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Tender evaluation methods in construction projects: a comparative case study

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Abstract

A review of tender evaluation practices from around the world revealed the inadequacy of the 'lowest bidder' criterion for contractor selection. In response to this inadequacy, many countries have introduced qualifications to this cri terion and established procedures for the evaluation process. The objective of the qualifications is to select a suitable contractor whilst fostering compet itiveness. Using a multi criteria decision making (MCDM) approach, the study identified eight contractor attributes from the literature, which are thought to be indicators of contractors' capability to execute a contract and meet certain project specific criteria. Employing a case study project, the tenders of eight contractors short listed for the project were evaluated with the attributes using the "lowest bid", multi attribute analysis (MAA) and analytic hierarchy process (AHP) methods. The results showed that the two multi criteria decision making methods indicated the selection of contractors other than what the 'lowest bidder' criterion indicated. Comparing the results of the MAA and AHP meth ods, it is evident that the two methods differed very little in their ranking of the contractors. This implies that the more complex nature of AHP and the extra efforts it requires have only a minor influence on the final ranking of contrac tors and seems to suggest that the extra cost of using AHP is not justified.

Keywords: analytic hierarchy process, contractor selection, multi attribute analysis, pre qualification, tender evaluation

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Abstrak

'n Oorsig van tender evaluerings praktyke van reg oor die wêreld, het die ontoereikendheid van die 'laagste bod' kriteria vir kontrakteur keuse bekend gemaak. In reaksie op hierdie ontoereikendheid, het baie lande kwalifikasies tot hierdie kriteria asook prosedures vir die evalueringsproses ingestel. Die doel van die kwalifikasies is om toepaslike kontrakteurs te kies terwyl mededingend heid gekweek word. 'n Multi kriteria besluitnemings benadering is gebruik in die studie en hieruit is agt kontrakteur bydraes geidentifiseer uit die literatuur wat gesien kan word as indikators van kontrakteurs se vermoëns om 'n kontrak te kan uitvoer en terselfdertyd te voldoen aan sekere projek spesifieke kriteria. Deur van 'n gevallestudie gebruik te maak, is die tenders van agt kontrakteurs op 'n kortlys geplaas en is ge evalueer deur die 'laagste bod' multi bydrae analise en analitiese hierargie proses metodes te gebruik. Die resultate het aangetoon dat hierdie twee multi kriteria besluitnemings metodes die seleksie van kontrakteurs ander as die 'laagste bod' kriteria aangedui het. Wanneer die resultate van die twee metodes vergelyk word, is daar min verskil in die plasing in volgorde van keuse van die kontrakteurs. Dit impliseer dat die meer komplekse natuur van die analitiese hierargie proses en die ekstra werk wat dit vereis slegs 'n klein uitwerking het op die finale plasing van kontrakterus en verder blyk dit dat die ekstra koste om van hierdie analitiese hierargie proses gebruik te maak, nie die gebruik daarvan regverdig nie.

Sleutelwoorde: analitiese hierargie proses, kontrakteur keuse, multi bydrae analysis, voorafkwalifikasie, tender evaluasie

1. Introduction

Tendering is the process of selecting the most suitable contractor for a construction project. The tendering process involves two distinct mutually exclusive activities. The first activity, according to Moselhi & Martinelli (1990), involves the preparation of tender estimates by contractors for the purpose of submitting a bid. The second activity deals with the evaluation of the bids submitted by contractors to enable the best contractor(s) to be selected and is normally carried out by owners and/or their professional advisors such as quantity surveyors and project managers. The tender evaluation method used is critical to the success of the project because it strongly affects the subsequent outcome of the project (Jaselskis & Russell, 1992). Thus contractor selection and evaluation methods can make or mar a project. Indeed a common contention of various investigations into the problems of the construction industry in the UK (Simon, 1944; Banwell, 1964; BEDC, 1967; CIC, 1994; Latham, 1993, 1994) has been that problems can be brought to a project as soon as the 'wrong' contractor is chosen. This study focuses on tender evaluation and is concerned with the issue of contractor selection; largely due to the confirmation by IOB (1979) that judicious selection of procurement route and contractor were prerequisites to project success. The study compares the traditional lowest bidder approach and the non-traditional multi-criteria decision making methods of multi-attribute analysis (MAA) and analytic hierarchy process (AHP).

2. Tender evaluation methods

It is of paramount importance that contractors to be invited to participate in tendering be pre-qualified prior to the bidding process (Holt *et al.*, 1994). According to Holt et al. (1994), a thoroughly and objectively pre-qualified contractor should be competent and able to execute the assigned project in accordance with all stipulated requirements. Seeley (1984) gave the criteria for pre-qualification assessment to include: contractor's reputation, financial stability, adequacy of resources, scope of work normally undertaken by contractors, availability to do the job, cooperation and price level. Literature on competitive tendering generally proposes models for the appraisal of the competitive value of tenders based only on the evaluation of factors which have an immediate financial impact. Hence it is traditional to select the contractor with the lowest bid after the process of pre-qualification. This is based on the assumption that the pre-qualification exercise eliminates all incompetent contractors and guarantees that a pre-qualified lowest bidder will successfully execute the project. The reality, however, is that contractor pre-qualification alone is not a definite indicator of project success. According to Cagno *et al.* (1999), this approach is hardly appropriate in environments in which increasing competition and client expectations have broadened the number of non-financial factors which should be considered in the evaluation of the 'best' tender.

In Nigeria, the use of the lowest bidder criterion is common for contractor selection, especially on public sector projects. In his comparative study of criteria for the award of contract in the public and private sectors of the Nigerian construction industry, Oyediran (1995) found that price was the overriding criterion for contract award. Jagboro & Ogunsemi (1997) also studied the effectiveness of cost criteria for appraising tenders and submitted that the lowest tender, the quantity surveyor's estimate and the average of contractors' tenders were all reliable cost criteria for appraising tenders in Nigeria. However, in the UK, the Latham report (1994) questioned the frequent practice of selecting the lowest tenderer. Instead, the report called for proper consideration and weighting of a range of selection criteria to be taken into account during contractor selection. According to Russell *et al.* (1990) and Crowley & Hancher (1995), awarding a construction contract to the lowest bidder without considering other factors can lead to cost and time overruns and other problems. Recognising the inadequacy of the 'lowest bidder' criterion, many countries have introduced qualifications to this criterion and established procedures for the evaluation process (Martinelli-Bello, 1986). These procedures include multi-attribute analysis (MAA) and analytic hierarchy process (AHP). This study compares the lowest bidder approach, MAA and AHP.

2.1 The Multi-criteria Decision-making (MCDM) Approach

In addition to contractors' pre-qualification assessment at the pre-tender stage, previous researchers emphasised the need to consider contractors' other attributes during the pre-qualification leading to contractor select ion apart from the 'lowest bidder' criterion alone. According to Moselhi & Martinelli (1990), a list of contractors' attributes to consider in contractor selection includes: capital cost (bid amount), life cycle cost, number of years in business, volume of business, financial capacity, previous performance, project management organisation, technical expertise, time of execution, and relation with subcontractors. In their survey of contractors' opinion on the use of multi-criteria in contractor's selection, Jennings and Holt (1998) employed the following criteria: low price, company experience of similar construction, company reputation, company financial standing, prior business relationship, early completion dates, experience of contractors' key persons, company image, qualifications of contractors' key persons, company negotiating skill, current workload of company, company informal contacts, company proximity to project, company nationality and company trade union record. In their survey of tendering practices in the Nigerian construction industry, Yusif & Odeyinka (2000) identified factors to be considered in contractor selection other than price to include: technical ability, financial base, relationship with client/consultants and past performance among others.

Although the rationale and need for contractor pre-qualification are obvious and well appreciated, the process is often performed in an ill-structured and intuitive manner (Russell *et al.*, 1990). According to Mahdi *et al.* (2002), this is because the process depends largely on the skill, experience and knowledge of the decision maker, with no minimum standards that can help to evaluate a contractor for a specific project in hand. Frequently, the evaluation is performed in an ad-hoc manner with variations in the amount of effort expended and focus of evaluation effort without an understanding of how these variations influence the achieved project outcome (Russell & Jaselskis, 1992). It is against this background that more objective, structured contractor selection methodologies have been introduced. Among them are the bespoke approaches (BA), multi-attribute analysis (MAA), multi-attribute utility theory (MAUT), multiple regression (MR), cluster analysis (CA), fuzzy set theory (FST) and multivariate discriminant analysis (MDA) which are detailed in Holt (1998). They also include the analytic hierarchy process (AHP) which is described in detail by Saaty (1990), Cagno *et al.* (1999) and Mahdi *et al.* (2002). An attempt is made here to briefly describe MAA, MAUT and AHP, which are the methods relevant to this study.

2.1.1 Multi-Attribute Analysis (MAA)

MAA considers a decision alternative with respect to several of that alternative's attributes. In this respect, an attribute is a characteristic that can be measured. An objective is a characteristic against which an attribute is measured and should be pursued to its fullest. Hence, a contractor attribute represents one aspect of a decision option with respect to a client's objective (Holt *et al.*, 1995). Attributes may be measured quantitatively or otherwise. Indeed, a feature of MAA is that some or all of the attributes may not be quantifiable (Hwang & Yoon, 1981). The simplest MAA equation may be expressed as:

$$ACr_j = \sum_{i=1}^{n} V_{ij} \qquad \text{(Equation 1)}$$

where: ACr_j = aggregate score for contractor *j*; V_{ij} = variable (attribute) *i* score in respect of contractor *j*; and *n* = the number of attributes considered in the analysis. These are termed 'simple scoring' MAA models and because of their simplicity are frequently employed by Decision Makers (DMs) in industry. Their biggest failing is that V_i (albeit numeric) is often a very subjective measure. That is;

$$V_i = \sum_{i=1}^{n} f(x_i) \qquad \text{(Equation 2)}$$

where: $f(x_i)$ are the *n* functions of V_i normally subjectively (often implicitly) considered by the practitioner during evaluation. An improvement of *Equation (1)* is the attachment of weighting indices (W_i) to V_i to accentuate the aggregated scores of contractors who perform better in higher weighted criteria and *vice versa*.

Hence;

$$ACr_j = \sum_{i=1}^{n} V_{ij} W_i \qquad \text{(Equation 3)}$$

W_i may be a function of:

1. sole practitioner experience/predilection
2. group consensus opinion
3. survey and analysis of data, from a sample pertinent to the selection setting in which the model will be applied (Holt *et al.*, 1994).

Where the components (V_i and W_i in this instance) are represented by an infinite range of integers, then a unified aggregate contractor score (designated $\mathbf{U}ACr_j$, i.e. $0 \leq \mathbf{U}ACr_j \leq 1.0$) may be achieved via:

$$\mathbf{U}ACr_j = \frac{ACr_j}{ACr_{j\,max}} \qquad \text{(Equation 4)}$$

where the components are as previously described; and $ACr_{j\,max}$ is the maximum attainable aggregate score utilising W_i. Holt (1998), however, suggested that the derivation of essential V_i and the strength of W_i should be further investigated (e.g. with respect to geographical location of project, nature of work, form of procurement option employed, etc.) in the light of previous research

2.1.2 Multi-Attribute Utility Theory (MAUT)

MAUT is an extension of MAA and, according to Holt (1998), is particularly suited to the problem of contractor selection. MAUT utilises 'utility' to quantify the subjective components of MAA. According to Moselhi & Martinnelli (1990), in order to facilitate the understanding of MAUT, it is important to define the main terms used, which are stated below:

'Objectives': An objective generally indicates the direction where efforts should be concentrated to do better. In contradistinction from goals, goals are defined as the level of achievement of objectives.

'Attributes': Attributes are the scales against which the levels of achievement of objectives are measured. The attributes may be tangible such as dollar or intangible such as safety, quality, prestige and public image, etc.

'Utility' (normally expressed as U_i) is a measure of desirability or satisfaction of a characteristic (attribute), of an alternative (contractor). The utility concept was introduced to provide a uniform scale to compare and/or combine tangible and intangible attributes.

According to Holt (1998), the overall concept of MAUT can be very complex with respect to both models and utility weight derivation. According to him, MAUT may be applied to the contractor selection problem in one of two fundamental ways. Consider:

$$ACr_j = \sum_{i=1}^{n} U_i \qquad \text{(Equation 5)}$$

where: U_i represents the n attributes considered by the Decision Maker (DM). These are a function of several dimensions i.e. $U_i = \sum f(ux_i)$. (ref. *Equation* 2). Hence the sum of integers U_i yield an aggregate score as described in *Equation 4*. Alternatively, U_i may be used in conjunction with scaling constants or weighting coefficients as follows:

$$ACr_j = \sum_{i=1}^{n} U_i W_i \qquad \text{(Equation 6)}$$

where components are as described previously and n is the number of attributes. According to Moselhi & Martinnelli (1990), *Equation* 6 can be applied by the DM (e.g. an owner or his representative such as the Quantity Surveyor) following the 3-step procedure described below:

Step 1: Establish the selection criteria as a value hierarchy, which represent the owner's objectives and the measurable attributes of the contractor. It is important to avoid overlapping and double counting in selecting the attributes, to maintain the applicability of the additive model of *Equation* 6.

Step 2: Determine the relative weights associated with each attribute. These weights represent the relative importance that the decision maker(s) assigns to each; indicating his willingness to give up in one attribute in order to gain in another. To determine the relative weights, a two-step ranking procedure is used. An 'ordinal ranking' is used in the first step to determine the order of priorities among the attributes. This can be done using the approach of subjective assessment suggested by Dalkey (1972) and known as the Delphi method. Experts in the field are asked to establish an order of preference among the different attributes, which may also include preference of an attribute over a combination of others. A 'cardinal ranking' is then used in the second step to assign weights to each one of the attributes and justify their judgements.

Step 3: Construct the utility functions associated with the attributes being considered. These functions represent the satisfaction of the decision maker over the range of achievement levels that could be attained on each attribute. They are the most important input to a multi-attribute decision analysis. In order to construct a utility function, the most and least desirable outcomes for each attribute are first identified, and then assigned arbitrary values of 1.0 and 0.0, respectively. More information on how the utility functions are constructed and their characteristics can be found in Moselhi & Martinnelli (1990) and Martinelli-Bello (1986).

According to Holt (1998), MAUT is similar to MAA in modelling terms but utilises a quantitative method of determining values for inclusion therein. Hence, MAUT can quantitatively consider both tangible (e.g. safety record) and intangible (e.g. contractor image) attributes during evaluation. The existence of such subjective measures characterises the contractor selection problem. According to Holt (1998), there is scope for future research with the developing of utility curves in respect of alternative scenarios and with respect to differing owner groupings.

2.1.3 The Analytic Hierarchy Process (AHP)

As stated earlier, the selection of a contractor for a project is based on the evaluation of the tenders submitted by a number of competing contractors in terms of a number of criteria. According to Triantaphyllou & Mann (1995), this problem may become a very difficult one when the criteria are expressed in different units or the pertinent data are difficult to be quantified. The analytic hierarchy process (AHP) is an effective approach in dealing with this kind of decision problems. An argument going for AHP in such a situation, according to Emblemsvag & Tonning, (2003), is that it also allows a check of the logical consistency of the answers provided by participants in the priority setting exercise.

Ramadhan *et al*. (1999) stated that when a set of criteria is considered for evaluation by a group of people, the main objectives of this group are:

- to provide judgment on the relative importance of these activities; and
- to ensure that the judgments are quantified to an extent which also permits a quantitative interpretation of the judgment among these criteria.

Thus many decision-making methods (including MAA) only attempt to determine the relative importance, or weight, of the alternatives in terms of each criterion involved in a given decision-making problem. AHP differs from these methods in that it uses pair-wise comparisons (as proposed by Saaty, 1990), which requires the DM to express his/her opinion about the value of one single pair-wise comparison at a time using what Saaty (2001) called a fundamental scale (Table 1).

Table 1: Fundamental Scale

Intensity of importance	*Definition*	*Explanation*
1	Equal importance	Two activities contribute equally to the objective
2	Weak	Between Equal and Moderate
3	Moderate importance	Experience and judgement slightly favour one activity over another
4	Moderate plus	Between Moderate and Strong
5	Strong importance	Experience and judgement strongly favour one activity over another
6	Strong plus	Between Strong and Very Strong
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
8	Very, very strong	Between Very Strong and Extreme
9	Extreme importance	The evidence favouring one activity over another is of the highest possi ble order of affirmation
Reciprocals of above	If activity *i* has one of the above numbers, when com pared with activity *j*, then *j* has the reciprocal value when compared with *i*	If x is 5 times y, then y 1/5x

Source: Saaty, 2001

The fundamental scale is a one-to-one mapping between the set of discrete linguistic choices available to the decision maker and a discrete set of numbers which quantify the linguistic choices. Many scales exist but the most popular is the one proposed by Saaty (2001) and shown in Table 1.

In comparing criterion A to criterion B, a decision maker may determine from the scale in Table 1 that A is of weak importance over B and accordingly assign a relative importance value of 2 to A. This means that the value of the relative importance of B to A is 1/2. The quantified judgment on pairs of criteria ci, and cj (pairwise comparisons) are represented by an n-by-n matrix

$A = (a_{ij}), \quad ij = 1,2,3\ldots\ldots,n)$

The entries a_{ij} are defined by the following entry rules:

Rule 1. If $a_{ij} = a$, then $a_{ij} = 1/a$, $a \neq 0$.

Rule 2. If C_i is judged to be of equal relative importance to C_j, then $a_{ij} = a_{ij} = 1$. Obviously $a_{ij} = 1$ for all i.

Thus the matrix A has the form:

$$A = \begin{bmatrix} 1 & a_{12} \ldots\ldots\ldots\ldots\ldots\ldots a_{1n} \\ & \\ 1/a_{12} & 1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots a_{1n} \\ \cdot & \cdot \qquad\qquad\qquad \cdot \\ \cdot & \cdot \qquad\qquad\qquad \cdot \\ 1/a_{1n} & 1/a_{1n} \qquad\qquad 1 \end{bmatrix} \qquad \text{(Equation 7)}$$

where the a_{ij} is the relative importance of criterion $_i$ to criterion $_j$. Having recorded the quantified judgments of comparisons on pairs (C_i, C_j) as numerical entries a_{ij} in the matrix A, what is left is to assign to the n contingencies C_1, C_2 , C_3, ..., C_n a set of numerical weights w_1, w_2, w_3, ..., w_n that should reflect the recorded judgments.

The eigenvector of the comparison matrix provides the priority ordering (weight), and the eigenvalue is a measure of consistency. To find the weight of each criterion included in the ranking analysis, the eigenvector corresponding to the maximum eigenvalue is to be determined from matrix analysis. The principal eigenvector is computed and normalised to give the vector of weights. Ramadhan *et al.* (1999) have suggested a simplified method to reduce the excessive computing time needed to solve the problem exactly. By their method a good estimate of the vector is obtained by normalising each column (i.e. dividing the elements of each column by the sum of that column) in the comparison matrix. The elements in each resulting row are then added and their sum divided by the number of elements in the row. This is expressed mathematically as

$$W_i = \frac{1}{n}\left[\left(\frac{a_{11}}{\sum_i a_{i1}}\right) + \left(\frac{a_{12}}{\sum_i a_{i2}}\right) + \ldots\ldots\ldots\ldots + \left(\frac{a_{1n}}{\sum_i a_{in}}\right)\right] \qquad \text{(Equation 8)}$$

or in general

$$W_i = \frac{1}{n} \sum_j \left[\frac{a_{ij}}{\sum_i a_{ij}} \right] \qquad \text{(Equation 9)}$$

where a_{ij} is the entry of row i and column j in a comparison matrix of order n.

Compared to MAA, which uses direct absolute estimates to rank decision criteria, AHP uses pair-wise comparisons. According to Cagno *et al.* (1999), this makes AHP a robust and flexible MCDM technique which gives a better decision support with the following advantages:

- It effectively manages to organise the decisional problem into a hierarchical structure. Structuring any decision problem hierarchically is an efficient way of dealing with complexity and identifying the major components of the problem
- The methodology is reliable due to the pairwise comparison process and the consistency check tool. It is common experience that estimates based on pairwise comparison are more reliable than direct absolute estimates. This is even truer for qualitative factors and also for quantitative factors where insufficient data is available to make absolute estimates. In addition, the elicitation of redundant judgements, which characterises the standard application of AHP, is useful to check the consistency of the DM's opinion. The level of inconsistency can be calculated and, if it exceeds a threshold value 0.1 (Saaty, 1990), the expert must review judgements more carefully.
- It deals effectively with group decision-making.

The use of AHP has been successfully demonstrated and/or applied in such diverse areas of construction research as architecture (Saaty & Beltran, 1982), facility location decisions (Yang & Lee, 1997), building maintenance (Shen *et al.*, 1998), construction management (Fong & Choi, 2000), business performance (Cheng & Li, 2001), construction procurement (Cheung *et al.*, 2001; Wong & Chan 2003), evaluation of oil pipeline project (Dey, 2004), benchmarking facility management (Gilleard & Yat-lung, 2004) and construction conflict analysis and resolution (Al-Tabtabai & Thomas, 2004) as well as contractor selection in competitive bidding (Cagno *et al.*, 1999; Fong & Choi, 2000; Mahdi *et al.*, 2002). It must be mentioned, however, that compared to other methods, AHP has the disadvantage that it takes much time (Zavadskas *et al.*, 2005) and requires more complex calculations and expert knowledge. This is why Cheng *et al.* (2002) have warned that the method could be misused to produce defective results if the underlying principles are not properly understood and mastered.

3. Data and methodology

Data were collected using a case study approach. Data collection was with respect to the tenders submitted for a residential project in Lagos, Nigeria. Eight contractors were short-listed for the project under consideration. The tender sum, completion duration and other details pertaining to each of the contractors are listed in Table 2. Apart from these details, eight attributes derived from literature and from discussions with industry practitioners as essential factors for contractor selection were identified. These are tender sum (TS), financial capability (FC), managerial capability (MC), technical expertise (TE), completion duration (CD), current workload of company (CW), number of years in business (NYB) and past performance (PP). Each of these attributes was scored on a scale of 1 to 10 for each contractor by the DM, i.e., the client's Quantity Surveyor. As previously explained, the MAUT is best suited for the contractor selection problem due to its ability to quantitatively consider both tangible and intangible attributes during evaluation. However, as a result of the complexity involved in generating relevant utility curves, the multi attribute analysis (MAA) was employed in this study and compared with the analytic hierarchy process (AHP).

Table 2: Details of Contractors' Tenders

Contractor Number	*Tender sum submitted (N)**	*Completion duration (Weeks)*	*Number of years in business*	*Client's QS estimate (N)*
1	62,988,555.25	40	8	63,331,648.67
2	65,800,510.00	48	8	
3	64,713,640.00	40	9	
4	67,080,000.00	44	5	
5	62,900,420.00	40	6	
6	62,853,000.00	40.5	7	
7	65,634,421.00	52	8	
8	66,577,600.00	48	7	

* N135 US$1

4. Applying the tender evaluation methods

On the basis of the 'lowest bidder' criterion, the conventional practice will be to award the contract to contractor number 6 after the eight contractors have been found suitable through a pre-qualification exercise. MAA and AHP are now applied using the same set of data to determine the best contractor for the job.

4.1 Evaluation of the Tenders Using Multi-attribute Analysis (MAA)

The data obtained from the Quantity Surveyor's scoring of each of the eight identified attributes for each contractor that tendered in each project is presented in Table 3. Using this data set, the multi-attribute analysis (MAA) was employed using the additive model in *Equation 3*, which is re-stated as follows:

$$ACr_j = \sum_{i=1}^{n} V_{ij}W_i \qquad \text{(Equation 3)}$$

From this equation, the V_{ij} component, whereby V_{ij} = variable (attribute) *i* score in respect of contractor *j* is represented by the data set in Table 3.

Table 3: Multi-Attribute Score for Each Contractor on the Project

Contractor Number	*LTS* (V_1)	*PP* (V_2)	*TE* (V_3)	*MC* (V_4)	*FC* (V_5)	*CD* (V_6)	*NYB* (V_7)	*CW* (V_8)
1	8	9	8	8	8	10	8	7
2	5	8	6	8	8	6	8	7
3	7	7	6	6	6	10	9	6
4	3	5	4	4	4	7	5	7
5	9	8	6	8	8	10	6	7
6	10	7	6	6	6	8	7	6
7	6	8	8	6	6	4	8	7
8	4	8	6	8	8	6	7	7

The W_i component, which represents the weighting factor, is to be determined for the model to be useful for tender evaluation.

In order to determine the weighting factor, the two-step approach suggested by Moselhi & Martinnelli (1990) was employed. This procedure is described under step 2 of the three-step procedure used in MAUT described above. Using the Delphi method, experienced construction professionals were asked to rank the eight identified attributes. This helped to produce an ordered list shown in column 2 of Table 4. This ordered list shows that construction professionals ranked 'low tender sum' first. In order to be able to attach the weighting factor (w_i) to each attribute, the technique of cardinal ranking was then employed. The procedure employed was to give the highest 'weight' to the attribute ranked first. Thus, using the maximum weight of 10, the attribute 'low tender sum' which was ranked first, was assigned the maximum weight of 10. This procedure was continued until the last attribute ranked eighth which was assigned the weight of 3, following the cardinal ranking. The result of this exercise is shown in column 3 of Table 4. Thus, the weighting factors generated in column 3 of Table 4 represents the W_i component of *Equation 3*.

Table 4: Weighting Factors for the Attributes

Attribute	*Ordinal ranking*	*Cardinal ranking (Weight W)*
Low tender sum (LTS)	1	10
Past performance on similar construction (PP)	2	9
Technical expertise (TE)	3	8
Managerial capability (MC)	4	7
Financial capability (FC)	5	6
Completion duration (CD)	6	5
No. of years in business (NYB)	7	4
Current workload of company (CW)	8	3

In order to determine the values for the MAA additive model of *Equation 3* and the unified aggregate score (*Equation 4*), the attribute scores (V_{ij}) in Table 3 were used to multiply the weighting factors (W_i) in Table 4. These values are shown in Table 5 as ACr_j representing values determined by the MAA model represented by Equation 3 and $UACr_j$ representing values determined by *Equation 4*. For instance, in order to determine these stated values for contractor number 1 on Table 5, the following procedure was followed:

Acr_1 = [(8x10) + (9x9) + (8x8) + (8x7) + (8x6) + (10x5) + (8x4) + (7x3)]   432

$\mathrm{ACr}_{j\ max}$ = [(10x10) + (10x9) + (10x8) + (10x7) + (10x6) + (10x5) + (10x4) + (10x3)]

= 520 (note that the maximum attribute score of 10 has been used here against the pre determined weighting factor)

UACr_j = 432/520   0.831

This procedure was carried out for each contractor on the project studied. The result produced by the additive model is presented in Table 5. It is evident from Table 5 that the result of the multi-attribute evaluation of tenders submitted indicates that the most suitable contractor among those short-listed is contractor number 1. However, if the 'lowest bidder' criterion alone had been used, the project would have gone to contractor number 6 who eventually ranked third with the use of MAA.

Table 5: Tender Evaluation Using the Attributes, Weighting Factors and the MAA Model

Contractor Number	V_1	$\mathbf{W_1}$	V_2	$\mathbf{W_2}$	V_3	$\mathbf{W_3}$	V_4	$\mathbf{W_4}$	V_5	$\mathbf{W_5}$	V_6	$\mathbf{W_6}$	V_7	$\mathbf{W_7}$	V_8	$\mathbf{W_8}$	ACr_j	$ACR_{j\,max}$	$UACr_j$	*Rank*
1	8	10	9	9	8	8	8	7	8	6	10	5	8	4	7	3	432	520	0.831	1
2	5	10	8	9	6	8	8	7	8	6	6	5	8	4	7	3	357	520	0.681	5
3	7	10	7	9	6	8	6	7	6	6	10	5	9	4	6	3	363	520	0.698	4
4	3	10	5	9	4	8	4	7	4	6	7	5	5	4	7	3	235	520	0.452	8
5	9	10	8	9	6	8	8	7	8	6	10	5	6	4	7	3	409	520	0.787	2
6	10	10	7	9	6	8	6	7	6	6	8	5	7	4	6	3	375	520	0.721	3
7	6	10	8	9	8	8	6	7	6	6	4	5	8	4	7	3	347	520	0.668	6
8	4	10	8	9	6	8	8	7	8	6	6	5	7	4	7	3	343	520	0.660	7

4.2 Evaluation of the Tenders Using the Analytic Hierarchy Process (AHP)

Using the simplified approach of Shen *et al.* (1998), the contractor selection problem was broken into a two-level hierarchy of interrelated decision elements as shown in Figure 1. This simple approach was chosen in preference to the more complex methods of Mahdi *et al.* (2002) and Dey (2004) to enable the decision makers (the client and his advisers) understand the new approach being introduced for the very first time in tender evaluation in Nigeria.

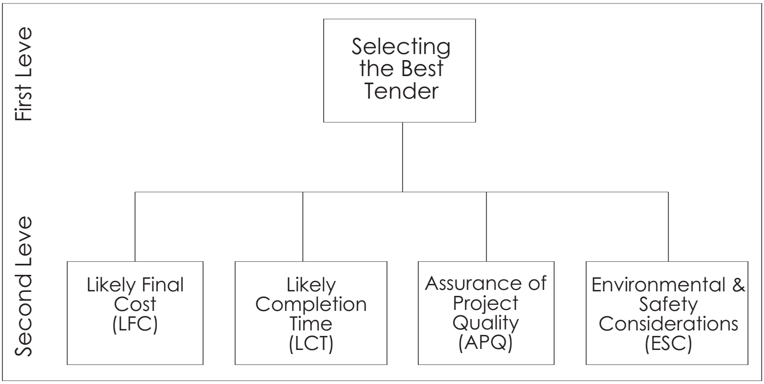

Figure 1: Decision hierarchy of competitive criteria and factors for the case study

The first level in Figure 1 describes the objective of the tender evaluation exercise required to achieve the ultimate goal, which is common to all project owners in all projects. The second level contains factors which Mahdi *et al.* (2002) refer to as project-specific criteria as determined by the project owner and his professional team for the case study project. The second level constitutes factors which experts (industry practitioners and academics) perceive as the attributes necessary to achieve the objective described in the first level. A pairwise comparison of the four second level factors, i.e. likely final cost (LFC), likely completion time (LCT), assurance of project quality (APQ) and environmental and safety considerations (ESC), was done by the project owner and his professional advisers after the researchers had taken enough time to explain the process to them.

The comparison matrix determined by the decision makers and the vector of priorities (weightings) of the four selection criteria are shown in Table 6. The eigenvector of the comparison matrix represents the priority weightings of the four criteria and is calculated using the approach of Ramadhan *et al.* (1999) earlier described. The next step in the analysis is to determine the logical consistency of the decision makers in their pairwise comparison of the criteria. This is done by calculating the consistency ratio (CR) of the comparison matrix in Table 6 using *Equation 10*.

$$CR = \frac{ConsistencyIndex(CI)}{RandomIndex(RI)} \qquad \text{(Equation 10)}$$

Table 6: Pairwise comparison of contractor selection criteria and their weightings

	LFC	*LCT*	*APQ*	*ESC*	*Weighting*
LFC	1	2.20	3.04	6.04	0.48
LCT	0.45	1	2.25	4.84	0 28
APQ	0.33	0.44	1	6.04	0.19
ESC	0.17	0.21	0.17	1	0.06

RI is obtained from tables created by Saaty (1990) and its value depends on the size of the comparison matrix. For the 4x4 matrix in this analysis, its value is 0.90. CI is obtained from $CI=(\lambda_{max}-n)/(n-1)$, where n is the size of the matrix and λ_{max} is the principal eigenvalue of the comparison matrix. The computation of λ_{max} is very complex but again Saaty (1990) has proposed a simple practical approach. To obtain λ_{max}, we multiply the comparison matrix M on the right by the eigenvector V and divide the corresponding components of the resulting column vector by the eigenvector to get a new column vector

$$M = \begin{bmatrix} 1 & 2.20 & 3.04 & 6.04 \\ 0.45 & 1 & 2.25 & 4.84 \\ 0.33 & 0.44 & 1 & 6.04 \\ 0.17 & 0.21 & 0.17 & 1 \end{bmatrix} \qquad \text{(Equation 11)}$$

$$V = \begin{bmatrix} 4.25 \\ 4.32 \\ 4.37 \\ 3.83 \end{bmatrix} \qquad \text{(Equation 12)}$$

We then find the mean of the components of this new vector to give 4.19 which is the value of $\lambda_{max.}$. Hence CI=(4.19-4)/(4-1)= 0.063 and CR=0.063/0.90=0.07. Since the acceptable consistency ratio is 0.10 or less (Saaty, 1990), the value of 0.07 obtained indicates that the decision makers were very consistent in their pair-wise rating of the four criteria. With this assurance of consistency, the analysis can proceed to rank the contractors with the four criteria.

From the literature and discussions with construction industry practitioners, the eight contractor attributes used for the MAA (described earlier) were matched with the four selection criteria according to the relevance of each attribute to a criterion. This is shown in Table 7. The decision maker, i.e. the project owner and his professional advisors, scored each of the eight short-listed contractors on a scale of 1 to 10 for each of the four selection criteria using the attributes in Table 7. Applying the method of Shen *et al*. (1998) to the resulting scores, the tender performance index TPI $_j$ for contractor $_j$ was obtained from the formula

$$TPI_j = TPI_{j1}*W_1 + TPI_{j2}*W_2 + TPI_{j3}*W_3 + TPI_{j4}*W_4, \qquad \text{(Equation 13)}$$

where TPI_{j1} is contractor $_j$'s score for criterion 1 and W_1, ...W_4 represent the relative weights of criteria 1 to 4 respectively as determined by pairwise comparison. Table 8 shows the contractors' scores, performance indices and rankings using AHP.

Table 7: Relevant contractor attributes for tender evaluation

Criterion	*Relevant contractor attributes*
Likely final cost (LFC)	Tender sum, financial capability, managerial capability
Likely completion time (LCT)	Completion duration, technical expertise, current workload
Assurance of project quality (APQ)	Technical expertise, number of years in business, past performance
Environmental and safety considerations (ESC)	Technical expertise, past performance

Table 8: Tender performance and ranking of contractors using AHP

Contractor Number	*Selection criterion*				*TPI*	*Rank*
	LFC (*W_1 0.48*)	*LCT* (*W_2 0.28*)	*APQ* (*W_3 0.19*)	*ESC* (*W_4 0.06*)		
1	10	10	10	10	10.10	1
2	6	9	10	10	7.90	4
3	7	9	8	8	7.88	5
4	4	6	6	7	5.16	8
5	9	10	8	10	9.24	2
6	9	8	7	8	8.37	3
7	8	7	8	9	7.86	6
8	5	9	9	10	7.23	7

The rankings of the traditional "lowest bidder", the MAA and the AHP approaches are compared in Table 9. These results indicate that if the 'lowest bidder' criterion alone had been used, the project would have gone to contractor number 6 who eventually ranked third in both the MAA and AHP methods. It is also indicated that with the exception of contractors numbers 2 and 3 whose rankings are different, the rankings of the other six contractors are the same using MAA and AHP.

Table 9: Comparison of contractors' rankings using three methods

Contractor Number	*Lowest bid method*	*MAA method*	*AHP method*
1	3	1	1
2	6	5	4
3	4	4	5
4	8	8	8
5	2	2	2
6	1	3	3
7	5	6	6
8	7	7	7

5. Summary and conclusion

This study has attempted to apply two multi-criteria decision making (MCDM) approaches (i.e. MAA and AHP) to tender evaluation using the case study approach. Results from the case study project evaluated showed that the two MCDM analyses indicated the selection of contractors other than what the 'lowest bidder' criterion indicated. In view of the wide criticism against the use of the 'lowest bidder' criterion, it is suggested in the light of this finding that quantity surveyors and other construction managers should endeavour to embrace the use of the multi-criteria approach in tender selection so as to ensure contract performance, rather than cheaper price and poor or no performance.

Comparing the results of the MAA and AHP methods, it is evident that the two methods differed very little in their ranking of the contractors. Thus indeed, as found by Shen *et al.* (1998), the more complex nature of AHP and the extra efforts it requires have only a minor influence on the final ranking of contractors. This may suggest that the much simpler MAA approach is adequate for tender evaluation and should be preferred to AHP. However, it is necessary to note that the simplified two-level hierarchy AHP adopted in this study is quite close to MAA in structure and this might be responsible for the closeness of their results. A comparative study of the two methods using a more complex project may provide a clearer picture.

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