An Application of Artificial Intelligence in Highway Noise Analysis

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ABSTRACT

The highway noise abatement program in the United States is still in the developmental stage, which is demonstrated by only 29 states having constructed one or more noise barriers to date. Explored in this paper is a method of making the expertise in highway noise analysis and control easily accessible to highway noise analysts. This relatively new activity in artificial intelligence is known as an expert system. A general discussion of expert systems is presented, followed by a discussion of a specific prototype system currently under development at Vanderbilt University.

Efforts to mitigate highway noise impacts are still in the developmental stage in this country (1). After more than a decade of federal involvement and the construction of more than 200 linear miles of noise barriers, only 29 states have constructed more than one noise barrier (2). Moreover, it was noted in a 1980 report by the National Cooperative Highway Research Program that 85 percent of the almost 190 linear miles of barriers had been constructed in only 9 states, with 39 percent in only 1 state, California (3). However, as the concept of mitigating highway noise impacts becomes more fully integrated into the project development process, it can be expected that many more states will develop barrier construction programs.

After a highway noise impact has been identified in accordance with FHWA, U.S. Department of Transportation regulations (4), the noise analyst must seriously consider mitigation measures. Information should be gathered from many different sources and then integrated through a series of mathematical and physical steps to form a basis from which to recommend abatement alternatives to administrators in the highway agency. Much of this information is straightforward and available from convenient sources; for example, horizontal and vertical alignment of the roadway many already have been determined and be available from the appropriate design office. However, other information is less evident and may require special knowledge or insight; for example, the corridor under development may be in the vicinity of an upcoming zoning modification that may significantly alter existing land use. Unless the analyst is able to consider such an eventuality, a selected noise abatement measure may become inappropriate.

After the noise analysis has been completed, there is likely to be an array of abatement options from which to choose. To convince the decision maker that an abatement measure is cost-effective and necessary, it is essential that the analyst be able to assign a priority for all of the options in a correct and consistent manner. Without this ability, it is possible that an agency will either make the wrong decision or no decision at all.

To alleviate this problem, the analyst must be able to use the expertise of other professionals in the field. How can this be accomplished most efficiently? Making expertise from a domain-specific area widely available and then easily accessing that expertise is a relatively new activity in the field of artificial intelligence (AI). The mechanism by which this concept is becoming a reality is known as the expert system (5). A general discussion of expert systems will be presented in this paper, followed by a discussion of a prototype expert system, CHINA-1 (Computerized HIghway Noise Analyst), currently under development by the Transportation Research Group at Vanderbilt University. Finally, the utility of the prototype system will be demonstrated by using an example problem.

EXPERT SYSTEMS

An expert system may be defined as an intelligent computer program that uses knowledge and inference procedures to solve complex problems that are difficult enough to require significant human expertise. Both the knowledge and inference procedures may be viewed as a model of the expertise of human experts in their field (5).

The expert system is typically made up of three primary components [see Figure 1 (6)]:

- A knowledge base containing the domain-specific facts and heuristics associated with a particular field
- A rule interpreter, or inference engine, that can utilize the knowledge base in the solution of a problem
- A global data base, or work space, that maintains the status and input data for the current problem.

Each of these components will be discussed further.

The knowledge base of an expert system is made up of two types of knowledge: facts and heuristics. Facts consist of general knowledge that includes the published definitions and theories found in the textbooks and references within the domain of study. However, expertise in a specialty usually involves knowledge that is not in the published literature. This private knowledge consists of rules of thumb that characterize expert-level decision making and has become known as heuristics (5). For example, the expert in highway noise knows that line-of-sight break with truck exhausts will improve the perception of barrier performance, regardless of prediction results. Thus, he may, as a rule of thumb, make certain that such lines of sight are broken where necessary.

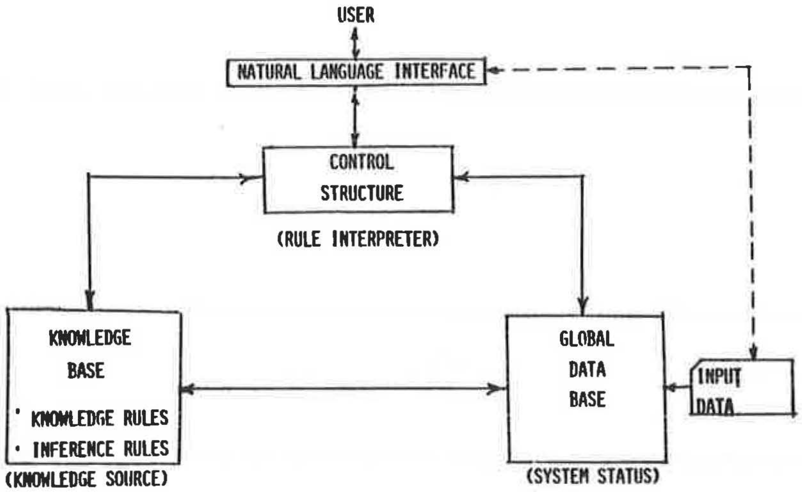

FIGURE 1 Generic expert system.

The rule interpreter, or inference engine, may be described as a type of reasoning mechanism that is capable of applying the heuristics or rules in the knowledge base to the facts about a specific problem (5,7). The performance of an expert system is primarily a function of the size and quality of its knowledge base, not of its particular inference engine. Several inference engines are available as skeletal structures that may be modified to fit the specific needs of a new system (5,8,9). As an option, the engine could be constructed from scratch by using one of the standard AI programming languages.

The final major component of an expert system is the global data base, or work space. This is a working memory that contains information that collectively describes the specific problem and maintains a current assessment of that problem.

The computer language LISP (LISt Processing) is chosen for most work in AI because of its ability to easily manipulate symbols (5). A program written in LISP uses symbolic expressions to work with data and procedures, just as humans work with pencil, paper, and words (10). A symbol manipulation program is able to recognize certain symbolic expressions, tear old ones apart, and assemble new ones. For example, it can interpret a conversational English question from a user by tearing the sentence apart and recognizing predefined technical terms, pronouns, or synonyms.

In LISP, the function to be performed is always given first, followed by the data with which the function is to work. These data are known as the arguments of the function. In the example below, the function SETQ assigns to the expression VANDERBILT the value of the list (A SOUTHERN UNIVERSITY).

```
(SETQ VANDERBILT '(A SOUTHERN UNIVERSITY))
```

In response to the user typing the expression "VANDERBILT", a compiled LISP environment will reply with the list "A SOUTHERN UNIVERSITY". Likewise, in a LISP program, any time the expression "VANDERBILT" is encountered, the list "A SOUTHERN UNIVERSITY" will be returned. A list is defined as an expression enclosed by parentheses. The individual pieces of that list are known as elements. In the example just given, "A SOUTHERN UNIVERSITY" is a list and each word is an element of that list.

The expert system differs from conventional computer programs in several ways (8). Because both functions and data written in LISP have the same form, the system can be more easily modified by users not very familiar with conventional programming techniques. In a conventional program, the data relative to a given problem and the methods of utilizing that data are intertwined so that it is often difficult to change the program. On the other hand, an expert system is usually characterized by a clear separation of general knowledge, information about a specific problem, and the method of applying the general knowledge to the problem. The program itself is only an interpreter and the system can be easily modified by adding or subtracting rules to the knowledge base. Thus, the expert system is not static; rather, it can be said that it learns.

The task of gathering knowledge and assembling it in program form is referred to as knowledge acquisition (5). Because the performance of the expert system is dependent on the completeness of the knowledge base, this task is key to the development of an acceptable system. Sources of knowledge include human experts, textbooks, journal articles, data bases, and personal experience. Because knowledge acquisition is an iterative process, commitment from an articulate expert is important. It is also important that the expert system builder be skilled in the interrogation of the expert to effectively assemble the knowledge base. Feedback from the expert about the performance of the system each time a rule is modified, added, or subtracted is essential. As more and more heuristics are added to the knowledge base, the system will approach (and possibly exceed) the competence of a human expert (6).

Because of the size and complexity of this knowledge base, the development of a prototype is an important first step in constructing an expert system. This prototype is designed to address a subproblem within the overall problem area. Through experimentation and revisions, the prototype will become the model from which the final expert system will be constructed. The remainder of this paper will focus on the prototype system, CHINA-1, currently under development at Vanderbilt University.

CHINA-1

CHINA-1 is written in UCI LISP (11) and is installed on the Vanderbilt University DECsystem 1099 mainframe computer. Access to CHINA-1 is through a Macro Interpreted Command (MIC) file (12).

CHINA-1 is designed to first classify highway noise-related impacts based on existing and future noise levels supplied by the user. This heuristic is based on past experience of the authors and others (13,14) and is meant to illustrate the use of heuristics in this context. Then, reading a file produced by a modified version of OPTIMA, CHINA-1 identifies those barrier segments over which the maximum or minimum sound energy is passing, and makes recommendations on how the barrier may be modified to best reach the design goals specified by the user. How a user might utilize CHINA-1 on a hypothetical problem is described in detail in the following paragraphs.

A fundamental question in any highway noise analysis is whether an impact actually exists. The answer to this question often dictates the type of abatement considered, or just as important, if any consideration will be given to reducing highway noise levels. CHINA-1 was programmed to perform this task based on criteria established by the user and illustrates how the knowledge base can be easily modified. Only exterior activity for single-family residences will be considered in this prototype system. However, this feature will adequately demonstrate the feasibility of expanding the basic concept of building such a model.

In making this impact determination, federal regulations require that an approach that considers absolute noise levels, as well as the increase over existing noise levels, be utilized (4). A number of procedures are available that recommend ways to address this requirement (13,14). A method has been devised for CHINA-1 that will classify noise-related impacts as none, moderate, or severe, on the basis of two rules. Considered in the first rule is the difference between the predicted noise level and a criterion level built into the model; the criterion level is displayed early in the process and the user is given the opportunity to change it. Considered in the second rule is the amount of increase between existing and predicted noise levels. Figure 2 shows the resulting matrix of impact zones.

To illustrate the use of this prototype system and the concept of using expert systems in this area, an interaction with CHINA-1 is described in the following paragraphs. In conjunction with the narrative, the reader's attention is also directed to Figure 3, which presents the actual session with CHINA-1.

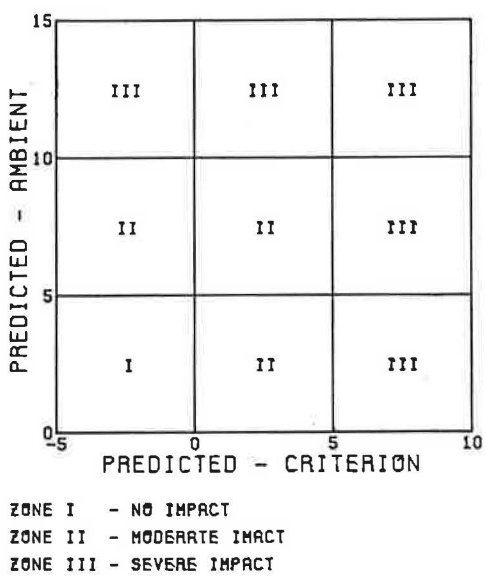

FIGURE 2 Impact classification guide.

It is assumed that the user has an idea about what the existing and future noise levels are at the receptor of interest. CHINA-1 uses this information in determining the degree of impact for a given receiver. After initially deciding not to select the barrier design feature, the user inputs this data to the work space through response to the next two questions asked by the program. Any time the user wants to end the session, he only has to type 'BYE'.

CHINA-1 then requests the user to classify the land use at the site that is under study. As mentioned earlier, abatement strategy can be influenced by land-use type, but for the purpose of the prototype model only single-family residences will be considered. The user is allowed to select between residential and public land use only to demonstrate the feasibility of options at this point. If the land-use type is misspelled, CHINA-1 asks the user to check the spelling.

The design criterion used in classifying the noise-related impact is displayed next, and the user is given the option of changing it. If the criterion is changed, the new level is displayed to verify that the change was as the user wanted. Then, CHINA-1 repeats the land-use type being considered, again to verify it is as the user intended it to be.

CHINA-1 now has enough information to rank the noise-related impact. For the purpose of demonstrating the prototype model, a menu is provided at this point, listing the options available. The user may select the option he desires by asking CHINA-1 the question in concise conversational English. If CHINA-1 does not recognize the request as stated, it will ask the user to rephrase the question. CHINA-1 is designed to recognize a user's question in several different ways. For example, to find out the degree of impact at a particular receptor, the user may simply type "CLASSIFY IMPACT", or he may use "RANK" or "RATE" as synonyms for classify. CHINA-1 looks for certain key words, such as "BARRIER DESIGN", which may be contained in any order within the user's question.

Because the noise barrier is the most common method of noise abatement in this country (3), it was decided that a primary function of an expert system in this domain should be the acoustic design of these structures. The user may access this feature in two ways: by going directly to the barrier design feature at the beginning of the program, bypassing the impact classification, or by proceeding through the impact classification.

At this point, CHINA-1 notifies the user that he must have already run the FORTRAN programs STAMINA 2.0/OPTIMA (15). STAMINA is the basic tool for calculating noise levels at a given location based on unique roadway geometrics and traffic characteristics. OPTIMA then allows the user to select certain combinations of barrier configurations for choosing the one combination that provides the most noise abatement in the most cost-efficient manner.

The human expert follows a certain thought process in this optimization task. CHINA-1 is designed to emulate that thought process. Efforts to integrate CHINA-1 with OTPIMA at this point in the barrier design process are still under development. In the interim, a FORTRAN subroutine has been developed for use in OPTIMA that creates a file containing all pertinent data. CHINA-1 reads the data from that file, recommends ways to change the barrier configuration to reach the optimum design, and prints out a summary of all data relative to a particular barrier design and impact status.

The initial barrier configuration is usually an educated guess by the user based on past experience. He uses the information provided by OPTIMA to change barrier heights or location, or both, in an attempt

```
 DO CHINA
.(CHINA)
*** ALL NOISE LEVELS ARE A-WEIGHTED LEQ VALUES ***
*
*
IF YOU WISH TO GO DIRECTLY TO THE BARRIER DESIGN FEATURE
OF THIS PROGRAM, TYPE 'BARRIER, <CR>'.
OTHERWISE , TYPE 'CONTINUE, <CR>'.
*
*CON
WHAT IS THE  EXISTING NOISE LEVEL AT THIS RECEPTOR ?*61
*
WHAT IS THE PREDICTED NOISE LEVEL AT THIS RECEPTOR ?*64
*
HOW WOULD YOU CLASSIFY THE LAND USE OF THIS SITE
(RESIDENTIAL OR PUBLIC) ?*RESIDENTIAL
*
*
THE DESIGN CRITERION CURRENTLY IN USE IS 60 DBA. IF
YOU WISH TO CHANGE IT, SIMPLY TYPE IN THE NEW LEVEL.
IF NOT TYPE 'NO <CR>'*55
YOU HAVE CHANGED THE DESIGN CRITERION TO 55 DBA.
*
*
YOU HAVE CLASSIFIED THE LAND USE AT THIS SITE AS RESIDENTIAL.
*
CHINA-1 WILL NOW ACCEPT YOUR QUESTIONS REGARDING THE IMPACT
AT THIS RECEIVER AND THE BARRIER OPTIMIZATION PROCESS.
PLEASE STATE YOUR QUESTION CONCISELY AND IN NATURAL ENGLISH.
*
TYPE 'C <CR>' WHEN YOU ARE READY TO CONTINUE.*C
*
FOR THE PURPOSE OF DEMONSTRATING THIS PROGRAM,
A LIST OF AVAILABLE OPTIONS FOLLOW:
*
 1. TYPE 'BYE' TO END SESSION
 2. TYPE 'RESTART' TO BEGIN A NEW CASE
 3. IMPACT CLASSIFICATION
 4. EXPLAIN THE REASONING IN THAT CLASSIFICATION
 5. CONVENTIONAL BARRIER DESIGN
*
*
*
PLEASE TYPE YOUR REQUEST ('LIST' WILL PROVIDE YOU WITH
THE AVAILABLE OPTIONS).
*CLASSIFY THE IMPACT AT THIS RECEPTOR
*
*
PREDICTED NOISE LEVELS AT THIS LOCATION INDICATE THAT EXTERIOR
ACTIVITIES WILL BE SEVERELY IMPACTED.
*
PLEASE TYPE YOUR REQUEST ('LIST' WILL PROVIDE YOU WITH
THE AVAILABLE OPTIONS).
*EXPLAIN THAT RESPONSE
*
*
AN INCREASE OF 3 DBA IN HIGHWAY TRAFFIC NOISE WILL
RESULT FROM THE IMPLEMENTATION OF THIS PROJECT.  IN ADDITION, THE
PREDICTED NOISE LEVEL OF 64 DBA IS  9 DBA ABOVE THE
CRITERION LEVEL YOU SPECIFIED.  THESE NOISE LEVELS ARE CONSIDERED
SUBSTANTIAL CHANGES AND WILL DEFINITELY AFFECT OUTDOOR ACTIVITIES.
*
PLEASE TYPE YOUR REQUEST ('LIST' WILL PROVIDE YOU WITH
THE AVAILABLE OPTIONS).
*DESIGN A BARRIER
*
*
*
BEFORE PROCEEDING YOU MUST HAVE RUN STAMINA2 AND OPTIMA.  THE
OPTIMA RUN GENERATES A TARIF THAT WILL BE USED BY CHINA-1 TO SUGGEST
HOW THE BARRIER SEGMENTS MAY BE ADJUSTED TO ARRIVE AT THE OPTIMUM
BARRIER DESIGN.  NOTE THAT CHINA-1 LOOKS FOR THE FILE OPT.LSP.
*
THE INSERTION LOSS PROVIDED BY THIS BARRIER IS 2.8
DBA BELOW THE MINIMUM YOU SPECIFIED.
*
WITH CONSTRUCTION OF THE BARRIER YOU PROPOSE, THE NOISE
IMPACT AT THIS SITE IS NOW SEVERE.
*
THE MAXIMUM CONTRIBUTION IS 57.3       DBA FROM SECTION 2. IF
YOU WISH TO INCREASE THE INSERTION LOSS AT THIS RECEIVER, TRY RAISING
THAT SECTION AND RE-RUN OPTIMA FOR REVISED NOISE LEVELS.
*
            SUMMARY
*
MATERIAL : CONCRETE
COST     : 98737.0 DOLLARS
INSERTION LOSS : 2.1        DBA
NOISE LEVEL(WITH BARRIER): 61.9       DBA
BARRIER SECTION HEIGHTS (IN FEET) : (10.0 10.0 10.0 10.0)
IMPACT CLASSIFICTION : SEVERE
*
****THE CURRENT SESSION IS ENDED****
```

FIGURE 3 Initial session with CHINA-1.

to obtain the maximum noise reduction for the least amount of money. In this example, the user began the analysis with a barrier of a constant 10-ft height. CHINA-1 noted that the impact was still severe and went on to suggest raising barrier section 2 to further reduce noise levels because the maximum noise contribution was coming from that section. In this prototype system, the model only considers that barrier segment contributing the maximum or minimum noise level at a given receiver. Subsequent work has led to the development of a heuristic that considers not only the maximum and minimum contributions, but also other significant or insignificant contributions at all affected receivers. This heuristic, in its final form, will allow the system to emulate more closely the human expert's thought process.

In this example, the user made the suggested changes, re-ran OPTIMA, and then executed CHINA-1 again. This time, he chose to go directly to the barrier design option. CHINA-1 then requests the existing noise level at the receiver and performs the same analysis as previously described, and again makes the appropriate suggestion.

This example only presents one iteration of the process. As it now exists, this is a somewhat complex procedure, but it does demonstrate the feasibility of emulating the thought process of a human expert with machine reasoning as the user attempts to optimize a noise barrier design. In addition, this prototype system adequately demonstrates the utility of a computer program that contains expert advice on a complex task.

CONCLUSION

A primary purpose of the prototype system at Vanderbilt University is to demonstrate the feasibility of constructing an expanded expert system that would synthesize the knowledge and experience of leading experts in the field of highway noise analysis and abatement. This concept can provide the engineer, who has the fundamental training required for highway noise analysis, with easy access to the experience of recognized experts in the field. This capability has the potential to enable the most inexperienced highway noise analyst to design effective, cost-efficient noise-abatement plans.

Planned enhancements of this concept, which are currently under development, call for the integration of the FORTRAN program OPTIMA into a LISP environment. The next generation of CHINA will be able to execute OPTIMA at the option of the user, analyze the results of an initial design chosen by the user, and then recommend ways to improve that design based on design goals specified by the user. With the expert knowledge encoded in the expert system, the CHINA model will be able to consistently design the optimum barrier directly from within the expert system.

This prototype system, in its present stage of development, also demonstrates the potential that exists for applying artificial intelligence technology to other disciplines of transportation engineering. For example, an expert system could aid in accident reconstruction, airport noise management, transit route maintenance, or traffic management on an urban street system. The potential is also obvious for using expert systems to provide a tutorial for educating users in the use of complex models.

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