Evaluation and Selection of Construction Contractors Based on Analytic Hierarchy Process (AHP)

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Abstract

Contractor selection is a multiple-attribute decision-making problem that influences the progress and success of any construction project. The use of inappropriate methods in selecting contractors leads to a poor decision and poses the risk of poor project performance. Analytic Hierarchy Process (AHP) is a method used in a multi-criteria decision. The AHP has the advantage of having the ability to calculate a measure of inconsistency for each set of judgments. This property enables decision-makers to identify errors and to revise their judgments in the case of high values of inconsistency. This paper presents the development of hybrid model based on AHP, aimed to solve the contractor selection problems for the award construction projects using Super Decisions software. The paper describes the AHP methodology and demonstrates the structuring multiple choice criteria into a hierarchy, assesses the relative importance of these criteria, compares alternatives for each criterion and determines an overall ranking of alternatives based on quantitative and qualitative criteria. Contractor selection criteria are determined based on the review of prior literature and expert judgment. This model has been tested with a hypothetical scenario where contractor candidates were evaluated. Results revealed that the model can be used as a tool for predicting the overall relative strength of each candidate. Thus, selecting the most qualified one is an easy, fast, and low-cost process leading to fewer problems to the client.

Keywords: Contractor selection, Analytic Hierarchy Process, Decision making

1- Introduction

In Malaysia, clients in the construction industry can be divided into two types (Hashim et al. 2006) namely, the public and private clients. The public clients consist of government-funded development agencies and local authorities. The private clients consist of property developers, owner-occupiers and investors. The Public Works Department (PWD) is responsible for the development, planning, design, construction and maintenance of public roads, bridges, public water supplies, common-user buildings and government quarters for the Ministry of Works. In Malaysia, most design work is prepared by the PWD but construction work is carried out by contractors (Somiah 1995). Malaysian contractors registered with Construction Industry Development Board (CIDB) fall within seven grades (G1 to G7) and are graded based on three main criteria: tendering capacity, financial capacity and availability of human resources.
According Table 1, Malaysian construction industry is a highly competitive industry. In Malaysia, public sector clients normally select contractors through open tendering (Jaafar et al. 2006). They advertise their proposed projects in mainstream newspapers (tender invitation) and then short list potential contractors after bid evaluation. In the final stage of the tendering process, the appointed Tender Board selects the successful tenderer giving due regard to technical and financial considerations (Somiah 1995). Nevertheless, many public projects suffered from late completion, cost overrun and poor post-construction functioning and day by day, many projects fail to be complemented with an acceptable level of quality (Jaafar et al. 2006). To continuously enhance the level of productivity and quality, the Malaysian construction industry will need to address some key areas. One of the key areas of concerns is contracting approaches (Malaysian Construction Industry Master Plan 2005-2015). That’s why it has become necessary to find new methodologies to qualify a contractor and determine if he’ll stand behind his work, will be financially responsible and will deliver what is specified.

Construction researchers and practitioners have proposed different methods or procedures related to contractor selection (discussed in the next section). The model of contractor selection process developed in this research study is based on Analytical Hierarchy Process (AHP) using Super Decisions software v1_6.exe. The AHP is a tool to quantify the qualitative trade-offs between various objectives to extract a single set of weights which reflect the level of importance of each of the factors in the overall decision making system (Saaty 1980). The AHP converts individual preferences into ratio-scale weights that are combined into linear additive weights for the associated alternatives (Forman and Gass 2001). These resultant weights are used to rank the alternatives and, thus, assist the decision maker in making a choice or forecasting an outcome. A unique feature of the approach is the possibility to calculate a measure of inconsistency for each set of judgments. This property enables decision-makers to identify errors and to revise their judgments in case of high values of inconsistency and thus improve the quality of the decision. This research was concerned only with the public sector client’s view during selection.

2- Contractor selection process

Contractor selection corresponds to an interface between a variety of construction industry clients and an equally varied array of construction companies (Alarcon and Mourgues 2002). Contractor selection process can be divided into two stages: prequalification and final selection (Holt 1998; Banaitienė and Banaitis 2006). Holt (1998) has presented review and analyses of the methodologies available to both stages of the contractor selection process. One of the main objectives in prequalification of potential bidders is to ensure a reasonable level of competitiveness for the work in hand (Russell et. al 1990).This reduces the number of contractors
on the list to those most qualified for the particular project. Moreover reduces the cost of bidding, while retaining the benefits of pure competition by screening according to predetermined non-price criteria (Ng and Skitmore 2001). The process of contractor qualification has been performed by many different methods which are proposed by construction researchers and practitioners. To name a few of them: a utility theory model by Hatush and Skitmore (1998); a fuzzy bid evaluation model by Nguyen (1985) and Lam et al. (2001); a statistic model by Jaselskis (1988); a dimensional weighing method by Jaselskis and Russell (1991); fuzzy set theory by Singh and Tiong (2005); Data envelopment analysis (DEA) by McCabe et al. (2005) and Quality-Based Performance Rating (QBPR) by Minchin and Smith (2005).

Recently, the analytical hierarchy process (AHP) has received a sufficient attention of research professionals to solve the problem of prequalification and final contractor selection. Mahdi et al. (2002) have introduced decision support system to assist the decision-maker in identifying the most appropriate contractor for specific project. They derived the relative weights of decision criteria using the Delphi method, while, they used AHP for assessing the specific project conditions. Abudayyeh et al. (2007) were used AHP to make prequalification decisions within the context of the three contracting methods (Design-build, cost-plus-time, and warranty). Al-Harbi (2001) presents the AHP as a potential decision making method for use in project management. The contractor prequalification problem was used as an example. Al-Dughaiither (2006) presents a modeling methodology for contractor pre-qualification. It demonstrates how a pre-qualification multicriteria decision making model (PQDM) using the AHP can overcome the difficulties of the prequalification process. Such difficulties arise from the complexity, subjectivity and lack of group consensus concerning the evaluation of entities potentially involved in the construction process.

Conflicting or inadequate contracting decisions in contractor selection procedures cause problems in carrying out construction projects. Banaityne and Banaitis (2006) have identified three prime causes of inadequate contractor selection: inappropriate criteria are selected, inappropriate significance is attributed to the criteria and inappropriate methodology is applied for the contractor evaluation and selection task. Therefore, the decision-making process for identifying the most appropriate contractor/tender requires skill and expertise, along with a systematic and predefined selection procedure.

### 3- Contractor selection criteria

Selection of the contractor for the job has long been primarily based on bid price alone (Merna and Smith 1990; Holt et al. 1995). The initial savings from price-based competition are erased over the long-term because of inferior performance leading to additional costs (Feldman 2006). However, selection of the lowest bidding contractor which relegates quality concerns to a secondary factor is one of the major causes of cost over-runs, delays and the poor performance of a construction project (Singh and Tiong 2006; Russell et. al 1990). Because of imperfect design plans, contractors must later put in for change orders which add time and costs to the project (Feldman 2006). The low-bid contracting system is based on flawed assumptions (Gransberg and Ellicott 1996). It assumes that contractor performance can be controlled by project manager management and inspection. But research shows that government management and inspection of construction is inefficient and results in poor performance (Feldman 2006). Therefore, it is important to use additional decision criteria other than the lowest tender and should be attributed to the highest weight (Mahdi et al 2002; Banaityne and Banaitis 2006; Hardy et al., 1981; Hauck & Kline, 1986; Jaselskis and Russell, 1992; Wong et al. 2001; Fong and Choi 2000; Pongpeng and Liston 2003). Although exact criteria used in selection and the relative weight given to each contractor may vary among different projects, owners or agencies, there are some key factors that should always be considered and used for evaluating competitors (Feldman 2006). Generally in construction, the criteria for selection contractor include contractor ability to complete a project on time, within budgeted cost and to expected quality standards (Ogunsemi and Aje 2006). There have been identified factors that are likely to influence the choice of criteria. These are client objectives (Russell et al. 1992) and decision-maker perceptions (Ng 1996). It is conventional to group clients into two broad categories, public and
private. Fellow (1988) has shown that each client may devise his own selection criteria (i.e.: time, cost and quality). He has been found that private clients rank time as the most important of the three criteria, while cost is considered the least important. In addition he states that public clients give highest importance to the quality and least importance to the cost. In addition, (Ng and Skitmore 1999) stated that the procurement method selection of public sector clients, are more stringent and well defined to eliminate any imprudent inclusion, or unlawful rejection of contractors. On the other hand private clients have greater flexibility in determining their qualification criteria than their public counterparts. While Mahdi et al. (2002) have identified three factors that affect the evaluation process. These factors are: (1) the level of experience, (2) the effort made by the decision-maker and (3) the quality of information, which may vary from one situation to another. Contractors should not be selected according to the lowest price, but it should be attributed to the highest weight (Banaitienė and Banaitis 2006).

Contractor selection criteria were determined based on the review of prior literature (Banaitienė and Banaitis 2006; Topcu 2004; Al-Harbi 2001; Mahdi et al. 2002; Singh and Tiong 2006; Ng and Skitmore 1999; Fong and Choi 2000; Kumaraswamy 1996; Palaneeswaran and Kumaraswamy 2001, Alfred 2006; Nmez et al. 2001; Jennings and Holt 1998, Hatush and Skitmore 1998; El-Sawalhi et al. 2007; Cheng and Li 2004). Table (2) shows the most important characteristics of contractors that influence project performance.

4- Analytic Hierarchy Process Methodology

AHP is a multiple criteria decision-making tool (Saaty 1980). This is an Eigen value approach to the pair-wise comparisons. It provides a methodology to calibrate the numeric scale for the measurement of quantitative as well as qualitative performances (Vaidya and Kumar 2006). The computational aspects of AHP involve several steps (Saaty 1994, 1980; Zahedi 1986) as shown in fig. 1.

4.1 Structure complexity

The goal is to structure the problem into a hierarchy. A hierarchy is a tree-like structure that represents a complex problem on a number of levels (Saaty, 1994). The first level is the goal to be achieved, followed by criteria, sub-criteria and so on down to the last level at which alternative are located. The number of levels in any hierarchy depends on the amount of information requested by the decision makers to evaluate the system and the complexity of the problem.

4.2 Construct comparison matrices:

The elements on the second level are arranged into a matrix, and the decision-makers make judgments about the relative importance of the element with respect to the overall goal of selecting the most capable contractor. Assign a relative weight to each criterion based on its importance in the final decision. Comparison matrices are constructed to determine the potency with which the various elements in one level influence the elements on the next higher level, so as to compute the relative strengths of the impacts of the elements of the lowest level on the overall objective. Each element is then evaluated against each of its peers in relation to its impact on achieving the objective of the parent element.

Table (2): The most important Contractor selection criteria from previous research
<table>
<thead>
<tr>
<th>Criteria</th>
<th>Sub-criteria</th>
<th>Details</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Past performance</td>
<td></td>
<td>Type and scale of the project completed in past, Technical performance.</td>
<td>Kumaraswamy 1996</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Timeliness, Compliance with specifications and quality standards</td>
<td></td>
</tr>
<tr>
<td>2 Performance potential of the contractor</td>
<td>Financial stability</td>
<td>Operations ratio, leverage ratio, and quality of financial statements.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Adequacy of banking arrangements</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Authorized and paid-up capital, Current commitments, Current and fixed assets, Liquidity status of the company, Finance arrangement.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Resources facilities</td>
<td>Working capital</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Staffing, Labor, Planning/Programming.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Qualification and experience of technical staffs.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Availability of owned construction plant and equipment, Manpower resources.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Contracting company’s attributes</td>
<td>Familiarity with local working culture.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Past failure</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Company negotiating skill, Managerial ability.</td>
<td></td>
</tr>
</tbody>
</table>

4.3 Pairwise comparison

To incorporate their judgments about the various elements in the hierarchy, decision makers compare the elements two by two. The Criteria will be compared as to how important they are to the decision makers, with respect to the Goal. The AHP methodology compares criteria, or alternatives with respect to a criterion, in a natural, pairwise mode. To do so, the AHP uses a fundamental scale of absolute numbers developed by Saaty (1980) shown in Table 3. The fundamental scale has been shown to be a scale that captures individual preferences with respect to quantitative and qualitative attributes just as well or better than other scales (Saaty 1980, 1994). It converts individual preferences into ratio scale weights that can be combined into a linear additive weight for each alternative. The resultant can be used to compare and rank the alternatives and, hence, assist the decision maker in making a choice.
4.4 Check consistency of matrices

The AHP is able to provide a measure of consistency and to reduce the inconsistency inherent in the judgment process (Ta and Har 2000). This measure is known as the consistency ratio (CR). The value of the consistency ratio should be 10 per cent or less. If it is more than 10 per cent, the judgments may be somewhat random and should perhaps be revised (Saaty 1988). The AHP is able to show one by one, in a sequential order, which judgments are the most inconsistent. The AHP also suggests the value that best improves inconsistency. The decision maker then could refine the information on the criteria. At various stages in the analysis, the consistency of the matrices must be checked to verify the reliability of the judgments of the decision maker (Saaty 1994).
Table 3: The Fundamental Scale for Pairwise Comparisons

<table>
<thead>
<tr>
<th>Intensity of Importance</th>
<th>Definition</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Equal importance</td>
<td>Two elements contribute equally to the objective</td>
</tr>
<tr>
<td>3</td>
<td>Moderate importance</td>
<td>Experience and judgment slightly favor one element over another</td>
</tr>
<tr>
<td>5</td>
<td>Strong importance</td>
<td>Experience and judgment strongly favor one element over another</td>
</tr>
<tr>
<td>7</td>
<td>Very strong importance</td>
<td>One element is favored very strongly over another; its dominance is demonstrated in practice</td>
</tr>
<tr>
<td>9</td>
<td>Extreme importance</td>
<td>The evidence favoring one element over another is of the highest possible order of affirmation</td>
</tr>
</tbody>
</table>

Intensities of 2, 4, 6, and 8 can be used to express intermediate values. Intensities 1.1, 1.2, 1.3, etc. can be used for elements that are very close in importance.

Source: Saaty, 1980

4.5 Perform sensitivity analysis

Sensitivity analysis allowed verifying the results of the decision (Saaty 1995). Sensitivity analysis can be performed to see how well the alternatives perform with respect to each of the criteria as well as how sensitive the alternatives are to changes in the importance of the criteria (Saaty 1988). In addition to this, each sub-criterion performs on each main criterion by increasing or decreasing the importance of the main criteria. It should be noted that if a criterion is not sensitive, it would be better to eliminate it from the AHP model.

4.6 Select the best alternative

Comparisons are made by ranking the aggregate scores of each candidate with regard to their performance against each of the criteria, and the candidate associated with the highest scores is the best contractor on this occasion.

5- Results and discussion

The first step in using AHP and the Super Decisions software is to develop a hierarchy by breaking the problem down into its components. The three major levels of the hierarchy are the goal, objectives, and alternatives.

A four level hierarchy was constructed as shown in Figure 2. The top level represents the overall goal of selection of most capable contractor. The four main criteria of past performance; performance potential of the contractor; tender price and safety management are being the second level. The third level comprising the sub-criteria of criterion “performance potential of the contractor”, include: financial stability; resources facilities; contracting company’s attributes and capacity to accomplish the work.
While the fourth level represents the alternatives. Three contractors (A, B and C) are supposed to be interested in bidding for a construction project. These contractors (alternatives) contribute to each criterion and sub-criterion in a unique way.

5.1 Prioritization

Based on the developed hierarchy, the elements on the second level (Past Performance...Safety Management) are arranged into a matrix and questionnaire was set out to make judgments about the relative importance of the element with respect to the overall goal of selecting the most capable contractor. A total of 30 expert judgments were mailed to a sample of public clients who had experience exceeding 10 years. Fig. 3 shows the priority indices for each criterion. Each criterion has a local (immediate) and global priority. The sum of all the criteria beneath a given parent criterion in each tier of the model must equal one. Its global priority shows its relative importance within the overall model.
As can be seen, the overall inconsistency index are less than 0.1, the judgments are acceptable. Similarly, the pair-wise comparison matrices and priority vectors for the remaining sub-criteria are computed with respect to the criterion “Performance Potential of the Contractor” (as shown in fig.4).

![Fig. 4: Priorities of criteria wrt Performance Potential of the Contractor](image)

The relative weights of sub criteria with respect to overall goal (contractor selection) are then determined by multiplying each priority by 0.4719 (the priority of criteria Performance Potential of the Contractor (see table 4)).

<table>
<thead>
<tr>
<th>Sub criteria</th>
<th>Priorities wrt contractor selection</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF</td>
<td>0.0751</td>
</tr>
<tr>
<td>FS</td>
<td>0.2034</td>
</tr>
<tr>
<td>CCA</td>
<td>0.0408</td>
</tr>
<tr>
<td>CCW</td>
<td>0.1527</td>
</tr>
</tbody>
</table>
The next step is to determine the priority selection of bids A, B and C by criterion type. Table 4 illustrates the prioritization of the three alternatives with respect to each criterion and sub-criterion.

Table 5: Comparison alternatives wrt each criterion

<table>
<thead>
<tr>
<th>Criteria</th>
<th>priority</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>*CI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>*LP</td>
<td>*GP</td>
<td>*GP</td>
<td>0.581552</td>
</tr>
<tr>
<td>PP</td>
<td></td>
<td>0.188207</td>
<td>0.100000</td>
<td>0.531330</td>
<td>0.0036</td>
</tr>
<tr>
<td>TP</td>
<td></td>
<td>1.000000</td>
<td>0.149380</td>
<td>0.446287</td>
<td>0.0824</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.626697</td>
<td>0.093616</td>
<td>0.279687</td>
</tr>
<tr>
<td>SM</td>
<td></td>
<td>0.531330</td>
<td>0.188207</td>
<td>1.000000</td>
<td>0.0036</td>
</tr>
<tr>
<td>RF</td>
<td></td>
<td>0.261405</td>
<td>0.136665</td>
<td>1.000000</td>
<td>0.0019</td>
</tr>
<tr>
<td>FS</td>
<td></td>
<td>0.398939</td>
<td>1.000000</td>
<td>0.119364</td>
<td>0.0311</td>
</tr>
<tr>
<td>CCA</td>
<td></td>
<td>1.000000</td>
<td>0.170997</td>
<td>0.584802</td>
<td>0.0237</td>
</tr>
<tr>
<td>CCW</td>
<td></td>
<td>0.398939</td>
<td>1.000000</td>
<td>0.119364</td>
<td>0.0311</td>
</tr>
</tbody>
</table>

*CI=consistency Index  
*GP= Global Priority  
*LP = Local Priority

5.2 Synthesis of Results

Synthesis is the process of weighting and combining priorities through the constructed hierarchy that lead to the overall results. The preferred candidate is the one with the highest priority. The final results show (see fig. 5) that the contractor B would be the best choice for this decision maker. The Normals column presents the results in the form of priorities. The Ideals column is obtained from the Normals column by dividing each of its entries by the largest value in the column. The Raw column is read directly from the Limit Super matrix.

Fig.5: The overall synthesized priorities for the contractors
5.3 Sensitivity analysis

Super Decisions provides tools for performing sensitivity analysis. Sensitivity analysis helps the decision makers to see how the different weights assigned to each criterion could affect the outcome of the model. The general purpose of the sensitivity analyses is graphically seen how the alternative change with respect to the importance of the criteria or sub-criteria. Fig. 6 shows the results of sensitivity analysis of each option. The sensitivity analysis shows how the alternatives were prioritized relative to other alternatives with respect to each criterion. The x axis represents the priority of the criterion, and the priorities of the alternatives are plotted on the y axis. The sensitivity graph shows the effect of changing the priority of criterion on the outcome. For example; at the point $TP = 0.5$ contractor A is about $0.425$, contractor B is about $0.303$ and contractor C is about $0.273$ (see fig. 6c). To change criterion’s priority, drag the vertical solid bar to either the left or right; then a vertical dotted bar showing the new criterion’s priority will be displayed. The graph shows if the priority of $TP$ is greater than $0.355$, contractor A becomes the preferred choice. Before that contractor B is the best alternative.

6- Limitation

AHP has some limitations. The elements should group into homogeneous clusters so that it is not necessary to use a number larger than $9$. It is not desirable to include more than seven to nine elements in any cluster or grouping of elements because experiments have shown that it is cognitively challenging for human beings to deal with more than nine factors at one time and this can result in less accurate priorities (saaty 2003).

7- Conclusion

This paper has illustrated the use of AHP as a decision-making method for contractor selection that allows the consideration of multiple criteria using a hypothetical example. The proposed technique depends on the relative judgments made by public clients. The final rating for criteria was found to be $28.58\%$ for past performance; $20.34\%$ financial stability; for $18.65\%$ tender price; $15.27\%$ for capacity to accomplish the work; $7.51\%$ for resources facilities; $5.58\%$ for safety management and $4.08\%$ for contracting company’s attributes. The difference between ratings was sufficient; so the design team was able to make the decision. Since each construction project is unique, final contractor selection through the AHP gives clients the flexibility to add or reduce the elements of a problem hierarchy regarding an individual project. Clients should develop their own set of scores for the criteria and sub-criteria matching their project requirements. Changes in the Judgments of the main criteria lead to a change in the outcome and explain the final decision. Sensitivity analysis on the effects of local priorities can be carried out by changing the weights of the decision criteria. Using the Super Decisions software, the sensitivity of the outcome to changes in priority can be easily investigated.

It is expected that the proposed model help a project manager select the best contractors to execute the project within budget, on schedule, and in accordance with the standards and specification. The success of the method heavily depends on the way the decision problem is structured and how the pairwise comparisons are carried out.
Fig. 6
Sensitivity analysis:
8. References

7. CIDB News (2005), Issue 2, 11-13