A MULTI-CRITERIA DECISION MAKING MODEL FOR CONTRACTORS PRE-QUALIFICATION

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ABSTRACT

This paper presents a modeling methodology for contractor pre-qualification. It demonstrates how a pre-qualification multicriteria decision making model (PQDM) using the analytic hierarchy process (AHP) can overcome the difficulties of the pre-qualification process. Such difficulties arise from the complexity, subjectivity and lack of group consensus concerning the evaluation of entities potentially involved in the construction process. The model provides a systematic and structured process for decision-makers to pre-qualify potential contractors. The model was applied to a mid-size construction project, and it revealed how simple and reliable it is. Expert Choice software, which incorporates the AHP methodology, enabled the author to build the tool, solicit and synthesize the judgments, and derive the intensity ratings.

KEYWORDS

decision making, AHP, pre-qualification process, construction, judgments

INTRODUCTION

Total project success is the goal of any business owner. To increase the probability of achieving this goal, it is usual to introduce a procedure to ensure that only experienced and competitive contractors are allowed to undertake the project in question [10]. This procedure involves investigating of the contractor's managerial, financial and technical capabilities and his experience on similar projects through an integrative assessment of the organization. This investigational procedure is known as contractor pre-qualification.

While minor decisions can be made intuitively without complicated analysis, complicated decisions with large managerial, financial and technical consequences in addition to dealing with numerous criteria and alternatives can make the decision more difficult. The difficulty here is how to evaluate the contractors potentially involved in the project. In order to reach the most competent and capable construction firm(s) that would perform the work if the owner awards one of these firms the contract.

Dr. Jeffrey Russel (1996) developed a chronological hierarchy of decision making models that comprise the contractor prequalification process. The main tasks module performing a risk analysis for multi evaluation criteria, collecting contractor data, and analyzing contractor data using quantitative and qualitative models. First, for those who are performing risk analysis they may apply two models in the process, one being macroeconomic, the other project-specific. Evaluators can then screen the contractors, utilizing the objective and subjective models. Both qualitative and quantitative models figure into the process in order to provide a balanced influence of fact and judgement. The overall process provides owners with a highly structured and formalized method by which they can make effective use of their resources in an attempt to avoid contractor failure on any level. The hierarchy models consist of three different levels of decision making (figure 1), the first model is to predict industry wide rate of contractor failure (Macroeconomic model), the second model is to predict odds of individual contractor failure on the project level (project-specific failure predictive model), and_the third is qualitative and quantitative contractor pre qualification decision models [11]. While the process has many details and evaluations; it could not overcome the difficulties of the prequalification process. Such difficulties arise from the complexity, and lack of group consensus that concern the evaluation of entities potentially involved in the construction process. In addition, lack of computer support make the process less practical in the real world application.

The objective of this paper is to analyze the entire contractor prequalification process and break it down into its component elements through a decision making tool which can rate and evaluate the entities potentially involved in the construction process. A multicriteria decision making model was developed to deal with these complexities and assist owners in rating and analyzing construction organizations with respect to their capabilities and characteristics of the project intended for biding. The decision making model assists in structuring and completing the analysis, and evaluates rates of the potential contractors.

The prequalification process is modeled in a way that can extract the knowledge and judgment of the owner's decision-makers. This knowledge and judgment can be used to analyze the potential contractors, through the decision analysis and decision-making tool in order to assist the owner in reaching his decisions.

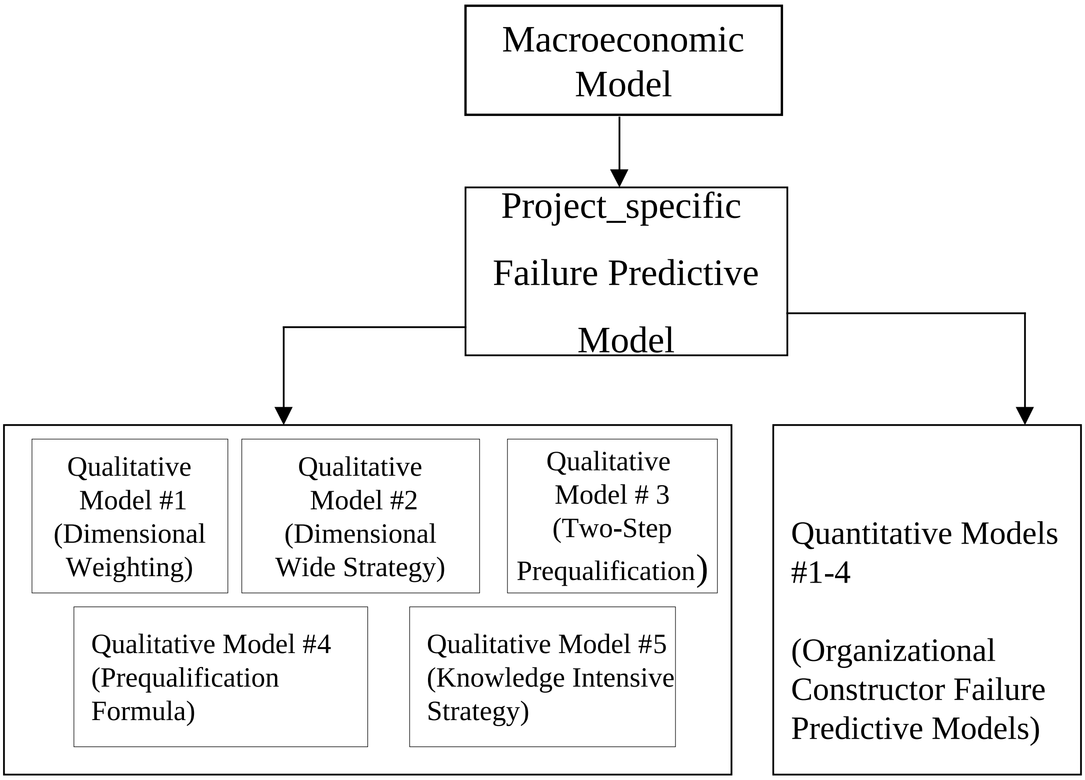

Figure 1: A chronological hierarchy of decision making models that comprise the contractor prequalification process.(Russel 1996)

THE ANALYTIC HIERARCHY PROCESS

Making a decision is a fundamental need for most engineers and professionals. The Analytic Hierarchy Process (AHP), developed by Saaty [4], has been widely adopted as a powerful multicriteria decision-making tool. The AHP is a sophisticated structured mathematical procedure and it is easy to implement for different applications. It is also structured in such a way that all individuals affected the decision can provide input into the decision making process [3].

In this research the AHP has been used where the issue was defined and understood by breaking the process down into its component elements, structuring the elements hierarchically, and then composing judgments on the relative importance of the elements at each level of the hierarchy into a set of overall priorities using the relative measurement. The absolute measurement approach was then used to rate the contractors according to their intensities. The methodology of AHP will be discussed next and followed by an example to show how the methodology is applied. The procedure of applying AHP is as follows :

Stage A:

1. Carefully understand and define the issue, and identify the overall goal (objective).

2. Identify the criteria that must be satisfied to fulfill the objective and the sub-criteria under each criterion, then specify the suitable intensities for each sub-criterion (attribute).

3. Construct the hierarchical structure.

4. Set priorities by constructing a pairwise comparison matrix to compare the criteria elements in pairs against a given criterion. A recommended scale from 1-9 is used to assign a judgment in comparing pairs of like elements in each level of the hierarchy against a criterion in the next higher level. The recommended scale used to quantify the relative importance is defined as follows:

- 1 Equal importance
- 3 Moderate importance
- 5 Essential or strong importance
- 7 Very strong importance
- 9 Extremely important

The values 2, 4, 6, and 8 are intermediate values between the two adjacent judgements. The reciprocals of these non-zero numbers are used when elements compared in pairs have the opposite relative importance of the above definitions.

Extracting the judgment enables the construction of a matrix A with n elements (A_n) compared to each other with respect to a specific criterion. The number of needed entries is according to the matrix size $\frac{n^2 - n}{2}$, where n is the criteria elements used.

5. Normalize the matrix by dividing each entry in each column by the sum of the entries in that column. This yields a new normalized matrix in which the sum of the entries in each column is 1.

6. Average over the rows of the normalized matrix by dividing the sum of each row by the number of entries in each row. These averages constitute the “priority vector”.

7. To check the consistency, the following steps should be done:

Step 1: Multiply the “priority vector” by the original matrix (pairwise comparison matrix)

Step 2: Compute the row totals of the new matrix.

Step 3: Take the column of the row totals and divide each of its entries by the corresponding entry from the “priority vector”, then take the average of the outcome. The average yields λ_{max} (or principle eignevalue). Then the consistency index (CI) = $\frac{\lambda_{\max} - n}{n - 1}$ can be computed. From the table of random consistency[1], the random value of CI for matrix size (n) is divided by the value of CI to determine the consistency ratio (CR). The value of CR should be 10% or less.

8. Repeat steps 4, 5, 6, and 7 for all matrices in each level of the hierarchy.

9. Multiply each priority vector at the lowest level by its corresponding criteria in the next higher level, and so on. Then add the results to yield the overall priority. Do the same thing for the other priority vectors in the lowest level. The result is the overall priority vector for the lowest level of the hierarchy (alternatives).

10. The consistency of the hierarchy can be evaluated by multiplying the consistency index of each matrix by the priority of its criterion and adding the product. The result is then compared with a similar number obtained for random matrices of the same size. The new consistency ratio should be 10% or less; otherwise, the work should be improved.

Stage B:

Absolute measurement, or scoring, is applied to rank the contractors in terms of the intensities of each attribute. For example, outstanding, good, or unsatisfactory. After setting priorities for the criteria and their attributes (sub-criteria), pairwise comparisons are also made between the intensities themselves to set priorities for them under their parent attributes. Then, the priority of each intensity is divided by the largest rated intensity to get the ideal intensity, which is then multiplied by the attribute's priority. Finally, contractors are scored by checking off their respective ratings under each attribute and summing these ratings for all the criteria [5].

EXAMPLE

To put the previous section in perspective, it is useful to provide an example to visualize how these AHP validity measures work. Assume that an architect compares three designs of windows, A, B, and C, with respect to their *esthetics* in a residential townhouse condominium. In this simple example, the most esthetic window is the objective which can be reached through three alternatives, A, B, and C. These four elements can be easily structured in a two-level hierarchy where the objective is placed at the top level and the alternatives in the lower level. A one-pairwise comparison (judgments) matrix can be obtained from this hierarchy. The matrix, then, is synthesized by adding the values in each column of the pairwise comparison matrix, as presented in (Figure 2).

Esthetics	A	B	C
A	1	0.5	0.25
B	2	1	0.25
C	4	4	1
Column total	7	5.5	1.5

Figure 2: Synthesizing the judgments

The matrix is normalized by dividing each entry in each column by the column total of the entries in that column. This yields to a normalized matrix in which the sum of the entries in each column is 1. Then, the priority vector or eigenvector is obtained by averaging the row of the normalized matrix (Figure 3). The average row sum represents the ranking of the three alternatives. High average sum represents the best alternative (A, B, and then C).

Esthetics	A	B	C	Row Sums	Average Row Sum
A	1/7	1/11	1/6	0.4	0.4/3 = 0.13
B	2/7	3/11	1/6	0.63	0.63/3 = 0.21
C	4/7	8/11	4/6	1.97	1.97/3 = 0.66

Figure 3: Normalized Matrix and Overall Priorities

To get valid results of the ranking obtained above, the consistency (eigenvalue) of the judgments must be computed. This can be done by multiplying the priority vector by the original matrix, (Figure4), then computing the row totals of the new matrix, (Figure5).

Esthetics	A (0.13)	B (0.21)	L (0.66)
A	1	0. 5	0.25
B	2	1	0.25
C	4	4	1

Figure 4: Priority Vector by the Original Matrix

Esthetic	A	B	C	Row Total
A	0.13	0.11	0.17	0.41
B	0.26	0.21	0.17	0.64
C	0.52	0.84	0.66	2.02

Figure 5: The Row Totals of the New Matrix

To obtain λ_{max} (or principle eigenvalue), take the column of the row totals and divide each of its entries by the corresponding entry from the priority vector, then take the average of the outcome. The calculations are shown below:

$$\frac{\{0.41,0.64,2.02\}}{\{0.13,0.21,0.66\}} = \{3.15,3.05,3.06\}$$

$$\lambda_{max} = \frac{[3.15 + 3.05 + 3.06]}{3} = 3.09$$

The consistency index (CI) = $\frac{\lambda_{max} - n}{n-1} = \frac{[3.09 - 3]}{2} = 0.045.$

From the table of random consistency, as cited by Saaty [4], the random value of CI for matrix size of n=3 is 0.58. The consistency ratio (CR) is 0.045 / 0.58 = 0.08, which indicates good consistency because 0.08 falls in the tolerated region of 10% or less.

THE MODEL DEVELOPMENT

This paper describes a decision making model which can rate and evaluate the potential construction firms that may bid for a specific project at the prequalification stage. The model analyzes the process of selecting the most qualified contractors by breaking the issue down to its component elements. This section and the next one describe the model and its application. The results including -sensitivity analysis are then presented. Finally, a conclusion is drawn.

A Pre-Qualification multicriteria Decision making Model (PQDM) based on the Analytical Hierarchy Process (AHP) is built and applied for the purpose of analyzing, evaluating and rating the pre-qualified contractors as illustrated in Fig.6. Each contractor should get a score between zero and one. Owners should have a range for the minimum acceptance level of contractors and chick if a contractor's score falls in this range. That is, if the minimum acceptance level is 0.40, pre-qualified contractors should strike scores between 0.40 and 1.00. Figure 6 (PQDM) represents a systematic and structured approach to the analysis and rating of contractors to enable decision-makers to prioritize their criteria and rank them according to each other in addition to the final objective. The model uses a four level hierarchy where "pre-qualifying contractors" is at the top level as the objective, and the intensities are in the bottom of the hierarchy at the lowest level (Fig. 7). Levels two and three represent the breakdown of the issue, leading to the intensities at the bottom of the hierarchy. Level two contains the main criteria of the model, and represents the driving forces of the decision making tool. The main criteria consists of seven criterions, which are technical experience, performance record, financial stability, management and employees' qualification, capacity, safety record, and operation and equipment. Each criterion in level two consists of a set of attributes, where each attribute is evaluated by a set of intensities at the lower level of the hierarchy. Such attributes have a direct impact and influence on the process of selecting the most qualified contractors.

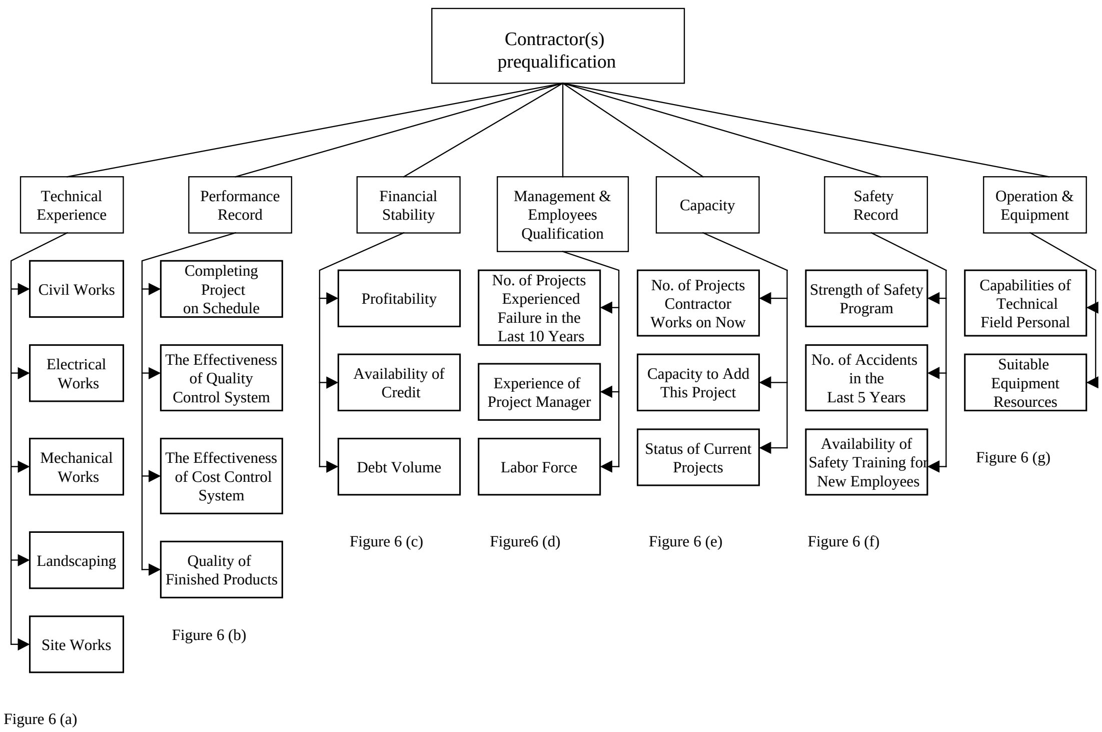

FIGURE (6): A Pre-qualification multi-criteria decision making model (PQDM) based on the analytic hierarchy process (AHP).

Criteria	Attribute	Intensities				
Technical Experience	Civil Works	Outstanding	Very Good	Average	Below Average	Unsatisfactory
	Electrical	Outstanding	Very Good	Average	Below Average	Unsatisfactory
	Mechanical	Outstanding	Very Good	Average	Below Average	Unsatisfactory
	Landscaping	Outstanding	Very Good	Average	Below Average	Unsatisfactory
	Site Works	Outstanding	Very Good	Average	Below Average	Unsatisfactory
Performance Record	Completing Project on Schedule	Always	Sometimes	Rarely		
	The Effectiveness of Quality Control System	Outstanding	Very Good	Average	Below Average	Unsatisfactory
	The Effectiveness of Cost Control System	Outstanding	Very Good	Average	Below Average	Unsatisfactory
	Quality of Finished Products	Outstanding	Very Good	Average	Below Average	Unsatisfactory
Financial Stability	Profitability	High	Average	Low		
	Availability of Credit	High	Average	Low		
	Debt Volume	High	Average	Low		
Management & Employees Qualification	No. Of Projects Experienced Failurein the Last 10 Years	Never	3 or Less	More than 3		
	Experience of Project Manager	Less than 5 years	From 5 to 10 years	More than 10 years		
	Labor Force	Strong	Moderate	Poor		
Capacity	No. of Projects Contractor Works on Now	Less than 5	From 5 to 10	More than 10		
	Capacity to Add This Project	Strong	Moderate	Weak		
	Status of Current Projects	Ahead of Schedule	As Scheduled	Behind Schedule	Stopped	
Safety Record	Strength of Safety Program	Outstanding	Very Good	Average	Below Average	Unsatisfactory
	No. of Accidents in the Last 5 Years	Less than 5	From 5 to 10	More than 10		
	Availability of Safety Training for New Employees	Available	Not Available			
Operation & Equipment	Capabilities of Technical Field Personal	Outstanding	Very Good	Average	Below Average	Unsatisfactory
	Suitable Equipment Resources	Very Suitable	Average	Acceptable	Unsatisfactory	

FIGURE (7):
The intensities of the PQDM

IMPLEMENTATION (CASE STUDY)

The author developed the PQDM for the contractor pre-qualification process and subsequently coded it into a computer program using Expert Choice software. To put the developed model into practice, a contractor pre-qualification committee (decision-makers), which was studying a seven story commercial and office building in Saudi Arabia was invited to apply the tool. The procedure for structuring the PQDM was demonstrated to the decision-makers. Using computer, the judgments were derived for the driving force criteria at level two of the model and the matrix was completed (Figure 8). The same thing was done to the attributes of each criterion at level three; the priorities were generated and the matrices were constructed. The judgments generated for the driving forces criteria and its attributes were highly influenced by the project type and its specifications. The intensities of each attribute (level four) were then pairwise compared with respect to their parent attribute. Matrices for level three and four are not presented here for the sake of brevity. Priorities were then divided by the largest intensity for each attribute which was then multiplied by the attribute's priority. Finally, each contractor was rated by assigning the intensity rating that applied to him under each attribute. The score of each contractor is the summation of his intensities rating.

Pairwise Comparison Matrix with Respect to Goal								
Criterion	**Technical Experience**	**Performance Record**	**Financial Stability**	**Management & Employees** Qualifications	**Capacity**	**Safety Record**	**Operation & Equipment**	**Priorities**
Technical Experience	1	2	5	5	6	6	2	0.328
Performance Record	-	1	6	6	7	6	2	0.293
Financial Stability	-	-	1	1	3	3	1	0.085
Management &Employees Qualifications	-	-	-	1	4	3	1/3	0.077
Capacity	-	-	-	-	1	2	1/5	0.037
Safety Record	-	-	-	-	-	1	1/4	0.033
Operation & Equipment	-	-	-	-	-	-	1	0.147
							Total	1
Inconsistency Ratio = 0.05								

Figure 8: A pairwise comparison matrix to compare the elements of the second level of the hierarchy in pairs with respect to goal.

The decision-makers' judgments, which are a compilation of their technical and managerial experience, are processed via the PQDM. The simulation results presented in (Table 1) show the rating and importance for the criteria (level two of the hierarchy) and the attributes of each criterion (level three of the hierarchy). The priority of each intensity with respect to each attribute (Figure 6a to figure 6g) are not presented here for the sake of brevity. The overall scoring of the five contractors, with respect to the main goal of the hierarchy, is presented in Table 2. The overall ranking shows that contractor 3 is highly qualified for the project with a rating value of 0.551. It also shows that contractors 2 and

1 are also qualified, with rating values of 0.474 and 0.402 respectively. Contractors 5 and 4 with very low rating (scoring), 0.252 and 0.149 respectively, are extremely unqualified. The consistency ratio for the whole judgment is 0.05, which falls into the tolerated region of 10% or less.

Table 1: The rating and importance to the criteria (level two of the hierarchy) and those for the attributes of each criterion (level three of the hierarchy).

Criteria		**Attributes**	
Level Two	**Eignvector**	**Level Three**	**Eignvector**
Technical Experience (1)	0.328	Civil Works (1)	0.19
		Electrical Works (4)	0.015
		Mechanical Works (2)	0.074
		Landscaping (4)	0.015
		Site Works (3)	0.033
Performance Record (2)	0.293	Completing Project on Schedule (1)	0.073
		The Effectiveness of Quality Control System (1)	0.073
		The Effectiveness of Cost Control System (1)	0.073
		Quality of Finished Products (1)	0.073
Financial Stability (4)	0.085	Profitability (2)	0.017
		Availability of Credit (1)	0.051
		Debt Volume (2)	0.017
Management & Employees Qualification (5)	0.077	No. of Projects Experienced Failure in the Last 10 Years (1)	0.06
		Experience of Project Manager (2)	0.009
		Labor Force (2)	0.009
Capacity (6)	0.037	No. of Projects Contractor Works on Now (2)	0.006
		Capacity to Add this Project (3)	0.007
		Status of Current Projects (1)	0.024
Safety Record (7)	0.033	Strength of Safety Program (2)	0.009
		No. of Accidents in the Last 5 Years (1)	0.021
		Availability of Safety training for New Employees (3)	0.003
Operation & Equipment (3)	0.147	Capabilities of Technical Field Personal (1)	0.092
		Suitable Equipment Resources (2)	0.005

Table 2: The overall scoring of the fine contractors with respect to the main goal
.

Level Two	Level Three	Contractor 3	Contractor 2	Contractor 1	Contractor 5	Contractor 4
Technical Experience	Civil Works	Outstanding 0.019	V. Good 0.097	V. Good 0.097	Average 0.048	Average 0.048
	Electrc. Works	Outstanding 0.015	V. Good 0.008	V. Good 0.008	Average 0.004	B. Average 0.002
	Mech. Works	Outstanding 0.025	V. Good 0.038	V. Good 0.038	Average 0.019	B. Average 0.009
	Landscaping	Outstanding 0.015	V. Good 0.007	V. Good 0.007	Average 0.004	B. Average 0.002
	Site Works	Outstanding 0.033	V. Good 0.017	V. Good 0.017	Average 0.008	Average 0.008
Performance Record	On Schedule	Always 0.073	Sometimes 0.016	Sometimes 0.016	Sometimes 0.016	Rarely 0.007
	Q. Control	V. Good 0.037	Average 0.018	V. Good 0.037	Average 0.018	Unsatisfied 0.005
	Cost Control	V. Good 0.037	Average 0.018	Average 0.018	B. Average 0.009	Unsatisfied 0.005
	F. Products	Outstanding 0.073	V. Good 0.037	V. Good 0.037	Average 0.018	B. Average 0.009
Financial Stability	Profitability	High 0.017	High 0.017	Average 0.004	Average 0.004	Low 0.002
	A. of Credit	Average 0.013	High 0.051	Average 0.013	Low 0.005	Low 0.005
	Debt Volume	Low 0.002	Low 0.002	Low 0.002	Average 0.004	Low 0.002
Management & Employees Qualifications	Project Failure	Never 0.06	Never 0.06	3 or Less 0.011	Never 0.06	More than 3 0.005
	P. Manager	More than 10, 0.009	From 5 to 10 0.004	More than 10, 0.009	From 5 to 10 0.004	Less than 5 0.001
	Labor Force	Moderate 0.002	Moderate 0.002	Moderate 0.002	Moderate 0.002	Poor 0.001
Capacity	No. of Projects	More than 10, 0.001	From 5 to 10 0.001	Less than 5 0.006	More than 10, 0.001	Less than 5 0.006
	This Project	Weak 0.001	Moderate 0.002	Strong 0.007	Weak 0.001	Strong 0.007
	Status	As Scheduled 0.011	As Scheduled 0.011	Behind 0.005	Behind 0.005	Behind 0.005
Safety Record	S. Program	Average 0.002	B. Average 0.001	B. Average 0.001	Unsatisfied 0.00	Unsatisfied 0.00
	No. of Accits.	More than 10, 0.002	Less than 5 0.021	Less than 5 0.021	More than 10, 0.002	From 5 to 10 0.005
	S. Training	Available 0.003	Not Available 0.00	Not Available 0.00	Not Available 0.00	Not Available 0.00
Operation & Equipment	F. Personal	V. Good 0.047	Average 0.023	Average 0.023	B. Average 0.011	B. Average 0.011
	S. Equipment	V. Suitable 0.054	Average 0.023	Average 0.023	Acceptable 0.009	Unsatisfied 0.004
Total		0.551	0.474	0.402	0.252	0.149

SENSITIVITY ANALYSIS

Sensitivity analysis is conducted to assist in gaining a better understanding of a decision, and to determine how sensitive the intensities at the bottom level of the hierarchy are to changes in the judgment or the importance of the criteria. Expert Choice [5] provides five graphical sensitivity analysis modes: performance, dynamic, gradient, 2D plot, and differences. However, all five graphical sensitivity modes provide similar views of priorities of criteria and intensities. Figure 9 shows a gradient sensitivity of the intensities rating with respect to changes in importance of the Technical Experience criterion. The vertical line shows that the current priority of the technical experience is 0.328. The height of the intersection of this vertical line with the intensity line determines the intensity weights if the importance of the technical experience criterion remains unchanged. If Technical Experience were to become more important, the vertical line would moved to the right and the overall priority of outstanding and very good would increase strongly. Those of below average and unsatisfied would change upward slightly.

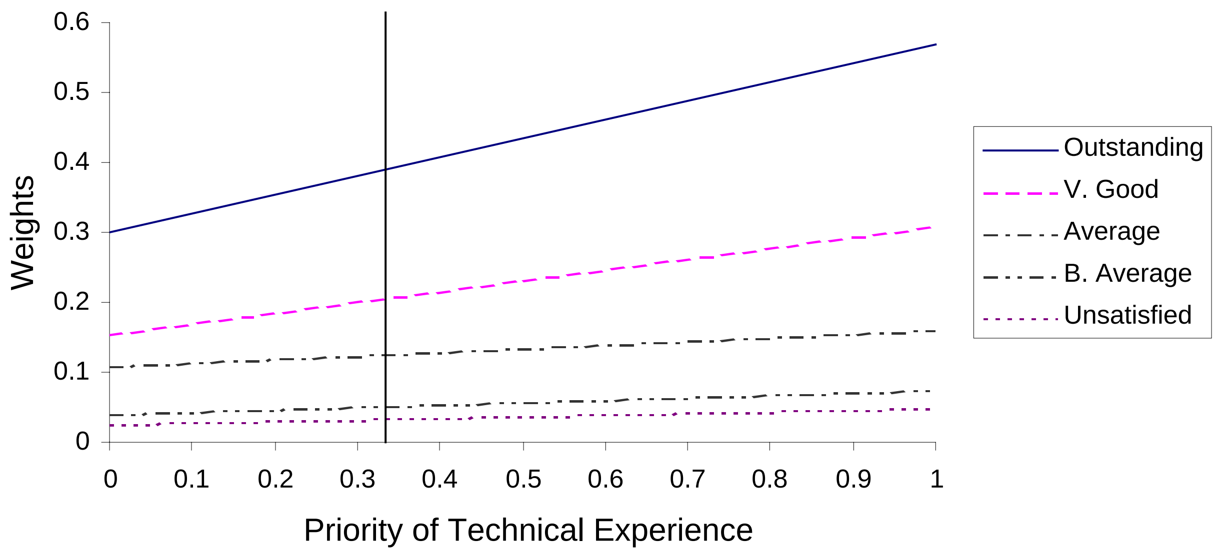

Figure 9: A gradient sensitivity of the intensities rating with respect to changes in importance of the Technical Experience Criterion.

SUMMARY AND CONCLUSIONS

This paper presents a decision-analysis modeling technique for the pre-qualification process of contractors (PQDM). The model used a four level hierarchy where pre-qualified contractors are at the top level as the objective, and the intensities are at the bottom of the hierarchy at the lowest level. The levels between consist of the criteria at the second level and the attributes (sub-criteria) at the third level of the hierarchy. PQDM incorporates different measures upon which a decision to select prequalified contractors for a construction project is made. The tool was implemented efficiently for the purpose of prequalifying contractors for a private construction project in Saudi Arabia.

PQDM provides a tool for selecting the most qualified contractors in an easy, fast, and low-cost approach. It enables the decision-makers to use all the necessary information they have about contractors, as well as their knowledge and expertise and incorporate them to the tool to evaluate and rate the potential contractors. This model is applicable to the real world contractors pre-qualification's environment. It incorporates all necessary information about the contractor in a very systematic, numerical and verbal approach. Such approach leads to durable calculated results.

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