Expert System for Determining the Disposition of Older Bridges

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The paper describes the development of an expert system that was designed to make recommendations for bridge management as to the proper courses of action that should be taken with regard to older highway bridges. Five basic options are possible; namely rehabilitation, improvement, replacement, abandonment, and routine maintenance. Based on an extensive set of rules, criteria and procedures as currently used by bridge engineers, this expert system offers a computerized approach that should reduce the time needed to evaluate the many thousands of older bridges yearly, as well as to provide a consistent basis for decision making.

INTRODUCTION

It is assumed that most engineers have by now heard about "expert systems;" that is, computer driven systems that generate decisions similar to those of human experts, founded on extensive knowledge bases of information. Such expert systems are particularly useful where there are complex and often fuzzy situations. One such situation, which this paper deals with is that of deciding what to do with the many thousands of older highway bridges in the inventory of the State of Virginia. As part of bridge management programs, a similar situation exists in every state in the country; representing in total, several hundred thousand bridges. Not only are there many factors to be considered for each bridge, but such bridges are generally re–evaluated every year. The collective task is thus quite enormous.

To provide a rapid and consistent way to make these many evaluations, an expert system was developed for the Virginia Department of Transportation (VDOT) at the Virginia Transportation Research Council (VTRC). Specifically, the expert system was designed to provide the user with a recommendation as to the disposition of a given bridge by one of the following five options.

1. Rehabilitate: To rehabilitate a bridge is to restore it to its original condition. The recommendation may stipulate rehabilitation of the deck, the superstructure, the substructure, or any combination of the three.
2. Improve: To improve a bridge is to improve its characteristics over and above its original condition. This is usually either by strengthening, widening, or both.
3. Replace: To replace a bridge is to remove or bypass the old bridge and replace it with a completely new one on the same or on a new alignment.
4. Abandon: To abandon a bridge is to take it out of service from the highway system. An abandoned bridge may be destroyed or put to a new use, possible at another site.
5. Maintain: To maintain a bridge is to keep it functioning essentially in the condition that it is in. The recommendation may call for maintenance of the deck, the superstructure, the substructure, or any combination of these three components.

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DEVELOPMENT OF THE EXPERT SYSTEM CALLED DOBES (*D*isposition of *O*lder *B*ridges *E*xpert *S*ystem)

The development of DOBES proceeded in four related phases. The first phase was devoted to a general overview of the subject to acquaint potential uses what expert systems are and how they could be useful to them in a variety of applications.[1] This phase was believed necessary as many engineers are fully acquainted with the emerging subject of expert systems. The second phase narrowed the subject down to a specific bridge management problem as explained in the Introduction. It also encompassed the acquisition of the necessary knowledge base and development of the inference procedure (*2*). Details of these acquisition and inference efforts are described later. The third phase utilized the knowledge base and inference procedure developed in phase two and converted them into user–friendly software (*3*). The resulting DOBES program is contained on two standard floppy disks intended to run on any IBM or compatible personal computer. Details of phase three are described later. The fourth and last phase deals with the field testing of DOBES and its possible refinement. As of this writing (September, 1990) only partial results are in, but preliminary indications are that this expert system is working rather well (*4*). More on this final phase is described later.

The Knowledge Base

Since DOBES is expected to reach essentially the same conclusions as human experts, the exact method experts arrive at their decisions had to be obtained. This was done by the author through a series of lengthy taped recorded individual interviews with a number of senior bridge engineers in VDOT whose responsibility it was to make decisions related to older bridges. Although their thinking processes were similar in general, there were some differences in regard to details and secondary considerations. Following the completion of the interviews, this bank of knowledge had to be evaluated, adjusted to resolve differences, organized, and then couched in the form of "if–then rules" as required for expert systems programming. A draft of these rules was written up and then re–submitted to the experts interviewed for their review. In the review process, some minor changes and adjustments were made. These rules form the basis of DOBES; of which there are 35. Since not all the rules were judged to be equally important, some were designated as being primary (P) and some secondary (S). A complete description of the rules can be found in reference (*2*); however, several are listed as follows for illustration.

Rule 1. If the sufficiency rating is more than 80, then recommended maintenance (P).

Rule 2. If the sufficiency rating is more than 50 and the sufficiency rating is less than 81, then recommend rehabilitation and recommend improvement (P)

Rule 8. If the substructure condition rating is less than 6, then recommend substructure rehabilitation (P)

Rule 13. If the sufficiency rating is less than 50 and the average daily traffic is less than 10 and the detour length is less than 2 and historic is no and political objection is no, then recommend abandonment (P)

Rule 15. If classification is Primary and road width is less than 12 times the number of lanes and the sufficiency rating is greater than or equal to 50 and the average daily traffic is more than 100 and type is deck truss or deck girder, then recommend improve by widening (P)

Rule 23. If the material is concrete and the classification is Primary or Interstate and loading capacity is less than 22 and average daily traffic is more than 100 and historic is no, then recommend replacement (S)

Rule 26. If the material is metal and the classification is Secondary and the loading capacity is less than 15 and the sufficiency rating is more than 50 and the average daily traffic is more than 100, then recommend improve by widening (S)

Rule 35. If type is through truss and material is metal and classification is Secondary and loading capacity is less than 15 and average daily traffic is more than 100 and historic is no, then recommend replacement (S)

As can be seen, some of the rules are rather involved, which suggests that a computer would be more likely to keep track of all these factors than would a human; thus providing a greater degree of decision making consistency.

In addition to a set of rules, a knowledge base also must contain specific data or attributes of a given bridge. These attributes relate to the needs of the various rules. For example in Rule 1, the sufficiency rating must be known. In other rules, the condition rating, average daily traffic, bridge type, material and the like must be known. In all, 24 attributes of a bridge are needed plus 4 relating to name and location of the structure. Six of these are designated as secondary (S) attributes; such as the detour length if the bridge were to be abandoned, or the bridge's historic importance. It is to be noted that DOBES is designed to work, even if these secondary attributes are not known; although the final recommendation would be qualified.

In actual use, a question concerning each the 28 attributes appears on the monitor with appropriate prompts, so that the user has only to select or type in a simple answer. The rules are stored in memory, but could be displayed on the monitor or printed out on command.

The Inference Procedure

The inference procedure by which a final recommendation is reached is based on a forward chaining process coupled with a multi–factored weighting system. The process begins by applying each of the separate rules to each of the separate attributes. This results in a listing of all applicable recommendations in tentative form. However, some rules conflict or overlap with others, and some rules and attributes are more important than others. It was therefore necessary to develop an inference or evaluation process to deal with these factors. A multiweighting system was chosen.

First, each attribute and rule is designated as primary (P) or secondary (S). These determinations are based on the judgments of the bridge engineers involved in this study. Each status of P or S can be changed if necessary by minor reprogramming of DOBES. When the rules are applied to the attributes, the possible combinations of options (such as replace, rehabilitate, etc.) involve primary rule with primary attribute (PP), primary rule with secondary attribute (PS), secondary rule with primary attribute (SP), and secondary rule with secondary attribute (SS). For any given bridge, a list is made of the various resulting options generated in applying the rules to the attributes, along with their (PP), (PS), (SP), (SS) category.

To provide for a wide range of weighting factors, 15 constants (potentially adjustable) were applied in the following manner to the 5 basic options: rehabilitate, improve, replace, abandon, and maintain. For example, with regard to rehabilitation, a numerical constant A is assigned as a multiplier or weighting factor to the sum of all the times on the option list cited that call for rehabilitation in the (PP) category. Then another numerical constant B is assigned as a multiplier to the sum of all the times on the option list that call for rehabilitation in the (PS) or (SP) category. The categories (PS) and (SP) are assumed to be of equal weighting value. Still another numerical constant C is assigned as a multiplier to the sum of all the times in the option list that call for rehabilitation in the (SS) category. By adding all the terms above involving A, B, and C, a new sum value D is determined.

In like manner, four other sum values for the improve, replace, abandon, and maintain options can be determined.

The final recommendation would be the option with the largest numerical sum value. In the DOBES program as currently written, the constants A, B, and C were chosen as 10, 7, and 3, respectively. Parallel constants for the improve option are 8, 5, and 2. For the replace option, the constants are 10, 7, and 3. For the abandon option, they are 6, 4, and 1. Finally, for the maintain option, the constants are 7, 5, and 2. The larger the constant, the more important is the related option. These constants were chosen intuitively as trial values. These values can and will be adjusted as further testing and evaluation indicate.

Two checks related to cost are built into the program.

1. If the rehabilitation or improve option has the highest sum value, but the cost exceeds 70 percent of the cost of a replacement bridge, then replacement is selected as the final recommendation.

2. If the rehabilitate or improve option has equal sum values, and these sum values exceed all others, then the rehabilitate or improve option costing the lesser amount is selected as the final recommendation.

The entire inference procedure described is done in a micro–second simply by selecting the "Analyze" item displayed on the main menu of the program. Both a summary of the numerical scores and a final recommendation are given. Should there be any qualifications or conditions regarding the final recommendation, such as the omission of any particular secondary attribute, that too will be noted. It is left for the user to decide how important the qualifications or conditions are, with respect to the final recommendation. All final recommednations are of course subject to the ultimate judgement of the user.

Software

Certain aspects of the software associated with its development and operation should be noted for a proper understanding of DOBES.

1. LISP programming language was used in the development of the program. As such, licensing by Gold Hill computers as well as approval by the Virginia Dept. of Transportation is required before duplicate disk copies of DOBES can be made.
2. DOBES is configured for two 5 1/4 inch floppy drives for IBM or compatible microcomputers. One disk contains

the master program and the other is used for collection and storage of the data base (attributes).

3. The program is essentially menu driven. For example, in connection with the record (data base) one can chose to add to the record, change the record, delete from the record, inspect the record, list the records or print the records. For other operations, one can choose from this main menu to inspect the rules, to analyze the problem (which leads to a final recommendation) or to exit the program.
4. Changes to the rules or any other aspect of this expert system are possible, but a knowledge of the LISP language is required. This feature should enable DOBES to stay up to date should situations or conditions change.
5. Because of time and budget constraints, the following limitations had to be imposed on the current DOBES program.
   a. A few of the rules are couched in overly precise terms. For example, several rules set the ADT (average daily traffic) at a precise 100. Obviously a count of 99 or 101 would make little difference in the final result. However, an incorporation of "fuzzy logic" in the program would add considerable complexity, which is not believed to be warranted.
   b. Interactive questions and answers concerning how the rules were arrived at, where data can be obtained, or the reasoning behind the inference have been left out. Should such information be necessary in an operational program, it could be added at a later date. Much of this information, however, already is available in the report cited in reference (2).
   c. The program is applicable to all single or multiple span girder or truss highway bridges of wood, metal, or concrete (either normally reinforced or prestressed). If in a multiple span bridge, one span (or more) is of a different basic material and/or of a different structural type from the rest of the bridge, that span or spans should be treated as if it were a separate bridge. The remaining span or spans would then also be treated as a separate bridge.
   d. A few relatively rare bridge types have not been included, such as covered wooden bridges, arch bridges, cable–suspended bridges, and plastic bridges. So few of these exist that it is believed these special ones could be handled individually.
   e. Recommendations concerning which of the many old bridges deserve expenditure of funds in a given year are not part of this program. Such recommendations would require that all of the old bridges be evaluated by this DOBES program, after which the total required costs would be compared to the total available funds on some rational basis such as a bridge management system using deficiency point ratings as a guide to prioritization. An expert system prioritization is quite possible, but would require additional programming.

Testing and Refining

At the time of this writing (September 1990) field testing of DOBES has been initiated, but not yet completed. Senior VDOT bridge engineers in all nine regions of the state who have responsibility for making decisions of the kind generated by DOBES, have been supplied with DOBES disks and instruction manuals. On–site field visits by the author or his associate were made as needed in order to see that the operation of this expert system was understood and working. These nine bridge engineers were asked to test DOBES using a number of actual older bridges they are familiar with (at least 15 per person) and answer the following eight questions:

1. Are the final recommendations from DOBES the same as would be obtained by a human expert? If not, what would be the expert's recommendation?
2. Are any of the rules incorrect? If so, what would be the correct rule?
3. Are any necessary rules omitted? If so, what are they (indicating whether primary or secondary)?
4. Should any of the attributes (bridge data) listed as primary be listed as secondary? If so, which ones?
5. Should any of the attributes listed as secondary be listed as primary? If so, which ones?
6. Should any of the rules listed as primary be listed as secondary? If so, which ones?
7. Should any of the rules listed as secondary be listed as primary? If so, which ones?
8. How could the DOBES program be improved to make it easier to use?

In addition to answers to the above questions, print–outs of the "Analysis" of the bridges investigated using DOBES were requested to assist in the evaluation.

When all replies to the questions have been received, they will be carefully evaluated. Changes and refinements in DOBES will then be made as required. Of particular focus will be the matching of recommendations between those by the experts and those by DOBES. Should there be inconsistencies unaccounted for by possible rule changes, or changes concerning the primary and secondary importance of attributes, a systematic exploration will be undertaken with regard to the 15 numerical weighting factors in the inference procedure. A specially written iterative computer program will be used to find the best match. Ultimately, by late 1990, it is expected that a refined DOBES program will result that will accomplish its intended mission.

CONCLUSIONS

At the initiation of this expert system project, there was an element of skepticism among some of the intended users, that any computer program could successfully deal with the many variables and uncertainties involved in a decision making process of this nature. However, as the work progressed, which required the involvement of the potential users from time to time, skepticism grew less and less, as the basis for the computer program became understood. It was realized that the factors (whether firm or fuzzy) used by experts in reaching a decision were the same ones used in this expert system. Furthermore, the software as developed is quite easy to use, requiring very little introductory instruction. Acceptance for accredited operational use, however is not to be expected before 1991, after the field tests have been run and the program fine–tuned. So far, based on preliminary results, DOBES appears to be working rather wellwith close to 90% agreement between recommendations made by DOBES and those by bridge engineers.

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