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A Fuzzy Expert System for Managerial Decision Making in Industrial Construction

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In this paper, we discuss a Fuzzy Expert System that has been designed and developed to facilitate decision making in the management and design of industrial construction projects. More specifically, the problem domain can be described as construction modularization which is defined as a method of constructing small modules of a facility at a fabrication shop or manufacturing plant, and installing them later at the final project site (Gupta et al. 1996).

1. Research Motivation And Problem Background

During the initial stages of industrial project planning, engineering and construction (E&C) firms, owners (the organizations who operate a facility when it is complete), and design engineers are often faced with the decision involving the choice of several options for project execution: various degrees of modular design and construction or conventional design and construction (Fisher and Skibniewski 1992). Under certain conditions such as remote sites, harsh weather conditions, etc., it is relatively easy to arrive at the decision to use modularization. However, in not-so-obvious cases, management traditionally avoided considering modularization as an option to conventional methods due to high cost of rigorous engineering and construction analysis necessary to know for certain which option will provide the lowest total cost of constructed facility.

Professionals in the construction industry have always expressed interest in the process of modularization. However, due to the lack of available expertise in the area of modularization decision making, some professionals have avoided the use of modularization. The major concern of the project teams has always been that of determining the project characteristics and their interrelationships that make modularization the best choice and a low cost alternative (Fisher and Skibniewski 1992). The only way in which companies have utilized modularization in the past has been when an expert in the field was consulted from within the organization or from a modularization consulting firm. However, due to lack of any scientific method of decision making, such approaches had limited utility. Therefore, we developed a prototype Fuzzy Expert System for Modularization Recommendation(FESMORE) to allow the nonexperts or line managers to utilize the existing knowledge in the area of conducting modularization feasibility studies and to provide intelligent and computer-aided problem solving. FESMORE has been implemented using CubiCalc® fuzzy expert system shell and Microsoft Visual Basic programming language.

The input to the FESMORE system are project characteristics, and output is the recommendation for the optimum degree of modularization- 80%, 50%, 20% or even 0%-that is best suited for that project. In the context of degree of modularization, 80% modularization means that 80% of total estimated direct field labor-hours needed to complete the project can be transferred to module fabrication yards. Limiting outputs to these four discrete choices allowed for the comparison between the FESMORE outputs and the actual decisions on modularization taken on real-world completed projects.

2. Fuzzy Expert Systems Methodology

This section has been omitted from the paper. We refer readers to Klir and Folger (1988), Levy et al. (1991), and Gupta (1995) for details on fuzzy sets and fuzzy expert system methodology.

3. FESMORE Design And Development

The knowledge acquisition sessions with a total of 24 modularization experts resulted in the development of a decision model for the modularization feasibility study process (Fisher and Skibniewski 1992). Subsequent modifications to this model resulted in the development of the detailed modularization feasibility model with 43 decision variables. A distributed approach to the FESMORE development involved the division of the decision model into separate logical components and identification of decision variables representative of these components. As evident by the construction modularization decision-making model, a natural distribution of the model into its seven major components, i.e., plant location module, labor related module, organizational issues module, plant characteristics module, project risks module, environmental issues module, and modularization decision-making logic module was apparent. In addition to these modules, fuzzy processing components were added to the system. The complete FESMORE system architecture is shown in Figure 1. This fully functional system is constructed of the following components:

1. User-interface: a customized user interface in Microsoft Visual Basic was developed to facilitate data input and output. This user interface also provides explanation for each query to the user, and describes the results of the expert system.

2. Fuzzification Interface: converts exact (crisp) input values provided by users into fuzzy values.

3. Expert Modules: six interconnected expert modules are used to take advantage of the distributed approach. Each expert module represents a major decision category of the complete modularization decision-making model, and provides a partial solution to the decision-making problem.

4. Defuzzification Interface: utilizes centroid method of defuzzification to convert resultant fuzzy set into a crisp value.

5. Modularization Decision-making Logic: this module combines outputs from six expert modules to arrive at the final modularization recommendation.

For each module of the system, we identified the natural grouping of variables to form three fuzzy input variables and one fuzzy output variable. Mathematical equations were used in the preprocessing stage to arrive at the value of the fuzzy variables. In other words, each module was designed as a three-input one-output system. The next step involved describing the membership functions on these variables. Human experts and relevant literature were again consulted in the design of membership functions. A Membership function is a function that maps one or more variables to a degree of membership (zero to one) in a fuzzy set. Membership functions are made up of function names (fuzzy labels) and membership values. Identification as to the number, size, and shape of the membership functions representative of a given variable is often subjective and arbitrary. Although any shape membership functions can be used, most real world fuzzy expert systems make use of trapezoidal and triangular functions (Kosko 1994). Therefore, overlapping trapezoidal and triangular functions were used to describe variables in our application.

The FESMORE fuzzy inference process uses the values associated with the input variables (provided by user) to derive and pass the resulting inference to the designated output variables. Each of the five expert modules (Labor Related, Organizational Issues, Plant Characteristics, Project Risks, and Environmental Issues) consists of 59 rules. The Plant Location module and the Modularization Decision-making module consists of 71 rules each. Therefore, the complete FESMORE system consists of a total of $5 \times 59 + 2 \times 71 = 437$ rules. Each rule has the form IF A, THEN B. This is a short for *IF X* is *A*, *THEN Y* is *B*. As an example, Rule 22 of the Plant Characteristics Module is given below:

IF *Physical Constraints of Plant* is **High**

AND *Project Type* is **High**

AND *Quality/Safety/Security Considerations* is **Low**

THEN *Project Characteristics* is **Medium**.

The FESMORE system user-interface presents the user with introduction screens explaining the benefits of the system and how to interpret the results of the system. The system also provides to the user a continuum scale [0-60] in which the user can select any point along the continuum in response to a specific query. This user specified numerical value is used to ascertain the appropriate membership functions and degree of membership for that particular value. For example, user specified value of 30 for the variable *Physical Constraints of Plant* indicates that this value has a membership of 0.50 in *Medium* membership function and 0.50 in *High* membership function. This process is called fuzzification of inputs, and is completed for all fuzzy input variables. These fuzzified input values may fire several rules, though the degree to which each rule is fired is not fixed. The input data fires the A part of each rule to some degree. This becomes the activation of each rule. The system then uses correlation-product inference to scale the fuzzy set of the B part by this activation level. Using a pointwise sum rule combination method, the system combines all scaled B sets to get a final output fuzzy set. Centroid defuzzification method is then utilized by the system to calculate the crisp output number from each module.

4. Verification Of The Fesmore System

A specific plan to test the FESMORE system was developed which included (1) modular and distributed development and testing, and (2) the use of test input data.

Geissman and Schultz (1988) stressed the need to verify that the objectives of individual system components are being accomplished successfully and independently as a part of the overall system verification process. The modular and distributed development of the FESMORE system contributed toward verifying that the individual system components accomplished their defined purpose as originally described in the overall modularization decision-making model. The modular development of the component programs allowed the focus of each program to be specifically directed toward defining the variables and coding the rules related to that particular module rather than a complicated maze of variables and rules related to the entire system. The modular development of the FESMORE system also played an important role in detecting and correcting logical inconsistencies, syntax errors, and mistakes in assigning rule-weights.

The simulation facility available within the CubiCalc® development system environment facilitated testing and tuning of the different expert modules during the development phase. As each rule base and its related input and output variables were defined and programmed, the simulation facility provided the opportunity to view the activation level of each rule, to analyze decision surfaces, and to view the graphical representation of the final output fuzzy set before defuzzification for various input sets. A data file consisting of input values encompassing the values of 0 to 60 in incremental steps of 3 was created and used for running simulations on each of the seven expert modules of the system. These possible combinations of input values were used to test the effect on the activation level of each rule, on the shape and size of the final output fuzzy set, and corresponding output values. The use of the simulation facility revealed several mistakes, most of which are common to most nonfuzzy expert system programming projects. The simulation facility was also very helpful in identifying rules which were not properly defined for the intended inference or which contributed little to the decision process. The system knowledge bases were modified to correct all mistakes identified using the input test data.

5. Conclusion

Incorporating fuzzy theory in the design and development of expert systems is one of the most challenging problem facing researchers in the area of artificial intelligence. This research highlights a real-world application of a fuzzy expert system to solve a complex problem. Several construction companies have shown interest in using the FESMORE at the inception of any pre-project planning study to determine the feasibility of modularization. The architecture developed in this research can easily be adapted to solve other real-world decision problems.

[References available from the first author].