# A DECISION-MAKING MODEL FOR SURETY UNDERWRITERS IN THE CONSTRUCTION INDUSTRY BASED ON FUZZY EXPERT SYSTEMS

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## ABSTRACT

Surety underwriters in the construction industry are required to make significant decisions when it comes to choosing which contractors to underwrite. In making these decisions, the risks inherent in providing bonds to individual contractors must be carefully evaluated. A number of factors that are both quantitative and qualitative in nature are considered. Combining these factors into a single decision on whether or not to underwrite a contractor requires complex decision-making. The goal of this paper is to present a method of formalizing this decision-making process by proposing a model that combines fuzzy logic with expert systems. This model has the unique feature of being able to account not only for the quantitative factors but also for the subjective and qualitative factors that are just as significant in reaching this decision. A prototype of the proposed model is presented to illustrate its concepts, followed by a discussion of future research required for its development.

## KEY WORDS

bonding, expert systems, fuzzy logic, surety, underwriting.

## INTRODUCTION

Surety underwriters in the construction industry are required to make significant decisions when it comes to choosing which contractors to underwrite. In making these decisions, the risks inherent in providing bonds to individual contractors must be carefully evaluated. A number of factors that are both quantitative and qualitative in nature are considered. Some of the factors can be evaluated objectively using available contractor performance data. Other factors are more subjective and are therefore more difficult to evaluate in a systematic fashion. Combining these factors into a single decision on whether or not to underwrite a contractor requires complex decision-making.

The goal of this paper is to present a method of formalizing the decision-making process used by surety firms in deciding which contractors to underwrite, by proposing a model that can account for all of the factors considered in this decision. By combining fuzzy logic with expert systems, this model has the unique feature of being able to account not only for the

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quantitative factors, but also for the subjective and qualitative factors that are just as significant in reaching this decision. Previous models developed to formalize the decision-making process used by surety firms and for contractor prequalification are described. A comprehensive classification of factors considered in the underwriting decision is compiled from previous research for use in the proposed model. A prototype of the proposed model is presented to illustrate its concepts, followed by a discussion of future research required for its development.

## THE UNDERWRITING PROCESS

Construction contractor evaluation for the purposes of prequalification and underwriting is a process that involves considerable uncertainty. Uncertainty exists as to which criteria to include, how the criteria influence performance, how to measure each criterion, and in the criteria themselves. The quality of data and the interpretation of the data by the decision maker are very subjective (Elton et. al. 1993). The risk of contractor default cannot be eliminated by the owner, but it can be transferred to a surety company by requiring contractors to obtain bonds. To date, no surety has discovered a way to underwrite with such perfection as to avoid all losses; 10-40% of surety premiums account for unexpected contingencies and contractor failure (Russell 2000). The underwriting process involves the evaluation of construction contractors to determine this risk of failure by evaluating a number of factors, similar to a bank lending process. Some of these factors are quantifiable and easy to evaluate and others are qualitative in nature, requiring subjective assessment.

Few decision-support models have been developed specifically for use by surety underwriters in evaluating contractors. Severson et al. (1994) developed an approach that uses contractor financial data to predict contractor failure and surety bond claims by comparing calculated ratios to industry averages. Al-Sobiei et al. (2005) used an artificial neural network and a genetic algorithm approach to predict the likelihood of contractor default. Many contractor prequalification models have been developed for use by owners to reduce the uncertainty of contractor evaluation. These models provide another source of information that can be used in developing a comprehensive decision-support system for surety underwriting.

## CONTRACTOR PREQUALIFICATION MODELS

Contractor prequalification is widely used by owners to select competent contractors by assessing their ability to meet specific requirements (Ng and Skitmore 1993). One limitation of owner prequalification is that owners have restricted access to certain types of information (e.g., financial, banking, accounting) that sureties have. The information used in contractor prequalification is therefore often qualitative, subjective and imprecise (Russell and Skibniewski 1988). Most contractor prequalification decision-making models are used by owners to assess and thereby reduce the risk of contractor default. Since owners defer this risk either partly or completely to surety companies, underwriters can benefit from these types of models when evaluating construction contractors. Models can be grouped based on the approach used: multi-criteria decision-support, linear, knowledge-based, multi-attribute and utility theory, artificial neural networks, fuzzy set theory, and various other methods.

Multi-criteria decision support models use a predetermined hierarchy of criteria to predict a particular outcome, in this case, the competence of the contractor (e.g., Russell 1990, Sonmez et al. 2002). Linear models combine decision criteria that are subjectively weighted and rated by a decision maker into a single measure (e.g., Russell and Skibniewski 1990). Problems with linear models such as information overload, personal bias and lack of experience can be reduced using knowledge-based models (e.g., Russell et. al. 1990). These models are rule-based expert systems that emulate an expert's evaluation process.

The multi-attribute decision-making approach is used to quantify weights of various factors. Utility theory allows the risk of variable contractor performance and the decision-maker's attitude towards this risk to be incorporated into the formulation (e.g., Diekmann 1983). Artificial neural network models are used to find the non-linear relationships between the input factors and the contractor's evaluation (e.g., Lam et al. 2001). Historical data are required to develop and train a neural network model. Fuzzy set theory has been used to model the contractor prequalification process by accounting for both the quantitative and qualitative factors used in evaluating contractors (e.g., Elton et al. 1993).

Each of these modeling approaches has both advantages and disadvantages. All of the models attempt to formalize a complex decision by enumerating, either implicitly or explicitly, the factors that affect the surety underwriting or contractor prequalification decision. The main limitations of previous models include:

- Lack of transparency in the decision-making process;
- Significant user input requirements or expertise;
- Large number of parameters that require user evaluation or assessment;
- Need for significant historical data for development and testing;
- Once developed, tend to be context-specific;
- Inability to handle the complexity of a large number of interacting factors;
- Inability to deal with qualitative factors, assessments, and expert judgment; and
- Inability to effectively capture linguistic uncertainty and the uncertainty associated with the data collected.

The proposed model attempts to overcome some of these disadvantages by combining fuzzy logic with expert systems, as described later in the paper.

## FACTORS CONSIDERED IN THE UNDERWRITING PROCESS

Contractor evaluation by underwriters can be classified into four categories: character, capital, capacity, and continuity, as defined by Russell (2000). Character evaluation is, in general, the contractors past performance, reputation and experience. It can be supported by references from prior clients, engineers, architects or suppliers. Capacity is the evaluation of the contractor's technical resources available, as well as project specific factors. Capital is based on an analysis of financial statements as well as the quality of data recorded and the accounting methods used by the contractor. Sureties generally require audited statements for initial review and annual updates. Continuity is illustrated most prominently by a company's plan to ensure business activities continue in the event of a tragedy (e.g., in the case that the owners of the company are no longer able to manage it). A list of criteria that help to determine the contractor's character, capital, capacity, and continuity is shown in Table 1 (Ng and Skitmore 1999, Ng and Skitmore 2001, Russell 2000, Russell et al. 1992).

Table 1: Contractor Evaluation Criteria

| **Character** | **Capacity** |
|---|---|
| Past Performance | Management Capability |
| Experience | Company Organizational Structure |
| Reputation | Company Philosophies and Procedures |
| Integrity | Business Plan |
| Previous Debarment | Regulatory Requirements |
| Fraudulent Activity | Progress of Work |
| Competitiveness | Resource Availability |
| Standard of Quality | Resource Quality |
| Safety Policy | Current Work Load |
| Projects that Incurred Losses | Working Capital |
| Contract Overruns | Amount of Sub-Contracted Work |
| Level of Technology | Project Complexity |
| Relationship with Owner | Project Size and Type |
| Relationship with Consultant | Form of Contract |
| Relationship with Sub-Contractors | Project Location |
| Personal Feeling of Underwriter | |
| **Capital** | **Continuity** |
| Financial Stability | Continuity Plan |
| Financial Statement Quality | Continuity of Organizational Structure |
| Long Term Debts | Company Ownership Characteristics |
| Cash Flow Projection Plans | Principle Stockholders |
| Income Recognition Method | Existence of Buy/Sell Agreement |
| Accounts Receivable | Owner Life Insurance |
| Accounting Method | Age of Company |
| Certified Public Accountant's Quality | Size of Company |
| Certified Public Accountant's Opinion of Contractor | Company Image |
| Credit Rating | Turnover History |
| Schedule of Completed Contracts | Formal Training Regime |
| Schedule of Contracts in Progress | Method of Procurement |
| Leasing Agreements | |
| Bank Financing Agreement | |

The complexity of contractor assessment stems from three main features: non-linearity, uncertainty and subjectivity (Lam et. al. 2001). The relationship between the characteristics of the contractor and the decision made by the underwriter is non-linear. Uncertainty lies in the underwriter's experience, the criteria, and the qualitative judgments made by the underwriter. Subjectivity is due to the diversity of criteria and the variability of the input. Contractor assessment remains largely an art where subjective judgment, based on the individual's experience, becomes an essential part of the decision process (Nguyen 1985). For these reasons, fuzzy set theory, which is specifically designed to deal with linguistic and qualitative data, naturally lends itself to the modeling of the surety underwriting decision and is therefore used in the proposed model.

## PROPOSED FUZZY EXPERT SYSTEM FOR SURETY UNDERWRITERS

An improved approach to modeling the surety underwriting decision, based on a fuzzy expert system model, is proposed. This model provides a comprehensive approach that accounts for both the quantitative and the qualitative factors affecting this complex decision. McCabe and Pilateris (2000) outlined a number of financial ratios that can be used to evaluate a contractor's financial performance, shown in Table 2. Each factor has an acceptable range; in other words, the transition from an acceptable to an unacceptable value is gradual. The modeling of these factors is therefore ideally done using fuzzy membership functions, which can represent gradual transitions between states of factors. Examples of factors used by surety underwriters in evaluating other contractor criteria are also listed in Table 2. Some of these factors are qualitative in nature and therefore require a subjective assessment, further lending themselves to modelling using fuzzy membership functions. The factors in Table 2 are used to develop the prototype of the proposed model to illustrate its concepts.

Figure 1 shows the overall model structure, which was developed in fuzzyTech® version 5.55e Professional Edition (Inform GmbH 2005). The input factors are grouped into categories (called intermediate variables) to reduce the number of rules required in determining the output variable. Figure 2 shows sample membership functions for an input variable, current ratio. The input can be expressed as a numerical value (e.g., 1.8) or as a linguistic term (e.g., medium). Figure 3 shows a partial rule base. Figure 4 shows the output, contractor evaluation, which can be expressed as a defuzzified crisp value (e.g., 6.6 on a scale of 10) or as a linguistic term (e.g., high).

Based on the user's input the model provides an evaluation of the contractor's rating relative to the input scenario given. Using this evaluation, the surety can determine the level of risk associated with bonding the contractor, and therefore make an informed decision that accounts for all of the characteristics of the contractor and the situation at hand. Other models, based on the same concepts, can be developed to help in establishing the contractor's level of bonding capacity, conditions that must be met prior to bonding being given, and the appropriate bonding premium (if it is variable).

The main advantage of the proposed model is its ability to formalize a very complex decision that involves numerous objective and subjective factors, while maintaining transparency in its logic through its rule base. The model will not replace the experienced decision of a surety underwriter; however, it can help in documenting the decision, exploring the impact of changes in the factors affecting the decision, and providing a method of verifying the correctness of a decision particularly to those new to the surety industry. This model also has the potential to be useful to contractors seeking bonding to help them better understand how they will be evaluated, and what criteria they may need to improve on in order to be successful in obtaining bonding.

Table 2: Factors Considered by Surety Underwriters Used in the Prototype Model

| Factor | Definition | Acceptable Values as per Literature (or Based on Canadian Averages) | Favourable If |
|---|---|---|---|
| Current Ratio | Current assets to current liabilities | 1.2 to 2 | Higher |
| Debt to Net Worth (Equity) | Total liabilities to total net worth or equity | 2.1 to 3.1 | Lower |
| Fixed Asset Ratio | Fixed assets to net worth | Less than 0.4 | Lower |
| Underbillings to Sales (%) | Volume of work completed and not billed | No upper limit (1% to 2% on average) | Lower |
| Overbillings to Sales (%) | Portion of contract volume billed to client but not completed on site | No upper limit (0% to 1.8 % on average) | Lower |
| Accounts Receivable | Average number of days to collect | 60 days or less | Lower |
| Accounts Payable | Average number of days to pay | 45 days or less | Lower |
| Accounts Receivable minus Accounts Payable | Delay of cash inflow and cash outflow | 15 days | Lower |
| Gross Profit to Sales (%) | (Revenues less direct expenses) to sales | No lower limit (14% to 19% on average) | Higher |
| Net Profit to Sales (%) | (Gross profit less company overhead expenses minus current and deferred income taxes) to sales | No lower limit (1.4% to 4.4% on average) | Higher |
| Net Profit to Net Worth (%) | Return on equity in the company | Greater than 15% (net profit before taxes to net worth) | Higher |
| Past Performance | Profitability, finishing on schedule, satisfaction of client, number of defaulted projects | Scale of 1 to 10 | Higher |
| Previous Experience | In type of work proposed, size of past projects, number of past projects | Scale of 1 to 10 | Higher |
| Resource Capability | Equipment, key people, credit | Scale of 1 to 10 | Higher |
| Reputation | Client satisfaction, ability to attract subcontractors and suppliers | Scale of 1 to 10 | Higher |

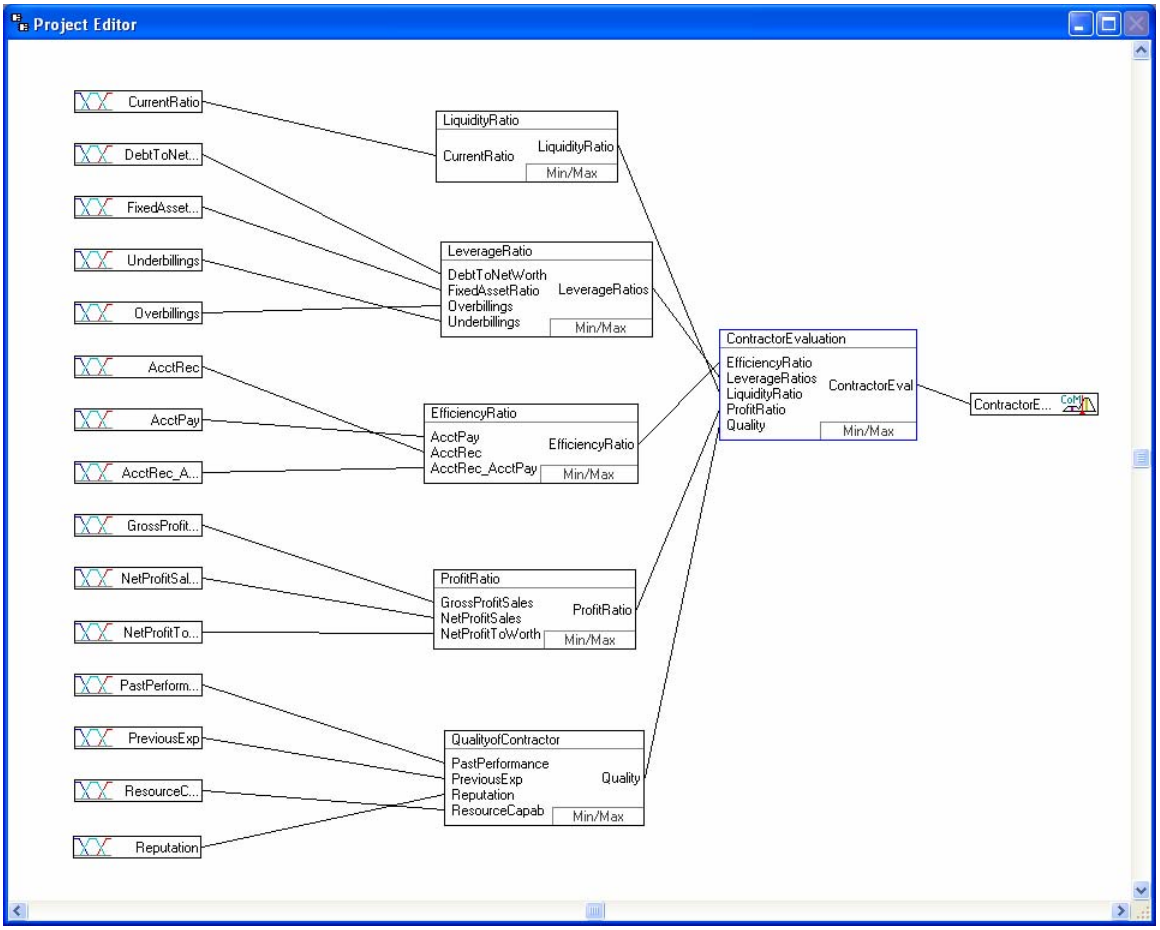



Figure 1: Overall Structure of Prototype Fuzzy Expert System

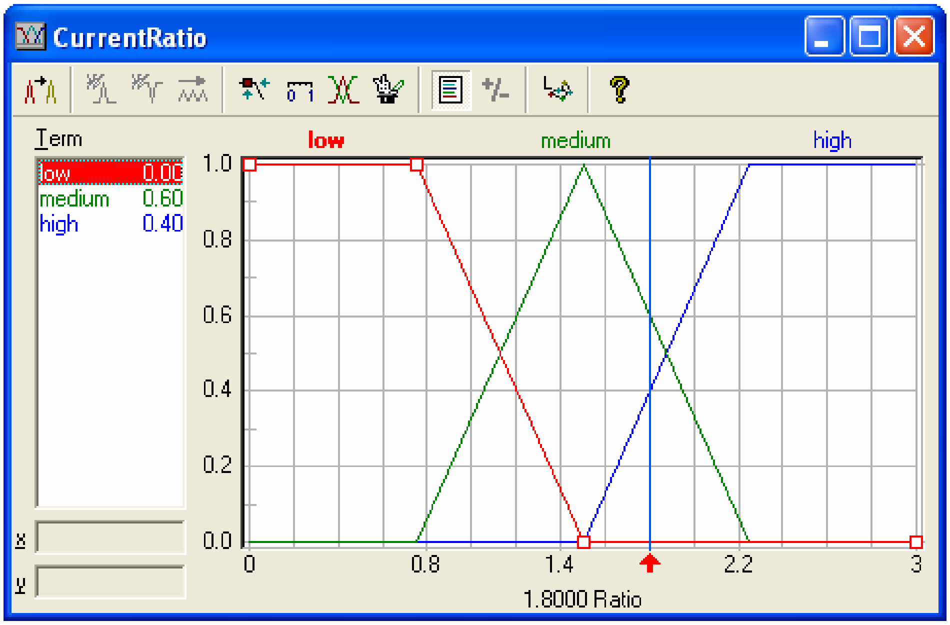
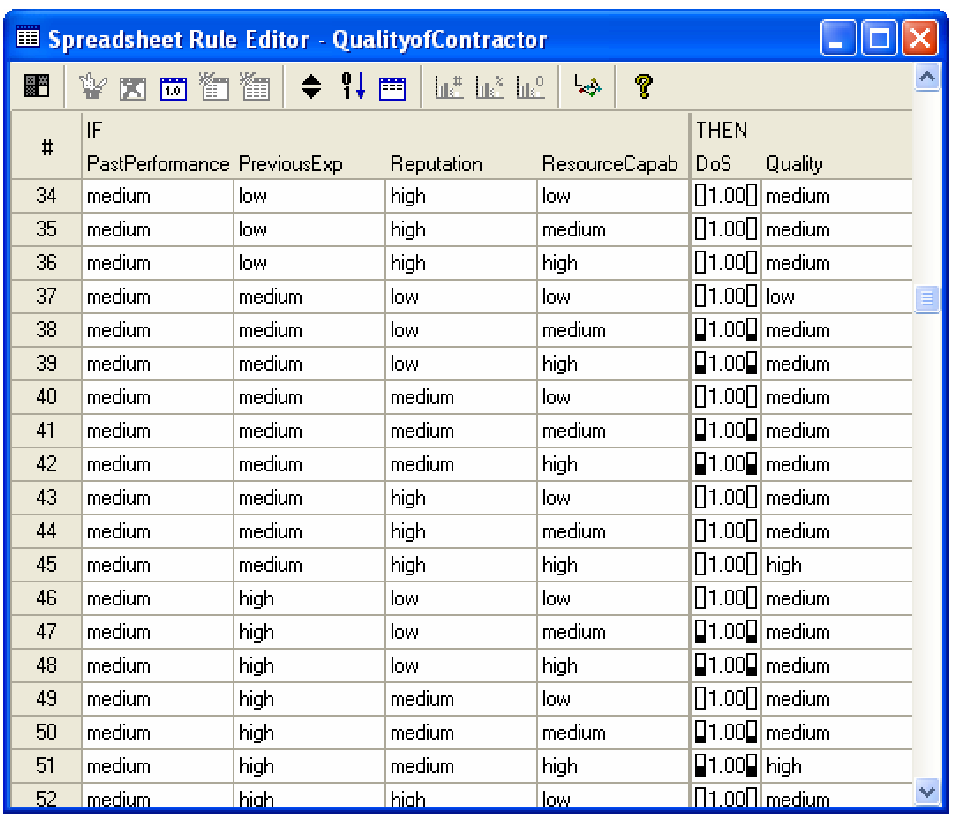



Figure 2: Sample Membership Functions for Input Variable, Current Ratio



Spreadsheet Rule Editor - QualityofContractor

| # | IF PastPerformance | PreviousExp | Reputation | ResourceCapab | THEN DoS | Quality |
|---|---|---|---|---|---|---|
| 34 | medium | low | high | low | 1.00 | medium |
| 35 | medium | low | high | medium | 1.00 | medium |
| 36 | medium | low | high | high | 1.00 | medium |
| 37 | medium | medium | low | low | 1.00 | low |
| 38 | medium | medium | low | medium | 1.00 | medium |
| 39 | medium | medium | low | high | 1.00 | medium |
| 40 | medium | medium | medium | low | 1.00 | medium |
| 41 | medium | medium | medium | medium | 1.00 | medium |
| 42 | medium | medium | medium | high | 1.00 | medium |
| 43 | medium | medium | high | low | 1.00 | medium |
| 44 | medium | medium | high | medium | 1.00 | medium |
| 45 | medium | medium | high | high | 1.00 | high |
| 46 | medium | high | low | low | 1.00 | medium |
| 47 | medium | high | low | medium | 1.00 | medium |
| 48 | medium | high | low | high | 1.00 | medium |
| 49 | medium | high | medium | low | 1.00 | medium |
| 50 | medium | high | medium | medium | 1.00 | medium |
| 51 | medium | high | medium | high | 1.00 | high |
| 52 | medium | high | high | low | 1.00 | medium |

Figure 3: Sample Partial Rule Base

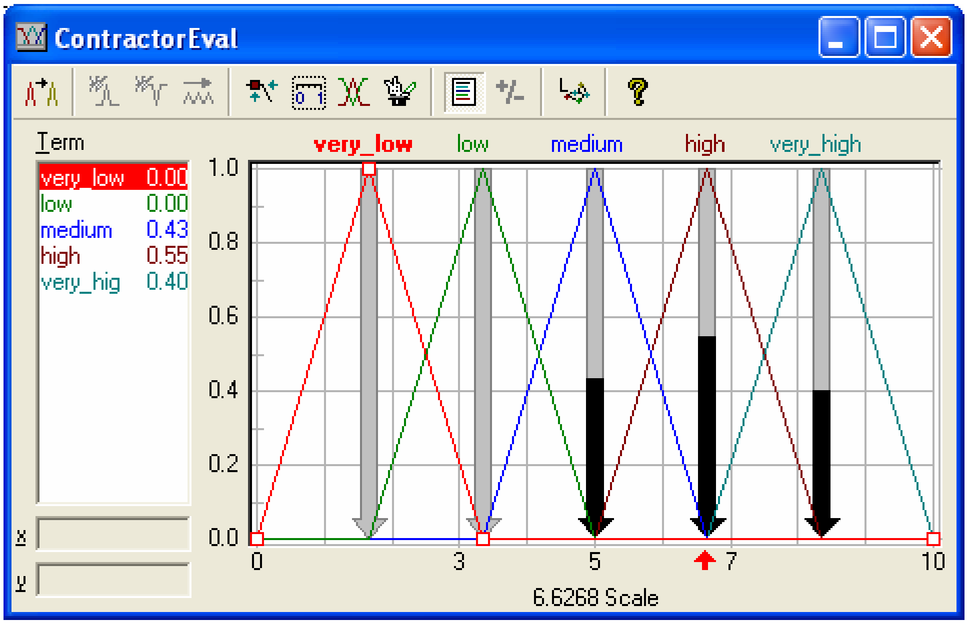



Figure 4: Sample Membership Functions for Output Variable, Contractor Evaluation

## CONCLUSIONS AND FUTURE WORK

A new approach to formalizing the decision-making process used by surety underwriters to evaluate contractors is proposed based on a fuzzy expert system model. The proposed model has a number of unique features, including: (1) its ability to explicitly model each factor affecting the decision; (2) its ability to handle both quantitative and qualitative factors and therefore user assessments; and, (3) its transparent logic, which enables the user to understand the impact of each factor on the output of the model.

In order to develop the proposed model, further research will be conducted to identify and document the decision-making process and factors involved in underwriting contractors through literature reviews and consultation with members of the surety industry. Data will be collected both in the form of expert opinion and case studies to implement and test the fuzzy expert system. Neuro-fuzzy training to train the membership functions and rules in the fuzzy expert system will be explored.

## ACKNOWLEDGMENTS

The authors would like to acknowledge Mr. Barry Peters for his insight into the surety underwriting process through a number of discussions.

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