Decision Analysis Framework for Evaluating Highway Contractors

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Contractor prequalification is not an accepted practice among all state departments of transportation (DOTs). Nevertheless, numerous states have formal procedures that require highway contractors to be prequalified in addition to submitting a project bid bond. These prequalification procedures are based on state laws and were developed in an ad hoc manner. A new prequalification model was based on data collected from prequalification officials of state DOTs. The Indiana Department of Highways has applied the model to a bridge construction project for which five contractors are seeking prequalification. Recommendations are presented to facilitate the model's implementation into existing state DOT prequalification procedures.

Before permitting a highway contractor to bid for public transportation works, a review of qualifications is usually performed. This process is not agreed on by all state departments of transportation (DOTs). Consequently, many state DOTs (e.g., Alaska, California, and New York) do not have formalized contractor prequalification procedures but rely on the contractor's ability to secure a bond. Thus, contractor prequalification is performed by a surety company.

Articles regarding the prequalification of highway contractors appeared as early as 1939, when Harrison (*1*) wrote a proposed standard for the qualification and prequalification of contractors. In 1948, Nettleton (*2*) described experiences with prequalification, and the process was reviewed again in 1964 by Plummer (*3*). Corwin (*4*) presented an analysis of pre- versus post-qualification practices, and in 1970, Burrill and Poe (*5*) performed a survey of state prequalification procedures. The topic remains an important and controversial issue in the highway construction industry. Netherton (*6*) analyzed state prequalification procedures in 1978, and as recently as 1985, Nittany Engineers and Management Consultants (*7*) evaluated the prequalification procedures of six state DOTs.

States currently performing prequalification use a formula to determine the contractor's maximum financial capabilities (*6*). This calculated value, based on parameters from a financial statement, is used to establish the maximum aggregate amount of uncompleted work (in most cases both public and private) a contractor may have on hand at any one time. These formulas have been developed on an ad hoc basis and can take a variety of forms.

For example, Ohio's formula incorporates a contractor's net current asset value multiplied by a coefficient of 10 (Revised Code 5525.02–5525.09, State of Ohio, 1963). Other states, such as South Dakota, use net current assets minus net current liabilities plus 80 percent of the book value of the contractor's construction equipment multiplied by a coefficient of 10 (South Dakota Department of Transportation, Regulations 70:01:05:02, 1975). Net worth multiplied by a coefficient of 10 represents the maximum amount of work a contractor can have under contract in the state of Alabama (Code Title 46, 65–83, State of Alabama, 1975). The formula used in Iowa includes total net current assets minus current liabilities plus one-half of noncurrent assets minus noncurrent liabilities (Iowa State Highway Commission, 1972).

The formulas use financially based values that are often subjectively modified (i.e., reduced by other items perceived to impact them). For example, contractor safety, organization strength, past performance, personnel experience, and cooperation with the owner's representatives are subjectively modified items. The study by Nittany Engineers and Management Consultants (*7*) revealed that some formulas do not adequately measure the capacity of work a contractor can perform. Thus, a prequalification model based on a more scientific approach needs to be developed.

Results of the state DOTs' evaluation of the perceived effect that various factors and subfactors have on contractor prequalification decision making are presented in the following sections. The mean impact responses of the questionnaire items have been calculated and are provided. A statistical technique, factor analysis, applied to the collected data provides the basis for the creation of a computerized linear prequalification model. This model represents a decision template that can aid in performing the prequalification task. The model and an example application are described, and recommendations for using the model with states' existing prequalification procedures are presented.

QUESTIONNAIRE STRUCTURE AND RESULTS

A sample of 50 prequalification officials was compiled from the AASHTO 1987 Reference Book, and each official was mailed a questionnaire to complete. A total of 45 questionnaires were returned, representing an overall return rate of 90 percent, with five states (Connecticut, Maine, New Hampshire, New York, and Rhode Island) not responding. Of the returned questionnaires, 34 were complete; therefore, in terms of usable data the response rate was approximately 68 percent. The other 11 respondents (approximately 22 percent of the sample) indicated that they do not currently prequalify contractors. These states were Alaska, California, Idaho, Louisiana, Maryland, Minnesota, Mississippi, Missouri, Montana, New Mexico, and Oregon.

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The questionnaire consisted of three parts: respondent classification (i.e., organization type), rating of the impact of major decision factors (DFs), and rating of the impact of decision subfactors used in prequalification decision making. The format, structure, DFs, and subfactors used in this questionnaire were based on 8 personal and 24 telephone interviews with construction professionals who currently perform prequalification (*8*).

The first part of the questionnaire (respondent classification) included the type of organization represented, type of construction activity typically engaged in, type of contracting strategy typically used on projects, and annual volume of construction. The questionnaire's second part contained 20 DFs relevant to contractor prequalification. These DFs were presented so that individuals could describe the impact of each DF on their decision process. The response alternatives ranged from 0 (little or no impact) to 4 (high impact), with 2 being moderate impact. The third part of the questionnaire contained 67 decision subfactors that could be used to make a more refined decision associated with a major factor. The questionnaire also requested information describing the respondent's prequalification process. A copy of the questionnaire can be obtained by contacting the author.

The contract method typically used by the sample was competitively bid unit price. The average annual construction volume was $375 million, with a standard deviation of $350 million and a range of $53 million (Hawaii) to $2,000 million (Texas). Only 41 of the respondents indicated their annual volume of construction work. The mean impact for each questionnaire item, presented in Table 1, was calculated to identify any trends in the data. The 10 DFs and subfactors with the highest and lowest mean impacts are presented in Tables 2 and 3, respectively.

Factor analysis was performed on the first 20 questionnaire items (major factors) using principal component factor analysis with varimax rotation. The theoretical description of this technique is presented in Harman (*9*). A reduced number of distinctive composite decision factors (CDFs) relevant in prequalification decision making were identified in the factor analysis procedure. Each CDF revealed through this analysis was assigned a descriptive name, on the basis of the nature of questionnaire items showing the highest correlations with the considered CDF. Because of the small number of transportation-related data points, other governmental agencies responding to the questionnaire were combined before performing this statistical technique, enlarging the sample by 25.

The CDFs presented in Table 4 include performance, type of contractor, capacity for assuming new projects, location, percentage of work performed, third-party evaluation, and financial capability. The correlation between the factor and a particular questionnaire item is defined as a loading factor. The questionnaire items with significant loading (greater than 0.4 out of 1.0) on a factor are presented in Table 4. Also shown is the standardized factor score determined by a regression procedure. The score or factor loading can be interpreted as being indicative of the contribution that the item makes to the determination of the factor's nature. The scores were standardized to facilitate a comparison across factors. The results presented in Table 4 represent the basis for the computerized prequalification decision support model described in the following section.

PREQUALIFICATION MODEL DESCRIPTION

The prequalification model, as described by Russell and Skibniewski (*10*), incorporates a dimensional weighting procedure. The model parameters are based on the factor analysis results of the questionnaire. Two terms are essential in the model: CDF and DF. A CDF represents a single underlying construct made up of interrelated decision factors. A DF is defined as a criterion that can be used to evaluate candidate contractors. An example using these terms is shown in Figure 1. As shown, the Type of Contractor CDF consists of the following DFs:

1. Experience. Amount of expertise a contractor has achieved within a certain class of projects (e.g., size and construction type);
2. Equipment Resources. Type, amount, availability, and suitability of construction equipment the contractor possesses; and
3. Company Organization. Type of ownership, management experience and leadership, and ability to respond to the owner's requests, among others.

The linear prequalification model is formalized by the following equation:

$$AR_k = \sum_{i=1}^{n} W_i \left[\sum_{j=1}^{m_i} (w_{ij})(R_{ijk}) \right] \quad (1)$$

where

AR_k = aggregate weighted score of candidate contractor k;
n = number of CDFs;
W_i = weight of CDF_i on a scale from 0.0 to 1.0 (0.0 is unimportant and 1.0 is important), where the summation of $W_i = 1.0$ for $i = 1$ to n;
m_i = number of DFs describing CDF_i;
w_{ij} = weight of DF_j describing CDF_i on a scale from 0.0 to 1.0, where the summation of $w_{ij} = 1.0$ for $j = 1$ to m_i and for $i = 1$ to n; and
R_{ijk} = score of the DF_j describing the CDF_i on a scale from 1.0 to 10.0 (1.0 is unsatisfactory and 10.0 is excellent) for candidate contractor k.

The assumption of additivity of the decision criteria for this model has been made, thus requiring independence of the model's criteria.

The CDF's weights (W_i) were obtained using the following equation:

$$W_i = \frac{\overline{CR}_i}{\sum_{i=1}^{n} \overline{CF}_i} \quad (2)$$

where

$$\overline{CF}_i = \frac{\sum_{j=1}^{m_i} \overline{DFMI}_{ij}}{m_i} \quad (3)$$

TABLE 1 MEAN IMPACT OF QUESTIONNAIRE ITEMS FOR STATE DOT RESPONDENTS

QUESTIONNAIRE ITEM NAME (1)	MEAN IMPACT[a] (2)
MAJOR FACTORS	
Financial Stability	3.82
Experience	3.44
References	2.06
Past Performance	3.09
Capacity of Firm	2.60
Current Work Load	2.18
Project Control Procedures	1.97
Staff Available	2.23
Location of Home Office	0.29
Experience in Geographic Location of Project	0.68
Safety Performance	1.70
Substance Abuse Policy	0.62
Project Management Capabilities	2.47
Quality Performance	2.85
Manpower Resources (Labor)	1.82
Company Organization	2.29
Amount of Work Performed with Own Forces	2.32
Contractor has Failed to Complete a Contract	3.35
Equipment Resources	2.79
Bonding Capacity	2.14
SUBFACTORS	
FINANCIAL STABILITY	
Credit Rating	1.72
Banking Arrangements	1.47
Bonding Capacity	2.32
Financial Statement	3.58
EXPERIENCE	
Success of Completed Projects	3.18
Size of Completed Projects	2.79
Number of Similar Completed Projects	2.56
Types of Projects Completed	2.91
INFORMATION OBTAINED FROM REFERENCES	
Review of Reputation and Ethics of Contractor	2.18
Willingness to Resolve Conflicts and Problems	2.24
Change Orders Frequency	1.44
Schedule Performance	2.47
Number of Times Claims Have Gone to Litigation	1.55
PAST PERFORMANCE	
Actual Quality Achieved (within specifications)	2.88
Actual Schedule Achieved	2.70
Number of Times Contractor has met Cost, Quality and Schedule	2.12
CAPACITY OF FIRM	
Last Year's Construction Volume in $	1.74
Construction Volume $ Averaged over the Last Three Years	1.62
Current Backlog of Work $	2.18
% of Current Backlog that an Additional Job Represents	1.68
This Year's Employment (Number of People)	1.06
Employment Averaged Over the Last Three Years	0.82
Employment Trends and Fluctuations	1.00
Staff Available for this Specific Project	1.68
The Number of Professional Personnel	1.68

TABLE 1 (*continued on next page*)

TABLE 1 (*continued*)

QUESTIONNAIRE ITEM NAME (1)	MEAN IMPACT[a] (2)
PROJECT CONTROL PROCEDURES	
Type of Control Procedures	1.70
Type of Safety Program	1.67
Type of Cost Control and Reporting System	1.25
Type of Scheduling System	1.42
Type of Quality Program	1.79
Sophistication of Control Procedures	1.38
Previous Experience with these Procedures	1.48
Your Judgement as to Whether Management is Able to Use the Procedures Effectively	1.70
LOCATION OF HOME OFFICE	
Home Office Location Relative to Job Site Location	0.42
GEOGRAPHIC LOCATION OF PROJECT	
Contractor's Familiarity with Weather Conditions	0.68
Contractor's Familiarity with Local Labor Agreements	0.88
Contractor's Familiarity with Local Politics	0.44
Market Conditions of the Geographic Area	0.68
Contractor's Familiarity with Subsurface Characteristics	0.91
SAFETY	
Existence of Contractor Safety Program and Director	1.44
Contractor's Experience Modification Rate (EMR) for the Last Three Years	0.88
Information from OSHA Log 200 Accident Reports	0.70
Apparent Management Awareness of Safety Issues in Contractor's Organization	1.20
Contractor's Faithfulness in Conducting Tool Box Meetings	0.79
PROJECT MANAGEMENT CAPABILITIES	
Key Personnel Experience, Include Number of Years in Construction & Projects Worked on	3.09
Complexity of Past Projects	2.64
Appropriateness of Project Organizational Chart	1.35
Track Record of Quality of Job (Length of Punchlist)	2.03
Track Record-Schedule	1.97
Track Record-Cost	1.41
Ability to Deal with Unanticipated Problems	1.79
Amount of Decision-making Authority in the Field	1.70
Amount of Work Performed with Own Forces on Past Projects	2.26
MANPOWER RESOURCES	
Amount of Manpower Available	1.68
Quality of Manpower	2.03
Existence or Effectiveness of Company Training Program	1.24
Whether the Contractor is Union or Open Shop	0.44
COMPANY ORGANIZATION	
Type of Ownership (Partnership, Corporation, Sole Owner, etc.)	0.65
Number of Years in Construction	2.12
Contractor's Licenses Held (by State and/or by Category of Work)	1.76
Number of Failures to Complete a Contract	3.06
Appropriateness of Company Organizational Structure	1.41
EQUIPMENT RESOURCES	
Type of Equipment	3.03
Size of Equipment	2.38
Condition of Equipment	2.54
Availability of Equipment	2.79
Suitability of the Equipment for this Project	2.56

[a]Rating scale used was 4 = High Impact, 2 = Moderate Impact, and 0 = Little/No Impact.

TABLE 2 RANK ORDER OF THE 10 DECISION FACTORS AND SUBFACTORS WITH THE LARGEST MEAN IMPACT BASED ON STATE DOT RESPONDENTS

Questionnaire Item Name (1)	Mean Impact (2)
(a) DECISION FACTORS	
Financial Stability	3.82[a]
Experience	3.44
Contractor has Failed to Complete a Contract	3.35
Past Performance	3.09
Quality Performance	2.85
Equipment Resources	2.79
Capacity of Firm	2.60
Project Management Capabilities	2.47
Amount of Work Performed with Own Forces	2.32
Company Organization	2.29
(b) DECISION SUBFACTORS[b]	
Financial Statement	3.58
Success of Completed Projects	3.18
Key Personnel Experience	3.90
Number of Failures to Complete a Contract	3.06
Type of Equipment	3.03
Types of Projects Completed	2.91
Actual Quality Achieved (within specifications)	2.88
Size of Completed Projects	2.79
Availability of Equipment	2.79
Actual Schedule Achieved	2.70

[a]Rating scale used was 4 = High Impact, 2 = Moderate Impact, and 0 = Little/No Impact.

[b]Decision subfactors characterize a major decision factor and aid in making a decision regarding that factor.

where $\overline{CF}_i$ equals the mean impact value of CDF_i and $\overline{DFMI}_{ij}$ equals the mean impact of DF_j describing CDF_i (on the basis of state DOT respondents).

The weights established by using Equation 2 are presented in Table 5. The weights (w_{ij}) for the DFs were calculated using the following equation:

$$w_{ij} = \frac{\overline{DFMI}_{ij}}{\sum_{j=1}^{m_i} \overline{DFMI}_{ij}} \qquad (4)$$

The weights established using this equation are also presented in Table 6.

COMPUTER PROGRAM DESCRIPTION

The computer program implements the model and calculates an aggregate weighted rating for each candidate contractor on the basis of the DF's subjective input rating. These aggregate weighted ratings are ordered by rank, and relevant statistics are calculated. A facility to review each rating input for a candidate contractor's DF along with statistics containing the complete sample of candidate contractors is provided. The decision system embedded in the program consists of three major parts:

1. Decision Parameters. Providing CDFs and DFs, which each candidate contractor will be rated against;
2. Decision Parameter Weight. Quantifying the perceived importance of each CDF and DF for the prequalification decision; and
3. Decision Parameter Statistics. Providing relevant statistical data for prequalification analysis and decision making.

The program has been implemented on the Gould PN-9080 UNIX-based and IBM PC DOS-based computers and was written in FORTRAN 77 and Microsoft FORTRAN (*11*), respectively.

A diagram of input requirements and the resulting outputs for the computer program is shown in Figure 2. The program needs several inputs before performing an evaluation. First,

TABLE 3 RANK ORDER OF THE 10 DECISION FACTORS AND SUBFACTORS WITH THE SMALLEST MEAN IMPACT BASED ON STATE DOT RESPONDENTS

Questionnaire Item Name (1)	Mean Impact (2)
(a) DECISION FACTORS	
Location of Home Office	0.29[a]
Substance Abuse Policy	0.62
Experience in Geographical Location of Project	0.68
Safety Performance	1.70
Manpower Resources (labor)	1.82
Project Control Procedures	1.97
References	2.06
Bonding Capacity	2.14
Current Work Load	2.18
Staff Available	2.23
(b) DECISION SUBFACTORS[b]	
Home Office Location Relative to Job Site Location	0.42
Whether Contractor is Union or Open Shop	0.44
Contractor's Familiarity with Local Politics	0.44
Type of Ownership	0.65
Contractor's Familiarity with Weather Conditions	0.68
Market Conditions of the Geographic Area	0.68
Information from OSHA Log 200 Accident Reports	0.70
Contractor's Faithfulness in Conducting Tool Box Meetings	0.79
Employment Averaged Over the Last Three Years	0.82
Contractor's Experience Modification Rate (EMR) for the Last Three Years	0.88

[a]Rating scale used was 4 = High Impact, 2 = Moderate Impact, and 0 = Little/No Impact.

[b]Decision subfactors characterize a major decision factor and aid in making a decision regarding that factor.

project-specific data containing the project name and number are required. Next, decision criteria are selected. These criteria include the following available alternatives:

1. Accept system-specified CDFs and DFs on the basis of program-supplied factor analysis results;
2. Modify the program-supplied CDFs and DFs by (a) deleting CDFs, DFs, or both; (b) adding up to 10 additional DFs to an existing system-specified CDF; or (c) creating and adding additional CDFs and DFs to the system (up to 10 individual CDFs characterized by up to 10 individual DFs each can be added); or
3. Create a personal prequalification decision system including CDFs and DFs. Twenty individual CDFs, characterized by up to 10 individual DFs each, can be input into the system.

Once the decision parameters have been specified, their weighting scheme must be selected. The user has two options in order to weight the CDFs and DFs established in the previous step:

1. Accept system-specified weights on the basis of the program-supplied mean impact results; or
2. Provide user-specified weights. This procedure allows the user to input the perceived importance on a scale from 0.0 to 1.0 for each CDF and DF. All CDFs are normalized so that the sum of the weights equals 1. All DFs that characterize a CDF are also normalized so that the sum of the weights equals 1. The system allows for the user to input the weights and then view the normalized weights. A facility permits the normalized weights to be modified by reentering the perceived importance on a scale from 0.0 to 1.0. A user can continue to modify input values until satisfied with the normalized weights given to each decision parameter.

The system-specified weights can only be chosen if the system-specified CDFs and DFs are selected. Otherwise, the weights must be input by the user. Once the selection has been made with appropriate queries and inputs, the program rates the candidate contractors.

The user is queried to input the contractor's name and a subjective rating for each DF using a scale of 1.0 to 10.0 (1.0 equals unsatisfactory and 10.0 equals excellent). The aggregate weighted rating is then calculated using Equation 1. This process is repeated until the list of candidate contractors has been exhausted.

TABLE 4 PUBLIC OWNERS FACTOR ANALYSIS RESULTS

Questionnaire Item	Factor Score
CDF 1—Performance	
Contractor has failed to complete a contract	0.15
Past performance	0.13
Quality performance	0.20
Project management capabilities	0.11
Staff available	0.06
Project control procedures	0.15
Safety performance	0.20
CDF 2—Type of Contractor	
Experience	0.21
Company organization	0.33
Equipment resources	0.46
CDF 3—Capacity for Assuming New Projects	
Capacity of firm	0.40
Current work load	0.42
Manpower resources	0.18
CDF 4—Location	
Location of home office	0.54
Experience of geographical location of project	0.46
CDF 5—Percentage of Work Performed	
Amount of work performed with own forces	1.00
CDF 6—Third Party Evaluation	
References	0.46
Bonding capacity	
CDF 7—Financial Capability	
Financial stability	1.00

NOTES: The results include 25 additional data samples obtained from other governmental agencies (e.g., state Departments of Administration and the U.S. Department of Defense). The questionnaire item "Substance Abuse Policy" failed to show up in any of the factors listed. Factor scores are based on regression results that have been standardized.

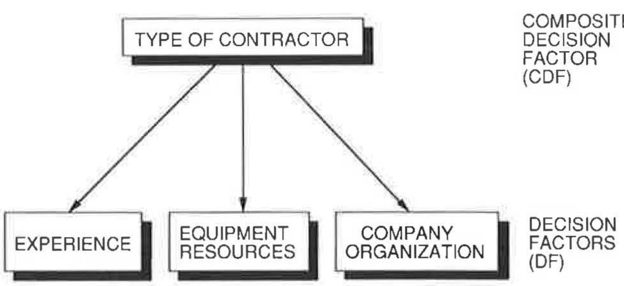

FIGURE 1 Example of the decision model structure.

Outputs of the program consist of two parts: (a) rank-ordered aggregate weighted ratings and (b) statistics for each DF and aggregate rating. Aggregate ratings are obtained using the previously described relevant inputs along with Equation 1. These values are then ordered by rank from highest to lowest. The program's final output consists of statistics for all input DF data and the aggregate weighted rating for all candidate contractors. The statistics calculated for each DF include the mean, $\overline{R}_{ij}$, and standard deviation, $\hat{\sigma}_{ij}$. The mean is calculated using

$$\overline{R}_{ij} = \sum_{k=1}^{n} R_{ijk}/n \tag{5}$$

where

$\overline{R}_{ij}$ = mean rating of the jth DF, which characterizes the ith CDF;
n = total number of candidate contractors; and
R_{ijk} = rating of the jth DF, which characterizes the ith CDF for candidate contractor k.

The standard deviation is calculated from

$$\hat{\sigma}_{ij} = \left[\frac{\sum_{k=1}^{n} (R_{ijk} - \overline{R}_{ij})^2}{n-1} \right]^{1/2} \tag{6}$$

For the aggregate weighted ratings, the mean $\overline{AR}$ and standard deviation $\hat{\sigma}_{AS}$ are also calculated. The mean aggregate weighted rating is calculated from

$$\overline{AR} = \sum_{k=1}^{n} AR_k/n \tag{7}$$

where $\overline{AR}$ is the mean aggregate weighted rating and AR_k is the aggregate weighted rating of candidate contractor k. The standard deviation of the aggregate weighted ratings is calculated using

$$\hat{\sigma}_{AS} = \left[\frac{\sum_{k=1}^{n} (AR_k - \overline{AR})^2}{n-1} \right]^{1/2} \tag{8}$$

A more complete description of this computer program was given by Russell (*12*). In the next section, an example application is provided.

EXAMPLE PROGRAM APPLICATION

The program was applied to a sample case by two prequalification officials from the Indiana Department of Highways (IDOH). Five previous bidders on bridge construction projects were evaluated using 3 years of information they had submitted on the IDOH Contractor's Statement of Experience and Financial Conditions forms. Information available from other sources was also used to determine subjective inputs for these contractors. The contractors are referred to as A, B, C, D, and E.

Table 7 presents the subjective ratings given to the DFs for each contractor by the prequalification officials. The CDF third-party evaluation was deleted from the analysis because of insufficient information. Thus, the weights input into the program for the CDFs were 0.19, 0.19, 0.16, 0.05, 0.16, and 0.25. A sample format of the program's output using these data is presented in Table 8. A minimum allowable aggregate rating or threshold can be established in order to select highway contractors permitted to bid on contracts. This threshold is established on the basis of the decision maker's judgment. For example, if a rating of 6.0 was chosen, contractors B, E, C, and D would be permitted to bid.

TABLE 5 WEIGHTS OF CDFs FOR STATE DOT RESPONDENTS

	CDF Index and Name (1)	Weight (2)
1	Performance	0.16
2	Type of Contractor	0.17
3	Capacity for Assuming New Projects	0.14
4	Location	0.03
5	Percentage of Work Performed	0.14
6	Third Party Evaluation	0.13
7	Financial Capability	0.23

TABLE 6 WEIGHTS OF DFs FOR STATE DOT RESPONDENTS

Questionnaire Item	Weight
CDF 1—Performance	
Contractor has failed to complete a contract	0.19
Past performance	0.17
Quality performance	0.16
Project management capabilities	0.14
Staff available	0.13
Project control procedures	0.11
Safety performance	0.10
CDF 2—Type of Contractor	
Experience	0.40
Company organization	0.27
Equipment resources	0.33
CDF 3—Capacity for Assuming New Projects	
Capacity of firm	0.39
Current work load	0.33
Manpower resources	0.28
CDF 4—Location	
Location of home office	0.30
Experience in geographical location of project	0.70
CDF 5—Percentage of Work Performed	
Amount of work performed with own forces	1.00
CDF 6—Third Party Evaluation	
References	0.49
Bonding capacity	0.51
CDF 7—Financial Capability	
Financial stability	1.00

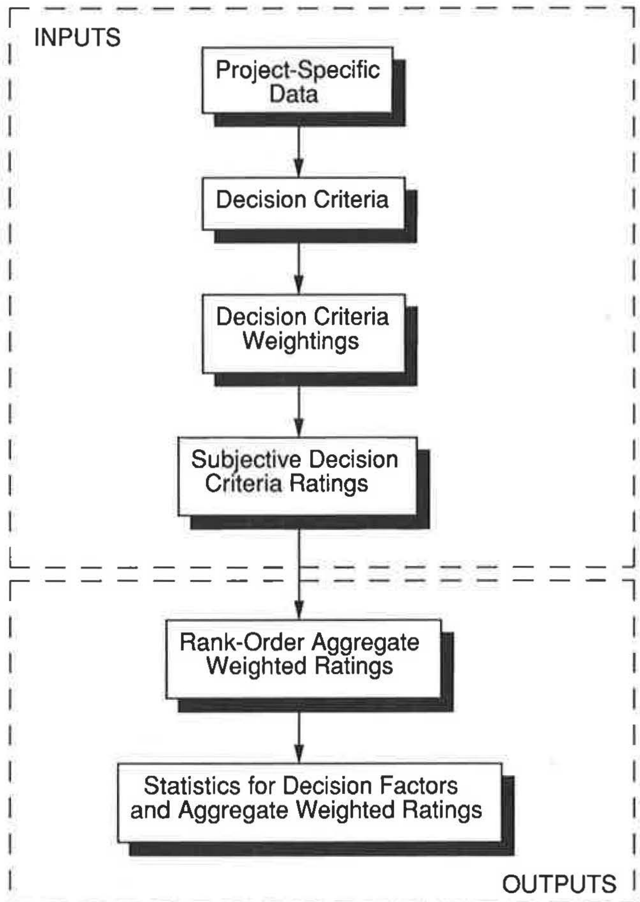

FIGURE 2 Input requirements and outputs of computer program.

SUMMARY AND PRACTICAL APPLICATIONS

The study that was the basis for a formalized computerized prequalification model was described. The linear prequalification model and the developed computer program were also described. The model's advantages are (a) its simplicity, which results in ease of understanding and use by prequalification officials; (b) its structured, systematic, and rational approach to contractor analysis and the subsequent decision making; and (c) its documentation of the reasons contractors were selected for the bid list.

One major disadvantage of this computerized prequalification model is that the rating inputs (R_{ijk}) depend on the user's ability to analyze and synthesize available contractor data and assign a value ranging between 1.0 and 10.0 for each decision parameter. A low rating on one decision parameter can be compensated by a high rating on another, thus impacting the calculated aggregate weighted rating. Consequently, a candidate contractor may have a high aggregate weighted rating even though certain significant decision parameters may have low ratings. The model also suffers from an inability to

TABLE 7 SUMMARY OF THE RATINGS INPUT FOR EXAMPLE APPLICATION

Parameter Name	Rating for Contractor A	B	C	D	E
(1)	(2)	(3)	(4)	(5)	(6)
(a) CDF 1. - Performance					
Contractor has Failed to Complete a Contract	7	8	8	8	7
Past Performance	7	8	8	8	8
Quality Performance	7	8	8	7	8
Project Management Capabilities	7	8	8	7	8
Staff Available	7	8	8	7	8
Project Control Procedures	7	8	8	7	8
Safety Performance	7	8	8	7	8
(b) CDF 2. - Type of Contractor					
Experience	6	8	8	7	8
Company Organization	7	8	8	7	8
Equipment Resources	6	8	7	6	8
(c) CDF 3. - Capacity for Assuming New Projects					
Capacity of Firm	6	8	8	8	8
Current Work Load	7	8	8	8	8
Manpower Resources	6	8	8	8	8
(d) CDF 4. - Location					
Location of Home Office	7	8	8	7	8
Experience in Geographical Location of Project	7	8	8	7	8
(e) CDF 5. - Percentage of Work Performed					
Amount of Work Performed with Own Forces	5	5	5	5	5
(f) CDF 6. - Third Party Evaluation					
References	-	-	-	-	-
Bonding Capacity	-	-	-	-	-
(g) CDF 7. - Financial Capability					
Financial Stability	5	8	7	5	8

TABLE 8 PROGRAM OUTPUT FOR EXAMPLE APPLICATION

Rank	Contractor Name	Aggregate Weighted Rating
(1)	(2)	(3)
1	Contractor B	7.52
2	Contractor E	7.48
3	Contractor C	7.21
4	Contractor D	6.34
5	Contractor A	5.93

Statistics on aggregate ratings are:

Mean Rating = 6.90 Standard Deviation = 0.72

adequately represent the risk profile of the decision maker and the uncertainty associated with the data collected on candidate contractors.

State DOT prequalification officials can use the model in several ways. These alternatives include (a) using the model to qualify contractors annually, (b) using the model to arrive at the modifying factor applied to the calculated value from the formula, and (c) abandoning current prequalification procedures (performed annually using a formula) and using the model to prequalify highway contractors on a project-by-project basis. These alternatives are described in detail in the following paragraphs.

First, the model could be used to perform an annual review of highway contractors. The current procedure determines a maximum amount of work a contractor may have under contract at any one time. The evaluation process would involve the establishment of a minimum threshold value to permit highway contractors to bid on forthcoming contracts. However, considerable thought is needed on the legal implications of this alternative.

Second, current formulas to prequalify contractors use modifying criteria applied to financially derived values, which have been developed in an ad hoc manner. The proposed model is based on a systematic study of expert opinion. The results obtained from the application of the model can represent or correspond to a modifying coefficient. For example, an aggregate rating of 5 can result in a 50 percent reduction in the value calculated from the formula. A formula can state that working capital is multiplied by 10 and then modified 40 percent by past performance, 20 percent by experience, 20 percent by equipment resources, and 20 percent by cooperation. Using the model, if the highway contractor's working capital is $100,000, his maximum allowable work program would be $1,000,000 ($100,000 multiplied by 10) times 0.50, or $500,000. A similar approach is used by the state of Utah.

Changing annual highway contractor prequalification formulas to prequalification on a project-by-project basis with the model described is a third alternative. In this case, an aggregate rating would be used to determine whether a contractor is permitted to submit a bid on a project. Similar to the application of annual prequalification, a minimum aggregate rating can be established to select contractors. Practical application considerations of this alternative include the level of detail contained within the model. Applying the model to every project let by a state DOT is not feasible; consequently, estimated project cost and complexity thresholds must be established to permit an efficient use of resources. This procedure would also eliminate the need to classify the type of work a contractor is permitted to do under the current procedure, which in many instances is a difficult task to accomplish accurately.

Before implementing the model in any of the proposed alternatives, further calibration through example applications should be performed. In addition, a contractor prequalification questionnaire would need to be redesigned to facilitate the gathering of relevant data needed to support the model.

ACKNOWLEDGMENTS

The decision analysis study that led to the development of the prequalification program was supported by the U.S. Army Construction Engineering Research Laboratory. The author thanks Chang-hsin Hsieh for his assistance in coding the model as well as Michael R. Beuchel, Prequalification Engineer, and Howard W. Bushman, Prequalification Auditor, of IDOH in Indianapolis, Indiana, for their review and development of an example application using the computerized prequalification model.

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Publication of this paper sponsored by Committee on Construction Management.