Irrigation Contractors' Selection And Evaluation Model Based On A Multi-Criteria And Data Analysis

Mohamed Abdel-Hamid, Hanaa Mohamed Abdelhaleem

Civil Engineering Department, Faculty of Engineering at Shobra, Benha University, Benha, Egypt;

Civil Engineering Department, Delta Higher Institute for Engineering and Technology, Mansoura, Egypt

Abstract: The irrigation structures such as bridges, culverts, weirs and syphons are the most important projects in development the countries. The aim of this study is to choose the most efficient irrigation contractors for government procurement based on a multi-criteria and data analysis. When proposals are presented, the awarding board will determine the tender assessment measures of the bids received in advance. The research recommend a decision-making framework to support the awarding board in this hard mission while retaining a clear process in line with government procurement rules and conditions, as well as ensuring equal and fair assessment of all proposals. In this respect, the cross-efficiency evaluation has been used among the eligible candidates to select the best contractor. The suggested methodology allows the evaluation of quantitative contractor choice data and preserves the transparency functionality required by government procurement. Additionally, all proposals are analyzed similarly without any subjective adjusting by the public officers according to the same quantitative weights. A case study linked to the tender of an Egyptian public organization for selecting the efficient irrigation contractors confirms the efficiency of this approach.

Keywords: bidding public organizations; data analysis; decision making; irrigations contractors; contractors' selection.

1. INTRODUCTION

A construction project will be effective if it attains planned budget, a certain deadline and construction of a structure with required features (Fethi H. et al. 2019). So, the selection of the contractors and their related evaluation process for any organization is a crucial management issue for construction project. Identifying the top contractors to reach the expected performance level of a client is a complicated challenge. Therefore, considerable attention has been received to the contractor selection process in the literature on projects management (Polat, 2016; Xie, 2016; Semaan, 2017; Lin, 2017). In reality, wrong contractor selection will lead to poor project management which is the greatest issue causing rework, bad quality of the projects, delays in the delivery of products and thus, dangerous troubles in the construction projects (Asad K. et al., 2019). With respect to government procurement, the study attention is driven primarily by a huge amount of the money invested in this field each year. Thus, Government policies seek to encourage competition among nominee contractors in terms of cost and other aspects. In most cases of tenders, when considering both costs and technical aspects, the choice of the winning contractor is considered a difficult process because the number of contractors is extremely large compared to what is required, typically one contractor for each bid. The ranking of available offers must be strict and unambiguous so governments have begun using new contractors selection methods based on established private sector practices in many countries over the past few years (Love, 2011; Horta, 2013; Saiful, 2015; Alhumaidi, 2017). Thus, these two sectors' procurement methods - government and private - share common characteristics. Some of these characteristics are the lowest price, the contractor assets, the productivity required, the efficiency, the quality produced by the contractor and the contractor performance. The suggested solution consists of innovative apply of technique to analyze multiple bids in a public tender awarded. The multi-criteria assessment process, to be outlined in the remarks below, selects the efficient contractor without public determining weights. This technique uses some variables to obtain what inputs can be reduced to achieve efficiency by inefficient contractors. Some data about potential contractors have been proposed, and then the method for comparing obtainable contractors was adapted. In this method, the risk assessment and the lowest price for efficient contractors are presented, and then the case study is used to validate the method and achieve the paper aims.

2. LITERATURE REVIEW

Every nation has recognized its specific offering assessment of public procurement, in agreement with its construction marketplace. For example, the European Union used The Most Economically Advantageous Tender (MEAT) technique (Panos LL., 2010). Lately in several states, this approache has obtained significant consideration (Abdelrahman M., 2008; Wang WC., 2013). This method selects special criteria, counting costs in its assessment of proposals. On the other hand, Rashvand et al. (2015) concentrated on a managing performing as a certain factor in choosing the contractors. Liu et al. (2017) gathered the contractor choosing factors into 3 parts: Health, safety, and environment (HSE); Technology; and Tender price. These classes has been assessed by numerous researchers (Alsugair AM. et al., 1999; Mahdi I. et al., 2002; Watt DJ., et al., 2009; Sarkis J., et al., 2012; Nasab HH., et al., 2015; Xie H. et al., 2016). Other study developed an outline for decision making to help general administrations in selecting the best contractors. This technique applies a grouping of approaches for fuzzy

logic concept and multi-criteria decision-making (MCDM) in the initial phase to decrease the quantity of contractors, so the only effective contractors are chosen. In the next phase, the effective contractor risk factors are identified and estimated using fuzzy logic technique (Ali Ch. et al., 2019). The lowest price criterion is usually used when the technological characteristics of the provided item, service or function are similar and the cost is the only factor that differentiates the supply. Various (quantitative and qualitative) considerations are weighed concurrently when the contract is allocated on the basis of the multi criteria selection. The multi criteria selections have also been used in Egypt in the last twenty years, particularly in the construction sector.
For example, (Lorentziadis, 2010; Sipahi, 2010; El-Abbasy, 2013; Rashvand, 2013) suggested linear programming to determine criterion weights by proposing that all applicant contractors choose the median of the least or most desirable weight collection. The weights depend on the limits set by the public consumer. In the evaluation, different levels of significance for contractors can be selected, but only if they are chosen on the basis of criteria that competitors know in advance. All participants must be aware of this evaluation mechanism when the proposal request is announced.

The aim of the research

This paper introduces a tender assessment approach focused on the data analysis and the associated principle of cross-efficiency in order to overcome the above-outlined constraints. In contrast, the empirical bid analysis is omitted and there is no need for weights or utility features. In fact, it is possible to compare various bid indicators even though their scales are not homogeneous. As a result, it is necessary to evaluate all financial and non- financial inputs and outputs concurrently. This strategy is the product of the need for public officials to minimize room for subjective decisions that may wrongly advantage a corrupt contractor. This method is outlined in the following section.

Research methodology

The approach employed in this study contains a model that chooses the best contractors. This aspect is measured exclusive of the requirement to usage individual assessment, that assures good and identical assessment of each proposal. Usually, several factors for each contractor do not have a particular optimum clarification, so the model in this study aims to convert the several factors for each contractor into a particular decision. As a result, several aspects have been proposed in this paper as inputs and outputs for each contractor. The technique is a linear programming applied to assess the efficiency of a group of items. Efficiency is a function of the input and the output values. The data analysis approach of quality analysis in several areas has been implemented by (Ho, 2010). This research also expands the use of such a technique to the specific contractors' selection. Scenario created uncertainty study was made for possible uncertainties in some input factors (Sourabh J., 2018). Price, execution time, and resources costs are viewed as input factors when implementing the data analysis cross-efficiency evaluation: these are the tools used to perform the work. Input criteria reflects the equality of the service provided to the customer. The H= 3 criteria are therefore called input criteria. In addition, post-delivery maintenance and quality scores are deemed to be output factors owing to their connection to the final delivery quality, whereas the K= 2 criteria are output criteria. The output quality is determined by the number of resources that the contractor requires to perform the required project. The input and output of contractor is usually defined as follows in the approach:

$$E_i = \frac{\sum_{k=1}^{K} u_k \cdot y_{ki}}{\sum_{h=1}^{H} v_h \cdot x_{hi}} \qquad (1)$$

Where, F: Contractors number; K: Outputs number; H: Inputs number; u_k: The output performance weight coefficient, and k From 1 to K; y_{ki} : The output performance value delivered by contractor i, and i From 1 to F; v_h: The input performance weight coefficient, and h From 1 to H; and x_{hi}: The input performance value used by the contractor i to perform the work.
It is worth noting that with specified values,F,H,K,x,hi, and y_{ki} are parameters. In contrast, u_k and v_h are decision variables that are derived by solving the model with optimum values. If $E_i = 1$ the contractor i is efficient; otherwise, the contractor i is considered to be inefficient.
The efficiency of each contractor is achieved in the model by establishing the group of coefficients u_k and v_h that enlarges this value and, at the same instant, by taking into account that $E_i < 1$ remains by default for each contractor i. The contractor efficiency measurement can, therefore, be found by resolving the next equation of optimization for each called contractor i.

$$Max\ E_i \qquad (2)$$

Subject to,

$$\frac{\sum_{k=1}^{K} u_k \cdot y_{ki}}{\sum_{h=1}^{H} v_h \cdot x_{hi}} \leq 1 \qquad (3)$$

$$u_k , v_h \geq 0 \qquad (4)$$

The equations from 2 to 4 can be solved by minimizing the inputs and holding the output constant or by increasing the outputs. The problem is as follows, according to the method of increasing the outputs:

$$Max\ E_i = \sum_{k=1}^{K} u_k \cdot y_{ki} \qquad (5)$$

Subject to,

$$\sum_{k=1}^{K} u_k \cdot y_{ki} - \sum_{h=1}^{H} v_h \cdot x_{hi} \leq 0 \qquad (6)$$

$$\sum_{h=1}^{H} v_h \cdot x_{hi} = 1 \qquad (7)$$

Analyzed contractors' efficiency can be calculated by resolving the equations from 5 to 7 and 4. Contractors can, therefore, be ranked on the base of value of E_i. The model separates both ineffective and effective contractors and does not allow efficient contractors to be rated. In addition, this method is often only used for the contractor choice pre-evaluation process (Wang, 2010). As per this technique the coefficient resulting from optimizing the efficiency of each contractor is used to measure all contractors' effectiveness. To apply this technique, the Matlab linear programming solver is used and discussed in the next section.

Matlab linear programming

Matlab is one of the high-performance programming languages, known and required in programming, engineering and mathematical applications, especially matrices. This program finds the minimum of a problem specified by Linear Inequality Constraints:

$$min_x f^T x \quad such\ that \begin{cases} A.x \le b \\ A_{eq}.x = b_{eq} \\ lb \le x \le ub \end{cases} \qquad (8)$$

Where, $f^T x$ is the input coefficient column; b and b_{eq} are inputs column vectors; lb is the lower bounds inputs vectors; ub is the upper bounds inputs vectors; A and A_{eq} are inputs matrices (MxN); and x is the column solution output vector with N variables.

CASE STUDY

In order to justify the suggested procedure for giving offers, the discussed technique is used to a case study on selecting contractors to carry out supply and installation of 4 precast culverts with length of 50 m and the internal diameter of 1 m and thickness of 6 cm of reinforced concrete mixing using a mesh of high-strength steel reinforcement grade 36/52 rate 5 ϕ 10 mm longitudinal meter in the direction of the culvert pipe axis and at a rate of 6 ϕ 16 mm longitudinal meter in the perpendicular direction according to the specifications of the General Authority for Roads and Bridges in Egypt. The installation of the underground culvert is very significant and several risk aspects with great impact and probability are to be considered. In selecting the most suitable contractors, the public organization deemed in this paper is very careful. The organization performed a competence study for all prospective contractors as a preliminary stage, and for confidentiality reasons, only ten contractors (F= 10) were eligible as capable (satisfactory), denoted C1 through C10. The resource cost is 750,000 EGP and the expected time is 6 months. The model of selecting the tender describes the i bid with C_i in the following. Each bid was assessed on the basis of five parameters specified in the request for proposals. Three parameters are the inputs and two parameters are the outputs as follow:

- Input, h1, Quoted price with the corresponding value x_{i1} for the contractor in question and $i = 1, \ldots .10$;
- Input, h2, the implementation time of the work planned;
- Input, h3, the financial value of the resources in terms of the supervision cost sustained by the public organization to observe the works of each contractor;
- Outputs, k1, the quality score, the tendering committee used a scale of 0-10 to assess the values of y_{1i} based either on prior collaborations or on the study of capability. Up to 3 out of 10 points are allocated to resources (labor, equipment and materials, etc.), 2 points are allocated to previous experience, 2 points for proposed installation methodology, 2 points are allocated to the required team in the same area Machinery (pickups, mini excavators, hi-ups, etc.) and the lasting 1 point for proposal logistic.
- Outputs, K2, The duration of free maintenance post-delivery with the corresponding value y_{1i} measured in days.

Using data collection from this case study and according to Equations 4, 5, and 7 the Matlab linear programming code is developed. Also, Input Matrix, Output Matrix and X solution vector with N variables are produced.

Input matrix:

Input Matrix	Quoted Price (x_{1i})	Execution Time (Day) (x_{2i})	Resources Cost (x_{3i})
$I_{[10 \times 3]}$ =	169,729.76	200	148,224,0
	239,944.72	100	954,880
	115,291.21	120	155,648,0
	130,000.00	250	242,048,0
	108,116.46	250	709,120
	78,505.33	90	117,376,0
	102,198.90	160	116,992,0
	150,000.00	80	800,000
	280,000.00	110	138,496,0
	280,000.00	400	114,432,0

Output matrix:

Output Matrix	Quality Score (y_{1i})	Delivery Maint. (y_{2i})
$O_{[10 \times 2]}$ =	3	120
	4	50
	4	120
	6	200
	2	30
	2	30
	4	50
	9	365
	7	130
	6	30

First Constraint: $A.x \leq b$

$$\sum_{k=1}^{K} u_k \, . y_{ki} - \sum_{h=1}^{H} v_h \, . x_{hi} \leq 0 \quad for \quad i = 1, \dots, F$$

$$A_{[10X5]} = \begin{bmatrix} 0 & 0 & 0 & 3 & 120 \\ 0 & 0 & 0 & 4 & 50 \\ 0 & 0 & 0 & 4 & 120 \\ 0 & 0 & 0 & 6 & 200 \\ 0 & 0 & 0 & 2 & 30 \\ 0 & 0 & 0 & 2 & 30 \\ 0 & 0 & 0 & 4 & 50 \\ 0 & 0 & 0 & 9 & 365 \\ 0 & 0 & 0 & 7 & 130 \\ 0 & 0 & 0 & 6 & 30 \end{bmatrix} - \begin{bmatrix} 169{,}729.76 & 200 & 148{,}224{,}0 & 0 & 0 \\ 239{,}944.72 & 100 & 954{,}880 & 0 & 0 \\ 115{,}291.21 & 120 & 155{,}648{,}0 & 0 & 0 \\ 130{,}000.00 & 250 & 242{,}048{,}0 & 0 & 0 \\ 108{,}116.46 & 250 & 709{,}120 & 0 & 0 \\ 78{,}505.33 & 90 & 117{,}376{,}0 & 0 & 0 \\ 102{,}198.90 & 160 & 116{,}992{,}0 & 0 & 0 \\ 150{,}000.00 & 80 & 800{,}000 & 0 & 0 \\ 280{,}000.00 & 110 & 138{,}496{,}0 & 0 & 0 \\ 280{,}000.00 & 400 & 114{,}432{,}0 & 0 & 0 \end{bmatrix}, \quad b_{[10x1]} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} 0 & 0 & 0 & 3 & 120 \\ 0 & 0 & 0 & 4 & 50 \\ 0 & 0 & 0 & 4 & 120 \\ 0 & 0 & 0 & 6 & 200 \\ 0 & 0 & 0 & 2 & 30 \\ 0 & 0 & 0 & 2 & 30 \\ 0 & 0 & 0 & 4 & 50 \\ 0 & 0 & 0 & 9 & 365 \\ 0 & 0 & 0 & 7 & 130 \\ 0 & 0 & 0 & 6 & 30 \end{bmatrix} - \begin{bmatrix} 169{,}729.76 & 200 & 148{,}224{,}0 & 0 & 0 \\ 239{,}944.72 & 100 & 954{,}880 & 0 & 0 \\ 115{,}291.21 & 120 & 155{,}648{,}0 & 0 & 0 \\ 130{,}000.00 & 250 & 242{,}048{,}0 & 0 & 0 \\ 108{,}116.46 & 250 & 709{,}120 & 0 & 0 \\ 78{,}505.33 & 90 & 117{,}376{,}0 & 0 & 0 \\ 102{,}198.90 & 160 & 116{,}992{,}0 & 0 & 0 \\ 150{,}000.00 & 80 & 800{,}000 & 0 & 0 \\ 280{,}000.00 & 110 & 138{,}496{,}0 & 0 & 0 \\ 280{,}000.00 & 400 & 114{,}432{,}0 & 0 & 0 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

Second Constrain: $A_{eq}.x = b_{eq}$

$$\sum_{h=1}^{H} v_h \, . x_{hi} = 1$$

$$A_{eq\,[10\,x\,5]} = \begin{bmatrix} 169{,}729.76 & 200 & 148{,}224{,}0 & 0 & 0 \\ 239{,}944.72 & 100 & 954{,}880 & 0 & 0 \\ 115{,}291.21 & 120 & 155{,}648{,}0 & 0 & 0 \\ 130{,}000.00 & 250 & 242{,}048{,}0 & 0 & 0 \\ 108{,}116.46 & 250 & 709{,}120 & 0 & 0 \\ 78{,}505.33 & 90 & 117{,}376{,}0 & 0 & 0 \\ 102{,}198.90 & 160 & 116{,}992{,}0 & 0 & 0 \\ 150{,}000.00 & 80 & 800{,}000 & 0 & 0 \\ 280{,}000.00 & 110 & 138{,}496{,}0 & 0 & 0 \\ 280{,}000.00 & 400 & 114{,}432{,}0 & 0 & 0 \end{bmatrix}, \quad b_{eq\,[10\,x\,1]} = \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \end{bmatrix}$$

$$\begin{bmatrix} 169{,}729.76 & 200 & 148{,}224{,}0 & 0 & 0 \\ 239{,}944.72 & 100 & 954{,}880 & 0 & 0 \\ 115{,}291.21 & 120 & 155{,}648{,}0 & 0 & 0 \\ 130{,}000.00 & 250 & 242{,}048{,}0 & 0 & 0 \\ 108{,}116.46 & 250 & 709{,}120 & 0 & 0 \\ 78{,}505.33 & 90 & 117{,}376{,}0 & 0 & 0 \\ 102{,}198.90 & 160 & 116{,}992{,}0 & 0 & 0 \\ 150{,}000.00 & 80 & 800{,}000 & 0 & 0 \\ 280{,}000.00 & 110 & 138{,}496{,}0 & 0 & 0 \\ 280{,}000.00 & 400 & 114{,}432{,}0 & 0 & 0 \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \end{bmatrix}$$

Third Constrain $lb \leq x \leq ub$

$$lb_{[5 \times 1]} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}, \quad ub_{[5x\ 1]} = \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \\ 1 \end{bmatrix} \qquad \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} = x = \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \\ 1 \end{bmatrix}$$

These results are represented in Table (1). From this table, the quoted prices range from 102,198.90 (see C7) to 280,000 (see C9, and C10); the execution time ranges from 90 (see C6) to 400 days (see C10); the resources cost ranges from 709,120 (see C5) and 954,880 EGP (see C8). The duration of the post-delivery maintenance ranges from 30 (see C5, C6, and C10) and 365 days (see C8). Hence, the enhancement plans by C8 is the best, while those by C5 and C6 are the worst.

Table 1. Input and output values and efficiency scores for the case study

Contractor (C_i)	Quoted Price (x_{1i})	The Execution Time (day) (x_{2i})	Resources Cost (x_{3i})	Quality Score (y_{1i})	Post-Delivery Free Maintenance (day) (y_{2i})	Efficiency (E_i)	Ranking
C_1	169,729.76	200	148,224,0	3	120	0.2946	10
C_2	239,944.72	100	954,880	4	50	0.3724	8
C_3	115,291.21	120	155,648,0	4	120	0.5782	4
C_4	130,000.00	250	242,048,0	6	200	0.7692	2
C_5	108,116.46	250	709,120	2	30	0.3232	9
C_6	78,505.33	90	117,376,0	2	30	0.4246	7
C_7	102,198.90	160	116,992,0	4	50	0.6523	3
C_8	150,000.00	80	800,000	9	365	1.0000	1
C_9	280,000.00	110	138,496,0	7	130	0.5657	5
C_{10}	280,000.00	400	114,432,0	6	30	0.4661	6

This research method is not depende on a set of weights; therefore, each offer is well examined as a whole and the evaluation is not influenced by a subjective definition of priorities among criteria. A different choice of weight might have dictated a higher bid score. In this situation, even if the weights are arbitrarily allocated for the specific tenders, the assessment defined consequences that could be considered objectively true.

CONCLUSION

This paper introduced a new method to public procurement. Egypt law prescribes straightforward and objective processes for all kinds of public procurement, while evaluating the cross-efficiency data analysis method is recommended to rate specific proposals. Unlike previous ideas, the solution brought forward can rank contractors with a significant gain in transparency without the need for subjective judgments. However, the method takes into account as the bidding criteria the distinction between the needed resources and the benefits produced (by considering their ratio). With these traits, some of the drawbacks characteristics of other forms of contractor choice for government procurement were discussed favorably in the suggested process. On the other hand, a case study in Egyptian government procurement tested the feasibility of the strategy. The optimization formulation was adopted as it was considered the most appropriate methodology for the aim of contractors' selection. In greatest states, general organizations are attempting to acquire the greatest worth for public capital. As presented in this study, the proposed technique fits this principle to aid general organizations to select contractors that offer great significance to nation capital and at the similar moment with the smallest cost. This approach can, thus, be believed as a support to present improvements in the public procurement, mainly in situations where general agencies aim to concentrate not only on the prices of contracting a project but also on the execution time, resources costs, post-delivery maintenance, and quality. These results are considered the implications from this research study.

Even if this study supplies to the literature by offering a technique that is reliable with the most current improvements in public procurement and counts several aspects in assessing the efficiency of possible contractors, but, The proposed methods is applied to a single case study which is infrastructure projects. This can be believed as a limitation. These weaknesses open spots for coming studies. For instance, in the future researchs, building projects can be used as an alternative of infrastructure projects to contain different requirements in the final contractor choice procedure.

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