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ASSESSMENT AND EVALUATION OF CONTRACTOR DATA AGAINST CLIENT GOALS USING PERT APPROACH

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ABSTRACT: A methodology for assessing and evaluating contractor data for the purpose of prequalification and bid evaluation is presented. The PERT approach is used to develop a linear model for the assessment of contractor data. The model incorporates a multiple ratings permitting the uncertainty in contractor data to be evaluated. An empirical study investigating the importance of different contractor criteria is described. A lexicographical ordering with aspiration levels and risk analysis with sensitivity methods are used to evaluate and select or rank order contractors against the main client goals of time, cost, and quality. A literature review is reported regarding client goals and current evaluation strategies. The assumptions, advantages and disadvantages of this work as well as an example is also presented.

Keywords: Prequalification, bid evaluation, PERT, criteria, client goals, contractor data.

INTRODUCTION

Prequalification is a pre-tender process used to investigate and assess the capabilities of contractors to satisfactorily carry out a contract if it is awarded to them. This involves a screening procedure based on a set of prequalification criteria and has been examined by several researchers (eg., Hunt *et al*, 1966; Helmer and Taylor, 1977; Russell and Skibniewski, 1988; Merna and Smith, 1990; Ng, 1992; Holt *et al*, 1994; Potter and Sanvido, 1994) and a common set of criteria have been identified that are currently in use (Hatush and Skitmore, 1996a). These prequalification criteria (eg financial capacity of contractors), however, are only indirect measures of likely performance of contractors in meeting project objectives (ie time, cost and quality of the project)For the prequalification process to be logically complete, the effect of the criteria on the predominant project objectives needs to be known. Hatush and Skitmore (1996b) have investigated this by a Delphic study in which a consensus was reached by several expert prequalifiers via the PERT approach.

This paper describes research aimed at developing this approach further into a system for contractor selection. A method is proposed by means of a lexicographical ordering of aspiration levels and risk analysis, with sensitivity methods and which provides a direct indication of the likelihood that a contractor will meet the main client goals in terms of time, cost and quality. The assumptions, advantages, and disadvantages of the proposed techniques as well as an example are also presented.

CLIENT GOALS

Despite the variety and alternatives in procurement systems, all procurers have goals that can be described in similar terms (NEDO, 1985). These comprise, to different degrees, the ultimate project goals of *cost*, *time*, *quality*, and associated operational goals including the level of *uncertainty* surrounding the likely cost and time, the *flexibility* to make changes, the allocation of *risks* and responsibilities and the ability of the contractor to cope with the level of *complexity* involved. All procurement systems have different levels and emphases on these goals (Ireland, 1985; Skitmore and Marsden, 1988; Franks, 1990; Curtis *et al*, 1991; Huru, 1992) and with different methods of accommodating them. The traditional tendering system of procurement, for instance, aims to achieve these goals by a combination of normative (contractual provisions governing time, quality, flexibility and risk allocation) and competitive (simultaneous identification of cost and contractor by auction) methods.

Cost: Historically, cost is the goal considered to be most important by clients as most seek value for money. It is from this premise that traditional competitive tendering system arose. One result of this is that cost, measured by the bid price submitted by the contractor, is often regarded as the sole criterion for selection. A large majority of projects, however, end up costing more than the original bid price (Hardy, 1978).

Time: The time to complete the project is scheduled to enable the building to be used by a date determined by the client's future plans and polices. Clients vary in their willingness to employ only those contractors who are able to meet target times. Some contracts include a bonus clause to encourage the contractor to speed up the construction process and to avoid any delays. Construction time progress is related to the cost of project and is considered good if the average ratio of cost to time is 0.4, average if the ratio is 0.25, and small if the ratio is 0.2 (NEDO, 1985).

Quality: Quality in construction is defined as " the totality of features required by a product or service to satisfy a given needs" (Hamzah, 1993, referring to BS5750) and is usually prescribed in project specification documents. It is thought that the implementation of new procurement systems has resulted in a decline in quality in recent years (Hindle and Rwelamila, 1993) and, for this reason alone, quality is regarded as a main criterion in contractor selection (Latham, 1994).

Uncertainty: Is a contractor able to finish the project on a scheduled time? Is he committed to the bid price? Is he capable of constructing the project? These questions of uncertainty may, though perhaps not often in practice, be addressed.

Flexibility: How well will a contractor respond to changes in circumstances during the construction process? Is he able to rearrange his programme and schedule accordingly? Where there is a high expectation of plan changes or other disruptive events in the course of construction, it may be better to select a contractor who can cope best with such changes.

Risk: In the competitive tendering procurement system, if the risk is small, clients are advised to ensure that all bidders understand the risks allocated to them and that they have made appropriate provision in their bids. If the risks are large, clients should consider specifying the proposed allocation of risk in the tender documents and requiring bidders to state their provision for risks in their bids. As Thompson and Perry (1992) point out, one of the biggest risks is that the final contract value will exceed the tender amount as there is always the possibility of physical changes to unforseen ground conditions, or design changes,in addition to mistakes made due to the limited time available to prepare bids. All these risk factors and their affect on the whole progress have to be considered and it may be better to select a contractor who best understands the risks involved and will accept responsibility when a loss occurs.

Complexity: Different clients have different needs relating to the complexity of their buildings in terms of level of specialisation, technological advancement or services requirement. The ability to cope with complexity depends on the contractor's degree of familiarity with the technology used in the construction process. Complex forms of construction may be unfamiliar to site staff or require an usually large number of operational steps to be followed. For this reason, and because of the differences in contractors' experiences in such situations, this attribute is considered by the client for evaluation where there is a highly specialised or advanced technique to be used.

Clients' needs vary according to their differences in emphasis on each of the seven goals described above. For a given client, the emphases vary for each project, depending largely on the type and size of the projects and other issues involving external constraints and conditions (Love and Skitmore, 1995). Fig 1 (from Skitmore and Marsden, 1988) shows the relation between the different criteria (goals) and the level of interest or utility of each for different procurement systems. This indicates that competitive traditional contracting (B), develop and construct (C), and competitive design and build (E) to be the systems that are most appropriate when the major emphasis is on the cost of project. Contract arrangements F,G,D,E on the other hand, are more appropriate when the emphasis is on the timing of the project. This indicates that the emphases on the different criteria can be matched with the characteristics of each system to identify the optimum system for the project (Skitmore and Marsden, 1988).

An important aspect of procurement system selection by this means is that there is a much greater variety of client criteria scores (each criteria having a range of scores from 1 to 20, ie., 7^{20} total possible permutations of criteria scores) than there are procurement systems available. Thus one procurement system will be optimal for a range of criteria scores. In other words, the procurement system alone is not sufficient to guarantee the client goals are met as it almost certainly will not exactly match the client and project needs. Furthermore, procurement selection by Skitmore and Marsden's approach is necessarily based on an aggregation of perceptions of what is likely to be achieved and does not take into account the performance characteristics of individual contractors. The problem then is to devise a method of assessing individual contractors' performance characteristics in such a way that they can be compared directly with the client's goals **within a particular procurement system**.

For the purposes of this study, only the client ultimate goals (ie time, cost and quality) were considered as, collectively, these alone are both necessary and sufficient to provide the solution required. The status of the operational goals (eg level of uncertainty, flexibility to make changes, risk allocation, ability of contractor to cope with the project complexity), is less certain as they are neither universally necessary (they are not always present) nor sufficient (the list given here is not comprehensive). Thus, although it is an empirical fact that the pursuit of operational goals often contributes substantially to the realistic achievement of the ultimate goals, they are subsumed within the theoretical framework provided by the ultimate goals.

Furthermore, in the face of a wide variety of procurement systems currently available, the study was restricted to the traditional competitive tendering system as it is the most frequent use today.

CONTRACTOR SELECTION CRITERIA

Several researchers (Holt *et al*, 1994; Russell *et al*, 1992; Ng, 1992) have identified different criteria in use for contractor selection. In a recent study, Hatush and Skitmore (1996a) found that all clients use what are implicitly the same **type** of criteria, but vary in the way they quantify the criteria, with most having to resort to a very subjective assessment based on information provided by the contractors. As a result, they proposed an explicit set of criteria which subsumes all the criteria identified previously and arranged to facilitate a more objective assessment of contractors both in prequalification and bid evaluation. This is summarised in Table 1 and comprises five **main criteria** relating to the contractors' *Financial* soundness **(F)**, *Technical* abilities **(T)**, *Management* capabilities **(M),** *Safety* performance **(S)**, and *Reputation* **(R)**. The main criteria are subdivided into further **subcriteria**, which are intended to be the main source for assessing main criteria.

Clearly, the degree of emphasis on each criterion will depend on the circumstances and specifics of the project as well as the preferences of the decision makers and their different experiences. This will, of course, be reflected in the weights attached to the criteria and is expected to vary from project to project or, in the case of prequalification for standing lists, across a range of types and sizes of projects.

CURRENT EVALUATION STRATEGIES

Previous research in the United Kingdom (Merna and Smith, 1990) suggests that most public sector clients use and evaluate different contractors criteria in prequalification and mainly based on the judgment of the individual personnel involved. In bid evaluation, no judgement is necessary as the bid price is the sole of selecting the best bidder. Fieldwork studies in prequalification practices in the USA by Russell and Skibniewski (1988) identified several evaluation strategies in use comprising dimensional weighting, two-step prequalification, dimension wide strategy, prequalification formula in addition to subjective judgment. In general, however, the bid price is still the sole criterion used at bid evaluation stage.

Additional criteria have been proposed. Ellis and Herbsman (1991), for example, suggest using time as a means of evaluating bids of highway construction contractors. By this method, bidders enter a bid price together with a time to finish the contract, the total combined project bid being converted into cost terms by the formula CT= C+R+T where

CT = Total bid C = Contractor's bid price

R = Time value of the road user cost T = Contractor's time bid

In a later paper (Herbsman and Ellis, 1992) they also propose the consideration of the past performance of contractors as a means of assessing likely quality to be achieved, and past accidents records as a means of assessing safety performance levels, the values of both these criteria values again being converted into cost terms to simplify comparison between bidders. A further approach by Vorster (1977) and Hardy (1978) considers the bid price as a series of payments to be made by the client over the course of the construction period. A discounted cash flow technique is used in this case to estimate a single cost in the form of a net present value.

From this brief review of previous work in the field it is clear that no current or proposed evaluation strategies fully link client goals with contractors criteria. Even the most advanced of these utilise only a few of the criteria for which information is available (often collected at considerable expense) and then by a somewhat arbitrary method of conversion into a single cost value. Furthermore, in reducing the bidders' attributes to a single cost value, some information is necessarily lost in the process. Finally, there is also the possibility that there is an **indirect** impact of different contractors criteria on different client goals. In the next section, a method is proposed for overcoming these weaknesses.

ASSESSING CONTRACTORS CRITERIA AGAINST CLIENT GOALS USING PERT APPROACH

In the absence of direct links between clint goals and contractor selection criteria in current evaluation procedures, it is assumed that, if contractors comply with the selection criteria, they will automatically be capable of meeting the client's goals. Similarly, the current evaluation procedures also assume that any trade-offs that are made between criteria measures (eg., where some doubt over a contractor's financial position is compensated by a superior technical capability) will be equally valid in terms of the time, cost, quality etc goals affected. In other words, it is assumed that trade-offs between the **means** of production are in one-to-one correspondence with trade-offs between the **ends** of the production process.

Hatush and Skitmore (1996b) have examined the nature of these links between means and ends in a Delphic study of the perceptions of several experienced prequalifiers of the probabilistic relationship between each of the contractor selection criteria and the three predominant client goals of time, cost and quality. The major outcome of this study was to reach a consensus agreement on the relationships involved through the Program Evaluation and Review Technique (PERT) approach (a more complete discussion regarding this technique can be found in Loomba, 1978; Harris, 1978; Horowitz, 1967) by employing the common assumption of a Beta distribution to adequately model the data[1].

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[1]The Beta distribution is a very common model that is applied *a priori* to subjective data of this kind on account of

Before these results can be utilised in contractor selection, it is first necessary to consider the underlying assumptions of the PERT model which have been considered valid for contractor selection criteria and client goals (Russell and Ahmad, 1990). These are that:

1 The client goals (time, cost, and quality) for each criterion for each contractor are random variables.

2 The random variables representing the client goals can be converted to a common continuous probability distribution when they added together.

3 The weighted sum of the expected means is the aggregate expected mean of different client goals described by a normal distribution whose standard deviation is the square root of the sum of the variances of all the criteria for each contractor.

Hatush and Skitmore's (1996b) research investigated the "relation coefficient" between different contractor criteria, and the "weights" of these criteria. The population correlation coefficient was found to be significantly greater than zero for only small number of these criteria. This result substantiates the third assumption of the PERT approach. The central limit theorem was therefore applied to calculate the desired aggregate values.

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its general validity, flexibility and ease of use.

The weights of the contractor selection criteria are shown in Table 2. These weights were obtained through interviews conducted with a sample of four construction professionals experienced in prequalification and bid evaluation. Part of the questionnaire used for this purpose is shown in Appendix 1. Firstly the interviewees were requested to describe the importance by giving a weight to the main five criteria, with a total weight of 100. Then, for each of the five main criteria, the interviewees were requested to give weight for the associated subcriteria, with a total weight of 100 for the subcriteria also.

The importance of each one of the subcriteria in the whole process for the criteria was then obtained by multiplying the weight of each main criterion by the weight of the its subcriteria, the total weight of the whole set of subcriteria again amounting to 100. The weights obtained here represent the opinion of the four professionals interviewed in this study, and not necessarily be taken as a default values.

For example, and referring to Appendix 1, the importance weight of the main criterion "financial soundness" is 0.21 (21%) and the weight of its four associated subcriteria "financial stability" is 0.20 (20%), "credit rating" is 0.20 (20%), "bank arrangements" is 0.20 (20%) and "financial status" is 0.4 (40%). Then the importance of these subcriteria in the whole set of criteria is:

financial stability = 0.21 x 0.2 = 0.042

credit rating = 0.21 x 0.2 = 0.042

bank arrangements = 0.21 x 0.2 = 0.042

financial status = 0.21 x 0.4 = 0.084

From the assumptions of the PERT approach and findings of the previous research, the formulas that are used for calculating the aggregate expected mean, variance and standard deviation are:

AE[t] = Sum of (W x E[t]) of all criteria

Var [At] = Sum of (W x Var[t]) of all criteria

Sigma [At] = Sqrt(Var[t])

AE[c] = Sum of (W x E[c]) of all criteria

Var [Ac] = Sum of (W x Var[c]) of all criteria

Sigma [Ac] = Sqrt(Var[c])

AE[q] = Sum of (W x E[q]) of all criteria

Var [Aq] = Sum of (W x Var[q]) of all criteria

Sigma [Aq] = Sqrt(Var[q])

where AE[t], AE[c] and AE[q] represent the aggregate expected mean of time, cost and quality due to the effect of all criteria, Var[At], Var[Ac] and Var[Aq] represent the variance of the aggregate expected mean of (time, cost, and quality), Sigma[A]t, sigma[Ac] and sigma[Aq] represent the aggregate standard deviation of time, cost and quality and W represents the weight of the criteria.

Assume, form the previous example, that the weights calculated for "financial stability" and "credit rating" are 0.8 and 0.2 respectively (0.8 + 0.2 = 1). Then the aggregate expected mean, variance, and standard deviation values of different client goals for contractor A will be:

AE[t] = (0.8x100.8) + (0.2x106.6) = 101.96

Var[At] = (0.8x6.25) + (0.2x10.89) = 4.44

Sigma[At] = Sqrt(Var[At]) = 2.1

AE[c] = (0.8x100.0 + 0.2x112.5) = 102.50

Var[Ac] = (0.8x2.56) + (0.2x6.25) = 1.89

Sigma[Ac] = Sqrt(Var[Ac]) = 1.37

AE[q] = (0.8x100.8) + (0.2x94.1) = 99.46

Var[Aq] = (0.8x6.25) + (0.2x6.25) = 4.25

Sigma[Aq] = Sqrt(Var[Aq]) = 2.1

Therefore Contractor A is predicted to score the following aggregate expected mean, variance, and standard deviation values for time, cost and quality:

AE[t]=102 Var[At]=4.44 Sigma[At]=2.1

AE[c]=102.5 Var[Ac]=1.89 Sigma[Ac]=1.37

AE[q]=99.46 Var[Aq]=4.25 Sigma[Aq]=2.1

Thus, Contractor A is expected to overrun on time by an average of 2% with a variance of 4.44, overrun on cost by an average of 2.5% with variance of 1.89, and produce a quality below the required standard by less than 1% on average but with a variance of 4.25.

METHODOLOGY FOR EVALUATION

The following proposed methodology considers the contractor criteria and client criteria. Fig 2 shows how the criteria may be assessed against each other. This is illustrated by the following example.

Using the contractors selection criteria in Table 1 and their relevant information, the client managed to investigate and assess the capabilities of all the necessary criteria of the four contractors (A,B,C,D) and how these criteria affect time, cost, and quality using the PERT approach described above. Aggregate expected means, variances and standard deviations for time, cost and quality were also calculated and these are shown in Table 3 for all bidders for different client goals. This shows that the maximum expected delay is by contractor D (112-100=12%, SD=2.5), the maximum expected cost overrun is by contractor B (110-100=10%, SD=2.2) and the maximum expected quality below standard is by contactor C (100-92=8%, SD=2.7).

Fig 3 shows the normal distributions curves of the four contractors in the three attributes time, cost, and quality. For plotting the curves, only aggregate values over or less than 100% are considered. A normal probability density function is assumed. The normal distribution curves can be used to find the probability that any value is less than or equal a selected value (SMv). This probability is equal to the area under the curve to the left of (SMv). The z values are calculated as follows:

$$z = \frac{\text{selected value (SMv) - calculated aggregate expected mean of T or C or Q}}{\text{aggregate standard deviation of T or C or Q}}$$

from which the area under the normal curve can be obtained by reference to standard statistical tables. For example, the probability that contractor A will delay by 10% or less is derived from z = (10-8)/2.2 = 0.909 from which the area under the curve is 0.8186. Thus the probability that the project carried out by this contractor will be delayed by at least 10% is 81.86%, similarly the probability for less than or equal 5% delay is 0.0869. Also, the probability that there will be at least a 8% delay is 0.5, ie., a 50-50 chance of an 8% delay. Of course, such predictions can also by made for each contractor and for each of the time, cost and quality factors.

Probabilities can also be obtained for a range of such events. For example, the probability that contractor A will delay between 5 and 8 percent is equal the probability of an up to 8% delay minus the probability of an up to 5% delay, ie., 0.8186 - 0.0869 = 0.7317.

Lexicographical ordering with aspiration level

Although the probability curves provide some insight into the expected performance of contractors and also give the range of uncertainty, it is quite difficult to draw any conclusion from these curves for selecting the rank order of the contractors. Analyses can be performed using the aggregate means and variance. For example, a lexicographical ordering with aspiration level decision technique (Keeney and Raiffa, 1993:77) can be used to evaluate and identify the rank order of these four contractors. In this technique, the three client goals are ordered according their importance, the importance or weights differing between cases (Appendix 2 gives some of the reasons of these differences).

In our example let us assume that the order of importance is time then cost then quality i.e time is more important than cost and quality and cost is more important than quality for this case. For each attribute (time, cost, quality) an aspiration level is set and the following rules applied:

Contractor A > (preferred to) contractor B whenever the aggregate value of contractor A in the attribute time is greater than the aggregate value of contractor B for the same attribute and the aggregate value of contractor B is less than the aspiration level set by the analyser for the same attribute. In this case, the attribute time overrides all others as long as its aspiration level is not met. If the aspiration level of time is met by contractor B, then the cost attribute overrides all others as long as the aspiration level of cost is not met and so forth. If all aspiration levels are met, then we may be willing to give up some of the time attribute for a suitably large increase in cost and so on.

In example of the four contractors A,B,C,D given in Table 3, let us assume the aspiration level is set to be the average of the aggregate expected mean and variance values of the four contractors, ie., the aspiration level for expected mean for time is (8+2+6+12)/4 = 7% and the aspiration level for variance for time is (4.84+7.84+3.61+6.25)/4 = 5.635%, in other words the client sets a maximum acceptable delay of 7% of the scheduled time with a variance of 5.635. It is clear that contractor C is the only one that meets the aspiration level of the expected mean and variance for the time attribute. If a different trade-off is made where the expected mean is increased to 8% and variance decreased to 5, in this case contractor A will met the new aspiration level along with contractor C. The aggregate values of both contractors B and D are quite far from the parameters of the reset aspiration level and they either excluded or just ranked in order after contractors A and C.

Now only contractors A and C are to be tested for the cost attribute. In a similar way, the aspiration level for cost is set first by taking the average of the aggregates of the two contractors A and C only in this case. The aspiration level could be set according the conditions and constraints at hand, the expected mean set to not exceed (6+2)/2 = 4% and variance is (3.57+4.41)/2 = 3.99%, both contractors will not meet the aspiration level, contractor A has an aggregate value higher than the aspiration level in terms of the mean while contractor C is higher in terms of variance. In this case the aspiration level may be reduced by choosing either to reduce the expected mean or the variance bearing in mind that if the mean was reduced the variance should increased and vice versa. If we reduced the mean of the aspiration level to 3% instead of 4% and the variance increased to 4.5, contractor C in this case will meet the requirements and contractor A will be disqualified or ranked as a second. Since only contractor C is left there is no need for investigating the quality. If both contractors meet the cost aspiration level then the quality attribute has to be checked similarly, bearing in mind that for time and cost the lower the aggregate expected mean value the better while for quality the higher the better and vice versa, but for the variance value the lower the better for the three attributes. If all aspiration levels set by the client for the three attributes are met by the two contractors, we may be willing to give up some of aspiration level of the first attribute for an increase in the second attribute and so on.

Fig 4 shows how the aspiration level technique could be used to observe the differences among the contractors and compare their results. This decision technique is mainly based on the order of the importance of the attributes and also on the aspiration levels set for selecting and passing the hurdles.

The problem with this method is that it is assumed that there is some value of variance above which a contractor will not be acceptable **irrespective of the expected (mean) value**. It is not difficult to think of situations where this may be a poor assumption. Consider the case of two contractors, contractor A and contractor B. Contractor A has an expected value of -2% and variance of 9 whilst contractor B has an expected value of 6% with a variance of 1. Following the above example and using an aspiration level of 7% expected value and 5.635 variance, Contractor B would be preferred to contractor A on the grounds that contractor A's variance of 9 exceeded the 5.635 limit. However, if we consider the contractors' likely range of values (typically the expected value plus or minus 2 standard deviations) we find the contractor A's range is -8% to +4% with contractor B's range being 4% to 8%. In other words, contractor A will always outperform contractor B! What is needed therefore is some method of ranking the contractors by considering the expected values and variances **simultaneously**.

Risk analysis technique

One approach to this is to consider the risks involved. What is the probability of a cost overrun, time overrun or quality shortfall for each of the potential bidders? This is equivalent to the area under the normal probability curve at SMv=0. If project cost, time and quality targets are all of equal importance, the smaller the sum of these risks for each contractor the better the contractor. If the cost time and quality targets are prioritised, then it is the weighted sum of these risks that are important.

This method would avoid the problem described above. Contractor A, with less risk of overrunning, would then be ranked above Contractor B with a virtual certainty of overrunning. But consider another example where Contractor C has an expected value of 8% with a variance of 25. This contractor has a smaller probability of overrunning than contractor B above and would therefore be ranked second, ahead of contractor B, but will on average overrun by 2% more than contractor B. If the client is intolerant of an overrun beyond, say, 10%, then contractor B must be preferred to contractor C as contractor B has less risk of overrunning beyond 10%. To take this into account in ranking contractors, it is therefore necessary to consider not just the probability of overrunning but the **degree** of likely overrun. The point at which a client becomes intolerant, or **cut-off** point, of an overrun becomes a crucial issue and it is the probability of overrunning beyond that point that is now the determining factor in ranking the contractors.

This is illustrated by referring once again to the four contractors in Table 3. Assuming, for the sake of simplicity, that cost, time and quality are equally weighted, the rank ordered contractors for a cost, time and quality cut-off of 0% is contractor 4, 2, 1 and 3. This represents the best ordering of contractors based on the criteria of minimum combined risk of overrun on time and cost and substandard quality. When the cost and time cut-offs are 0% and the quality cut-off is 1%, 2% and 3%, the contractor rankings are still 4, 2, 1 and 3. When the quality cut-off is raised to 4%, the positions of the two leading contractors reverse and the rankings become contractors 2, 4, 1 and 3. This ranking holds up to a quality cut-off of 10%, beyond which contractor 3 becomes second ranked with contractors 4 and 1 being third and fourth ranked respectively.

Holding quality and cost cut-offs at 0%, the contractor rankings change at 2% and 3% time cut-offs to contractors 4, 3, 2 and 1. At the 4 to 6% time cut-offs the rankings change to contractors 4, 3, 1 and 2 and at 7 to 10% time cut-offs to contractors 4, 1, 3 and 2. The full results of this analysis are shown in Fig 5 for all percentage increments of time and quality cut-offs between 0 and 20% at 0% cost cut-off. Figs 6 and 7 give the results for 5% and 10% cost cut-offs respectively. The analysis is easily extended to different time, cost and quality weightings (but not shown here for brevity).

Perhaps the most striking aspect of this analysis is the sensitivity of the rankings obtained by this method to slight changes in cut-off values. Ideally, we would hope to find the same optimum ranking for all cut-off values, but this is clearly not the case in this example even though the expected values and variances are quite different between contractors and client goals. Closer inspection however indicates that there are a few consistencies of note. For the 0 and 5% cost cut-offs, for example (Figs 5 and 6), contractor 1 is never ranked higher than second, irrespective of the time and quality cut offs. As the usual aim in practice is to find the top five or six contractors rather than optimum rankings as shown here and it is possible that, with a much larger set of potential contractors, this top set will be generally quite stable even though the order within the set may change with different cut-offs.

ADVANTAGES, DISADVANTAGES AND LIMITATIONS

Assessment of expected performance of contractors in relation to client goals implies an assumed independence among the contractor selection criteria. The advantage of this approach is that it permits an assessment to be made of the imprecision and/or uncertainty in the contractor data, the contractor data is **directly** evaluated against client goals, and the clients subjective evaluation of the contractors data is formally incorporated into the analysis process. This research is limited to the predominant client goals in terms of time, cost and quality. Other limitations is that the tradeoff in the parameters of the aspiration level for the same attribute and between the aspiration levels between different types of attributes is largely subjective.

It is also important to report here that the ratings of the three values of the pessimistic, average and optimistic for the whole set of criteria for different types of contractors were investigated in previous research (Hatush and Skitmore, 1995b) and a default values were suggested to minimise the effort of assessing the contractors and therefore could be used for this purpose.

CONCLUSION

This research is based on the premise that selection should concentrate on determining contractor potential for achieving project goals. The major benefit of this work is that it provides a means using the PERT methodology to incorporate uncertainty and/or imprecision associated with the assessment of contractors data, this all in terms of the ultimate project goals of time, cost, and quality. The paper presents a quantitative technique to combine the contractor data in terms of these goals. The study also presented an evaluation strategy that involves the consideration both the client goals as ends and contractor data as the means, the strategy based on the aspiration level, risk analysis for the final selection or rank ordering of the contractors based on the preferences of the client using the traditional competitive tendering system of procurement.

The paper should help clients selecting contractors and the contractors themselves for selecting sub-contractors in offering a means of broadening their analysis of tenderers beyond that of simply relying on tender values. It also alerts contractors to the importance of increasing their ability to satisfy the needs of the clients in terms of their ultimate project goals.

Several opportunities for further reserach in this area exist. One is that the relatively small sample of prequalifiers involved in the study could be extended to a much larger sample, possibly divided into different types of prequalifiers (eg., clients and consultants) engaged on different types and sizes of projects. Another possibility is that the ultimate project goals of time, cost and quality are extended to include other goals such as quality, uncertainty, flexibility and risk, perhaps to suite alternative procurement forms or types of project in future. This would be a simple job if the system were computerised. It is also clear that this work may be extended to the evaluation of contractors by means of multiattribute utility theory.

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Appendix 1

Questionnaire on the importance of criteria for contractor selection

Q1. The criteria shown in the Table below deal with the selection of contractors for standing or project list. What is the importance of each of these main criteria on successful selection of a contractor? simply give weight from 0 to 100 for each criterion.

Example

Financial soundness F	Technical ability T	Management capability M	Health and safety S	Reputation R
21	25	18	7	29

note: the total weight of the criteria must be equal 100
i.e (F+T+M+S+R) must equal 100
(21+25+18+7+29)=100 o.k.

Please fill your scores in the following Table

Financial soundness F	Technical ability T	Management capability M	Health and safety S	Reputation R
20	20	15	10	35

Q2. Each of the previous main criteria is broken down to subcriteria. What is the importance of each of the subcriteria on identifying its main criterion and on successful selection of a contractor? simply give weight from 0 to 100 for each subcriteria.

Example

Financial soundness F			
Financial stability 1	Credit ratings 2	Bank arrangements 3	Financial status 4
20	20	25	35

note: The total weight of the subcriteria must also be equal 100
i.e (F1+F2+F3+F4) must equal 100
(20+20+25+35) = 100 o.k.

Please fill the following Tables in a similar way

Financial soundness F			
Financial stability 1	Credit ratings 2	Bank arrangements 3	Financial status 4
20	20	20	40

Appendix 2: Reasons of the differences in the importance of client goals

1. Prequalification stage

1.1 In prequalification the contractors usually categorised according to different size of contracts they can afford, this size usually is not a fixed number but it is on some margin say contractors category A between (£ 500,000 - 1,000,000) Category B, (£ 1,000,000 - 4,000,000) and son, so there is a wide a gab that allows a possibility for different contractors of different capabilities to get in the list in the same category.

1.2 Usually in prequalification the number in the standing list will end up with thirty to forty contractors, so if there is any miss judgment or any decision mistakes in the assessment and evaluation during the prequalification stage that a contractor got in the list, still there is no harm since the client has a chance and a plenty of time (usually prequalification is done every 1, 3, 5 years to revise and has the right to disqualify the contractor at any stage and at any time he feels the contractor is not capable.

1.3 There is no legal contracting arrangement that forcing the client to invite a contractor that he is not happy with.

1.4 There is enough time to revise and recheck the documentation and the contractors criteria.

1.5 There is no commitment for the client to pay any money, and he will not be counted for that, this makes the evaluation process during the prequalification stage much easier and any decision mistakes will not have any impact if the contractor get into the standing list.

The prequalification is a pretender stage and is done purposely for selecting the most suitable contractors that are eligible to bid later when they are invited and to make the evaluation of bids easer, but due to the gabs in time between the prequalification stage i.e the time when the contractor get in to the list and the time when he is in a bidding stage there is some quite changes that might occurred to the capabilities of the contractors, this support the view that the evaluation at the prequalification stage is not fully guaranteed to provide good contractors all over the time.

2. Bid Evaluation stage

2.1 The size of the project in this case is almost fixed to certain budget limit, this makes the evaluation of contractors much more difficult.

2.2 In bid evaluation the client has to end up with only one contractor, so if there is any miss judgment or any decision mistakes during the bid evaluation stage, there is a negative impact on the whole process, and this affecting the clients goals(Time, cost, Quality, ...), specially in this case there is no chance to repeat the evaluation if the contractor was selected for specific contract.

2.3 There is legal contracting arrangement and obligation that forcing the client to cooperate with contractor and a legal battle and disputes.

2.4 There is a commitment for the client to pay money to the contractor, and he will be counted for that, this makes the evaluation process during the bid stage much more difficult and any decision mistakes in this stage will have its legal suits for the client in front of the public.

2.5 During the bid evaluation the four or six contractors have different levels of achievement in different clients criteria, this is due to the nature and, type, and size of projects they are executed which gave them an opportunity to gain an experience, for example if one contractor is used to build a high complex buildings so he gained an experience in terms of projects complexity, while another one is doing a simple type of building of simple nature but of large size that makes him in the same category with the first one, in this situation when they both competing for one project they are certainly have different criteria or capabilities.

All these factors in the prequalification and bid evaluation stages makes the difference in weights assigned to the client attributes and it affects the strategy adopted for both stages.

Financial Soundness (F)	1. Financial stability 2. Credit rating 3. Banking arrangements and bonding 4. Financial status
Technical Ability(T)	1. Experience 2. Plant and Equipment 3. Personnel 4. Ability
Management Capability (M)	1. Past performance and quality 2. Project management organisation 3. Experience of technical personnel 4. Management Knowledge
Health and Safety(S)	1. Safety 2. Experience Modification Rating (EMR) 3. Occupational Safety and Housing Administration OSHA Incidence rate 4. Management safety accountability
Reputation (R)	1. Past failures 2. Length of time in business. 3. Past client/contractor relationship 4. Other Relationships

Table 1: The main and source of criteria for contractor prequalification and bid evaluation

Criteria	Subcriteria	Weight
Financial Soundness (F)	1. Financial stability 2. Credit rating 3. Banking arrangements and bonding 4. Financial status	0.05175 0.04100 0.04575 0.06650
Technical Ability(T)	1. Experience 2. Plant and Equipment 3. Personnel 4. Ability	0.07250 0.03625 0.07875 0.07500
Management Capability (M)	1. Past performance and quality 2. Project management organisation 3. Experience of technical personnel 4. Management Knowledge	0.044375 0.040625 0.046250 0.043750
Health and Safety(S)	1. Safety 2. Experience Modification Rating (EMR) 3. Occupational Safety and Housing Administration OSHA rate 4. Management safety accountability	0.018875 0.016875 0.014500 0.019750
Reputation (R)	1. Past failures 2. Length of time in business. 3. Past client/contractor relationship 4. Other Relationships	0.068125 0.085000 0.086250 0.048125

Table 2: The weights of the twenty criteria

Client goal	Aggregate expected means, variance and standard deviation values of the four contractors				
	parameter	A	B	C	D
Time	AEt	108	102	106	112
	V of(AEt)	4.84	7.84	3.61	6.25
	S of (AEt)	2.2	2.8	1.9	2.5
Cost	AEc	106	110	102	104
	V of (AEc)	3.57	4.84	4.41	3.24
	S of (AEc)	1.89	2.2	2.1	1.8
Quality	AEq	99	98	92	100
	V of (AEq)	4.84	6.25	7.29	4.84
	S of (AEq)	2.2	2.5	2.7	2.2

Table 3: Expected mean, variance and standard deviation values for contractors A,B,C,and D in different client goals