{k \neq i} \left\{ \left| '_{i,j,k} \right| \right\}, \textit{for all } M \geq i \geq 1 \text{ and } N \geq j \geq 1; \quad (12)$$

$$Sens(a_{ij}) = \frac{1}{'_{i,j}}, \textit{for all } M \geq i \geq 1 \text{ and } N \geq j \geq 1. \quad (13)$$

Table 6 illustrates the most sensitive alternative with respect to the 15 work packages.

5. Pros and cons of IPD

IPD has the potential to be a "win-win" for all participants in the design and construction of a project (Andre 2011). Some of the great advantages that IPD has to offer are: innovative and collaborative design, reduced overall budget, reduced change orders, reduced construction timelines, better quality buildings, and better working relationships (Fish 2011). In addition, there are specific potential benefits include such as: (i) reduced risk of design and construction defects resulting from the collaborative, teamwork approach, and (ii) reduced liability for the designers and contractors resulting from the agreed upon limitations of liability and dispute avoidance (Andre 2011).

Even with the advantages that IPD offers, there are obstacles as there are with any new delivery method. Three of the main obstacles are: contracts, insurance, and structure of facilitation. These three obstacles are more concerns than disadvantages and can usually be solved with flexibility and knowledge within the industry (Fish 2011). Moreover, there are other possible disadvantages of IPD which include (Andre 2011): (i) decline of highly capable designers or contractors to participate in an IPD project for their unfamiliarity with IPD, (ii) Getting all of the core IPD team members to agree on one form of multi-party agreement could prove to be impossible, (iii) owners might have difficulty securing financing because lenders are not familiar with IPD or dislike its approach for any number of reasons, such as the potential for bonuses to be paid or the limitations of liability.

6. Results and discussion

The development phase of a project usually involves consideration of alternative procurement/delivery systems, in order to determine the most suitable system for the project. Upon applying SMART in this research and utilizing quantitative values developed in accordance with its requirements, it has been concluded that the procurement/delivery system with the highest preference, with respect to almost all of the 15 contractual packages under study, is the integrated project delivery method (IPD), followed by performance-based contracting (PBC), and construction management (CM). This is attributed to the IPD method having attained the highest performance/effectiveness values with respect to almost all selection sub-criteria. Despite discussing the pros and cons of IPD with experts during structured and unstructured interviews, their responses and accordingly the results obtained revealed that the benefits of IPD outweighed its possible disadvantages and/or concerns specifically for these types of projects.

The relative performance/effectiveness values presented in this paper constitute validated data (all calculated coefficients of variation (C_v) are between 0 and $\sqrt{N}$–1) that can be used in future research. However, it is recommended to re-evaluate the performance/effectiveness of alternative procurement/delivery systems with respect to sub-criteria for which experts' responses led to a relatively high coefficients of variation (i.e. $C_v \geq 1.0$). The highest coefficients of variation are associated to the performance/effectiveness values of DB method with respect to criteria C23, C24, C26, & C27, and performance/effectiveness values of IPD method with respect to criterion C1.

Furthermore, and in order to validate the IPD selection, a methodology for performing a sensitivity analysis on the weights of the decision sub-criteria and the performance/effectiveness values of alternatives has been presented. It has been proven that the sub-criterion with the highest weight is not necessarily the sub-criterion which can change the ranking of alternatives if subjected to the slightest change in its weight. The minimum change which has to occur on the current value of a_{ij} performance measure such that the current ranking between alternatives A_i and A_k will change has also been determined. it has been observed that the alternatives with the highest sensitivity coefficients, i.e. the most sensitive alternatives, with respect to all packages are interchangeably the Multiple Prime (MP), Design Build (DB), Construction Management (CM), Management Contracting (MC), and Performance-Based Contracting (PBC) methods. It has been noted that Design Bid Build (DBB) method has relatively high criticality degrees, and consequently low sensitivity coefficients. In addition, it has been observed that IPD method has zero sensitivity values with respect to all sub-criteria and all work packages. This is attributed to IPD having infeasible criticality degrees which result from IPD attainment of infeasible relative threshold values of a_{ij} performance measures with respect to all work packages. Accordingly, IPD method is the least sensitive alternative to changes occurring on the current values of a_{ij}.

Conclusions

This paper provided a decision support tool developed to select the most efficient procurement/delivery system for multiple contracts Combined Cycle Power Plants (CCPP) constructed in Egypt. The same selection methodology could be utilized with different types of electric power plants projects, and in other countries since CCPP projects possess much similar complexity all over the world. However, some quantitative values might change based on the client culture and experience, and also on the project external environment.

Under this study, various procurement routes were identified, and it was concluded that public-sector clients prefer best-value procurement, and would arrange for a bidding competition and select a two-step method in evaluating contractors. Moreover, it was concluded that a Lump-Sum Unit Price compensation format would be more efficient. SMART was employed in the process of evaluating 7 procurement/delivery alternatives which are: DBB, MP, DB, MC, CM, IPD, and PBC methods. Results revealed that the best procurement/delivery system for all work packages of a CCPP project is IPD under which the PBC and CM methods could be utilized to constitute the project contractual model. Accordingly, it is recommended for future research that the selection alternatives for a somehow similar decision problem would be hybrids of the procurement/delivery systems presented under this paper.

References

Abdi, H. 2010. Coefficient of variation, in N. Salkind (Ed.). *Encyclopedia of research design*. Thousand Oaks (CA): Sage, 169–171.

American Institute of Architects (AIA). 2007. *Integrated project delivery: A guide*. American Institute of Architects (AIA National l AIA California Council). 102 p.

Andre, G. R. 2011. *Integrated project delivery: a teamwork approach to design and construction* [online], [cited 04 May 2014]. Available from Internet: http://www.klgates.com/integrated-project-delivery-a-teamwork-approach-to-design-and-construction-09-15-2011/

Arain, F.; McFarlane, T.; Mah, D.; Zahed, M. 2014. Emerging project procurement trends in the Canadian construction industry, in *Proc. of Construction Research Congress*, 2014, 1399–1407.

Bausman, D.; Chowdhury, M.; Tupper, L. 2013. Best practices for procurement and management of professional services contracts, *Journal of Professional Issues in Engineering Education and Practice* 140(3). No 04013019.

Clough, R. H.; Sears, G. A.; Sears, S. K. 2000. *Construction project management – a practical guide to field construction management*. New York: Wiley. 408 p.

Donohoe, S.; Brooks, L. 2007. Reflections on construction management following Great Eastern Hotel Company v. John Laing, *Construction Management and Economics* 25(7): 701–708.

Fish, A. 2011. *Integrated project delivery: The obstacles of implementation*. MSc Thesis. Kansas State University, USA.

Freund, J. E. 2004. *Modern elementary statistics*. 11th ed. New Jersey: Pearson Education, Inc. 576 p.

Gruneberg, S. 2007. Performance-based contracting: an alternative approach to transacting in construction, *Construction Management and Economics* 25(2): 111–112.

Iacobucci, D.; Duhachek, A. 2003. Advancing alpha: measuring reliability with confidence, *Journal of Consumer Psychology* 13(4): 478–487.

Kenig, M. 2007. *Understanding project delivery method* [online], [cited 04 May 2014]. Available from Internet: https://www.agc.org/galleries/projectd/Kenig-20070321-PDS.pdf

Laedre, O.; Austeng, K.; Haugen, T. I.; Klakegg, O. J. 2006. Procurement routes in public building and construction projects, *Journal of Construction Engineering and Management* 132(7): 689–696.

Luu, D. T.; Ng, S. T.; Chen, S. E. 2003. Parameters governing the selection of procurement system – an empirical survey, *Engineering Construction and Architectural Management* 10(3): 209–218.

Luu, D. T.; Ng, S. T.; Chen, S. E. 2005. Formulating procurement selection criteria through case-based reasoning approach, *Journal of Computing in Civil Engineering* 19(3): 269–276.

Martins, M. 2009. Procurement, in C. Wankel (Ed.). *Encyclopedia of Business in Today's World*. Thousand Oaks (CA): Sage Publications, 1309–1311.

Marzouk, M.; Amer, O.; El-Said, M. 2013. Feasibility study of industrial projects using Simo's procedure, *Journal of Civil Engineering and Management* 19(1): 59–68.

Ngowi, A. B. 1998. Is construction procurement a key to sustainable development?, *Building Research & Information* 26(6): 340–350.

Oyetunji, A. A.; Anderson, S. D. 2006. Relative effectiveness of project delivery and contract strategies, *Journal of Construction Engineering and Management* 132(1): 3–13.

Pishdad, P. B.; Beliveau, Y. J. 2010. Analysis of existing project delivery and contracting strategy (PDCS) selection tools with a look towards emerging technology, in *Proc. of 46th Annual International Associated School of Construction (ASC)*, 2010, Boston, MA, USA. 8 p.

Ruparathna, R.; Hewage, K. 2013. Review of contemporary construction procurement practices, *Journal of Management in Engineering* 31(3): 04014038. http://dx.doi.org/10.1061/(ASCE)ME.1943-5479.0000279

The World Bank. 2006. *Sample bidding documents, procurement of works and services under output-and performance-based road contracts*. Washington, D.C.: The World Bank. 249 p.

Tookey, J. E.; Murray, M.; Hardcastle, C.; Langford, D. 2001. Construction procurement routes: re-defining the contours of construction procurement, *Engineering Construction and Architectural Management* 8(1): 20–30.

Triantaphyllou, E.; Sanchez, A. 1997. A sensitivity analysis approach for some deterministic multi-criteria decision making methods, *Decision Sciences* 28(1): 151–194.

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