CRT terminal. The second, PLOT, is for use with a CALCOMP-type hard-copy plotter. Because these programs are system specific and because their use is quite simple, they will not be discussed here.

Figure 1 shows an example of a plan (X,Y) view plot of a STAMINA input file named EX4.DAT. Figure 2 shows the profile plot (X,Z) for the same file. Figure 3 shows a levels plot (in plan X,Y) for a receiver in the STAMINA input file.

SUMMARY

Use of coordinate-based computer models for highway noise prediction has become widespread in recent years, with resulting increases in accuracy and design flexibility as well as in error potential. For such programs as STAMINA 1.0 and STAMINA 2.0, these errors can manifest themselves as resulting from reading coordinates from plans, from coding coordinates onto forms, and from typing data into computer files. Another problem associated with such models is analyst disorientation, where a preponderance of numbers may cause the analyst to lose his or her ability to visualize the physical meaning of the input and output.

VUTRG has developed an interactive computer graphics package named VUPLOT that allows the analyst to plot, either on a CRT screen or hard copy, plan or profile representations of roadways, barriers, and receivers. The SCHEME subroutine of VUPLOT allows the analyst to plot a labeled series of roadways, barriers, and receivers from either a standard STAMINA input file or from separate unlimited storage files for roadways, barriers, and receivers. The LEVEL subroutine allows the analyst to overlay segment noise level contributions for a particular receiver, on a plan view plot of selected roadways near that receiver.

REFERENCES

1. T.M. Barry and J.R. Reagan. FHWA Highway Traffic Noise Prediction Model. Federal Highway Administration, FHWA-RD-77-108, 1978.
2. F.F. Rudder, D.F. Lam, and P. Chueng. User's Manual: FHWA Highway Traffic Noise Prediction Model, STAMINA 1.0. Federal Highway Administration, FHWA-RD-78-138, 1979.
3. User's Manual: Barrier Cost Reduction Procedure, STAMINA 2.0 and OPTIMA. Federal Highway Administration, Arlington, VA, Draft Rept., 1982.
4. L.F. Cohn, W. Bowlby, and L.W. Casson. STAMINA 1.0 Experiences on the Dulles Access Highway Extension Project. TRB, Transportation Research Record 789, 1981, pp. 29-34.

Highway Construction Noise Modeling

WILLIAM BOWLBY AND LOUIS F. COHN

A model and interactive computer program for predicting highway construction noise levels have been developed and evaluated for the Federal Highway Administration (FHWA), as part of its on-going efforts to provide state-of-the-art tools for highway-noise analysis. The model addresses noise sources as points, lines, or areas and has a built-in data base for 53 different sources. Noise barrier attenuation may also be analyzed. The results of the calculations are the total 8-h equivalent sound levels [L_{eq}(8h)] at noise receptors as well as the individual contributions from each source. Use of the model will not be required by FHWA; however, the model can serve as a useful tool for meeting the requirements of the FHWA noise standards for impacted areas and for evaluating abatement measures. It may also be used during construction as a diagnostic tool for investigating citizen complaints and for designing mitigation strategies, if necessary.

In its efforts to provide the latest tools for analysis of highway noise, the Federal Highway Administration (FHWA) conducted a research project to develop a model and computer program for predicting levels of highway construction noise (1). At the completion of the project, Vanderbilt University was asked to evaluate the model and prepare a user's manual (2) and construction noise-analysis handbook. This paper outlines the highway construction noise model and program. It discusses basic features, data input requirements, program output, and several applications.

BACKGROUND

FHWA has recognized the need to address the impacts of highway construction noise from federal-aid projects for many years. The FHWA noise standards state that the following steps are to be performed when doing a highway noise study (3):

1. Identify receptors that are sensitive to highway construction noise;
2. Determine mitigation measures for those receptors impacted by construction noise, considering the cost and feasibility of such measures; and
3. Incorporate the needed abatement measures into the plans and specifications for the project.

The states were given total flexibility to meet the requirement of this paragraph. No maximum permitted noise levels were included in the noise standards, and the use of specific procedures to determine impact was neither specified nor required. FHWA thought that the level of effort applied for mitigation of construction noise depended on the type of project and its circumstances. Requirement of specific analysis techniques or imposition of maximum permitted noise levels would be an added regulatory incumberance that would often be more extreme than warranted.

However, FHWA recognized its leadership role in providing guidance to state noise analysts. As a result, it embarked on a program to provide state-of-the-art information on construction noise. The first part of this effort was an in-house staff study on highway construction noise measurement, prediction, and mitigation (4). This report presented simplified measurement and prediction tools and sample contract specifications for different categories of construction noise control. The report has served as a useful reference to state noise analysts for the last six years.

FHWA's second effort in the study of highway construction noise was a symposium held in 1977 on construction noise mitigation. It brought together experts from federal and state governments, contractors, equipment manufacturers, and consulting firms. The purpose of the symposium was to evaluate potential strategies for mitigation of construction noise and then develop a reference guide on mitigation. The resulting report has also served as a useful reference to state noise analysts (5).

The latest part of the FHWA efforts in the study of construction noise has been a research contract to develop a highway construction noise-prediction model and to demonstrate noise-abatement techniques at actual construction sites. Wyle Laboratories conducted the study and produced a series of unpublished reports that document its work. The study included extensive noise level and equipment operation monitoring at four major construction sites around the country. An analytical model for predicting construction noise was then developed by using the field operations to calibrate and validate the model. The abatement demonstrations included equipment muffling, equipment shielding, and equipment substitution.

Vanderbilt University was then called on by FHWA to take the Wyle Laboratories work and develop a clear, comprehensive reference for construction noise analysis. Work tasks included (a) evaluation of the Wyle results, (b) recommendations for computer program changes, (c) implementation of those changes, (d) preparation of a user's manual for the program, (e) preparation of simplified calculation methods, and (f) preparation of the comprehensive construction noise-analysis guide.

The final products of these efforts will give state noise analysts a set of state-of-the-art tools for addressing construction noise when deemed necessary and appropriate. The model permits detailed analysis of the impact of construction noise and permits analysts to design abatement measures for specific problem sites. However, by not requiring its use on federal-aid highway project studies, FHWA continues its efforts to minimize regulation while providing up-to-date analysis tools.

FEATURES

A review of previous attempts at modeling construction noise (both highway and industrial) reveals that such models contained numerous assumptions that reduced user flexibility (6). The intent, then, in this model's development was to maximize flexibility and applicability, which suggested implementation as a computer program. The model and resultant program developed by Wyle Laboratories was called HICNOM for highway construction noise model.

The model's basis for calculation is the 8-h equivalent sound level [$L_{eq(8h)}$]. An 8-h period was deemed approriate to represent a construction workday for the purpose of noise analysis. The results of the calculations would be the $L_{eq(8h)}$ at one or more noise receptors (receivers) from the variety of operations occurring on a construction site throughout the day.

Geometric Representation

Three geometric configurations were defined to represent noise sources

1. At a point,
2. Along a line, and
3. Over an area.

Examples of each would be a compressor, a motor grader or haul truck, and a bulldozer, respectively.

Attenuation of sound propagating from these sources is addressed in three ways:

1. Geometric wave spreading,
2. Excess attenuation due to interference with absorbing ground, and
3. Shielding by a physical barrier.

The excess ground attenuation feature allows the user to specify an excess attenuation rate in terms of decibels per doubling of distance (dB/DD) from a reference distance of 50 ft (15.2 m). Vanderbilt expanded this feature so that a separate rate could be specified for each receiver.

Barrier Attenuation

Barrier shielding is modeled by using Maekawa's formulation for point sources and the Kurze-Anderson incoherent line source method for nonpoint sources (1). Single equivalent frequencies are assigned to each source for the attenuation calculations.

Product Rate Coordination

The model is also designed to consider the situation where the operation of one type of equipment is dependent on another piece of equipment. An example would be where the number of trucks on a haul road would depend on the ability of a front-end loader to fill them. The model addresses such a situation through coordination of production rates. In the case just cited, the model would compute the number of trucks (N) based on their capacity (C_1) and the bucket capacity (C_2), cycle time (t_2), and duration of operation (T_2) of the loader.
Mathematically,

$$N = T_2 (C_2/C_1)(1/t_1) \quad (1)$$

where N is in terms of vehicles per hour.

Data Base

Based on the literature review and the data collection done as part of the model development, a noise level data base for 53 different equipment models was compiled. These models were grouped into 16 types of sources, as shown in Table 1. Examination of Table 1 reveals that a source type may represent a type of equipment (e.g., scraper) or a type of operation (e.g., concrete). The model numbers in Table 1, therefore, refer to particular equipment or operations, as appropriate.

Both the basic construction noise model and the computer program have flexibility for the addition of new sources or models for which the user has noise level and operational data. These sources may be permanently added to the program or specified on each computer run through use of a user-defined source entry.

Certain of the source types are automatically assigned to a particular geometric type. For example, pumps may only be analyzed as point sources. Other sources, such as a loader, may be analyzed as a point, line, or area source, depending on the situation.

Interactive Format

To facilitate use and provide flexibility, the computer program was written in an interactive format. The computer makes data requests to which the user responds. Based on the responses, the appropriate next question is asked. For example, if the user responded to the request, "enter source type", with "pump", the program would recognize

Table 1. Noise source data.

Type	Model No.	Description	Allowable Geometry Types[a]	Reference Level [dB(A)]	Source Acoustic Height (ft)	Source Acoustic Frequency (Hz)
Backhoe	1	Nominal[b,c]	1, 2, 3	83.5	6	500
	2	Caterpillar, Koehring	1, 2, 3	85	6	500
	3	P&H	1, 2, 3	89	6	500
	0[d]	Defined by user	1, 2, 3	UD[e]	UD[e]	UD[e]
Loader	1	Nominal[b,c]	1, 2, 3	84	6	500
	2	3-yd capacity	1, 2, 3	76	6	500
	3	5-yd capacity	1, 2, 3	77	6	500
	4	7-yd capacity	1, 2, 3	78	6	500
	5	10-yd capacity	1, 2, 3	80	6	500
	0[d]	Defined by user	1, 2, 3	UD[e]	UD[e]	UD[e]
Compressor	1	Nominal[b,c]	1	89.3	4	1000
	2	Standard	1	86	4	1000
	3	Quiet, doors open	1	75	4	1000
	4	Quiet, doors closed	1	65	4	1000
	0[d]	Defined by user	1	UD[e]	UD[e]	UD[e]
Pile driver	1	Nominal[b,c]	1	91.3	20	1500
	2	Current data	1	107	20	1500
	0[d]	Defined by user	1	UD[e]	UD[e]	UD[e]
Pump	1	63 dB at 50 ft	1	63	4	800
	2	76 dB at 50 ft	1	76	4	800
	3	Nominal[b,c]	1	71	4	800
	0[d]	Defined by user	1	UD[e]	UD[e]	UD[e]
Crane	1	Nominal[b,c]	1	81.5	15	500
	2	Low	1	65.5	15	500
	3	Medium	1	74	15	500
	4	High	1	77.5	15	500
	0[d]	Defined by user	1	UD[e]	UD[e]	UD[e]
Breaker	1	Rock drill, nominal[b,c]	1, 2, 3	89	2	1500
	2	Standard jackhammer, nominal[b,c]	1, 2, 3	80	2	1500
	3	Muffled jackhammer	1, 2, 3	69	2	1500
	0[d]	Defined by user	1, 2, 3	UD[e]	UD[e]	UD[e]
Concrete	1	Concrete pour[b]	1	73	10	500
	2	Nominal batch plant[b,c]	1	90	10	500
	3	Batch plant	1	82	10	500
	4	Pump[b]	1	85	6	500
	5	Cement mixer[b]	1	82.8	8	500
	0[d]	Defined by user	1	UD[e]	UD[e]	UD[e]
Generator	1	Low level	1	73.5	4	1200
	2	Nominal[b,c]	1	81	4	1200
	0[d]	Defined by user	1	UD[e]	UD[e]	UD[e]
Miscellaneous	1	Grinder[b]	1	71	2	1200
	2	Concrete saw[b]	1	88	1	1200
	3	Fan[b]	1	83	4	1200
	4	Welder, nominal[b,c]	1	71	4	1200
	0[d]	Defined by user	1	UD[e]	UD[e]	UD[e]
Bulldozer	1	Nominal[b,c]	1, 2, 3	88.1	6	500
	2	Caterpillar D6, D7, D8	1, 2, 3	78	6	500
	3	Caterpillar D9	1, 2, 3	83	6	500
	4	D9 without muffler	1, 2, 3	94	6	500
	0[d]	Defined by user	1, 2, 3	UD[e]	UD[e]	UD[e]
Grader	1	Nominal[b,c]	1, 2, 3	83	8	500
	0[d]	Defined by user	1, 2, 3	UD[e]	UD[e]	UD[e]
Compactor	1	Low	3	80	8	500
	2	Nominal[b,c]	3	86	8	500
	3	High	3	93	8	500
	0[d]	Defined by user	3	UD[e]	UD[e]	UD[e]
Paving	1	Nominal[b,c]	1, 2, 3	83.8	4	500
	2	Concrete paver	1, 2, 3	82.8	4	500
	3	Asphalt paver	1, 2, 3	82.5	4	500
	0[d]	Defined by user	1, 2, 3	UD[e]	UD[e]	UD[e]
Trucks	1	10-yd dump, quiet	4	-[f]	8	500
	2	10-yd dump, noisy	4	-[f]	8	500
	3	Dual 20-yd trailers	4	-[f]	8	500
	4	Nominal[b,c]	4	-[f]	8	500
	0[d]	Defined by user	4	UD[e]	UD[e]	UD[e]
Scraper	1	Caterpillar 631, muffled	4	84	6	500
	2	Caterpillar 631, not muffled[b,c]	4	95	6	500
	3	Caterpillar 623	4	90	6	500
	4	Caterpillar 637	4	81	6	500
	0[d]	Defined by user	4	UD[e]	UD[e]	UD[e]

[a] 1 = point, 2 = nonhaul line, 3 = area, and 4 = haul line.
[b] Use this model number if a generalized value is needed.
[c] "Nominal" means that the data represent an averaging of data from previous literature.
[d] A model number of zero means that the user has different reference level height and frequency data.
[e] UD = user-defined.
[f] See Figure 3.

"pump" as a point source and respond with, "point source - enter location (X,Y,Z)."

Cartesian Coordinates

All geometric data are specified in terms of Cartesian coordinates. For example, line sources are defined by a series of endpoints that are connected by straight-line segments. Although use of coordinates complicates data input, it allows specification of many receivers, sources, and barriers in the same computer run, which ultimately leads to saving analyses time. Current program limits are set at 10 receivers, 10 point sources, 6 line sources, 5 area sources, and 3 barriers; however, these limits are easily modified.

POINT-SOURCE MODEL

The first type of source geometry to be discussed is the point source. Examples of point source include stationary equipment such as a compressor, quasi-mobile equipment such as a rock drill, and mobile equipment such as a backhoe. The particular source types in the program that may be analyzed as points, as listed in Table 1, are as follows:

1. Crane,
2. Pump,
3. Compressor,
4. Generator,
5. Pile driver,
6. Paving,
7. Concrete,
8. Backhoe,
9. Loader,
10. Breaker,
11. Bulldozer, and
12. Miscellaneous

The point source model is as follows:

$$L_{eq(8h)} = \text{Maximum reference emission level} - \text{Cycle time adjustment} - \text{Usage factor} - \text{Distance adjustment} - \text{shielding adjustment} \quad (2)$$

The first two terms represent the L_{eq} over the duty cycle of the equipment. They are specified in this manner because most of the data on emission levels in the literature are reported as maximum levels. The usage factor accounts for equipment operation for less than a full 8-h day. The distance adjustment is based on a 6 dB/DD rate plus an excess ground-attenuation rate, if specified by the user. As previously stated, barrier shielding calculations are based on Maekawa's formulation.

In analyzing barriers at absorptive sites, the program compares the excess ground attenuation to the barrier attenuation and does not show any noise reduction due to the barrier until barrier attenuation exceeds the soft site ground attenuation. This is a simplistic, yet reasonable, attempt to address the real-world problem of the possible loss of excess ground attenuation due to the insertion of a barrier because of the elevation of the effective height of the source to the top of the barrier.

LINE SOURCES

The model and program classify line sources as either haul or nonhaul; each is analyzed differently. The haul sources in the program are trucks and scraper. The nonhaul sources are backhoe, loader, bulldozer, grader, and paving.

Nonhaul Line Sources

A nonhaul line source may be considered conceptually as a point source that has its sound intensity spread out along a line. As such, it is modeled by

$$L_{eq(8h)} = \text{Maximum reference emission level} - \text{Cycle time adjustment (if appropriate)} - \text{Usage factor} - \text{Source density adjustment} - \text{Distance adjustment} - \text{Finite line segment adjustment} - \text{Barrier shielding} \quad (3)$$

The first three terms are similar to those for the point source. The source is spread along the line through the source density adjustment. This adjustment is simply a logarithmic function of the inverse of the length of the line along which the source is traveling.

The distance adjustment is based on a 3 dB/DD rate with excess ground attenuation, as appropriate. The finite line-segment adjustment scales down the contribution of a finite segment from the theoretically infinitely long line on which the calculation is initially based. Barrier shielding is done by using the Kurze-Anderson incoherent line-source model. To analyze sources and barriers accurately with changing vertical profiles, the program divides the barrier into successively smaller segments until the change in total attenuation from additional divisions is less than 0.4 dB.

Note that the speed of the nonhaul line source does not affect the L_{eq}. This is because the emission levels for these sources are independent of speed. Thus, the L_{eq} contribution from a fast-moving source that makes many passes by a receiver (e.g., a grader) would equal that from a slow-moving source that makes one pass (e.g., paving), all other parameters being equal.

Haul Line Sources

The second type of line source in HICNOM is the haul line source, that is, equipment involved in earth-hauling operations. The two specific source types in the model are trucks and scrapers. The modeling is analogous to that used in the FHWA highway traffic noise prediction model (7). In its simplest form, the 8-h equivalent sound level may be predicted by,

$$L_{eq(8h)} = \text{Reference emission level} + \text{Flow adjustment} - \text{Distance adjustment} - \text{Finite line segment adjustment} - \text{Barrier shielding} \quad (4)$$

For trucks, the reference emission level is a logarithmic function of vehicle speed; for scrapers, it is independent of speed. The flow adjustment is a logarithmic function of the ratio of the average hourly volume of vehicles to their average speed. The distance, finite segment, and barrier adjustments are the same as for the nonhaul line sources.

One feature of the HICNOM program is the capability of generating a turn-around loop at the end of the haul road. Figure 1 shows the seven types of loop recognized by the program (type 7 is actually not a loop but more of a U-turn). Given the type of loop and its radius by the user, HICNOM will compute the coordinates of a series of points on the loop. In this manner, the loop is approximated as a series of straight-line segments.

Another feature of HICNOM is then put into use. The program has an acceleration-deceleration profile built into it that will compute an average speed on each segment of the loop based on the loop type and approach and departure speeds. Figure 2 illustrates loop generation, where three line points (A,B, and C) and a type-6 loop with radius r were given.

The acceleration-deceleration feature is also useful where the haul vehicles are dropping their loads without immediately turning around. The program can be instructed to decelerate and accelerate the vehicles around some loading-unloading point along the line.

Figure 1. Types of haul road loops recognized by HICNOM.

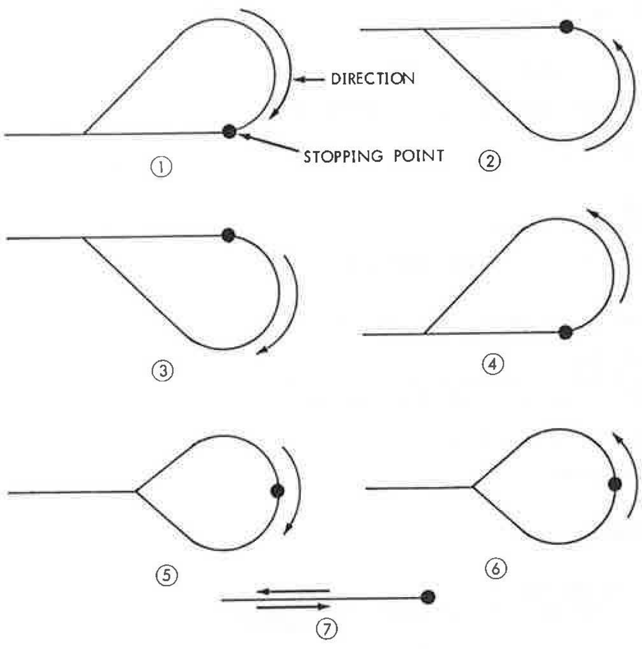
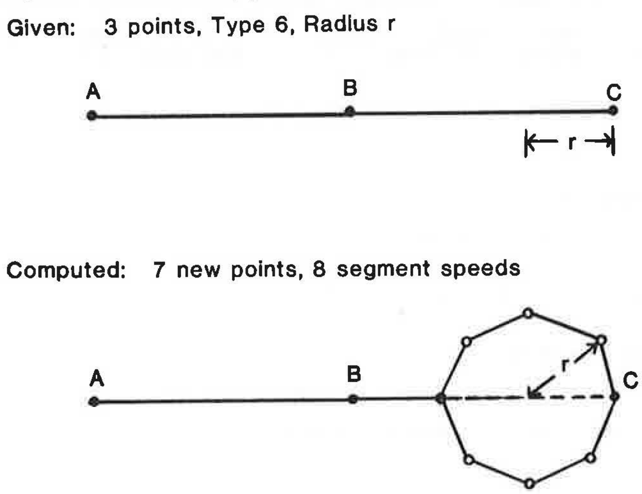


Figure 2. Illustration of loop-generation concept in HICNOM.



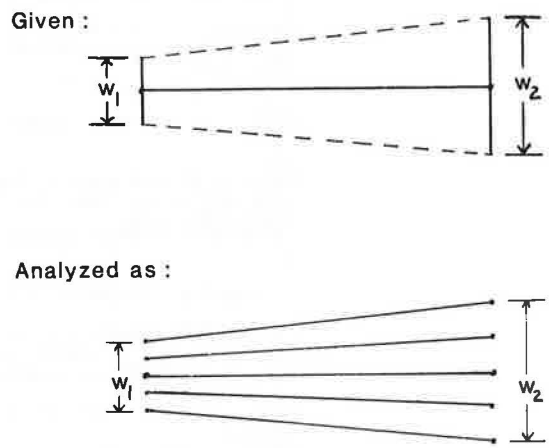
AREA SOURCE

The third geometric category is the area source. Examples would include bulldozers involved in clearing and grubbing or compactors working in a fill area. Six sources may be analyzed by the computer program as area sources:

1. Compactor,
2. Bulldozer,
3. Loader,
4. Backhoe,
5. Paving, and
6. Grader.

Area sources are analyzed by representing the area as a series of four-sided subareas and then breaking each subarea into a series of strips. Each strip is then represented as a nonhaul line source. Figure 3 illustrates schematically the area source approximation for one subarea. The number of strips that the area is divided into is a function of the area's width and the distance from the area's centerline to the nearest receiver. The intensity of

Figure 3. Area sources defined by a centerline and end widths and simulated as a series of nonhaul line sources.



the source is then divided among these lines and spread along them as is done for a regular nonhaul line source.

PROGRAM FORMAT

HICNOM is an interactive FORTRAN program. The user enters data by responding to program requests. The creation of a data file for a one source-one receiver problem is illustrated in Figure 4. The first line of each pair of lines represents the computer request, and the second line is the user response, which has been underlined. During this data entry, HICNOM will make decisions based on the responses as well as some intermediate calculations. It will then create an intermediate data file that contains three types of data:

1. User-supplied (coordinates, source types description, and user-defined data);
2. Program-supplied (source frequency and height); and
3. Program-calculated [L_{eq} (reference), source density, and loop point coordinates].

The user may obtain a printout of this file for project documentation. Figure 5 illustrates the data file report for the data illustrated in Figure 4.

HICNOM will then read from this intermediate file to do its final L_{eq} calculations and produce a report on the results. This report contains the total $L_{eq(8h)}$ for each receiver as well as the contributions from each source. For line and area sources, these contributions are broken down by segment. This breakdown provides a good diagnostic tool for assessing problem areas and evaluating abatement measures. Figure 6 presents the results report for the data in Figures 4 and 5.

MODEL APPLICATIONS

FHWA does not require that construction site noise be analyzed through modeling; the analyst is left to judge the need for modeling. However, the federal highway program manual (3) does require that the potentially impacted sensitive areas be identified and abatement measures be developed where needed and feasible. HICNOM is an appropriate tool for meeting either of these requirements.

First, it may be used during project planning and design as a screening tool for potentially impacted areas. Construction noise is generally studied by

Figure 4. Interactive data input for example problem.

```
ENTER TITLE FOR THIS PROBLEM:
EXAMPLE OF ONE SOURCE AND ONE RECEIVER
ENTER NUMBER OF RECEIVERS (MAXIMUM IS 10)
1
ENTER A DESCRIPTION OF RECEIVER # 1
(MAXIMUM OF 16 CHARACTERS - BLANK IF NONE)
1012 MAIN ST
ENTER X, Y, Z AND EXCESS ATTENUATION (DB/DD) FOR  RECEIVER # 1
0 0 0 1.5
ENTER SOURCE TYPE - BLANK IF FINISHED

PUMP
ENTER A DESCRIPTION OF THE SOURCE
(MAXIMUM OF 16 CHARACTERS - BLANK IF NONE):
NEAR PROP. LINE
ENTER MODEL NUMBER (ENTER 0 TO DEFINE NEW MODEL NUMBER)
1

PROGRAM HAS AUTOMATICALLY ASSIGNED A GEOMETRY TYPE TO THIS SOURCE

ENTER HOURS WORKED DURING 8-HOUR DAY
(ENTER -1 TO COORDINATE THIS SOURCE'S PRODUCTION RATE WITH THAT OF
THE LAST PREVIOUSLY ENTERED SOURCE HAVING A  PRODUCTION RATE)
8
POINT SOURCE:  ENTER X, Y, Z OF SOURCE LOCATION
30 30 0
ENTER SOURCE TYPE - BLANK IF FINISHED
______
ENTER NUMBER OF BARRIERS (MAXIMUM IS 3)
0

ENTER THE NAME OF THE FILE FOR HICNOM USE;
MAXIMUM OF 10 (6.3) CHARACTERS, DEFAULT = HICNOM.DAT :  EXTRB.DAT
```

Figure 5. Example of input data file.

```
EXAMPLE OF ONE SOURCE AND ONE RECEIVER
  1  RECEIVERS
       X          Y          Z       EX. ATT.(DB/DD)     DESCRIPTION
      0.00       0.00       0.00    1.5000000       1012 MAIN ST.
  1  POINT SOURCES
       X          Y          Z        LEQ(REF)    FREQ.    SOURCE          DESCRIPTION
     30.00      30.00       4.00       63.00     800   PUMP    1        NEAR PROP. LINE
  0  LINE SOURCES
  0  AREA SOURCES
  0  BARRIERS
```

Figure 6. Example of results report.

```
EXAMPLE OF ONE SOURCE AND ONE RECEIVER

RECEIVER NUMBER           LEQ            DESCRIPTION


           1              64.8        1012 MAIN ST.


COMPONENT CONTRIBUTIONS FOR RECEIVER NUMBER:  1

INDEX   INTENSITY    LEVEL      SOURCE              DESCRIPTION

    1   0.300839E+07  64.8     PUMP     1         NEAR PROP. LINE


KEY TO INDEX:
     X - POINT SOURCE, WHERE X OR XX IS INPUT SEQUENCE # OF POINT SOURCES.
    XX
   YXX - LINE SOURCE, WHERE XX IS INPUT SEQUENCE # OF LINE SOURCES
  YYXX                      AND Y OR YY IS SEQUENCE # OF POINTS FOR THE XXTH LINE.
 1YYXX - AREA SOURCE, WHERE XX AND YY ARE ANALAGOUS TO LINE SOURCE VARIABLES.
```

construction phase (1,4,5). With some knowledge of project features, such as location of structures and major cuts and fills, and with some general assumptions about duration of phase and typical equipment used in the phase, an initial assessment of potential problem areas can be made.

During final design, where exact locations of cuts, fills, and structures are tied down and where there is better knowledge of needed construction operations such as rock drilling or pile driving, the model may be used to refine impact assessments and quantify impact. At this point, use of the model as an abatement design tool would be appropriate. Temporary noise barriers near sensitive sites may be analyzed and designed. The effectiveness of a strategy of building traffic noise barriers early in the project construction may be evaluated. The use of work-hour limitations or alternative equipment or processes may be studied. Recommendations or restrictions on the location of haul roads, material stockpiles, or stationary equipment can be developed.

When construction is under way, the model may be used as an assessment tool if citizens complain about the construction noise levels. The model would allow the major noise sources and their sound level contributions to a particular receiver to be identified. If the severity of the impact or the strength of the complaint warrants action, the model may be used to evaluate the effectiveness of potential abatement measures.

For example, use of the model near a rock drill site might show that a requirement to use compressors that meet U.S. Environmental Protection Agency standards would be ineffective because they contribute little to the total level that is dominated by the drills. Instead, the model might show that a temporary noise barrier of a certain height along the right-of-way line would provide adequate noise reduction. In another situation, for example, the model might show that a temporary barrier would be ineffective but that a strategy such as shifting the location of the haul road to take advantage of terrain shielding would provide significant noise reduction.

SUMMARY

A model and interactive computer program for predicting highway construction noise levels, called HICNOM, has been developed for FHWA. The model addresses noise sources as points, lines, and areas and also calculates noise-barrier insertion loss. A data base for 53 types of equipment and models has been developed from extensive field measurements and a literature review. The final product of the computer program is a list of $L_{eq(8h)}$ at each noise receptor as well as the contribution from each noise source.

Although use of the model is not required by FHWA, HICNOM can serve as a useful tool for identifying potentially impacted areas, quantifying that impact, designing abatement measures, and evaluating their potential effectiveness. Vanderbilt University has developed a manual calculation method and a series of programs for a handheld programmable calculator (Texas Instruments TI-59) based on the HICNOM model.

ACKNOWLEDGMENT

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REFERENCES

1. K.J. Plotkin. A Model for the Prediction of Highway Construction Noise. Wyle Research, Arlington, VA, Rept. WR 80-58, 1980.
2. Highway Construction Noise: Environmental Assessment and Abatement, Volume IV: User's Manual for the FHWA Highway Traffic Noise Prediction Model. Vanderbilt Univ., Nashville, TN, Draft Rept. VTR 81-3, 1981.
3. Procedures for the Analysis and Abatement of Highway Traffic Noise and Construction Noise. Federal-Aid Highway Program Manual, FHWA, Vol. 7, Chpt. 7, Sect. 3, 1974.
4. J.A. Reagan and C. Grant. Highway Construction Noise: Measurement, Prediction, and Mitigation. FHWA, 1975.
5. Report of the 1977 Symposium on Highway Construction Noise. FHWA, Rept. FHWA-TS-77-211, Federal Highway Administration, 1978.
6. W.R. Fuller and others. Summary Report: Task A Literature Review: Highway Construction Noise. Wyle Research, El Segundo, CA, Rept. WR 79-3, 1979.
7. J.A. Reagan and T. Barry. The FHWA Highway Traffic Noise Prediction Model. FHWA, Rept. FHWA-RD-77-108, 1978.

Noise Control Through Land Use Planning: The Calgary Case

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Noise attenuation measures are not often seen as an integral part of roadways. The need for attenuation, however, is determined by the adjacent land use and its noise sensitivity. Calgary, Alberta, Canada, uses land use planning and land use development as a major way of providing attenuation for surface transportation noise sources. Through enabling provincial legislation, the city has the mandate to negotiate attenuation measures as a condition of residential developments. Three scenarios provide opportunities to attain the design noise level objective of 60 dB (A) $L_{eq}(24)$: (a) construction or upgrading of a roadway adjacent to existing development, (b) development or redevelopment adjacent to an existing transportation corridor, and (c) development or redevelopment adjacent to a future transportation corridor. To take advantage of these three opportunities, the concept of potential noise impact zones was developed and is being integrated into the normal planning process to assist in flagging potential noise problems. The procedures and practices have been in place on an informal basis for several years and have proved successful in obtaining livable residential noise environments.

Calgary is becoming the economic center of Alberta's oil-based prosperity and a major financial center in western Canada. Located on the eastern edge of the Canadian Rockies, it is similar to Denver, Colorado, in terms of location, prosperity, and growth. Alberta's tremendous oil resources and resultant booming petroleum industry liken it to Houston and Dallas, Texas.

Calgary typifies growth and economic opportunity, perhaps better than does any other major center in Canada. The oil industry and a prosperous agricultural community provide both a strong regional economy and a vibrant local economy. The favorable employment market has created a growth rate of roughly 5 percent/year; some 2000 people take up residence in Calgary each month.

To provide the necessary services, utilities, and urban amenities for a rapidly growing population of 600 000 is both a challenge and a nightmare for planners, engineers, politicians, and citizens. The demand for housing has made the Calgary area a desirable place for land developers. During the 1970s, Calgary's total area grew to approximately 195 miles^2 through annexation, primarily initiated by the development industry. This reserve of developable land was needed to provide Calgarians with housing and associated urban amenities. One of these amenities is the provision of a good transportation network.