QUALIFIER-2: KNOWLEDGE-BASED SYSTEM FOR CONTRACTOR PREQUALIFICATION

By Jeffrey S. Russell,[1] Associate Member, ASCE, Miroslaw J. Skibniewski,[2] Member, ASCE, and David R. Cozier,[3] Associate Member, ASCE

ABSTRACT: Among other concerns, contractor prequalification involves the evaluation of a candidate contractor's reputation, past performance, financial stability, experience record, firm capacity, current workload, and technical expertise. Qualifier-2, a prototype knowledge-based expert system that aids construction owners in performing contractor prequalification, is presented in this paper. A description of a previously developed algorithmic model for contractor prequalification, Qualifier-1, is also discussed and its shortcoming are outlined. The hierarchical decision model applied in Qualifier-2 is described along with sample decision rules implemented within the developed system followed by a description of the prototype system's structure and facilities. The system prompts the user for pertinent contractor data and performs the evaluation. A help, explanation, and recommendation facility have been included to aid the user during a consultation. The system provides an automated contractor evaluation process through which rational and consistent prequalification decisions can be made.

INTRODUCTION

Prior to allowing candidate contractors to participate in a project bid, a review of their qualifications should be performed. A formal evaluation of parameters such as reputation, past performance, financial stability, experience record, firm capacity, current workload, and technical expertise is usually included. Previous discussions of topics regarding contractor prequalification include a description of bidder selection by multiattribute utility theory (Diekmann 1981), tender and bid proposal evaluation by fuzzy sets (Nguyen 1985, Juang et al. 1987), the evaluation of six state departments of transportation prequalification procedures ("A Synthesis" 1985), and contractor qualification procedures and decision factors (Wright 1986).

Contractor prequalification decision making involves a wide range of criteria that often consists of both qualitative and subjective information. Frequently the criteria used in this process must be modified in light of the particular construction owner and project. The process remains largely an art, where subjective judgment based on the individual's experience becomes an essential part of the process [see also Nguyen (1985)]. Thus, contractor prequalification typically requires the use of heuristic knowledge or "rules of thumb" in the form of "if-then" decision rules. The process is often performed in an ill-structured and intuitive manner without the use of computer aids.

[1]Asst. Prof., Dept. of Civ. and Envir. Engrg., Univ. of Wisconsin–Madison, Madison, WI 53706.

[2]Asst. Prof., School of Civ. Engrg., Purdue Univ., W. Lafayette, IN 47907.

[3]Lieutenant and Asst. Resident Ofcr. in Charge of Construction, Portsmouth Naval Ship Yard, Portsmouth, NH 03801.

Note. Discussion open until August 1, 1990. To extend the closing date one month, a written request must be filed with the ASCE Manager of Journals. The manuscript for this paper was submitted for review and possible publication on February 15, 1989. This paper is part of the ***Journal of Construction Engineering and Management***, Vol. 116, No. 1, March, 1990. ©ASCE, ISSN 0733-9364/90/0001-0157/ $1.00 + $.15 per page. Paper No. 24473.

This paper describes Qualifier-2, a prototype knowledge-based expert system that has been developed to aid owners in making the contractor prequalification decision. In regard to knowledge engineering, the system represents a large amount of effort in the knowledge acquisition and compilation areas. As a result of the use of this system, a more structured approach to the process can be achieved. Thus, consistent, rational, and timely decisions can be made regarding the admission and participation of contractors to the bidding process.

The decision model presented contains a procedure to be followed by a prequalification official that will result in systemizing the contractor analysis process. This can be achieved by representing the prequalification problem by a hierarchy of decision parameters. A decision tree of each parameter contained in the hierarchy is implemented. This knowledge representation is coded within a commercial knowledge-based expert system shell.

Pertinent domain knowledge is represented by "if-then" production rules. As a result of a consultation with Qualifier-2, it is determined whether a candidate contractor should be permitted to participate in a project bid. Numerous facilities (e.g., help, explanation, and recommendation) are also provided to aid in a consultation. The system, as developed to date, evaluates a candidate contractor's references, reputation, past performance, and financial stability.

In the subsequent section, a description of an algorithmic model for contractor prequalification, Qualifier-1, is presented, and its shortcomings are outlined. Next, the decision model applied in Qualifier-2 is described, followed by a description of the prototype system's structure and facilities. Finally, conclusions regarding the developed system are highlighted.

Background

Qualifier-1, a computerized algorithm to aid in the performance of contractor prequalification, has been previously developed (Russell and Skibniewski 1990). The model consists of a linear combination of decision parameters where the assumption of additivity among its decision parameters has been made. The decision parameter structure and the corresponding weights embedded within the program are based on statistically analyzed questionnaire data. The program permits the user to modify these weights to place proper emphasis on the criteria relevant to the given project circumstances. Similarly, the model's decision parameters can be modified in light of prevailing project circumstances.

Qualifier-1 calculates an aggregate weighted rating for each candidate contractor based on subjective input ratings (on a scale of 1 to 10, where 1 is unsatisfactory and 10 is excellent) for each decision factor. The ratings are then rank-ordered, and the means and standard deviations for the complete sample are provided with respect to each decision factor and aggregate weighted rating. Thus, this model permits a low rating on one criterion to be compensated by a high rating on another. The calculated values provide a guide for rational prequalification decision-making relative to these criteria. The current implemented version of Qualifier-1 does not permit sensitivity analysis to be performed on the calculated ratings to evaluate the variation in the subjective input data. This enhancement to the program is currently being made.

Many sources and items of data are availalble to arrive at a decision regarding the condition of a decision parameter. One disadvantage of Qualifier-1 is that it requires a user to possess expertise for a subjective analysis and synthesis of the available contractor data, and to place this evaluation on a preference scale from 1 to 10. In reality, the evaluation process is often performed in an ill-structured, implicit, and subjective manner.

Therefore, numerous items can impact the obtained results, including information overload, incompetent personnel, personal biases, and lack of experience and knowledge within the domain. The problems associated with this decision-making process are reduced by a heuristic knowledge representation contained in Qualilfier-2. This is accomplished by evaluating the input data by heuristic decision rules and suggesting a prequalification decision.

To highlight the differences between these models, the following example is offered. The decision parameter "financial stability" is implemented in both models. Qualifier-1 does not specify the necessary data sources, the data items to be evaluated, or the process that should be used to perform the analysis of this criterion. Thus, this model represents only a decision template to aid in structuring the analysis process. On the other hand, Qualifier-2 contains an explicit format for which data are required and a corresponding analysis is performed. A complete description of the data and the evaluation process used for this criterion is presented in the subsequent section.

Decision Model for Contractor Prequalification

Development of the model and acquisition of pertinent domain knowledge implemented in Qualifier-2 was accomplished by a series of knowledge engineering steps. A complete description of these steps is given in Russell and Skibniewski (1988). The majority of knowledge contained in the current version of Qualifier-2 was obtained through interviewing four construction professionals who have extensive experience with contractor prequalification, primarily in the area of general building-type construction: three surety-company agents and an owner's construction representative. Four separate interviews with each participant were performed. Two of the surety-company agents were interviewed simultaneously, while the other study participants were interviewed individually. A complete description of the interviewees' characteristics and the interview process is provided in Russell (1990).

The developed decision model separates the contractor prequalification problem into a number of subproblems. These subproblems are a linear combination of decision parameters and consist of five distinct levels within the model hierarchy. Each level is referred to as a composite decision factor (CDF) and is evaluated individually. A CDF is characterized by numerous decision factors (DF), which represent lower-level decision parameters pertinent to making inferences regarding a CDF. Inferences made at each CDF level are based on a set of "if-then" production rules. For a given CDF, the related DF responses are represented individually and/or combined, depending upon the depth of the hierarchy and the relationship among the DFs. They are combined in the form of production rules that are used to arrive at a decision.

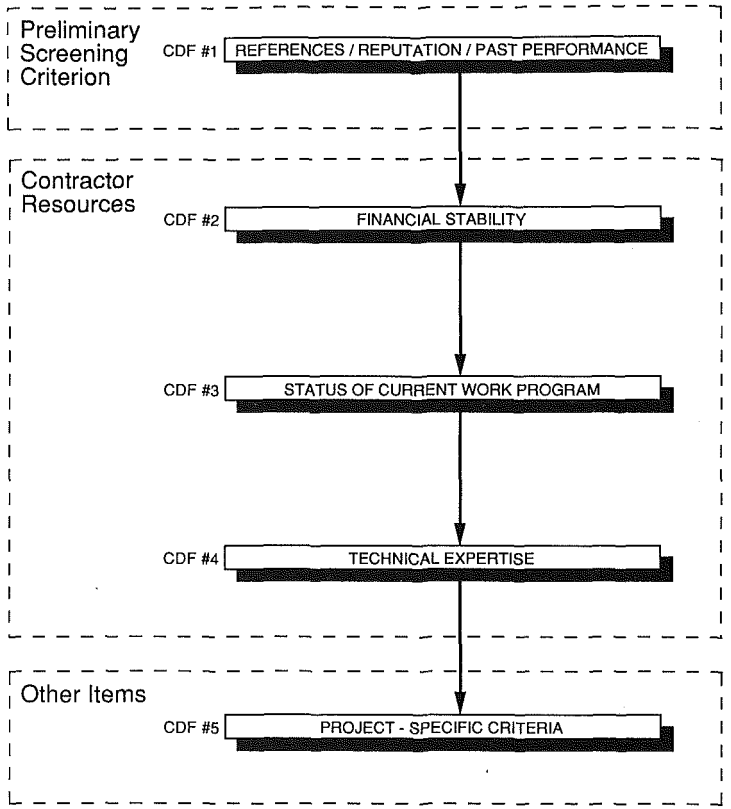

FIG. 1. Decision Model for Contractor Prequalification

A representation of the model's CDF levels is shown in Fig. 1. As shown, the model is comprised of the following CDFs:

1. References/reputation/past performance—preliminary screening criterion.
2. Financial stability—to evaluate the financial condition and longevity of each candidate contractor.
3. Status of current work program—to evaluate contractor's current workload and determine any severe difficulties with ongoing projects.
4. Technical expertise—to evaluate technical characteristics of contractor.
5. Project-specific criteria—to evaluate if candidate contractor can provide unusual expertise or specialized facilities required by the project.

The preliminary screening mechanism of the process is represented in the given number 1. Numbers 2, 3, and 4 address the contractor's resource base, and 5 denotes project-specific elements.

The evaluation of a candidate contractor is performed at each CDF level (e.g., references/reputation/past performance). Three decision alternatives exist at each CDF: (1) Disqualify the contractor and thus the analysis is terminated; (2) qualify the contractor and proceed to the next CDF in the

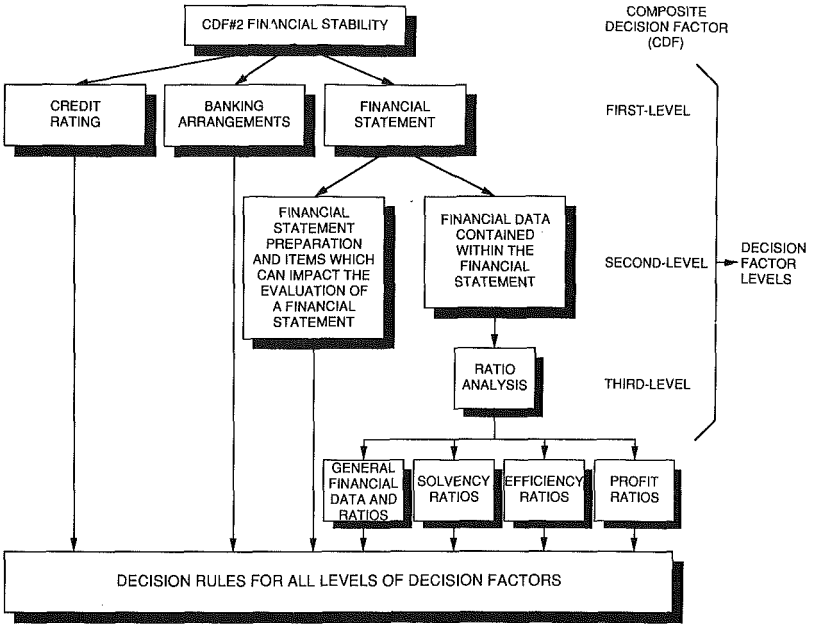

FIG. 2. Hierarchical Framework for Composite Decision Factors

hierarchy; or (3) no decision, i.e., items revealed at this CDF level have raised further questions that require more data to be collected prior to the prequalification decision.

In illustration, the debarment history of a candidate contractor is of interest in the evaluation process. A candidate contractor would be disqualified if he had a history of being debarred from bidding on projects by a public owner. Consequently, the analysis can be terminated. Currently the system does not combine the CDF responses to suggest a prequalification decision. In some instances such an approach is used in practice and thus could be implemented within the system.

Each of the CDFs contained in the decision model can be further represented by the framework shown in Fig. 2. The framework consists of five distinct parts: (1) CDFs contained within the hierarchy shown in Fig. 1; (2) first-level decision factors, which characterize a CDF; (3) second-level decision factors, which characterize a first-level DF; (4) third-level decision factors, which characterize a second-level DF; and (5) decision rules (DRs) associated with each level of DFs.

An example of this framework using the CDF for financial stability is shown in Fig. 2. As shown, this hierarchy represents a tree of DFs pertinent to the evaluation of this CDF. Associated with the DFs, although not shown in Fig. 2, are heuristic decision rules to aid in the prequalification decision process.

As an example, decision rules can state the following: If "financial statement preparation and items which can impact the evaluation of a financial statement" equals "qualify" and "financial data contained within the finan-

cial statement" equals "qualify," then "financial statement" equals "qualify;" and if "credit rating, banking arrangements, and financial statement" equals "qualify," then "financial stability" equals "qualify."

Decision rules related to another CDF, references/reputation/past performance, can include statements such as: if the "candidate contractor has no past experience with this project type," then the prequalification decision is "disqualify."

Each CDF hierarchy has its unique characteristics. Some CDFs have a shallow hierarchy (e.g., references/reputation/past performance), while others represent considerable depth and breadth within their hierarchy (see Fig. 2). A more complete description of the model's CDFs, as well as the complete enumeration of the decision rules associated with each of the DFs, can be found in Russell (1990) and Russell (1988). In the subsequent section a description of the prototype system Qualifier-2 is given.

PROTOTYPE OF QUALIFIER-2

A prototype knowledge-based expert system, Qualifier-2, demonstrates the evaluation process described in the prior section. Qualifier-2 is implemented within a commercially available expert system shell, Knowledge Engineering System (KES) (*Knowledge* 1986). The current working system is operational on a Gould PN9080 UNIX-based mainframe computer and on IBM PC and compatible DOS-based microcomputers.

A backward-chaining inference mechanism is used in the current working system (Cozier 1988). The evaluation of a particular CDF is represented as a rule-based production system of DFs. Each CDF is expressed as a hierarchical system of subgoals that must be satisfied to perform the evaluation. As an example, the first goal is to determine if the candidate contractor fulfills the requirements present in the initial step of the evaluation process.

Qualifier-2, in its present state, is a prototype system that has embedded two CDFs, references/reputation/past performance and financial stability. For efficient processing of data and subsequent decision-making, the CDF for reference/reputation/past performance has been broken down into two parts, the initial prequalification decision and the second prequalification decision. The initial prequalification decision can be viewed as a screening mechanism that a contractor must pass in order to continue in the evaluation process. All three represent a decision point in the system's analysis process. The system has four possible decision responses that can be rendered at each decision point: (1) Qualify (continue to next CDF); (2) disqualify (terminate the analysis); (3) unsure (prior to making the decision, the judgment of the user must be exercised, e.g., more data collection and analysis may be required); and (4) unknown (based on the variable responses input, the system's knowledge base does not contain rule(s) that incorporate these variable responses to draw a conclusion).

Appendices I and II present a selection of representative rules in a grammarlike syntax for DFs contained in the initial and second prequalification decision areas, respectively. As shown, due to the implemented rules, a number of pertinent questions can be raised prior to drawing a final conclusion. Such detailed questions aid in preventing incorrect conclusions from being drawn from incomplete information. These rules have been coded within the program without the inclusion of the questions that appear in the consequent of

the listed rules. These questions highlight the complexity associated with the prequalification domain.

Prior to a decision being made by the system, an evaluation of numerous DFs associated with each evaluation step must be performed. An individual response to a DF can automatically cause a conclusion to be drawn. For example, a DF used in the evaluation of the initial prequalification decision is "contractor's labor type" compared to "project labor type" specified. The decision rule implemented within the system states the following:

rule10:

if project labor type = union and contractor labor type = open shop

then initial prequalification decision = disqualify.

Explanation: "The contractor is open-shop (nonunion) and the owner desires to use only union labor for this project."

Another example including the evaluation of the second prequalification decision is "type of projects performed in the past" relative to "subject project type." The decision rule contained in the system states the following:

rule22:

if type of past projects # project type

then second prequalification decision = disqualify.

Explanation: "The contractor does not have experience with this type of project."

In this and many other cases, the user may not support the conclusion drawn by the system and elect to override the system's response. In some instances, performing the evaluation of a CDF such as financial stability requires an evaluation of many lower-level DFs prior to arriving at a solution.

Besides facilities to perform the evaluation and qualification of candidate contractors, Qualifier-2 contains a rule explanation facility. The system is also capable of suggesting where additional information is required before a conclusion can be drawn, as well as editing and viewing the user input data and overriding system conclusions by a user. In addition, an online "help" feature to aid in difficulties encountered during a consultation is included.

System Description

A flow diagram representing the Qualifier-2 decision process is shown in Fig. 3. As shown, the program consists of a main menu and three primary decision points:

1. Initial prequalification decision—an evaluation of the candidate's references, reputation, and failed contract history.

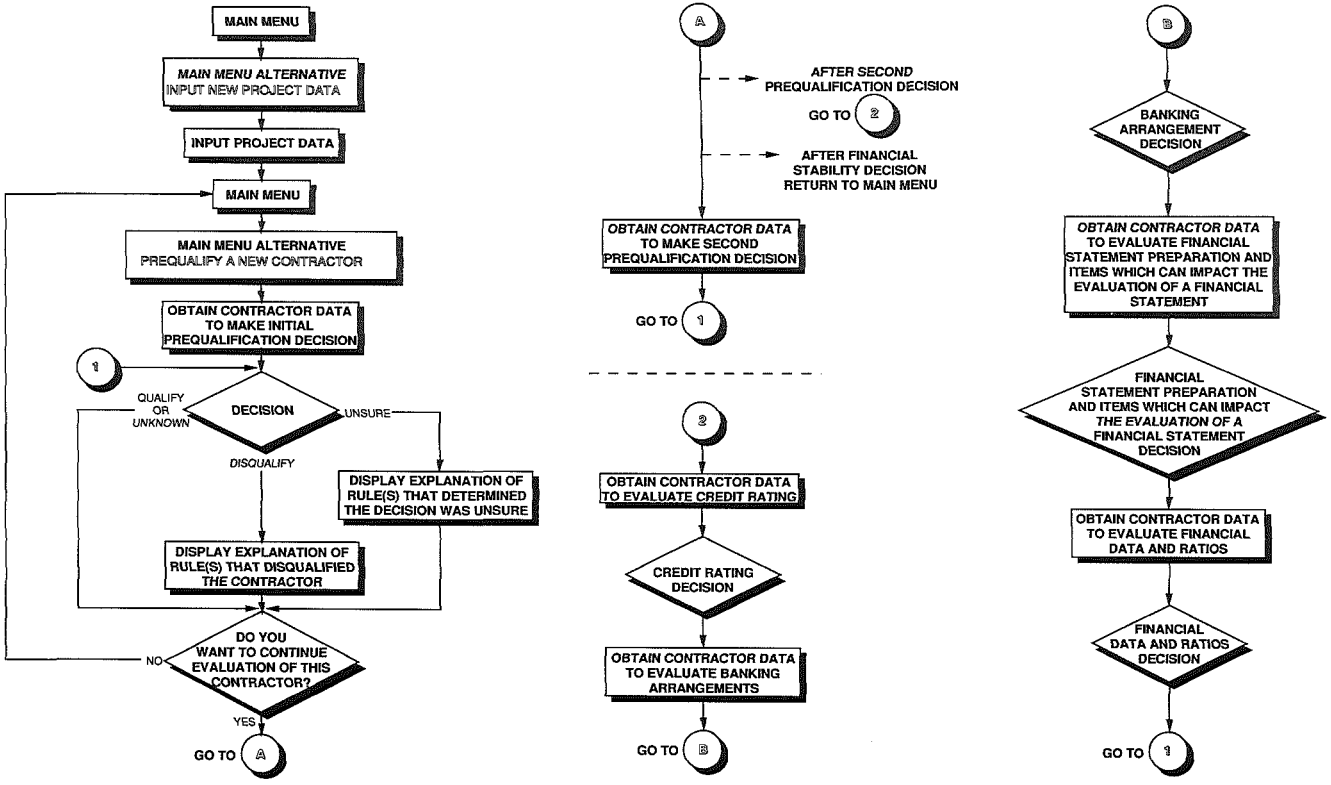

FIG. 3. Flow Diagram of Qualifier-2 Program

TABLE 1. Decision Factors Evaluated by Qualifier-2 to Determine Initial Prequalification Decision of Contractor

DF name (1)	Source of data (2)
Mean categorical performance rating	References
Debarment record	Questionnaire
Reputation	References
Failed contract history	Questionnaire
Failed contract time	Questionnaire
Contractor labor type (union, open-shop, merit shop)	Questionnaire

2. Second prequalification decision—comparison of the candidate's ability to perform relative to the subject project requirements.
3. Decision based on the CDF for financial stability—to evalulate the financial condition and longevity of the candidate contractor.

The main menu, which provides the control structure of the program, consists of 12 options that are listed and briefly described in Appendix III.

The linearity of the decision model permits an evaluation to be performed at each level in the decision hierarchy. Each decision point contained in the hierarchy has its own set of decision rules (rule clusters) to evaluate the input data. This structure facilitates adding more decision rules to the existing knowledge base, modifying existing rules contained within the knowledge base, and adding additional CDFs not contained within this prototype.

Pertinent data required by the program to infer a conclusion are requested of the user. Quantitative data are used in the calculations of various values and are incorporated in decision rules employed in the inferencing process. For example, a comparison is made between the size of the project under consideration and the largest similar project of this type performed previously by a candidate contractor. If the estimated cost of the project being considered is two times larger than any similar project performed by the contractor in the past, then the second prequalification decision is "unsure." This calculation and comparison is performed within the program.

Another example of quantitative data is the financial data contained in the balance sheet and income statement, which are input by the user. Calculations performed by the program include, among others, current assets minus current liabilities (amount of working capital), ratio of debt to net worth, and ratio of current assets to current liabilities ("quick ratio"). Based on the DF values selected and input by the user, conditions necessary to invoke a specific rule or rules can be met, and the corresponding conclusion can be made.

Project specific data required by the program include project name, project number, project type, estimated cost, bond requirements, and project labor type. This information is obtained from the project owner. The specific DFs evaluated at each decision point are presented in Tables 1 and 2 and Appendix IV respectively.

Tables 1 and 2 show where a particular DF value is obtained. A questionnaire completed by the contractor, reference evaluations, and the contractor's surety agent all represent sources of data needed to obtain DF values

TABLE 2. Decision Factors Evaluated by Qualifier-2 to Determine Second Prequalification Decision of Contractor

DF name (1)	Source of data (2)
Length of time in business	Questionnaire
Length of time company controlled by current management	Questionnaire
Type of projects performed in past	Questionnaire
Largest project performed in past ten years	Questionnaire
Largest similar project performed in past five years	Questionnaire
Amount of current uncompleted work-on-hand	Questionnaire/financial statement
Largest amount of uncompleted work-on-hand (past three years or highest historical value)	Questionnaire
Bond decision	Surety agent
Bond cost	Surety agent

such that the system can be used. The mean categorical performance rating is obtained from a questionnaire containing relevant performance parameters sent to previous clients of the candidate contractor, to be completed anonymously.

Each decision parameter contained in the questionnaire (e.g., safety, quality of work performed, field supervision) is rated on a categorical scale of unsatisfactory, poor, average, good, excellent, and superior. These ratings are summarized in the form of a histogram. By artificially quantifying the categorical rating scales (i.e., 0, 2, 4, 6, 8, and 10, respectively), other mathematical manipulations of these data can also be performed (e.g., calculation of sample mean and standard deviation). A more complete explanation, as well as an example illustration of this past performance data collection scheme, can be found in Russell and Skibniewski (1988). This data collection scheme allows a more structured and comprehensive approach than has previously been used to gather past performance data. Traditionally, attempts to collect such data were achieved by telephoning past clients of the candidate contractor.

The DFs contained in Appendix IV can be obtained through trade suppliers, credit rating service reports, contacting banking partner(s), interviews with the contractor, and an audited financial statement. A complete description of the sources for contractor data is given in Russell (1988).

System Facilities

In addition to the prequalification evaluation procedure, a number of facilities exist that aid the user during a consultation with the system. The rule explanation facility provides the user with information to further clarify what is being asked regarding a specific parameter. For example, a question in the evaluation process states the following: "Has this contractor ever been debarred from bidding on a project by a governmental agency?" If the user requests an explanation of this question, the system will respond with the following statement:

Debarment could be for a criminal conduct, discrimination, or for other activities not acceptable to local, state, or federal government.

Within the rule explanation facility, a facililty to explain why the system is requesting a variable response is also contained within the working system. For example, given the question stated above, if a "w" or "why" is input as a response, the following output is provided by the program:

KES is asking for a value for 'debarment' because:

The value of 'debarment' is required by the rule labelled 'rule12' to determine a value for 'initial prequalification decision'.

A command in the knowledge base's actions section or an interactively specified command is assigning a value to 'initial prequalification decision'.

Do you want to see more information? (If yes, enter 'y' ⟨Return⟩) y

Name: rule12
Is: Production Rule

if debarment = yes

then initial prequalification decision = disqualify.

endif.

Has the contractor ever been debarred from bidding a project by a governmental agency?
If unknown, select 'no.'

1. yes
2. no

=? 1

After a conclusion is drawn (i.e., a decision rule has been fired), an explanation is provided by the program to inform the user why the particular decision was reached. For example, referring again to the previously stated question, the initial prequalification decision is "disqualify." The following explanation will be produced:

The reason for this decision is:

Debarment from bidding a governmental project constitutes contractor disqualification.

Some response data input into the system will invoke a system decision of "unsure." When this occurs, suggested questions or items that warrant further investigation will be produced by the program for review by the user. These suggestions must be evaluated in light of their impact on the final decision. Thus, depending on their impact, the user may have to gather more data prior to making the decision.

In illustration, if the user inputs "yes" regarding the question "Is the candidate contractor engaged in ongoing litigation?," a message will be produced stating that the user should assess the impact of the outstanding litigation case(s) on the contractor's financial stability. Thus, the magnitude of impact of such problems on his financial stability must be determined by the decision-maker himself. Other parameters pertinent to determining the contractor's financial stability, including credit rating and banking arrangements, must also be considered when making a final decision regarding this CDF.

An example application session with Qualifier-2 is presented in Russell (1988).

Conclusions

The linear design of the knowledge base and the prequalification decision rules have received favorable reviews by numerous industry professionals, including a state Department of Transportation official, representatives of large industrial and power plant owners, and several individuals representing large construction management firms. No explicit treatment of the uncertainties associated with the heuristic knowledge contained in the knowledge base of Qualifier-2 has been applied, thus constituting a need for further enhancements. Extensions of Qualifier-2 currently under development include implementing other CDFs not contained in the current version of the prototype such as "status of current work program," "technical expertise," and "project-specific criteria." Further work validating the system will include the testing of the program on various project data, interfacing data bases (e.g., historical performance data), and computer graphics to enhance the system's performance and utility.

Acknowledgments

The first writer wishes to thank the four interviewees who participated in the interview process that led to the development of the decision model contained in the presented knowledge-based expert system. Also, support from the National Science Foundation's Young Presidential Investigators Program is gratefully acknowledged and appreciated.

Appendix I. Selection of Representative Rules for DFs Related to Initial Prequalification Decision

1. If comments from references—in-house personnel, current clients, competitors, subcontractors, suppliers, previous clients, architects, bonding company, banker, insurance company, and accountant regarding contractor's per-

formance—are poor; then investigate further why the candidate contractor is perceived to be a poor performer.

2. If debarment is yes, then analysis is terminated, and it is recommended that the user investigate the circumstances in which the debarment occurred. Has the situation or problem been corrected?

3. If the reputation is an unacceptable business practice, then the prequalification decision is to disqualify.

4. If there is a failed contract, and the failed-contract time is less than two years, then the analysis is terminated, and it is recommended that the user investigate the circumstances in which the failure occurred. Has the situation or problem been corrected? If not, the prequalification decision is to disqualify.

Appendix II. Selection of Representative Rules for DFs Related to Second Prequalification Decision

1. If the length of business is less than two years, then investigate the following items: principal owner's past construction experience, principal owner's management experience, and depth of management to oversee work (e.g., superintendents and foremen). It is initially recommended that the candidate contractor be only considered for small projects in order to demonstrate his capabilities.

2. If there is no experience with this type of project, then ask the candidate contractor why he thinks he can perform the work on this project when he has no experience with this type of construction. How does he plan to execute the project?

3. If twice the largest past executed project of similar nature (in dollars) is less than the estimated project cost (from feasibility study or engineers estimate), then ask the candidate contractor why he thinks he can perform project, which is considerably larger (in dollars) than work he has completed in the past. Ask the contractor the following questions: What is his plan of project execution? How is he going to finance this project? Has this project been planned as an opportunity to expand the contractor's operation? Is there management staff available for this project? If not, and the staff is moved from his ongoing projects, will that significantly impact the execution of the contractor's ongoing projects ("depth of management")?

4. If there is no bond, then contact the bonding company to determine why the candidate contractor cannot obtain a bond.

Appendix III. Main Menu Alternatives

Help: to provide a facility to answer questions a user has during a consultation.

Input new project data: to prompt the user for project-specific data that is utilized by the program.

Input project data from a data file: to allow data to be input via a data file.

Prequalify a new contractor: queries user to input candidate contractor data needed to perform the evaluation.

Requalify an existing contractor: to requalify an existing contractor after the contractor's data has been modified.

View current project data: to view current project data input by the user.

Edit project data: to permit project data input to be modified.

View (initial and second prequalification) contractor data: to view current contractor data input by the user.

Edit (initial and second prequalification) contractor data: to allow current contractor data to be changed.

View current financial stability data: to view financial input data by the user.

Edit financial stability data: to allow input data to be modified.

Quit: to terminate the consultation.

Appendix IV. Decision Factors Evaluated by Qualifier-2 to Determine Financial Stability of Contractor

Credit Rating

Supplier/trade credit evaluation.
Dun & Bradstreet composite credit rating.
National Association of Credit Managers report.

Banking Arrangements

Banking arrangements (do they exist?).
Number of banking partners in last five years.
Number of years associated with current bank.
Maximum short-term line of credit available for this project.
Interest rate for short-term financing.
Interest rate long-term financing.
Level of bank debt.
Foreclosure history.

Financial Statement

The following are items related to financial statement preparation and items that can impact the evaluation of a financial statement.

Number of accounting partners in last five years.
Number of years doing business with current accountant.
Accountant's knowledge of construction.
Quality of financial statement.
Type of accounting method.
Quality of financial control procedures.
Frequency of home office and field job-site communication.
Taxes paid.
Union dues paid (union contractors).
Adequate insurance.
Litigation in progress.
Engaged in business ventures unrelated to construction.

Financial data contained within the financial statement is another category.

Ratio Analysis

General Financial Data and Ratios

Amount of working capital.
Amount of debt.
Amount of net worth.

Amount of common capital stock.
Debt of net worth ratio.

Solvency Ratios
Quick ratio.
Current ratio.
Current liabilities to net worth ratio.
Fixed assets to net worth ratio.

Efficiency Ratios
Collection period.
Inventory turnover.
Uncompleted work-on-hand to net worth ratio.
Uncompleted work-on-hand to working capital ratio.

Profitability Ratios
Net profit after taxes to net sales.
Net profit after taxes to total assets.
Net profit after taxes to net worth.

APPENDIX V. REFERENCES

Cozier, D. R. (1988). "Expert system software development for contractor prequalification." *Technical Report,* School of Civ. Engrg., Purdue Univ., West Lafayette, Ind., Sep.

Diekmann, J. E. (1981). "Cost-plus contractor selection." *J. Tech. Councils,* ASCE, 107(1), 13–25.

Juang, C., Burati, J., and Kalidindi, S. (1987). "A fuzzy system for bid proposal evaluation using microcomputers." *Civ. Engrg. System,* 4(3), Sep., 124–130.

Knowledge base author's manual. (1986). Knowledge Engrg. Systems (KES™) Production System (PS), Software Architects and Engrg., Inc., Arlington, Va.

Nguyen, V. U. (1985). "Tender evaluation by fuzzy sets." *J. Constr. Engrg. and Mgmt.,* ASCE, 111(3), 231–243.

Russell, J. S. (1988). "A knowledge-based system approach to the contractor prequalification process," thesis presented to Purdue University, at West Lafayette, Ind., in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

Russell, J. S. (1990). "Model for owner prequalification of contractors." *J. Mgmt. in Engrg.,* ASCE, 6(1), 59–75.

Russell, J. S., and Skibniewski, M. J. (1988). "Knowledge engineering in a knowledge-based system for contractor prequalification." *Proc., Microcomputer Knowledge-Based Expert Systems in Civil Engineering,* ASCE, 169–185.

Russell, J. S., and Skibniewski, M. J. (1990). "QUALIFIER-1: Contractor prequalification model." *J. Comp. in Civ. Engrg.,* ASCE, 4(1),77–90.

"A synthesis of the prequalification procedures of six state departments of transportation." (1985). *Report for the Federal Highway Administration,* Nittany Engineers and Management Consultants, Inc., Washington, D.C.

Wright, M. D. (1986). "Qualification of contractors." *Technical Report,* School of Arch., Univ. of Kansas, Lawrence, Kans., 132–136.