Enhancements for Computer-Based Environmental Models

WILLIAM BOWLBY, LOUIS F. COHN, BOGUE WALLER, and ROSWELL A. HARRIS

ABSTRACT

The procedures and techniques used to predict environmental impacts of transportation projects have been enhanced significantly in recent years. One of the remaining parts of an environmental study that is time consuming and error prone, however, is the creation of the input data files, particularly data on coordinates such as those for highways, noise barriers, and receptors. To overcome this problem, the Vanderbilt University Transportation Research Group has developed an interactive computer digitizing system, DIGIT-1, designed to measure and record coordinate data for input to the FHWA STAMINA 2.0 highway noise prediction program. The system allows recording of coordinates from plans of any size and scale and produces a practically complete, formatted STAMINA input file. Use of the system at Vanderbilt has resulted in reduction by more than half of data-file creation time in addition to significantly improved accuracy. The interactive measurement and recording of coordinates through the use of the DIGIT-1 system is examined in detail as well as enhancements for other environmental models.

Over the last dozen years, numerous improvements have been made to computer programs used to study noise and air quality impacts of proposed transportation projects. These improvements may be divided into four major categories:

1. Input,
2. Data bases,
3. Calculation algorithms, and
4. Output.

IMPROVEMENTS TO COMPUTER PROGRAMS

Input

One of the earliest enhancements regarding data input was the development of preprinted coding forms that were specific to each program. Such forms permitted the user, while working over highway plans, to organize the needed input data in the format and order required for program execution before keypunching or program execution. Examples include forms for the FHWA STAMINA 1.0 noise prediction program (1,2) and for the FHWA SNAP 1.1 noise prediction program (3).

A second major enhancement for data input was the development of interactive data-input modules within the programs. Rather than assembling a deck of cards or creating a data file external to program execution, the user could work at a computer terminal and enter the data in response to a series of requests from a program. Chances for format or sequence errors were greatly reduced because the user would simply follow the step-by-step requests of a program. Examples of programs with interactive data-input modules include the early Michigan computerization (4) of the NCHRP Report 117 model (5), the Florida modification (6) to the CALINE air quality model (7), the California version (8) of the FHWA STAMINA 2.0 program (9), and the FHWA highway construction noise model (10,11).

Data Bases

The second category of enhancements deals with data bases. For traffic noise prediction models, a major revision to the data base for truck emission levels was made in the mid-1970s with the dividing of truck data into two classifications: heavy (three or more axles) and medium (two-axle, six-tire) (12,13). Current FHWA regulations (14) require traffic noise studies to be done with these emission levels or levels determined by a state agency following prescribed measurement procedures (15). California, Michigan, New Jersey, and Georgia have conducted such measurement programs to determine statewide emission levels (16,17). In addition, more specialized studies have been conducted to determine levels from slow-speed trucks (18), buses (19), and other transit vehicles (20).

Algorithms

The third area of enhancements deals with the algorithms that form the heart of a prediction model. For noise from freely flowing traffic, the independently developed NCHRP and Transportation Systems Center (TSC) models (15,21) underwent a series of modifications and refinements through the 1970s (22-24) that were ultimately integrated into the FHWA Highway Traffic Noise Prediction Model in 1978 (25). These modifications dealt with virtually all of the prediction algorithms, including emission levels, propagation, barrier attenuation, nonbarrier shielding, effects of roadway grade, and sound level descriptors.

The FHWA model was first computerized as the SNAP 1.0 program (26), and later a major revision was made to the TSC MOD-04 program (24), resulting in STAMINA 1.0 (27). STAMINA 1.0 was subsequently modified as STAMINA 2.0 for use with the interactive noise barrier optimization program OPTIMA (9). STAMINA 2.0 algorithm revisions included changes to functions dealing with excess ground attenuation in the presence of barriers and nonbarrier shielding.

New developments continue to be made in the modeling of sound propagation over barriers and ground (28), reflections between parallel highway noise barriers (29), and stop-and-go urban traffic noise (30).

There have also been many air quality models developed over the years for handling various situations and conditions that may be encountered in analyzing impacts of a new or expanded highway. Although many of these models use different mathematical approaches, they can be divided into two major categories: emission and dispersion (diffusion).

Emission modeling consists of calculating the total rate of pollutant emissions by motor vehicles

on a given highway network. The output of this effort is used as part of the input for the dispersion modeling. These models are also useful in network analysis techniques used in assessing the effects of the overall transportation plan in urban areas.

The state-of-the-art emissions model is MOBILE-2, developed by the U.S. Environmental Protection Agency (EPA) Office of Mobile Source Air Pollution Control (31). MOBILE-2 is a refinement of MOBILE-1 (32), which was originally developed by EPA as a means of more accurately calculating carbon monoxide (CO), hydrocarbon, and nitrogen oxide emissions of highway traffic.

Dispersion models have experienced even more development. HIWAY-2 (33) is the second-generation microscale dispersion model originally published by EPA in 1975. Similar to HIWAY-2, CALINE-3 is a third-generation dispersion model developed by the California Department of Transportation (7). Both HIWAY-2 and CALINE-3 are accepted by EPA as state-of-the-art models for calculating inert pollutant concentrations (e.g., CO) produced by vehicular traffic over short time periods.

There are also dispersion models available for calculating inert pollutant concentrations at intersections. EPA's Intersection Midblock Model (IMM) was released in 1978 (34). Less rigorous procedures for estimating pollutant concentrations at intersections include the use of the Hot Spot Guidelines (35) and "Volume 9" (36), both of which were developed by EPA.

The most recent intersection analysis model to be released is the Texas Intersection Model (TEXIN) (37), which was developed jointly by the Texas Transportation Institute and the Texas State Department of Highways and Public Transportation under the sponsorship of FHWA. TEXIN incorporates the MOBILE-2 and CALINE-3 models with established traffic and excess emission techniques to produce a model capable of estimating CO concentrations at simple signalized intersections.

Output

The fourth area of enhancements for environmental models is output. Some early basic modifications dealing with layout of results tables have greatly improved readability and usability of the computer printout (3,9). Also, the development of the fully interactive OPTIMA program provided designers with immediate feedback on design changes (9). Finally, the introduction of graphics for the plotting of plan and profile views of data files has demonstrated significant usefulness for detection of input data errors, improved analysis, and study documentation. Plotting programs have been developed by Vanderbilt University for both the STAMINA noise prediction program (38) and the CALINE-3 air quality prediction program (39) and by FHWA as part of its enhanced version of STAMINA 2.0.

DIGITIZING

In its continuing efforts to advance the state of the art in environmental modeling, the Vanderbilt University Transportation Research Group has recently developed another enhancement that has significantly improved data file creation: use of a computer digitizing system to automatically record the coordinates by which a highway project is modeled. This system is currently in use at Vanderbilt University for highway noise modeling with the STAMINA 2.0 program.

Advantages of Digitizing

In order to observe the advantages of the system called DIGIT-1 more clearly, a review of the traditional procedure for modeling a highway noise project, that is, the preparation of a STAMINA 2.0 input data file, is presented. First, each roadway and planned noise barrier is represented by a series of straight line segments; each segment terminus is an (x,y,z) set. Each receiver is represented by a single (x,y,z) set. Next, the numerical values (i.e., coordinates) for all of these (x,y,z) sets must be determined. Typically this is accomplished by overlaying a grid system onto the highway plans and scaling off the coordinates manually. Once these coordinates have been obtained, they must be organized. This step is usually handled by filling out coding forms. From the coding forms, the data are typed into a file at a computer terminal or punched onto cards. At that point, graphics programs may be used to view the scenario, and the analyst may begin to correct any human errors that have occurred during the manual process. For example, Figure 1 shows how a miscoded data point would appear on the graphics display.

Experience indicates that errors can easily occur, because these numbers are manipulated so much by hand and eye. Potential trouble includes incorrect reading of the scale when the coordinates are measured; incorrect writing of the coordinates on the plans or the coding forms, such as interchanging the x and y coordinates or filling in the wrong box; and miskeying or misreading when the data are entered into the computer.

The digitizing program eliminates most of these sources of error and at the same time significantly reduces the time necessary to produce a data file. The process is briefly described in the following, with a more detailed explanation of the hardware and software. The process follows the same steps as those previously described but the computer handles most of the data manipulation. This in turn speeds the process and minimizes the possibility of human error.

The roads, barriers, and receivers are represented on the plans in the same way; however, rather than measurement of the coordinates by hand, the plans are placed on a digitizing table where the computer can measure the coordinates of any spot activated by the user. The user touches the locations to be measured while interactively communicating the significance of each point, that is, which road, barrier, or receiver, to the computer. The
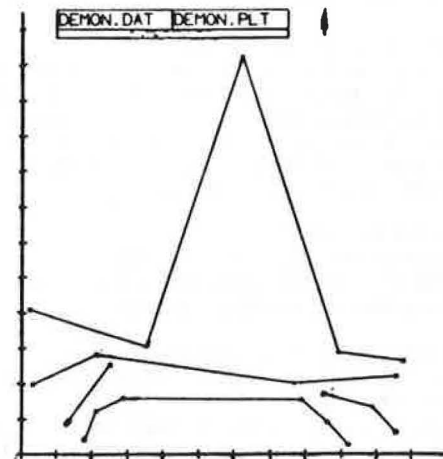

FIGURE 1 Miscoded point in data.

computer stores all of this information and at the
end of a session writes it into a properly formatted
STAMINA 2.0 input file. This file, being no differ-
ent in format from any other STAMINA 2.0 file, may
be edited, changed, rearranged, and so forth, as
desired. The entire digitizing process can be com-
pleted in approximately the same time that it takes
to manually scale the points by hand. Time otherwise
spent in writing coordinates onto the plans or cod-
ing forms or both and in keypunching them into the
computer is saved. In addition, the time spent cor-
recting errors is practically eliminated because of
the greater accuracy of the digitizing system.

Digitizing System

The Vanderbilt digitizing system uses Tektronix
graphics equipment. When it is connected to a DEC-
System 1099 mainframe computer, it is possible to
use the graphics equipment directly from a FORTRAN
program such as DIGIT-1. It should be noted, how-
ever, that the concepts laid out here could easily
be adapted to other computers and other graphics
equipment.

The digitizing station consists of three main
components. First there is a Tektronix 4954 tablet
(or table) on which the plans are laid. Next there
is the cursor, which is used to touch a spot on the
plans, which are secured to the table. Finally there
is a Tektronix 4010 terminal with a screen and a
keyboard.

The analyst touches a point with the cursor, the
table measures the coordinates, and the terminal
allows control over the whole process. The graphics
tablet consists of a series of small wires wound
parallel to the x and y axes. The cursor generates a
magnetic field, and the circuits in the tablet can
determine where the cursor is by sensing which of
the many wires has a current induced in it. The
Tektronics 4954 tablet used at Vanderbilt has a
resolution of 0.01 in., which on a typical scale of
1 in. = 200 ft on highway plans amounts to 2 ft.
Ordinary use of the system has resulted in an ac-
curacy of approximately 3 to 5 ft at this same
scale. This is deemed to be sufficiently accurate.

Use of DIGIT-1

After initiation of the DIGIT-1 program, the screen
displays instructions to arrange the plans and then
to press the RETURN key when ready. The portion of
the plans that is of interest should be arranged on
top of the table and taped down so that it cannot
move.

The next step is to orient the axes of the plan
sheet. North can be up or down or some arbitrary
direction. In order for the system to maintain
proper orientation, however, an initialization pro-
cess must be completed each time the plans are
moved, as shown and then described in the following
(user responses are underlined):

ARRANGE PLANS ON TABLE.
PRESS <RETURN> WHEN READY TO CONTINUE
          (the user tapes down the appropriate part of
          the plans and presses <RETURN>)

DIGITIZE FIRST POINT FOR INITIALIZATION
          (the user digitizes a point in a corner of
          the pad)
WHAT IS THE X-COORD, IN FT. OF THAT POINT? 3000
WHAT IS THE Y-COORD. IN FT. OF THAT POINT? 45000

DIGITIZE SECOND POINT FOR INITIALIZATION
          (the user digitizes a point in the opposite
          corner of the pad)
WHAT IS THE X-COORD. IN FT. OF THAT POINT? 12000
WHAT IS THE Y-COORD. IN FT. OF THAT POINT? 51000

TO VERIFY INITIALIZATION, DIGITIZE A POINT FAR FROM
THE FIRST TWO POINTS.
          (the user digitizes a third point)
THE COORDINATES OF THAT POINT ARE CALCULATED TO BE:
          X = 300   Y = 50997
IF THESE ARE NOT SATISFACTORY, YOU MAY RE-INITIALIZE.
ARE THE COORDINATES SATISFACTORY? YES

When the program instructs the user to digitize the
first point for initialization, the user places the
cursor on a point on one edge of the plan sheet
where the grid lines intersect and pushes the button
on the cursor. This procedure will be referred to as
"digitizing a point". The program responds by asking
for the x- and y-coordinates of that point. Next the
program instructs the user to digitize a second
point for initialization. After doing so, the user
is asked for the coordinates of that second point.
The strategy is to choose two points on the table as
far apart as possible. Thus, when the program cal-
culates the origin and the orientation of the axes
of the plans on the table, it can accurately cal-
culate the coordinates of all other points on the
part of the plans that is on the table at that time.
As a check, the program asks the user to digitize a
third point for verification. On doing so, the user
is presented with the calculated x- and y-coordi-
nates of that point. If the initialization process
has been done properly, these coordinates should be
accurate to within approximately 3 to 5 ft on a
scale of 1 in. = 200 ft. The program asks if these
coordinates are satisfactory. If for some reason
they are not, the user answers no and the initiali-
zation process is repeated. If the user answers yes,
the program goes on to the data-entry routines.

The beginning of the data-entry routines is a
menu of choices:

          1: Digitize a roadway,
          2: Digitize a barrier,
          3: Digitize a receiver,
          4: Continue a roadway,
          5: Continue a barrier,
          6: Reorient the plans,
          7: End digitizing and write data file, and
          8: Abort program and lose all data.

Each of these functions will be explained as though
an actual project file were being built for the
scenario shown in Figure 2.

At this point the plans have been taped to the
table and the coordinate system has been initial-
ized. Typing the number 1 from the menu and <RETURN>
indicates that a roadway is to be digitized. As
shown in the following, the program then asks for
the name of the roadway, which will appear in the
STAMINA data file. In this case, the user enters
RDW-1. Next the program will ask for the name of the
roadway point to be digitized. In this case the user
types RDW-1-A. The program then instructs the user
to digitize point RDW-1-A. As before, the user moves
the cursor to the spot on the plans where RDW-1-A is
marked and pushes the cursor button. The program
responds by displaying the coordinates of that point
(for reference) and asking for the z-coordinate or
elevation. The user has the option of immediately
reading the elevation from the plans and typing it
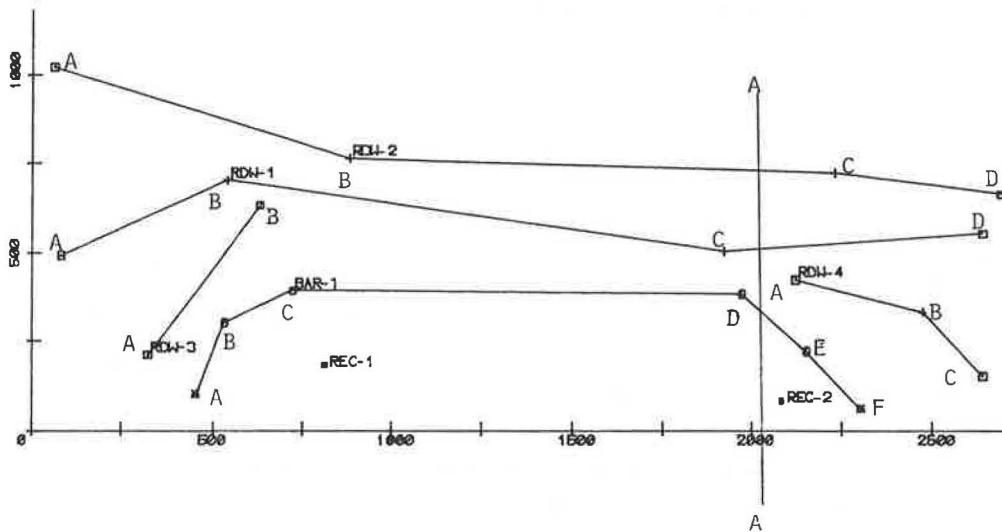in or simply pressing <RETURN>, which enters a

FIGURE 2 Typical roadway scenario.

value of zero in the file for later editing. This process is then repeated; the program asks, "What is the name of the next roadway point?" The user responds with RDW-1-B. The program instructs: "Digitize point RDW-1-B." This interaction is shown as follows (user responses underlined):

***PLEASE ENTER MENU CHOICE: 1

WHAT IS THE TITLE OF THE ROADWAY? RDW-1
WHAT IS THE NAME OF THE NEXT ROADWAY POINT? RDW-1-A
DIGITIZE POINT RDW-1-A.
     X = 9274   Y = 51707   Z = 138

WHAT IS THE NAME OF THE NEXT ROADWAY POINT? RDW-1-B
    (the user digitizes the point)
ROADWAY POINT: RDW-1-B
     X = 7944   Y = 48032   Z = 145

WHAT IS THE NAME OF THE NEXT ROADWAY POINT?
    (etc.)

When all of the points for a particular roadway have been digitized, the user responds by holding the CNTRL key down while pressing the Z key. The program then returns to the main menu of commands. Another roadway may be started with the same method: typing 1 to start a road, naming it, and digitizing each point. This process may be continued until all of the roadways on the table have been digitized.

The interaction for barriers is the same as for roadways. When option 2 is chosen from the menu, the user is asked for the name of the barrier to be digitized. Each barrier point name is then requested before the user is instructed to digitize each point.

Digitizing receivers is less complex, because each receiver consists of only one point. When option 3 is chosen from the menu, the program asks for the name of the receiver to be digitized. The user then digitizes the point and enters the elevation of the receiver. The program then returns to the menu.

Although the process is relatively simple, there is a potential complication. The digitizing table is limited in size (approximately 40 in. by 30 in.) and frequently a roadway or barrier will extend past the edge of the digitizing surface. For this situation, there are functions 4, 5, and 6 in the menu. Suppose that the scenario shown in Figure 2 has been com-

pletely digitized to the left of line A-A (see Figure 3). Roads RDW-1, RDW-2, and barrier BAR-1 had to be temporarily ended when the edge of the table was reached. As a result, RDW-1 temporarily consists of only three points, RDW-1-A, RDW-1-B, and RDW-1-C. Likewise, RDW-2 and BAR-1 consist of only two and four points, respectively. Obviously it is necessary to include the rest of the roads and the barrier to properly model the site. Option 6 is then selected to reorient the plans. The program will respond with an instruction to arrange the plans on the table. The user shifts the plans to put the next section on the digitizing table, as shown in Figure 4, tapes them down, and presses <RETURN>. The process then continues exactly as before.

The main menu is once again presented. The next task is to continue digitizing the unfinished roads and barrier, so option 4 is chosen:

***PLEASE ENTER MENU CHOICE: 4

ROADWAYS CURRENTLY STARTED:
    RDW-1
    RDW-2
    RDW-3
WHAT IS THE TITLE OF THE ROADWAY YOU WISH TO CONTINUE? RDW-1
POINTS CURRENTLY ENTERED FOR RDW-1:
    RDW-1-A
    RDW-1-B
    RDW-1-C
WHAT IS THE NAME OF THE NEXT ROADWAY POINT? RDW-1-D
DIGITIZE POINT RDW-1-D
    (the user digitizes the point)
ROADWAY POINT: RDW-1-D
     X = 1193   Y = 50462   Z = 119
    (return to the main menu)

The roadway may be continued as just shown. Note that this process can be repeated as many times as necessary. In addition, there is no practical limit to the number of roadways or barriers that can be continued from one frame to the next. In this example, the other road would be continued in the same manner, as would the barrier. The receivers, of course, can be entered whenever they are on the digitizing surface.

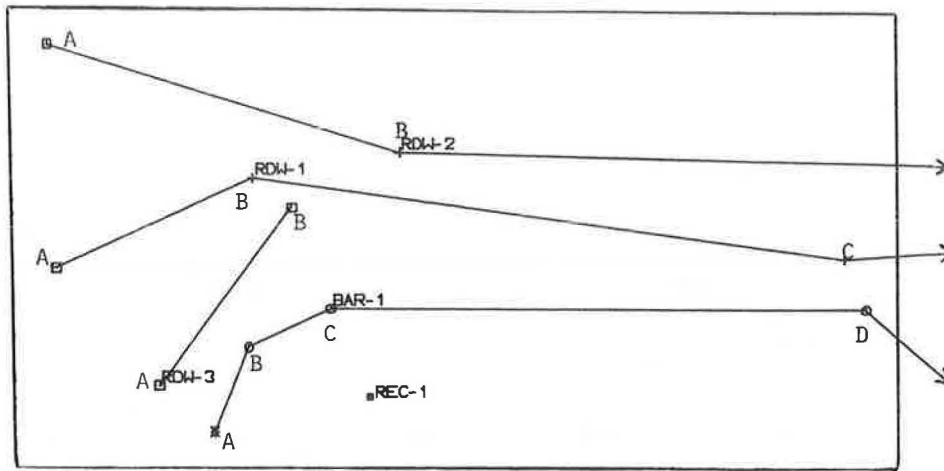When the last point in a particular scenario has

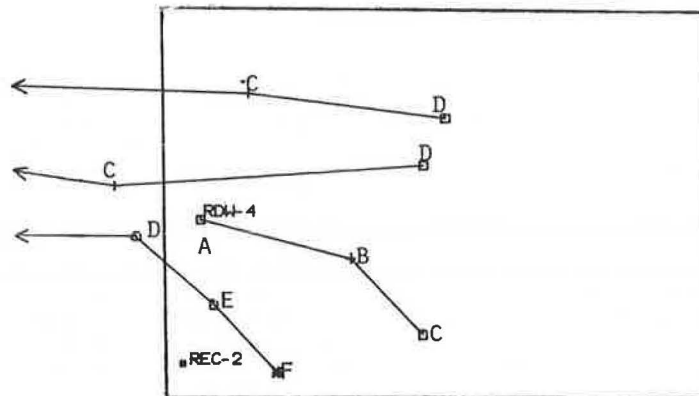FIGURE 3 Segments extend past edge of table.

FIGURE 4 Reorientation of plans on digitizing table.

been digitized, the program is ready to write the STAMINA data file. Option 7 will start this process. The user is asked for the problem title for the scenario, which will be written at the beginning of the data file, and for the disk file name under which the data is to be stored. Once this information has been entered, the program writes the data file and terminates the session.

Option 8 provides the means to abort the session and delete everything without writing a data file. On the selection of this option, the program asks for verification of the user's intentions. The program informs the user of the work that has been done and gives the user a second chance to save everything.

The file that was produced for the scenario in Figure 2 is shown in Figure 5. Note that it is in the proper format for reading by the FHWA STAMINA 2.0 program. However, parts of the file are not complete, such as the traffic data, the grade adjustment factors, and propagation and shielding factors. At present, this additional information is inserted via a DEC-System file editor before the STAMINA run. This is not a time-consuming process, especially because the vehicle-type keywords (CARS, MT, and HT) have already been put into the file, and it has therefore not been automated.

Those familiar with STAMINA 2.0 input requirements will recognize that many of the tedious parts of creating the file have already been done. At the

beginning, there is an option line and the problem title that was entered at the end of the digitizing session. There are three vehicle types, which is the default assumed by the digitizing program. Next is the roadway identifier, indicating that there are four roads in the scenario. This count is maintained automatically by DIGIT-1. The vehicle identifiers follow, after which the traffic volumes must be manually added. The program automatically inserts the 'L'/ separators and then continues to the coordinate data. For each point the name given in the digitizing session is recorded between the required single quotation marks on the line along with its x-, y-, and z-coordinates. If the user had entered blanks for the elevations during digitizing, zeros would appear as the z-coordinates, which would be changed during the editing session. The rest of the roadways are handled in the same way. The barriers are next, headed by the barrier identifier and count and followed by the barrier titles, point names, coordinates, and separators (which default to A). For receivers, the identifier and count are followed by a receiver block title and each point name and set of coordinates. The user may complete the file through the system editor by adding grade adjustments to the roadway data and propagation and shielding factors after the receiver data. A graphics program such as Vanderbilt's ST2PLT can then be used to view the scenario as the computer model will see it (Figure 6), and then the STAMINA program may be run.

```
*NNN
SAMPLE DIGITIZING SCENARIO
1   3
2   4
RDW-1
'CARS'
'MT'
'HT'
'L'/
'RDW-1-A'  18160 7660 130
'RDW-1-B'  18620 7870 132
'RDW-1-C'  20000 7670 128
'RDW-1-D'  20720 7720 120
'L'/
RDW-2
'CARS'
'MT'
'HT'
'L'/
'RDW-2-A'  18140 8190 135
'RDW-2-B'  18960 7930 138
'RDW-2-C'  20310 7890 125
'RDW-2-D'  20770 7830 130
'L'/
RDW-3
'CARS'
'MT'
'HT'
'L'/
'RDW-3-A'  18400 7380 123
'RDW-3-B'  18710 7800 127
'L'/
RDW-4
'CARS'
'MT'
'HT'
'L'/
'RDW-4-A'  20200 7590 131
'RDW-4-B'  20550 7500 127
'RDW-4-C'  20720 7320 134
'L'/
3 1
BAR-1
'BAR-1-A'  18530 7270 138
'BAR-1-B'  18610 7470 139
'BAR-1-C'  18800 7560 141
'BAR-1-D'  20050 7550 139
'BAR-1-E'  20230 7390 138
'BAR-1-F'  20380 7230 137
'A'/
5 2
SAMPLE RECEIVER BLOCK
'REC-1'  18890 7350 121
'REC-2'  20160 7250 118
```

FIGURE 5   STAMINA 2.0 data file
created by DIGIT-1.

SUMMARY

To summarize this latest development, one of the most time-consuming, labor-intensive, and error-prone parts of a noise analysis is the creation of the data file, especially the roadway, barrier, and receiver coordinate data. Through the use of an interactive digitizing system, the basic framework of a STAMINA data file can be quickly created, complete with coordinate data and much of the other data items that would otherwise need to be manually keyed in at the terminal. Use of the system at Vanderbilt has cut overall data-file creation time more than 50 percent and has eliminated the need for much of the data checking that would have to be done before STAMINA was run.

The DIGIT-1 system has been a valuable tool for the Vanderbilt Transportation Research Group, offering tremendous benefits of increased quantity and quality of work produced when compared with older manual schemes for building data files.

Future plans for the digitizing system include a postdigitizing, interactive file-completion program. The DIGIT system will be expanded to create air quality input files for the CALINE-3 and TEXIN programs and for other environmental models requiring geometric coordinates to be measured and recorded, such as the HICOM highway construction noise prediction program.

The DIGIT-1 system represents the latest enhancement for environmental models, with others to follow. For example, the dramatic increase in microcomputer technology over the last few years has already led to the development of highway air quality pre-
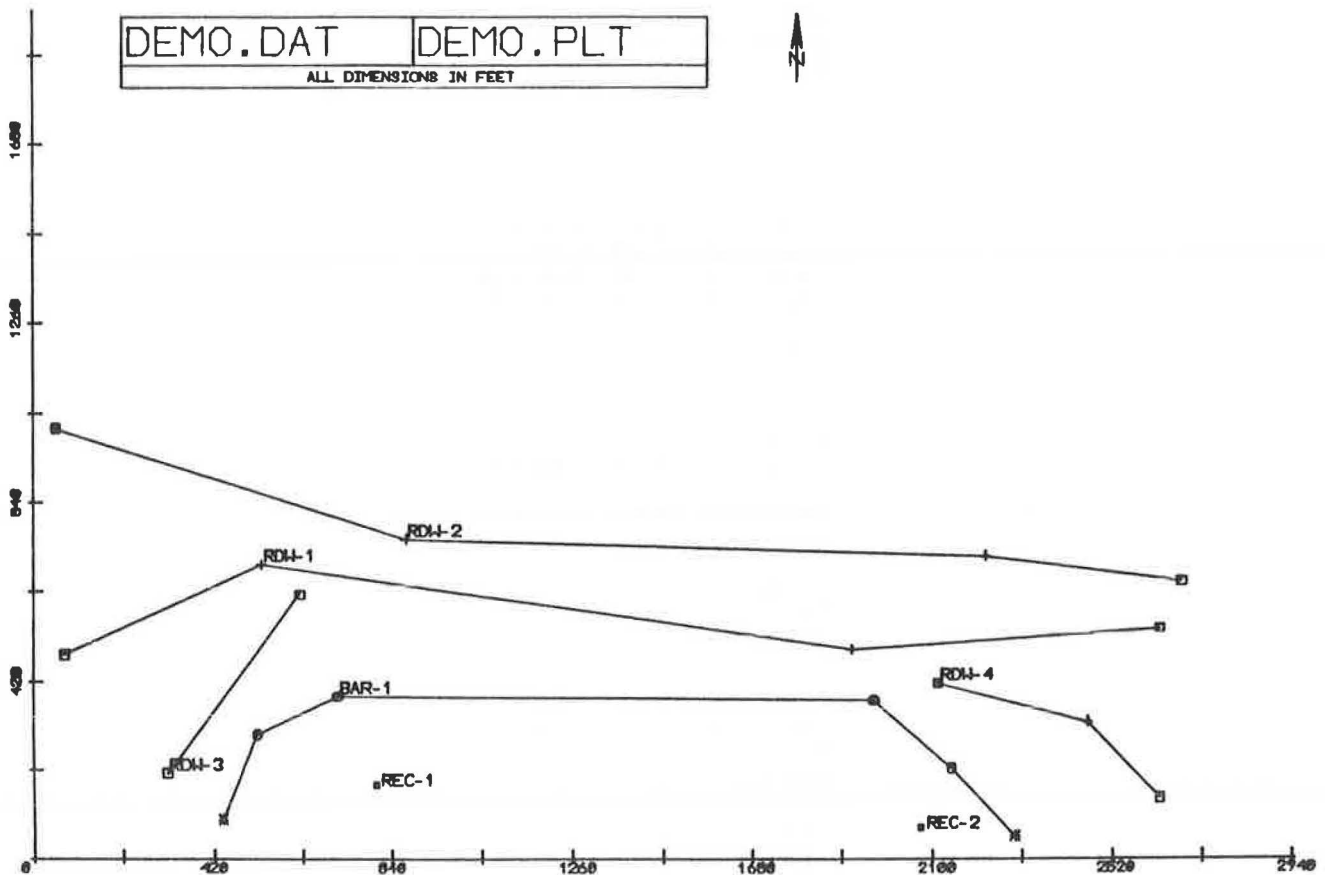
FIGURE 6 Plot of file in Figure 5 as seen by ST2PLT program.

diction programs for microcomputers. Development of a microcomputer version of the FAA Integrated Noise Model is nearing completion, and the adaptation of traffic noise models may not be far away.

Other enhancements for environmental models will likely evolve, such as three-dimensional perspective plotting of data files. Although perspective plotting is currently available through computer packages such as the Roadway Design System (RDS), the ability of the noise analyst to study a scenario as modeled for STAMINA (with data on acoustical effectiveness) could prove to be a valuable design aid. For example, plots could be produced from different viewpoints, such as the receptor's yard, to help study the visual impact as well as the acoustical effectiveness of a barrier. A logical follow-up to this enhancement would probably be the integration of the noise or air quality prediction models with roadway design system programs such as RDS or Computer Geometry (COGO).

Finally, the rapid development of sophisticated interactive graphics systems, which use light pens for data entry and design, may lead to their application to environmental modeling. In such a system, the user could view a highway from different angles at a sensitive receptor, use a light pen to insert a barrier, and check for design weaknesses. After initial analysis, the barrier section lengths or heights could then be changed directly on the screen with the light pen and the new noise levels and barrier costs could be computed and displayed on the perspective plot.

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