Knowledge-Based Preprocessor for Traffic Noise Prediction

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A knowledge-based preprocessor system has been developed to assist the engineer in creating data input files for the STAMINA 2.0 traffic noise prediction program. The preprocessor uses rule-based heuristic knowledge for certain decisions, algorithmic routines to provide data to the rules and to help automate the file creation process, and linkages to editing routines for manual manipulation. The system is used as the engineer works with a design project's plans. The system requests certain data from the user, and ultimately creates two STAMINA input files. The first file contains the baseline noise barriers as starting points for final barrier design with a companion program called OPTIMA, and the second file contains only the ground-line elevations for accurate assessment of no-barrier levels. System performance was tested on two major analysis areas on each of two design projects previously done by human experts. In all cases, the system created syntactically correct STAMINA input files that resembled those of the experts and produced meaningful sound level results when run. In some cases, these STAMINA files resulted in barrier insertion loss predictions very similar to those produced by the experts using the OPTIMA program. Although it was not the intent of this work to replace use of OPTIMA, the files produced by the system should reduce time spent using OPTIMA, as well as time typically spent making modifications to the STAMINA files. Although fully functioning, the system should be considered an operational prototype until further testing and refinement.

Highway traffic noise is a major public concern with the construction of noise barriers being the most common method for control used by state departments of transportation. Noise barrier analysis and design is typically done using the barrier cost reduction (BCR) procedure (*1*) that involves sequential use of two computer programs, STAMINA 2.0 and OPTIMA (*2*).

STAMINA 2.0 mathematically models the noise levels from a highway project on the basis of user-defined geometric coordinates (x,y,z) of the sound receptor points (receivers), roadway, and proposed barriers, as well as traffic volumes and speeds, ground cover conditions (alpha factors), and level reductions due to shielding from buildings and terrain. To produce the needed barrier design information for OPTIMA, a baseline barrier height is specified in STAMINA for each barrier segment, as well as desired perturbations of this height. STAMINA 2.0 then calculates the sound energy at each receiver that passes over each of the multiple barrier heights for each barrier segment. STAMINA 2.0 generates an acoustics file that contains these sound energy data, which are required by OPTIMA as input. The designer then uses OPTIMA in an iterative fashion to test various designs, working toward a goal of selecting the lowest-cost barrier for a given amount of noise control. The most efficient design for barrier height can only be obtained if the STAMINA input data have the optimal lateral location of each barrier and the proper range in heights above and below the baseline height for each barrier segment. In many cases, the input data can only be developed properly through a time-consuming process of changing the STAMINA input file and rerunning STAMINA before rerunning OPTIMA.

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Several years ago, the knowledge-based system Computerized HIghway Noise Analyst (CHINA) (*3*) was developed. This system ran the OPTIMA program to produce a good noise barrier design after the human engineer had separately created the STAMINA 2.0 input file and had run STAMINA. However, that barrier design would only be as good as the original site modeling permitted it to be. If the engineer did a poor job locating the barrier in plan view, choosing baseline barrier segment heights, or choosing receivers, then it would be unlikely that the human engineer or CHINA could accomplish a satisfactory design.

This paper presents an overview of the results of research on the development of a knowledge-based system to assist in highway noise modeling (*4–6*). The major objective of the research was to develop a tool to help an inexperienced designer in the difficult task of building a good input file for STAMINA 2.0. Additionally, an experienced designer can take advantage of the computing ability of the system to speed file creation and to reduce the number of iterations in the noise analysis, thus saving time.

The resultant final product when one uses the system is actually two input data files for STAMINA 2.0 that contain the needed data for receivers, roadways, barriers, ground-covering factors, and shielding factors. The first file contains the initial barrier design, and is used by STAMINA to produce the acoustics file for OPTIMA. The second file, with ground-line barriers only (no-barrier or without barriers), may be used to determine impacts without noise abatement features.

PROBLEM IDENTIFICATION

The major problem areas in the creation of input files for STAMINA 2.0 for most highway noise analysis projects include (a) selecting representative receivers, (b) modeling highway systems to correctly represent the noise sources, (c) determining the best lateral locations to build noise barriers and a good set of initial heights aimed at reaching a design goal, (d) choosing proper alpha factors for ground effects on noise propagation, and (e) choosing proper building shielding values.

These types of problems must be considered regardless of the highway noise prediction method selected, but they are critical when using STAMINA 2.0. In addition, the sheer volume of (x,y,z) coordinate data required to create a file calls for ways to automate the process as much as possible.

KNOWLEDGE ACQUISITION

Although some simple rules are provided in reports or manuals, the solutions to most of the problems require human experience, which is primarily heuristic knowledge. Thus, it is very important to ensure that the quality of the rules used in the expert system is consistent and well accepted by other experts. In this research, the resources employed for knowledge acquisition included the following:

1. Learning from a short course: The lead author attended a short course for highway noise barrier design, taught by three leading domain experts (including the coauthor).
2. Analyzing public domain knowledge: Four major design manuals (*3*, *7–9*) were carefully analyzed to examine the applicability of the rules cited in those manuals.
3. Conducting a survey: A survey consisting of 32 questions was answered by three engineers with extensive state department of transportation (DOT) experience in barrier design.
4. Studying the experts' performance: Previous projects done by the domain experts were analyzed and actual designs were done on state DOT projects in cooperation with a domain expert.

TOOL EVALUATION

Selecting a proper knowledge-based system developmental tool is important for programming and for maintenance of the system. The basic requirements for this research were rule-based knowledge representation, flexible problem-solving mechanism, integrated development environment, easy interface with procedural languages, compatibility with existing microcomputers, ease of learning and use, and low cost of the software.

Among all types of knowledge representation schemes, the rule-based scheme has been used most often because of its discrete nature, which is simple and flexible for most engineering designs. This research has already organized more than 100 rules to represent knowledge and experience. Also, for real-world applications of this knowledge-based system, the program must be able to call computer programs in other languages, such as computational routines in FORTRAN that process data for use by the rules. Additionally, software development is a repetitive and time-consuming process; an integrated development environment can help decrease programming time.

When this research began, tool evaluations showed that most commercial software was generally quite expensive or did not offer good interfacing capabilities. However, the low price and powerful interface of the knowledge-based developmental tool VP-Expert (*10*) led to its testing for suitability for this study. Implementing a small prototype on an IBM-compatible system led to the conclusion that this software was acceptable for this study. After completion of the project, it was concluded that use of a microcomputer with expanded memory capabilities was desirable.

PROGRAMMING THE KNOWLEDGE-BASED SYSTEM

The first stage in constructing the system was to design a framework that emulated the human expert's thought process. After that, numerous rules were organized and programmed into this design frame to accomplish the required functions. The rules were built into the system either implicitly as logical expressions or mathematical functions, or explicitly as guidance to help the user. The system was expected to be capable not only of executing the program correctly, but also of meeting two important concerns: (a) user-friendly interface, and (b) ease of future modification and maintenance. Thus, the program structure was divided into two parts. Figure 1 shows an overview of the structure of the system. The upper part of the figure is the knowledge base (or rule base) that was developed under VP-Expert. The lower part contains several data manipulation processes that were written in FORTRAN. The results generated from the knowledge base of each module need to be rearranged by an associated data manipulator before those data can be accessed by the next module.

A total of 14 rule-based routines and 16 FORTRAN routines were developed to form the major modules shown in Figure 1. System execution begins with a title block and then goes to a control block that is designed as a shell for the system. This shell links each design module to provide a more flexible design process for the user. Using the shell, the designer may make changes in a certain module without repeating the entire design process.

Centerline Module

The centerline module was designed to simplify the data representation scheme. Because the major task in file creation is to determine the receiver, roadway, and barrier points in three-dimensional coordinates, a simplified data representation scheme reduces the chance of accidental error input and saves analysis time. In this system, the user only needs to define (x,y) coordinates for designated stations of the roadway centerline. Points on the same plan may then be specified by station numbers with offsets, which are then converted to (x,y) coordinates based on the centerline data. This scheme is much more convenient than reading the coordinates of each point from design plans and is flexible for future enhancements such as interface with a digitizing table or a roadway computer-aided design (CAD) program. The required length of the centerline depends on the project requirements and the distribution of the noise receivers. To determine the length of the centerline, the user must first identify the receiver at each end with the longest offset distance. The centerline is then extended as follows:

1. If the offset is less than or equal to 250 ft, then extend the centerline by 4 times the offset.
2. If the offset is between 250 and 500 ft, then extend the centerline by 1,000 ft.

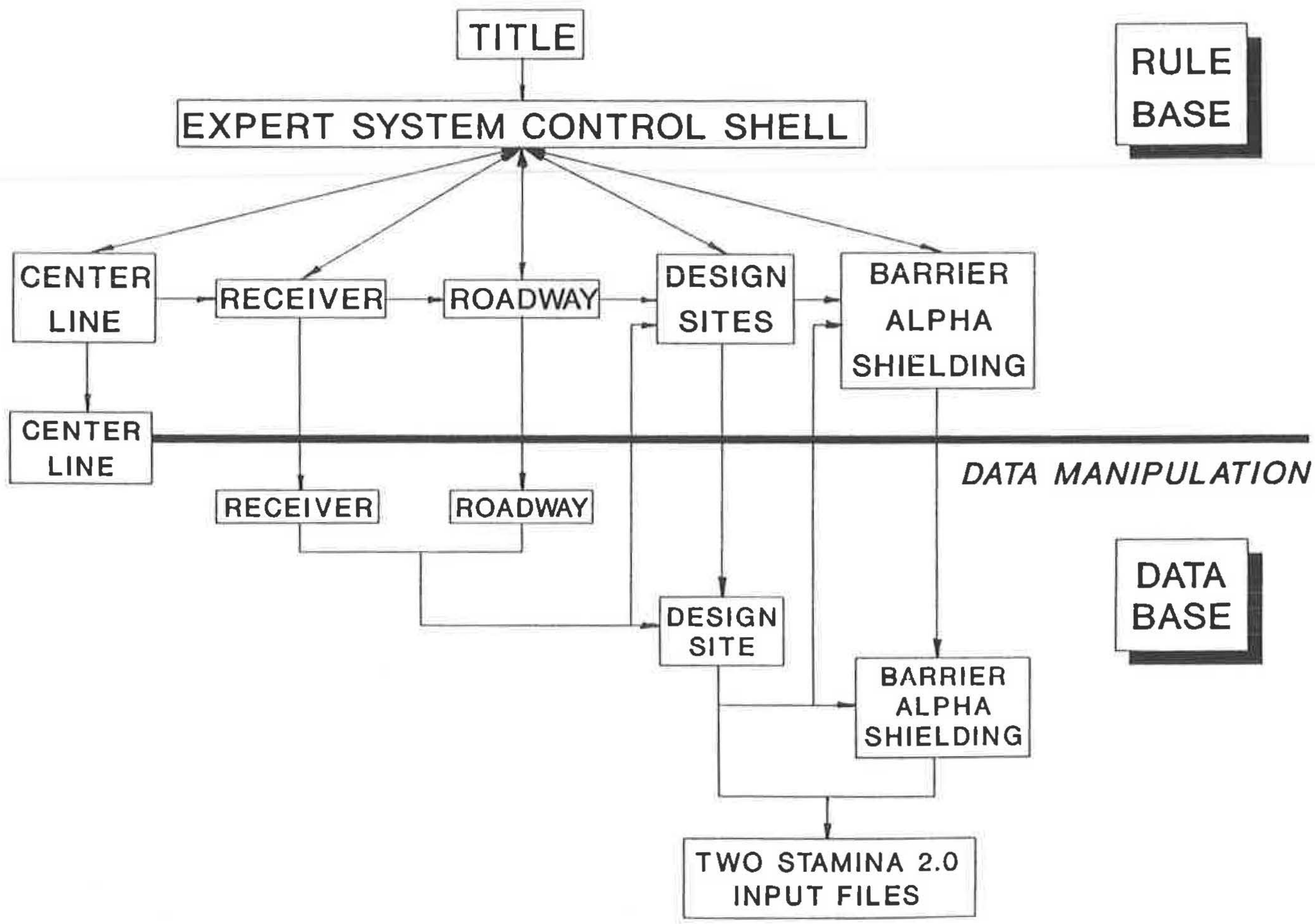


FIGURE 1 The knowledge-based system structure.

3. If the offset is greater than 500 ft, then extend the centerline by twice the offset.

The multipliers were determined during knowledge acquisition based on sound propagation characteristics and guidance from the experts.

The major requirement of this scheme is to express the centerline by both the station numbers and the (x,y) coordinates at the minimum number of points that can still provide the required accuracy. For instance, a straight roadway centerline can be expressed by just the two end points and the user needs to provide (x,y) coordinates for these two points to the system. For a more complicated highway plan, the required points are determined by the horizontal alignment of the centerline. Horizontal curves can be approximated by several straight lines. After testing the system with several design cases, the maximum offset of each straight line to the arc of the curve was determined to be 5 ft to avoid cumulative errors.

Receivers Module

This module presents the option of creating receiver data for the input file either manually or automatically. If the receiver distribution is fairly uniform, the receiver data can be generated automatically by the system with only a few input parameters: the desired distance between receivers, and one offset distance and one z-coordinate for each group of receivers. The system will then generate receiver title, station number, offset distance, and (x,y,z) coordinates for each receiver. As with the centerline module, this scheme is amenable to future interface with a digitizer or a CAD system.

If the user chooses to enter the receiver points manually, the system will call either a word processor or a spreadsheet program at the user's request. In this option, the user needs to define the receiver title, station number, offset, and z-coordinate for each receiver, and the program computes the (x,y) coordinates. A series of textual rules is provided as a guideline for the inexperienced designer for manual selection of meaningful receivers. These rules include the following:

1. For a row of houses, if the distance from one house to the next is less than 200 ft, then select the two end houses and every third house as the receiver points.
2. For a row of houses, if the distance from one house to the next is greater than 200 ft and less than 500 ft, then select the two end houses and every second house as receiver points.
3. For houses separated by more than 500 ft, select each house as a receiver point.
4. If the terrain of one receiver location is different from the surrounding area (e.g., top of a hill), then this location should be selected as a receiver point.

Roadways Module

This module assists the designer in dividing a highway system into representative noise sources called "roadways" in STAMINA. The first parameter considered for breaking a highway down into roadways is the number of lanes. Generally, each modeled roadway represents two or three real lanes and each ramp is considered as a single roadway for noise analysis.

In addition, the user is told to longitudinally divide the highway into separate roadways for changes in traffic parameters. The user must define the traffic volumes and speeds for each roadway. However, a set of rules was built to define the traffic speed on ramps. The speed is determined on the basis of AASHTO guidelines (*11*) by the shape of ramp (directional, semidirectional, or loop), the type of ramp (on, off, or interchange), and the presence of traffic control devices at the end of the ramp.

The system also provides advice to assist the user in further breaking down the highway system into more roadways on the basis of ground cover conditions. For instance, the system suggests to the user to divide a modeled roadway into two or more shorter roadways when the surface covering conditions between this roadway and the receivers vary more than 25 percent, such as at a large paved area or at a large water-covered site surrounded by a grass-covered surface. The use of shorter roadways permits the ground absorption factors (alpha factors) to be defined more accurately.

Additionally, each roadway needs to be broken into a number of segments. A 400-ft length for each roadway segment is typically used as a default by the experts consulted during knowledge acquisition and is therefore initially suggested to the user by the system. The user may also specify other segment lengths. These lengths are then used as starting points by the module as it begins the process of dividing the roadways into segments and computing (x,y) coordinates for all endpoints. The system uses the information from the centerline module and also inquires about vertical curves using a maximum allowable offset elevation of 2 ft between the actual curve and the STAMINA roadway segment in its decisions.

Design Sites Module

One philosophy incorporated into the knowledge base is that each side of the highway should be analyzed as a separate design site. Basically, the rules used in this module are determined by the restrictions or limitations of the STAMINA 2.0 program. If the proposed numbers of receivers or roadways in a data file are greater than the upper limits of STAMINA 2.0, the system will help the user to divide the data file into smaller files.

Other reasons to divide a noise analysis site into several design sites are (a) to save computation time for each STAMINA run and (b) to simplify noise barrier design and alpha and shielding factors selection. The system has a set of rules to help the user to define the range of main roadway system (length of roadways beyond the end receivers) and to determine if any ramps that may be present should be included in the file for a design site (essentially on the basis of ratios of ramp traffic to mainline traffic).

Barriers Submodule

After the design sites are defined, barrier locations and baseline heights are determined. Figure 2 indicates the process for both barrier design and alpha and shielding identification. Although these two tasks are conducted in one module, their rules will be discussed separately. The system offers a capability beyond the simple creation of properly formatted barrier data for the input file. It actually performs an initial barrier location and height analysis. This analysis was not meant to replace the design process using OPTIMA but to provide the user with an intelligently determined starting point.

Longitudinal Location

The first step followed by this module is to determine the longitudinal location of the endpoints of all barrier segments relative to the roadways. The second step, discussed in the next section, is to determine the lateral (cross-sectional) location of the barrier points. The barriers are initialized to match with the endpoints of the defined roadways. In many cases, the roadways and barriers are parallel to each other. If the endpoints of each roadway are matched by barrier endpoints, there is a reduction in the chances of making errors such as creating an unrealistic low point in the barrier top on a crest vertical curve or crossing a barrier over a roadway. However, in most cases, it is useful to define the length of a barrier segment to be shorter than that of a roadway segment. Shorter segments allow the user to fine-tune the barrier height during the OPTIMA design process. A common length applied by human experts is 100 ft. The system also checks with the user to see if highway bridges are present in the analysis area. Because a barrier wall built on a bridge may require special structural support or use of lighter-weight materials, it is useful to delineate these areas in the definition of the noise barriers. Therefore, the user has the opportunity to insert new barrier section points for bridges.

The program then automatically generates the longitudinal location of each barrier section point using the 100-ft default value or different user-supplied value. Extra barriers may also be generated if overlapped barriers are needed for locations such as an interchange area with barriers along the ramp as well as in the gore area between the mainline and the ramp. The rules used for calculating the endpoint location of a barrier between a ramp and a main roadway are based on the merging sight distance requirements cited by AASHTO (*11*).

Lateral Location

The second barrier endpoint determination problem relates to the best lateral offset location from the road for a given barrier point. The decision on the location of this point is related to the needed attenuation, and as a result, the needed barrier height above existing ground. The first step in this process is for the user to supply an insertion loss (IL) design goal. For receivers located more than 200 ft from a noise source, the user-supplied IL is revised downward by the system because, in practice, the more distant receivers will experience less noise reduction for a given barrier design than the

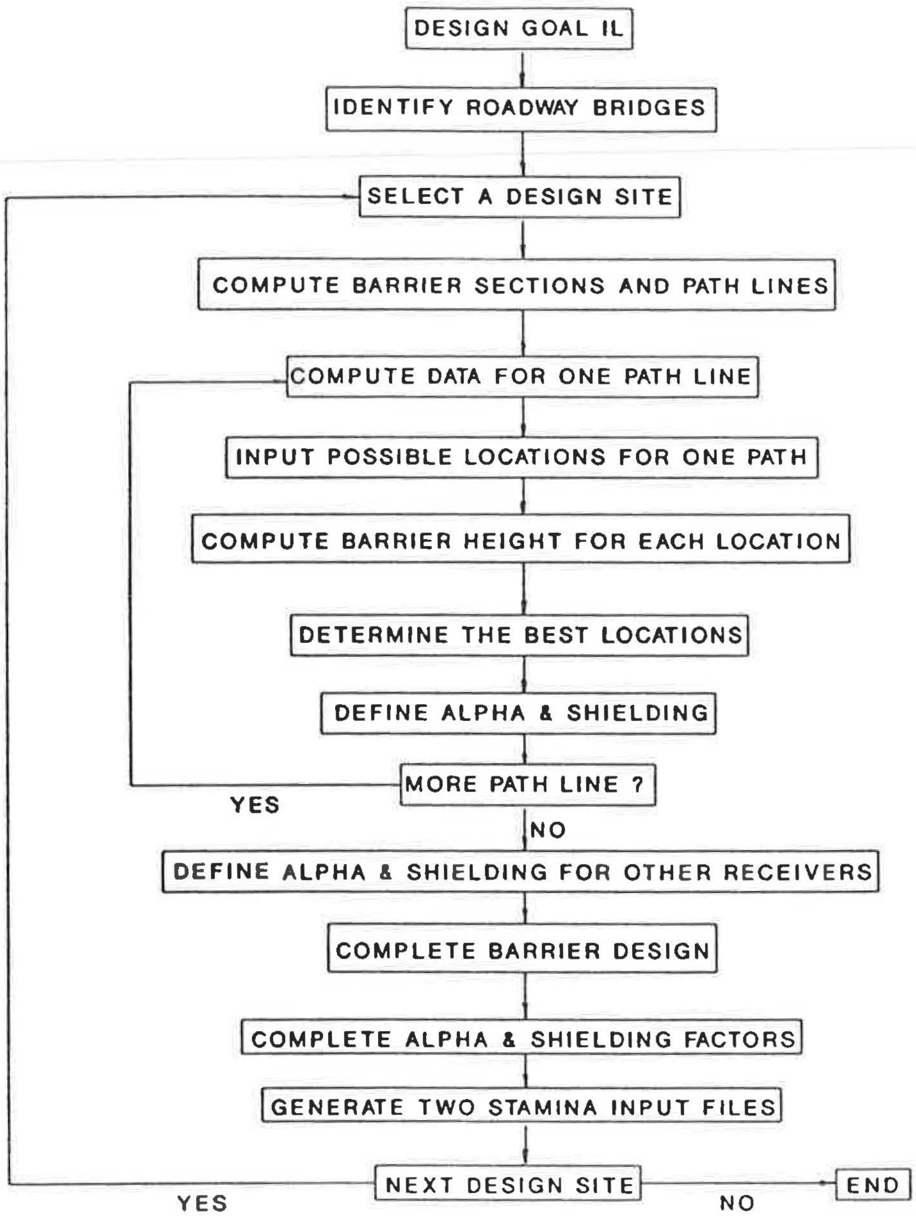


FIGURE 2 Barrier analysis procedure used by system.

closer receivers (for which the design is generally being done). The purpose in choosing a design goal during STAMINA input file creation is to give the system information to use in selecting an initial barrier location and baseline height.

The system then determines a number of paths representing receiver-source pairs, as shown in Figure 3. For all but the end receivers, a path is the perpendicular offset line from one of the first row receivers to the centerline. However, for both ends of a design site, several extra paths are generated to extend the barrier design to the end of the modeled roadways. The path of the first (and last) receiver-source pair runs from the nearest end of the centerline in the design site to the end receiver with the longest offset distance as shown in Figure 3. This receiver may not be in the first row. If not, an additional path is generated by connecting the end receiver of the first row with the corresponding centerline endpoint.

For each receiver-source pair, the offsets and elevations of the receiver and the sources, which include near lane, far lane, and ramp lane (if existing), are extracted from the previously created data base. The designer is asked to examine the highway plans to input the offsets and z coordinates for all potential barrier locations along each path. Some guidelines are provided for this assignment. Again, this procedure was established with the thought of ultimate transition to automated interface with a CAD system.

Based on an algorithm developed in this research, the system then calculates the barrier baseline heights for all the barrier locations entered by the user for each path. The basic concept of this algorithm is to determine the required break height at each barrier location for the needed barrier attenuation (on the basis of a heavy truck source), which is determined by the IL entered by the user, as explained next.

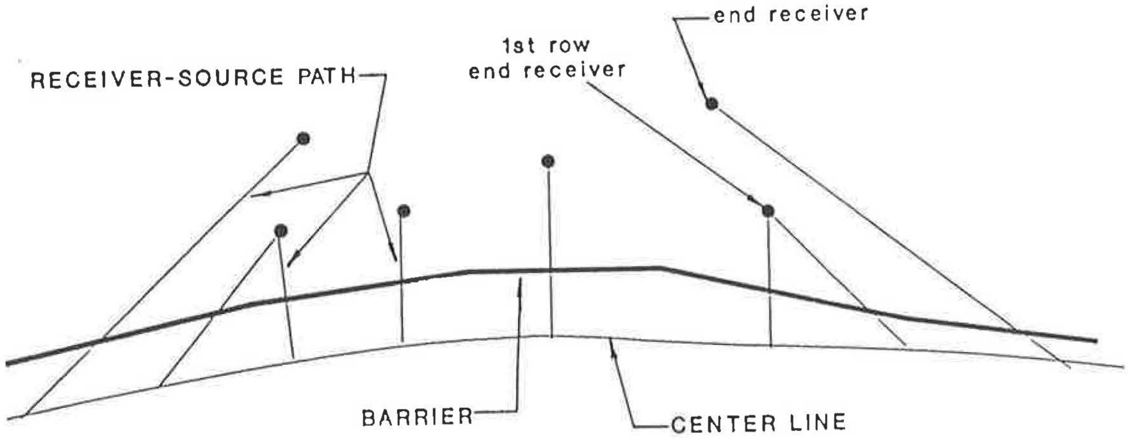


FIGURE 3 Plan view of paths used in determining initial barrier location and height.

The first step is to compute two line-of-sight (L/S) functions, one from the near lane and one from the far lane, and their distances (C) to the receiver (see Figure 4). Then the barrier attenuation for each L/S is determined. Because the attenuation caused by soft ground covering may be lost due to the insertion of a barrier, the barrier attenuation used in this analysis is set to be 2 dB higher than the IL goal if the receiver is located up to 200 ft from a noise source (*9*). The effects of distance in reducing attenuation are then introduced to adjust the IL for the receivers located more than 200 ft from a noise source. The barrier attenuation used for barrier break height calculation is determined by the following equations:

For $C < 200$ ft,

$$A_0 = \text{IL} + 2 \qquad (1)$$

For $200 < C < 500$ ft,

$$A = A_0 + 10 \log [100/(C - 100)] \qquad (2)$$

For $C > 500$ ft and $A_0 \leq 12$ dB,

$$A = 4 \qquad (3)$$

For $C > 500$ ft and $A_0 > 12$ dB,

$$A = A_0 - 8 \qquad (4)$$

where A_0 is the barrier attenuation in decibels for a path length less than or equal to 200 ft and A is the barrier attenuation in decibels for a path length longer than 200 ft.

It needs to be emphasized that these attenuations are not being recommended for use in barrier design. Rather, they are being used by the program to determine a reasonable set of baseline barrier heights in the STAMINA file for subsequent design by the user.

The needed path length difference δ for a desired barrier attenuation may be approximated as follows:

For $A < 5$ dB,

$$\delta = 0 \qquad (5)$$

For $5 \leq A \leq 9$ dB,

$$\delta = 10^{(-2.6154 + 0.2564A)} \qquad (6)$$

For $9 < A \leq 15$ dB,

$$\delta = 10^{(-1.6536 + 0.162A)} \qquad (7)$$

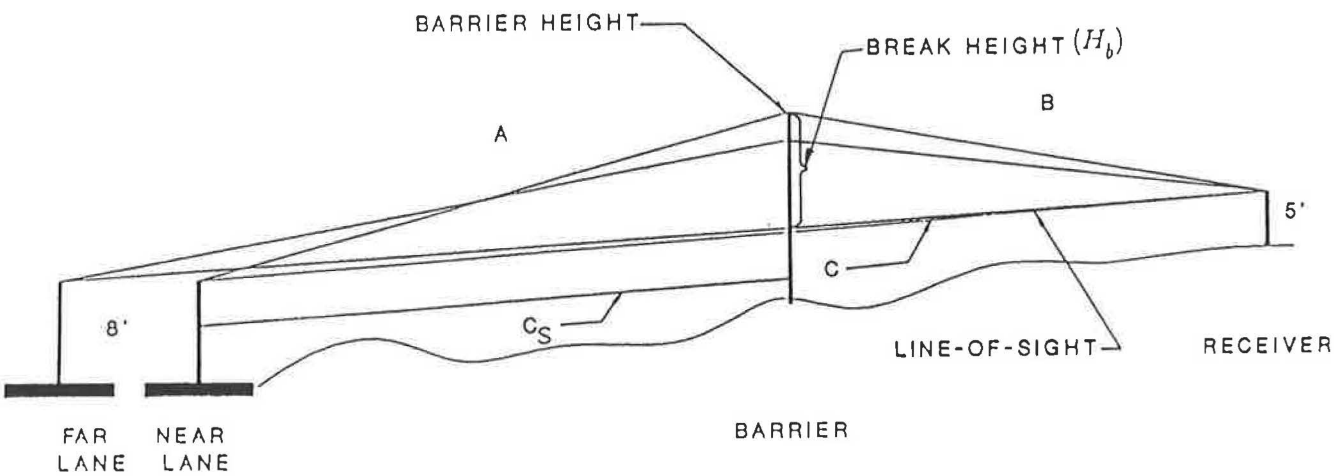


FIGURE 4 Section view for source-barrier-receiver paths.

In barrier analysis for a flat (at-grade) site, the location that provides the least path length difference for a given barrier height is the midpoint of the path. Therefore, the midpoint was used as a reference point for calculating the required break height $(H_b)_r$ which is the barrier height above the L/S line (see Figure 4). Because δ (equal to $A + B - C$ in Figure 4) can be calculated by Equations 5 to 7, the break height may be approximated as

$$(H_b)_r \approx [(\delta C)/2]^{1/2} \quad (8)$$

The break height for any barrier location other than at the midpoint that results in the same path length difference as the midpoint can be approximated by the following equation (*12*):

$$H_b = 2\,(H_b)_r\,[(C_s/C)(1 - C_s/C)]^{1/2} \quad (9)$$

where C_s is the distance between barrier and source (see Figure 4). After testing this approximation method with various C_s/C ratios, it was found that Equation 9 was only good for a C_s/C ratio from 0.1 to 0.9. If the ratio was less than 0.1 or greater than 0.9, a good approximation for the break height would be produced by using the value associated with a C_s/C ratio of 0.1 or 0.9, respectively. Through this procedure, the system determines the needed break height for a given barrier location and ground elevation. Then, the baseline barrier height and top elevation are calculated using the break height, the L/S height, and the ground elevation of each location.

For each barrier location, the calculations are performed separately for both near and far lanes, as they represent different sources. The final barrier height for a given barrier location is determined by comparing the results for the two sources. In terms of acoustical performance, for a given path the best location for a noise barrier is the location with the lowest barrier height that provides the needed attenuation. Nevertheless, some modifications in that location may be necessary to ensure barrier continuity in transition areas (e.g., going from a cut section to a fill section) or to address other concerns such as drainage or special construction requirements. Thus, for each path, the barrier results calculated by the system for the other lateral locations are also stored in a data base.

The process is repeated for all the paths determined by the system. After this initial barrier analysis is completed, the best barrier heights for all paths determined by the system are summarized in a file. The user may verify this baseline barrier design by a printout of this data file. The user may also modify the design manually by following the guidelines provided by the system.

Height Adjustment

After the verification, a data manipulation process is used to adjust the heights resulting from the analysis. For each barrier, the number of paths and resultant barrier heights generated by the system are usually greater than one. Thus, the first step in adjusting the barrier heights is to coordinate the baseline height for each barrier. This is the initial baseline height for the STAMINA 2.0 input file. A first simple rule of thumb by which to determine the baseline height for each barrier is to use the tallest barrier height required by one of the paths for this barrier. For more complicated cases, if the difference in baseline heights between two consecutive path lines is greater than 6 ft, the barrier is divided into two separate barriers.

After this adjustment of the baseline heights, a second set of adjustments is made by the rules presented in Table 1 to give a more standardized look to the heights. In addition to the baseline height, associated height increments for the STAMINA file are also presented in this table. The number of increments and the increment sizes listed in the table allow the user to have maximum changes for barrier heights. These values are also commonly used by the human experts as the initial values in their designs.

Two data files are produced by this data manipulation process, one containing no noise barriers other than the natural

TABLE 1 RULES FOR REFINING BARRIER HEIGHTS AND DEFINING HEIGHT INCREMENT

Computed Baseline Height (ft)	Refined Baseline Height (ft)	Number of Increments	Increment Height (ft)
0	0	0	0
0-6	6	3	1
6-15	6,9,12,15	3	2
15-20	15,18,20	3	3
20-30	20	3	3
30 or more	30	3	4

terrain (i.e., ground line barrier), and the other containing the results of the initial barrier height analysis, namely the baseline barriers with height increments for production of the acoustics file for use by OPTIMA.

Alpha and Shielding Factors Submodule

Figure 2 shows that alpha and shielding factors are assigned by the same module that does the barrier analysis. The rules presented in the FHWA traffic noise prediction model report (*7*) for determining alpha and shielding factors are applied by the system as general guidelines. To apply these rules, the user first defines a series of paths for certain receiver-source pairs. The pairs include each receiver and the roadway directly in front of it; some extra paths are defined for the end receivers for extending the design to the end of the design site, as was done in the barrier analysis. The designer then only has to assign alpha and shielding values for this subset of all possible receiver-source pairs. Rules are built in to enable the system to generate a complete alpha or shielding matrix with this relatively limited information.

Figure 5 indicates by solid lines the paths for which the user must supply factors. The dashed lines (which are shown for Receiver 2 only) indicate the other receiver-source pairs that will have their factors automatically generated by the program. These factors are assigned by the program through an examination of the factors for the user-specified path lines that cross the path line of interest. The results of this submodule are then combined with all the data generated in the preceding steps to create a STAMINA 2.0 input file for one or more design sites.

TESTING AND EVALUATION OF THE SYSTEM

As mentioned earlier, the major goal of this study is to provide a good input file with which to begin the noise analysis. The final design results using a program like OPTIMA will be strongly dependent on the quality of this initial file. A good initial input file should at least contain all correct information to run STAMINA and to start a noise analysis, reducing iterative modifications of the STAMINA input data. As it turned out, the initial barrier heights produced by the system could be close to the final design using OPTIMA, especially for at-grade sites, an unexpected benefit of the results of this research.

During programming, the system was verified and evaluated step by step in order to ensure that the information was complete and accurate for further development. Verification cannot be accomplished, however, by using a case with a simple geometric configuration. Thus, the overall performance of the system was tested against two full-scale design projects that were completed by two domain experts at Vanderbilt University. A full presentation, discussion, and documentation of the results of the evaluations are available for study (*4*).

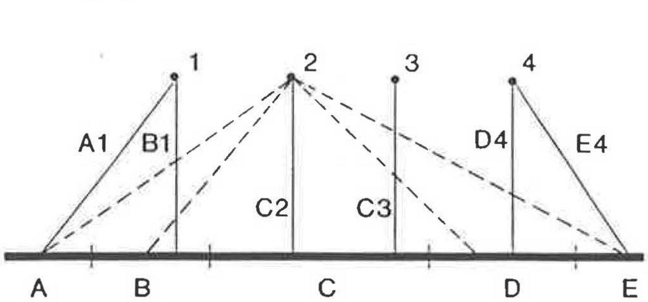


FIGURE 5 Plan view of roadway-receiver pairs for alpha and shielding factor identification.

The first project was a 1.5-mi section of the planned six-lane I-68 in Bowie, Md. Two design sites—the north and south sides of the project—were modeled by both the experts and the system. The second design project was the existing 10-lane I-95 in northern New Jersey, where the goal was to design noise barriers to be added alongside the existing highway. Four design sites were modeled for this project: two adjacent areas to the south and two adjacent areas to the north. The two northern areas were chosen for system evaluation (*4*). The design sites were neither simple nor straightforward. Collectively, they included such features as ramps, cut, fill and at-grade sections, fairly steep roadway grades, and a mixture of hard and soft ground cover. In order to compare the results of the system's files to those of human experts, virtually the same receiver and traffic data used by the experts were used when running the system. All the other results were determined according to the guidelines provided in the system or generated by the system directly.

In the testing and evaluation, the design accomplished by the human experts represented the final results arising from a series of iterations, which include modifying the STAMINA input files as well as running the OPTIMA design program. The results of the knowledge-based system, on the other hand, were generated directly by the system without any subsequent modification to the STAMINA input file and prior to any final design with OPTIMA. The usefulness as well as the limitations of the knowledge-based system can be illustrated through the comparison of the human experts' final OPTIMA design with the system's initial STAMINA design.

It is very difficult to specify quantitative benchmarks to evaluate system performance. In all cases, the system produced syntactically correct files that could be directly run with STAMINA. On a second level of evaluation, the STAMINA files produced by the system were very much like those produced by the experts. Similar numbers of roadways and barriers were defined and the locations of these features were comparable. This similarity was expected because, assuming correct programming, the heuristics used were the same. However, the system has not yet been compared to designs of other experts. The similarity of the files would depend very much on the similarity of the heuristics used by each set of experts. Different experts often do create STAMINA input files in different manners using different rules. These files should, however, lead to similar sound level results. The experts just approach the goals in different ways.

When differences between the system files and the experts' files existed, they involved the barrier heights for the most part. In one case, the user working with the system read a different set of ground line elevations from the contour mapping than did the experts. Until a fully integrated CAD system interface is developed to automatically read elevation data, this specific problem will plague any method of creating STAMINA files, including all existing digitizer preprocessors.

In a second case, the experts had taken their final acoustically optimized results and increased barrier heights in certain areas beyond what was needed to give the top of the wall a smooth transition profile.

In a third case, the road was on a grade and changed from fill to a deep cut, with the houses on an even steeper grade along the top of the cut. The height selection rules in the system for all but the end sections of a barrier are based on perpendicular paths between the source and receiver. On grades, the user needs to be concerned about sound leaks over the barrier top from oblique angles. Revision of the barrier height selection mechanism would be needed to cover these situations. However, even these differences need not be viewed as fatal because the resultant file could indeed be run by STAMINA 2.0 to produce the acoustics output file for subsequent use with the OPTIMA design program.

To illustrate the performance of the system, the results for one of the design sites (the south side of I-68) will be discussed. Figure 6 is a map of the site. This project area included the main lanes of I-68 with ramps for an interchange at the west end. The road passed through rolling terrain, such that it was depressed for certain sections, at grade for others, and on fill elsewhere. Figure 7 provides two plan view plots of the STAMINA files for this site. The lower plot was generated from the file created by the system (and its human user), whereas the upper plot was created from the file developed by the human experts. The upper plot illustrates that two possible barrier lines were assigned by the human experts for the west (left) end of the site. The experts included both lines because they could not tell, a priori, which would be better. However, in the knowledge-based system, various barrier locations were evaluated according to the user-supplied IL goal, and only one was chosen by the system for the input file. Evaluation of the STAMINA results confirmed that this barrier location was indeed the correct choice. As a result, only one barrier line needed to be added to the STAMINA input file when using the system.

Figure 8 compares elevations of the ground line barriers produced by the human experts and the system (Lines C and D, respectively), and the barrier top elevations for each (Lines A and B, respectively). The first difference to note deals with the ground line elevations between Stations 18 and 28. The contour mapping in this area was read differently by the user of the system and the experts. No system can deal with this type of human error: judging the correctness of what otherwise would seem to be reasonable elevations. An enhancement to allow the system to read CAD roadway design files would eliminate this particular type of problem. Because the system then selected barrier heights based on IL goals, the difference in ground elevations was largely responsible for the resulting difference in barrier top elevations.

The data presented in Table 2 help to illustrate system performance. The first five columns show STAMINA 2.0 results for each receiver based on the two input data files created by the system [ground line barriers only (WITHOUT BARR) and baseline noise barriers (WITH BARR)]. The difference in the predictions is shown in the IL column. The next four columns show the OPTIMA results for the human experts' design. The last three columns of the table compare each set of results for the three quantities.

Because of the ground line and barrier top elevation differences caused by the human data entry error between Stations 18 and 28, both the without-barrier and with-barrier noise levels of the receivers located in this range (RS18 through RS28 and S1820 through S2760) were predicted to be higher by the system than by the human experts. Note, however, in the last column of Table 2, that despite the problem with the correct ground elevation, there were only small differences in IL for most of the receivers between Stations 18 and 28.

Because different barrier ground elevations were used in certain areas by the two designs, as shown in Figure 8, it is not entirely appropriate to evaluate the results in terms of the actual wall heights. However, the overall comparison of ILs indicates that the system achieved good agreement with the human experts' design. As presented in Table 2, the IL differences of all the receivers, except for the first three, were 1.5 dB or less. The IL differences of the first three receivers were caused by different barrier designs. The system analyzed the need to extend a barrier along the roadway to Station 11 in an attempt to meet the design goal IL at the first three receivers. However, there was a creek between Stations 14 and 18 and the human experts designed the barrier to stop at

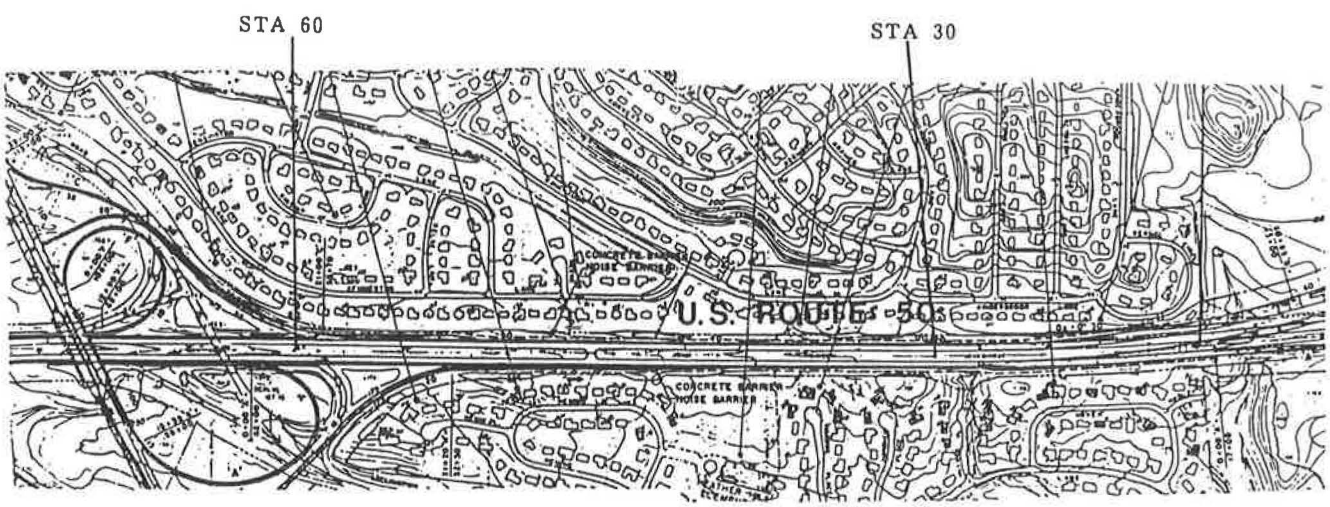


FIGURE 6 I-68 between Maryland Routes 197 and 301.

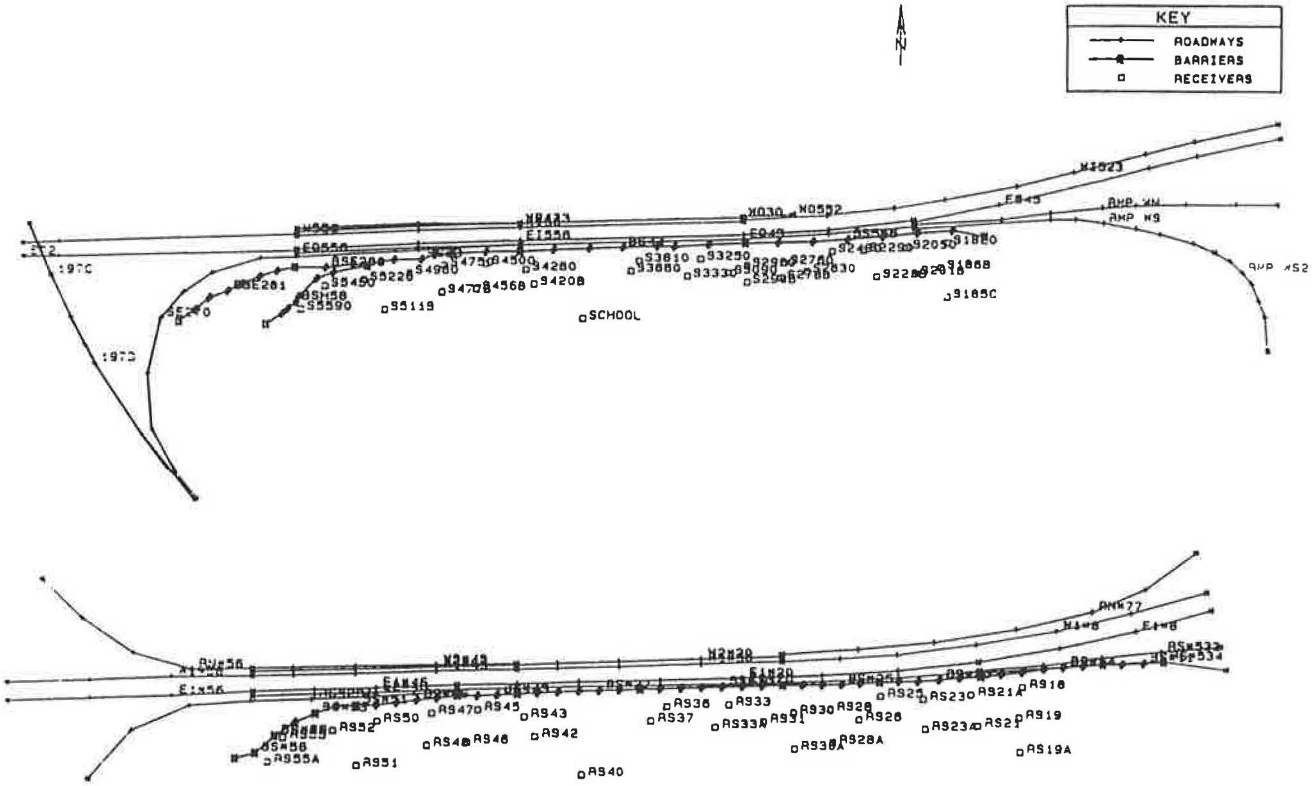
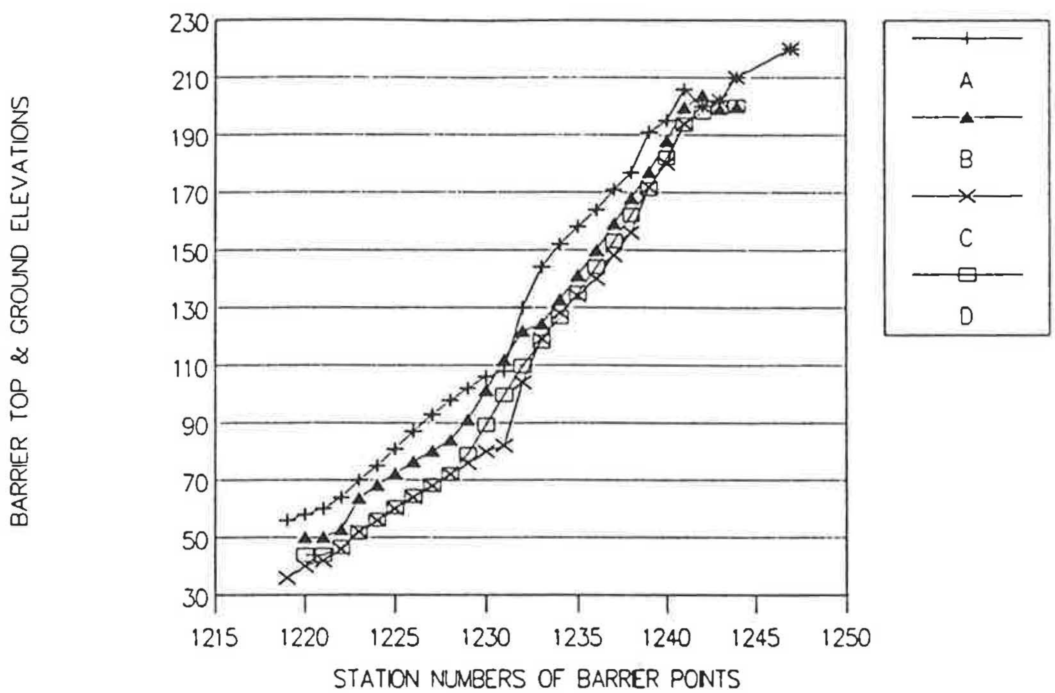


FIGURE 7 **I-68S plan view plots of files created by human experts (*top*) and by knowledge-based system (*bottom*).**



A: Barrier top elevations designed by human experts

B: Barrier top elevations designed by expert system

C: Ground elevations defined by human experts

D: Ground elevations defined by expert system

FIGURE 8 **Profile of initial barrier selected by system for STAMINA and final OPTIMA barrier designed by human experts.**

TABLE 2 COMPARISON OF SYSTEM AND HUMAN EXPERT RESULTS FOR I-68S CASE

(A) EXPERT SYSTEM'S DESIGN					(B) HUMAN EXPERT'S DESIGN				DIFFERENCES BETWEEN A & B		
RECEIVER ID	OFFSET (FT)	WITHOUT BARR (dB)	WITH BARR (dB)	IL (dB)	RECEIVER ID	WITHOUT BARR (dB)	WITH BARR (dB)	IL (dB)	WITHOUT NO-BARR (dB)	WITH W/BARR (dB)	IL (dB)
RS18	200	71.7	61.1	10.6	S1820	68.2	59.9	8.3	3.5	1.2	2.3
RS19	350	65.7	58.5	7.2	S186B	65.5	60.1	5.4	0.2	-1.6	1.8
RS19A	520	61.5	55.8	5.7	S185C	62.5	58.9	3.6	-1.0	-3.1	2.1
RS21	360	64.0	56.7	7.3	S201B	63.0	56.4	6.6	1.0	0.3	0.7
RS21A	200	71.9	62.4	9.5	S2050	70.3	60.5	9.8	1.6	1.9	-0.3
RS23	190	72.1	61.7	10.4	S2290	70.8	60.1	10.7	1.3	1.6	-0.3
RS23A	340	64.3	56.0	8.3	S223B	63.0	55.3	7.7	1.3	0.7	0.6
RS25	160	73.7	62.9	10.8	S2480	71.7	61.2	10.5	2.0	1.7	0.3
RS26	270	69.1	60.7	8.4	S2630	67.9	59.5	8.4	1.2	1.2	0
RS28	210	70.5	60.4	10.1	S2760	68.5	59.1	9.4	2.0	1.3	0.7
RS28A	375	61.3	52.8	8.5							
					S278B	63.5	54.8	8.7			
					S298B	63.8	55.4	8.4			
RS30	220	70.2	61.0	9.2	S2980	69.6	59.9	9.7	0.6	1.1	-0.5
RS30A	400	61.0	53.2	7.8							
RS31	260	66.1	58.3	7.8	S3090	68.5	60.3	8.2	-2.4	-2.0	-0.4
RS33	170	72.4	63.7	8.7	S3250	71.4	61.8	9.6	1.0	1.9	-0.9
RS33A	280	65.2	56.6	8.6	S3330	67.9	58.8	9.1	-2.7	-2.2	-0.5
RS36	170	71.8	61.3	10.5	S3610	72.2	60.4	11.8	-0.4	0.9	-1.3
RS37	240	66.6	57.5	9.1	S3660	70.3	60.2	10.1	-3.7	-2.7	-1
RS40	500	64.7	57.2	7.5	SCHOOL	61.6	53.9	7.7	3.1	3.3	-0.2
RS42	300	65.3	56.9	8.4	S420B	65.2	56.1	9.1	0.1	0.8	-0.7
RS43	200	70.9	61.0	9.9	S4260	70.3	59.8	10.5	0.6	1.2	-0.6
RS45	160	72.2	61.9	10.3	S4500	71.6	59.8	11.8	0.6	2.1	-1.5
RS46	320	64.4	56.4	8.0	S456B	64.1	55.0	9.1	0.3	1.4	-1.1
RS47	170	71.7	61.9	9.8	S4750	70.5	60.1	10.4	1.2	1.8	-0.6
RS48	330	63.9	56.3	7.6	S477B	62.7	55.0	7.7	1.2	1.3	-0.1
RS50	200	66.9	62.0	4.9	S4960	66.5	60.2	6.3	0.4	1.8	-1.4
RS51	420	62.7	55.9	6.8	S511B	61.2	54.8	6.4	1.5	1.1	0.4
RS52	240	67.5	59.2	8.3	S5220	66.9	57.9	9.0	0.6	1.3	-0.7
RS55	270	69.1	60.8	8.3	S5450	69.0	62.0	7.0	0.1	-1.2	1.3
RS55A	390	66.3	62.9	3.4	S5590	66.1	62.9	3.2	0.2	0.0	0.2

the creek at Station 18 for nonacoustical reasons. This nonacoustical concern could have been taken care of by a user of the system during a subsequent OPTIMA design session.

Two other receivers with significant differences in the predicted without-barrier noise levels are RS37 and RS40. In the system's design, RS37 was defined as a second row receiver and a 3-dB building shielding factor was introduced. The human experts, however, did not assign shielding to this receiver in their design. Conversely, for RS40 the human experts considered building shielding whereas the system did not. The situation of a partially shielded second-row receiver needs more consideration in future rule refinement with the system.

It is again important to note that the human expert design is the result of using the OPTIMA program whereas the knowledge-based system has only run the STAMINA program. It was not the objective of this work to have the system eliminate the use of OPTIMA, but to provide a good starting point for an engineer to use OPTIMA. The fact that the system gave initial results comparable to the humans' final OPTIMA results is an interesting and important side benefit of this work and supports the conclusion that the system is providing good results.

It is also important that the results of the knowledge-based system are obtained on the basis of the inputs provided by the user in response to the requests from the system. Thus, the user of the system, as it currently stands, is an integral part of the design system, and the accuracy of the responses is important for good performance of the system. The user must be able to react to the system's messages to read certain data from the plans and enter the data into the computer. This relatively extensive user interaction is a current weakness, but the system is still a substantial improvement over a person working without any type of input enhancement tool.

In general, comparison of the results presented in these figures and the table indicates that the knowledge-based system was able to create a good input file for a case as com-

plicated as this I-68 case. Both files consisted of approximately 350 lines of data. With the system, the STAMINA files were completed by one of the authors in about 8 hr. Producing this same file without the help of a preprocessor (or a digitizer) would easily take 2 person-days or more. With certain exceptions, the data produced by the system were accurate. Moreover, the insertion losses provided by the initial barrier heights determined by the system were comparable in some instances to the human experts' final design, which was accomplished using OPTIMA.

FINDINGS

The following findings are summarized from all the cases studied in this research:

1. The centerline module handled all cases without any conversion errors and provided the user a much more convenient scheme for data acquisition (i.e., station number coupled with offset).
2. For a fairly uniform site, it was found that the receivers could be generated automatically by the system. Obviously, for a large-scale project, this function could save a great deal of time in data input. This function was tested in one of the cases to ensure its accuracy.
3. The roadway configurations determined by the system were found to be as good as those modeled by the human experts. This finding was tested by the existing conditions of all the cases.
4. In general, the good agreement of the no-barrier predicted levels indicates that the system was properly choosing the best lateral location for the ground line barrier. Moreover, if more than one ground barrier exists in a receiver-source path (i.e., rolling terrain), the system could detect the location that would provide most nonbarrier shielding for the no-barrier model case, which is important in accurately predicting the no-barrier levels. However, the system has no means of judging the accuracy of a user-specified elevation.
5. For cases with complicated surface absorption conditions or building shielding, it was found that the system could generate the alpha and shielding matrices with limited information in a much shorter time than the human experts, and provide acceptable results in nearly all cases.
6. For a modeling area without steep roadway grades, the barriers designed by the system were found to be good enough not only to be used for a starting point for the STAMINA program but also to be comparable with the final designs accomplished by the human experts using OPTIMA. Thus, with the site as modeled by the system, the iterative design steps using OPTIMA could be reduced significantly.
7. For a site with steep roadway grades, the initial barrier specified by the system will not be as good as one specified for a roadway on a slight grade; however, the system still created a valid STAMINA input file. The rules used in choosing source-receiver pairs for the barrier attenuation analysis would have to be expanded to cover oblique angles to address this problem.
8. For sites with all receivers beyond 500 ft from the noise source, it was found that the design goal strategy for selecting an initial barrier height may not be suitable. However, in general, these receivers are rarely the controlling factor in highway noise control projects, and trying to accommodate this situation probably should have been beyond the scope of the system. Nonetheless, the system still produced an executable STAMINA file.
9. The memory size of the 80286 machine used in system development is a limiting factor for future enhancements. Useful future work probably should be done on an 80386 machine with expanded memory.

CONCLUSION

The system described in this research was developed to assess the potential for a knowledge-based approach for automating file creation for traffic noise modeling. The specific goal was to assist a user in creating a good initial input data file for the STAMINA 2.0 traffic noise prediction program in less time than without use of an input enhancement tool. The results have demonstrated that the system and its user can indeed produce large input files for relatively complex situations.

However, the system should still be considered in an operational prototype stage and some improvements would be helpful. These include (a) an expanded barrier height algorithm to use oblique analysis paths in addition to perpendicular paths, (b) more rules for identifying the factors for shielding and ground absorption, and (c) an expanded interactive environment that might include a graphic display feature for data presentation and more help information for the inexperienced designer.

Additionally, the full time-saving benefits of a knowledge-based approach to assistance in file creation will probably not be obtained until the system is interfaced at least with a digitizing system. Even then, the possibility of human error remains in entering elevation data, a problem faced by all current preprocessors. Ultimately, interface with a CAD-based roadway design system would eliminate many of the situations where human error could occur. Nonetheless, the system does not, will not, and should not eliminate human participation in the highway noise analysis or noise barrier design process.

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