EXPERT-BASED DECISION SUPPORT SYSTEM FOR TENDER SELECTION: IMPACT ON KUWAIT’S CONSTRUCTION INDUSTRY

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ABSTRACT

Improper tender selection could result in several drawbacks during construction which usually are reflected as cost over-runs, delays and poor quality. This is occurring in many public construction projects in Kuwait, which are managed by different ministries and authorities such as the Ministry of Public Works (MPW) and National Authority for Housing Care (NAHC). As an attempt to escape such drawbacks due to the current selection process of one major public agency, the MPW, this research suggests a new systematic approach for tender selection and ranking that would optimize client objectives. This system is a Knowledge-Based Expert System (KBES) that utilizes available expertise of decision-makers for tender evaluation, contractor’s pre-qualifications, current capabilities and submitted plans. The KBES is flexible enough to consider the varying project conditions and objectives with contractor’s qualifications. The system is specially designed to suit the construction environment in Kuwait and similar environments.

Keywords: expert system, decision support system, tender evaluation.

1. INTRODUCTION AND BACKGROUND

The appropriate selection of a contractor has a great effect in achieving the required project objectives. Awarding a contract on the lowest bid price basis may result in the appointment of an inappropriate contractor, which could lead the project to encounter problems such as cost over-runs, delays, or poor quality which lead to disputes and claims [1-4]. That is due to the many uncertainties associated with construction projects, the bidding contractor’s approach in factoring these uncertainties in the cost estimating process, and contractors different qualifications and capabilities in planning and construction. This is more complex in Kuwait because the labor market consists of many different nationalities resulting in different cultures’ work objectives and willingness. Given these uncertainties this paper tries to address the question of how the client, owner of public projects, can select the most appropriate contractor.

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considering different factors in addition to the lowest cost.

As the representative of the major public construction projects in Kuwait, the Ministry of Public Works (MPW) avoids taking risks due to construction uncertainties by delegating these risks to other participants in the projects, mainly the contractor [5]. By doing so, the MPW protects itself from public criticism of not conducting proper project planning, should problems rise at later stages of the project lifecycle. Risk delegation to the contractor is notable in publicly funded projects because funding is limited and any overspending is subject to public scrutiny [6]. In addition for public projects in Kuwait, the MPW tends to avoid public criticism in two other areas:

1. “Favoritism” in tender selection and
2. Overspending on public projects

For most of the awarded public projects in Kuwait, the lowest qualified tenders were selected according to the MPW’s regulations. Unfortunately, many of these projects encountered problems in time, cost and quality control during construction. Accepting the lowest price bid only is a dilemma routinely faced by public agencies [7].

In addition to selecting the lowest tender, the MPW approach included strict guidelines and conditions in the selection process for tenders of public projects [5]. These guidelines include a paper-based (if-then) approach for narrowing the list of qualified contractors allowed to enter the bidding process. Despite its benefits, using a checklist is found to be not sufficient for the following reasons [8]:

1. It can identify the most qualified contractor but it does not necessarily mean it is the optimum contractor for the project in hand.
2. It does not consider the project specific conditions.
3. The evaluation process is limited to the evaluators’ knowledge and experience that may not be sufficient for the proper evaluation process.

The improvement of the tender selection process in construction has been going on for many years. Several innovative evaluation processes that do not depend exclusively on the tender sum have been introduced in recent years. For example, both the minimum project’s time and the lowest tender sum are considered in selecting the optimum contractor in certain competitive tender processes [4]. Another example is where limited schedule is considered as being more important than the tender sum for highway projects in congested cities [8].

1.1 Objective

This research presents clients, namely in the public sector, with an expert-based decision support system (EDSS) that encompasses three major factors in tender evaluation that are: project specific conditions, contractor’s capabilities and previous experience and the proficiency and expertise of the evaluators. The research would enhance the one-dimensional approach that is based on the contractor’s past experience and low bid criterion in tender selection being adopted in many public agencies such as in the Ministry of Public Works (MPW) in Kuwait.
1.2 Research Methodology
The design of the research program includes the following stages:

3. Validation of the evaluation system developed.

2. DESIGN OF A TENDER EVALUATION DECISION SUPPORT SYSTEM (TEDSS)

The design of the evaluation system for tender selection process includes two main phases:

1. Design of the evaluation decision criteria.
2. Design of the evaluation techniques.

2.1 Design Phase 1: Design of Decision Criteria
The probable criteria that can be incorporated in the evaluation process are initially designed on the basis of the survey conducted by Mahdi in the UK and Egypt as indicated in Appendix A [8].

Appendix A
Table 1A. Sample of decision criteria initially designed for the survey

<table>
<thead>
<tr>
<th>Code of Criterion</th>
<th>Criterion Description</th>
<th>Egypt</th>
<th>UK</th>
</tr>
</thead>
<tbody>
<tr>
<td>SDC1-1</td>
<td>Working Years in similar projects (SPs)</td>
<td>95.50%</td>
<td>92.75%</td>
</tr>
<tr>
<td>SDC1-2</td>
<td>Working Years in Construction projects (CPs)</td>
<td>82.44%</td>
<td>25.00%</td>
</tr>
<tr>
<td>SDC1-3</td>
<td>Maximum Project Delivery Rate within Last 3 years</td>
<td>77.94%</td>
<td>67.75%</td>
</tr>
<tr>
<td>SDC1-4</td>
<td>Total Work Volume in Performing SPs - Last 10 Years</td>
<td>58.67%</td>
<td>100.00%</td>
</tr>
<tr>
<td>SDC1-5</td>
<td>Total Work Volume in Performing CPs - Last 10 Years</td>
<td>92.72%</td>
<td>75.00%</td>
</tr>
<tr>
<td>SDC1-6</td>
<td>Average Work Volume in Performing SPs - Last 3-years</td>
<td>80.09%</td>
<td>78.50%</td>
</tr>
<tr>
<td>SDC1-7</td>
<td>Average Work Volume in Performing CPs - Last 3-years</td>
<td>100.00%</td>
<td>25.00%</td>
</tr>
<tr>
<td>SDC1-81</td>
<td>Work Volume for SPs - Lump Sum Contract</td>
<td>83.94%</td>
<td>82.25%</td>
</tr>
<tr>
<td>SDC1-82</td>
<td>Work Volume for Construction Project - Lump Sum Contract</td>
<td>85.44%</td>
<td>67.75%</td>
</tr>
<tr>
<td>SDC1-83</td>
<td>Work Volume for SPs - Unit Price Contract</td>
<td>63.17%</td>
<td>71.50%</td>
</tr>
<tr>
<td>SDC1-84</td>
<td>Work Volume for Construction Project - Unit Price Contract</td>
<td>80.09%</td>
<td>82.25%</td>
</tr>
<tr>
<td>SDC1-85</td>
<td>Work Volume for SPs - Const. Management Contract</td>
<td>89.51%</td>
<td>28.50%</td>
</tr>
<tr>
<td>SDC1-86</td>
<td>Work Volume for Construction Project – Const. Management Contract</td>
<td>75.16%</td>
<td>85.75%</td>
</tr>
<tr>
<td>SDC1-9</td>
<td>Owner-Contractor Work Volume (Familiarity) within SPs</td>
<td>65.31%</td>
<td>25.00%</td>
</tr>
<tr>
<td>SDC1-10</td>
<td>Owner-Contractor Work Volume (Familiarity) within CPs</td>
<td>54.39%</td>
<td>78.50%</td>
</tr>
<tr>
<td>SDC1-11</td>
<td>Work Volume in Similar Weather Conditions within SPs</td>
<td>80.09%</td>
<td>67.75%</td>
</tr>
<tr>
<td>SDC1-12</td>
<td>Work Volume in Similar geographical Conditions within SPs</td>
<td>65.95%</td>
<td>89.25%</td>
</tr>
<tr>
<td>SDC1-13</td>
<td>Work Volume in Similar geographical Conditions within CPs</td>
<td>51.81%</td>
<td>70.75%</td>
</tr>
</tbody>
</table>
These criteria are reassessed by the expertise from the Kuwaiti construction industry to identify their relevance to the Kuwaiti construction environment. The results of this assessment and its comparison to that assessed in the UK and Egypt are shown in Appendix B.

Table 1B. Comparison of decision criteria groups

<table>
<thead>
<tr>
<th></th>
<th>Egypt</th>
<th>UK</th>
<th>Kuwait</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCG1: Past Experience</td>
<td>83.87%</td>
<td>86.54%</td>
<td>90.29%</td>
</tr>
<tr>
<td>DCG2: Past Performance</td>
<td>87.50%</td>
<td>93.37%</td>
<td>100.00%</td>
</tr>
<tr>
<td>DCG3: Financial Stability</td>
<td>90.12%</td>
<td>94.20%</td>
<td>90.29%</td>
</tr>
</tbody>
</table>

The decision criteria are divided into three major divisions to include:

Division 1- Decision Criteria Related to the Project Specific Conditions: The criteria of this division can differ from one project to another according to its specific conditions. Such criteria may include: 1) project budget, 2) project schedule, 3) the required quality level, 4) project unique feature, 5) environmental requirements etc. There is a flexibility to add other criteria during the evaluation system implementations.

Division 2- Decision Criteria Related to the Contractor Pre-qualifications: The criteria that are related to the contractor pre-qualifications are divided into three groups 1) contractors' past experience, 2) contractors' past performance, and 3) contractors' financial stability. Each group has quantitative and qualitative criteria. For example the number of working years, the total work volume, the average work volume in the last three years and the different contract type encountered, quantifies past experience in previous projects. The contractor level of performance in previous projects is measured by how well the contractor did in meeting projects' objectives of controlling cost, schedule and quality, especially in similar projects. Financial stability is measured by contractor's credit level, banking arrangements and quality of financial statement decision criteria.

Division 3- Decision Criteria Related to the Qualified Contractors' Current Capabilities and Submissions to the Project in Hand: Its assessment includes 1) company's quality of workmanship, 2) management abilities, 3) current resources against workload, and 4) cost, time, quality, safety and resource plans to the project in hand. For more details about the different decision criteria for each division either quantitative or qualitative and their purposes see Mahdi [8].

2.2 Design Phase 1: Design of the Evaluation Techniques

There are different evaluation techniques that can be used in handling the multiple criteria required in the evaluation process as indicated in the previous section. As for dealing with criteria of quantitative and/or qualitative measures, the Analytic Hierarchy Process (AHP) was found to be an appropriate technique to identify the optimum contractor based on multi-criteria. The AHP is a scientific and easy to use method that helps in identifying and setting priorities on the basis of decision-maker's experience [9]. The strength of the AHP lies in its ability to structure a complex and multi-attribute problem by dividing it in hierarchical levels and
combining the results as the analysis progresses [10].

To reduce the time required for assessing the relative importance of the decision criteria especially the contractor criteria, the Delphi method was found to be an appropriate method for that purpose. The Delphi method is a systematic procedure to evoke and reflect the expert opinion [11]. This can enhance the quality of the decision and can avoid, as possible, the personnel judgment [8].

2.3 TEDSS Model

The mathematical solution for the evaluation model includes the following steps:

1. A weight vector pertaining to the decision criteria \( DCm \) is constructed directly in the following form (1).

\[
[DC_1] = \\
[DC_2] \\
[DC_3] \\
\vdots \\
[DC_m]
\]

(1)

This vector consists of the set of weights for each criterion, reflecting its relative degree of importance to others.

2. The decision criteria related to the project specific conditions are determined by the decision-maker for the evaluation process on the basis given in Table 1. Then, their relative weights \( (PFi) \) are determined by solving a matrix of the AHP method. The result of weight assignment for each pair of factors \( (PF_i, PF_j) \) is presented in a matrix form as shown in (2).

<table>
<thead>
<tr>
<th>Intensity of Importance</th>
<th>Definition</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Equal importance of both elements</td>
<td>Elements contribute equally to the property</td>
</tr>
<tr>
<td>3</td>
<td>Weak importance of one element over another</td>
<td>Judgement slightly favors one element over another</td>
</tr>
<tr>
<td>5</td>
<td>Essential or strong importance of one element over another</td>
<td>Experience strongly favors one element over another</td>
</tr>
<tr>
<td>7</td>
<td>Demonstrated importance of one element over another</td>
<td>An element is strongly favored and its dominance is demonstrated in practice</td>
</tr>
</tbody>
</table>
9. Absolute importance of one element over another

Favoring one element over another is of the highest possible order

2, 4, 6, 8 Intermediate values between two adjacent judgements

Table 2. Random Index (RI) values, Saaty (1980)

<table>
<thead>
<tr>
<th>N</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>RI</td>
<td>0.00</td>
<td>0.00</td>
<td>0.58</td>
<td>0.90</td>
<td>1.12</td>
<td>1.24</td>
<td>1.32</td>
<td>1.41</td>
<td>1.45</td>
<td>1.49</td>
</tr>
</tbody>
</table>

\[
[P_F] = \begin{bmatrix}
PF_1 & PF_2 & PF_3 & \ldots & PF_n \\
1    & PF_2 & PF_3 & \ldots & PF_n \\
1    & 1    & PF_3 & \ldots & PF_n \\
& & & \ddots & \vdots \\
& & & & 1 \\
\end{bmatrix}
\]

(2)

3. The weight vector pertaining to the project factors \([PF_n]\) can be estimated by calculating the eigenvector \((v_r)\) corresponding to the maximum eigenvalue of the matrix. This vector consists of the set of weights for each project factor reflecting its importance relative to others as indicated in (3).

\[
[PF_n] = \begin{bmatrix}
PF_1 \\
PF_2 \\
PF_3 \\
\vdots \\
PF_n \\
\end{bmatrix}
\]

(3)

4. Assess the impact of criteria \((PFn)\) on the criteria \((DCm)\) using a matrix through AHP to produce another vector matrix \([DCm, PFn]\) as follows:

One) The relative weight of the decision criteria \([DCm]\) is determined with respect to each decision criterion of \((PFI)\). The decision criteria matrices \([DCm, PF1], [DCm, PF2], \ldots, [DCm, PFn]\) can then be established.

Two) The eigenvector corresponding to the largest eigenvalue for equations from the matrix \([DCm, PF1]\) to the matrix \([DCm, PFn]\), is estimated. Then the components of the vector corresponding to the maximum eigenvalue of the matrix become the weights. The resulting matrix is equal to \([DCm, PFn]\).

5. Alternative construction companies \((CCr)\) are evaluated with respect to decision criteria by
assessing the impact of each decision criterion on the construction companies. Therefore, the relative weight for each construction company with respect to each criterion can be obtained. The matrices \([\text{CCrDC1}], [\text{CCrDC2}], ..., [\text{CCrDCm}]\) are formed. Then, from the matrix of the \([\text{CCrDCm}]\), the eigenvector matrix which represent the relative weight of contracting companies \((\text{CCr})\) with respect to the integrated decision criteria can be obtained from the following equation:

\[
[\text{CCr}] = [\text{CCr}]_{\text{DCm}}[\text{DCm}]
\]

A short list of contracting companies \((\text{CCs})\) can be obtained from the last step. These CCs are then invited to submit their tenders to be evaluated in the second part of the evaluation model, as will be described in the following section.

2.4 Checking for Consistency

The consistency of response of a comparison matrix can be measured by its consistency ratio [12]:

\[
\text{CR} = \frac{\text{CI}}{\text{RI}}
\]

where:

- \(\text{CI} = \left( \frac{\lambda_{\text{max}} - n}{n-1} \right) \)
- \(\text{CI} : \) Consistency Index
- \(n : \) Dimension of a particular matrix
- \(\lambda_{\text{max}} : \) Largest eigenvalue
- \(\text{RI} : \) The random index computed from the average of CI for a large sample of random matrices.

3. DESIGN OF KNOWLEDGE-BASED EXPERT SYSTEM

Based on the design concept mentioned above, an integrated system is required to complete the evaluation process. The main approach to perform this concept is to design an expert system or select an expert system shell, which has the capability to communicate with other computer programs as one package. There are many expert system shells that can be used for the system design purpose. Three shells are tested which represent the recent available shells, EXSYS, Level-5 Object and NExpert Object expert system shells. Level-5 Object was selected for the following reasons:

- EXSYS expert system shell rules are IF-THEN-ELSE type. This type has limited flexibility to build the required rules for the tender evaluation system proposed. An enormous number of rules are required to compensate for this inflexibility.
- NExpert Object expert system shell rules are more flexible than EXSYS. With NExpert, rules other than IF-THEN-ELSE can be built.
- Level-5 Object expert system shell rules have similar flexibility to that of the NExpert but it is easier to learn, less expensive and provides the possibility of interfacing with other software.
3.1 Design of Mathematical Program

- The mathematical model for AHP technique was designed using Basic language which was written through the Microsoft Excel’s Macros for the following reasons:
- The mathematics of the model is based on the solution of matrices that can be written easily using Basic language.
- The Basic program developed can be written through Microsoft Excel’s Macro (Visual basic).
- Level-5 Object can interface with Microsoft Excel.

3.2 Design of Database Program

The expert system shell can access any database program. The required data was designed using Paradox program. The required data was divided into five files, which include: (1) past experience data file, (2) past performance data file, (3) financial stability file, (4) contractor’s current capabilities file and (5) the submitted plans for the proposed project file.

4. PROGRAM IMPLEMENTATION AND VALIDATION

The evaluation system designed was tested using one assumed project and one real project. The assumed project had been used to make sure that the system developed output match with the input data. The real project was implemented to determine the system soundness in the practical side, as shown in Appendix C. The results of validations indicated that the system has the capability to select the optimum tender with acceptable confidence [8].

<table>
<thead>
<tr>
<th>Code of Criterion</th>
<th>Criterion Description</th>
<th>Contractor 1</th>
<th>Contractor 2</th>
<th>Contractor 3</th>
<th>Contractor 4</th>
<th>Contractor 5</th>
<th>Contractor 6</th>
<th>Contractor 7</th>
<th>Contractor 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>SDC1-1</td>
<td>Working Years in SIs</td>
<td>3</td>
<td>10</td>
<td>6</td>
<td>6</td>
<td>3</td>
<td>1</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>SDC1-2</td>
<td>Working Years in CPs</td>
<td>10</td>
<td>15</td>
<td>8</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>7</td>
<td>10</td>
</tr>
<tr>
<td>SDC1-3</td>
<td>Delivery Rate within Last 3 years</td>
<td>2500</td>
<td>2220</td>
<td>2470</td>
<td>1800</td>
<td>2200</td>
<td>2300</td>
<td>1950</td>
<td>2000</td>
</tr>
<tr>
<td>SDC1-4</td>
<td>Total Work Volume in Performing SPS - Last 10 Years</td>
<td>6000</td>
<td>15000</td>
<td>10000</td>
<td>9000</td>
<td>6000</td>
<td>12000</td>
<td>12000</td>
<td>16000</td>
</tr>
<tr>
<td>SDC1-5</td>
<td>Average Work Volume in Performing CPs - Last 10 Years</td>
<td>25000</td>
<td>18000</td>
<td>28000</td>
<td>19000</td>
<td>20000</td>
<td>18000</td>
<td>19000</td>
<td>22000</td>
</tr>
<tr>
<td>SDC1-6</td>
<td>Average Work Volume in Performing SPS - Last 3 years</td>
<td>4500</td>
<td>6000</td>
<td>6600</td>
<td>5100</td>
<td>3500</td>
<td>1600</td>
<td>10000</td>
<td>6600</td>
</tr>
<tr>
<td>SDC1-7</td>
<td>Average Work Volume in Performing CPs - Last 3 years</td>
<td>4500</td>
<td>10800</td>
<td>8000</td>
<td>7600</td>
<td>5100</td>
<td>8810</td>
<td>10000</td>
<td>9000</td>
</tr>
</tbody>
</table>
5. CONCLUSIONS

The current disputes and claims in construction call for a review of appointing a contractor, based on the lowest price bid. The use of multiple decision criteria in the evaluation process and selection of an optimum contractor minimizes the sensitivity of using one decision criterion and leads to better value of money.

The Delphi method was found to be a very suitable method for extracting experts’ judgments. This can enrich the quality of decisions made and mitigate the difficulties of setting decision criteria. As well, the AHP was found as a very suitable method to combine the contractors’ criteria with the criteria of the specific project conditions in selecting an optimum contractor on a case-by-case basis. This combination gives more flexibility to modify and/or add new decision criteria according to the actual project needs and objectives.

Using a short list of contracting companies in the second part of the evaluation process
reduces time and effort. At the same time, contractors which were found to be unsuitable, had no obligation to prepare any documents to the proposed project. The developed system provides reason(s) for contractors’ exclusion, which would add to the contractors’ experience for future tendering. The use of this system, as a part of a knowledge-based expert system, can reduce cost, time and enhance the quality of the evaluation process.

REFERENCES