TRANSPORTATION RESEARCH RECORD 963

Environmental Aspects of Transportation

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. 1984

Transportation Research Record 963
Price $7.80
Editor: Naomi Kassabian
Compositor: Lucinda Reeder

mode
1 highway transportation

subject areas
12 planning
17 energy and environment

Transportation Research Board publications are available by ordering directly from TRB. They may also be obtained on a regular basis through organizational or individual affiliation with TRB; affiliates or library subscribers are eligible for substantial discounts. For further information, write to the Transportation Research Board, National Research Council, 2101 Constitution Avenue, N.W., Washington, D.C. 20418.

Printed in the United States of America

Library of Congress Cataloging in Publication Data
National Research Council. Transportation Research Board.
Environmental aspects of transportation.

(Transportation research record; 963)
Reports prepared for the 63rd annual meeting of the Transportation Research Board.
1. Transportation, Automotive--Environmental aspects–United States. I. National Research Council (U.S.). Transportation Research Board. II. Series.
TE7.H5 no. 963 380.5s 84-25439 [TD195.T7]
[363.7'31] ISBN 0-309-03719-0 ISSN 0361-1981

Sponsorship of Transportation Research Record 963

DIVISION A – REGULAR TECHNICAL ACTIVITIES
Lester A. Hoel, University of Virginia, chairman

GROUP 1 – TRANSPORTATION SYSTEMS PLANNING AND ADMINISTRATION
Kenneth W. Heathington, University of Tennessee, chairman

Environmental Quality and the Conservation of Resources Section
Carmen DiFiglio, U.S. Department of Energy, chairman

Committee on Environmental Analysis in Transportation
Louis F. Cohn, Vanderbilt University, chairman
J. Paul Biggers, Illinois Department of Transportation, secretary
J. Barry Barker, Martin J. Bernard III, David Gates Burwell, James F. Charlier, Camille Cleveland, Denise Constantopoulou, Robert S. De Santo, John H. Gastler, William C. Grenke, C. Leroy Irwin, Rajendra Jain, Walter A. W. Jetter, Wayne W. Kober, Leon N. Larson, Peter A. Lombard, George E. Mouchahoir, Malcolm L. Steinberg, Thomas L. Weck

Committee on Transportation and Air Quality
Norman L. Cooper, U.S. Department of Transportation, chairman
Salvatore Bellomo, George A. Bonina, Earl H. Bowman, David L. Calkins, William A. Carpenter, Walter F. Dabberdt, Denis E. Donnelly, Alan Eschendroeder, John H. Gastler, Charlotte J. Hopper, Joel L. Horowitz, William C. Lockett, Paul F. Maxwell, Roderick D. Moe, Carlton Thomas Nash, Kenneth E. Noll, Ronald J. Piracci, Tom K. Ryden, Phillip S. Shapiro, N. Thomas Stephens, Lawrence R. Taylor

GROUP 3 – OPERATION AND MAINTENANCE OF TRANSPORTATION FACILITIES
D.E. Orne, Michigan Department of Transportation, chairman

Committee on Methodology for Evaluating Highway Improvements
William D. Glauz, Midwest Research Institute, chairman
William T. Baker, Federal Highway Administration, secretary
Gerson J. Alexander, William D. Berg, Eugene D. Brenning, Charles Philip Brinkman, Myung-Soon Chang, Forrest M. Council, John F. Di Renzo, Robert L. Gordon, William C. Grenke, David L. Guell, Alfred-Shalom Hakkert, David L. Helman, Robert David Henry, Ruediger Lamm, Ernst Meyer, David Perkins, Jerry G. Pigman, Roy W. Taylor, Harold T. Thompson, Leonard B. West, Jr., James M. Witkowski, Paul H. Wright

Stephen E. Blake and David K. Witheford, Transportation Research Board staff

Sponsorship is indicated by a footnote at the end of each report. The organizational units, officers, and members are as of December 31, 1983.

963

Contents

Addresses of Authors

Bellomo, Salvatore, Ecosometrics, Inc., 4715 Cordell Avenue, Bethesda, Md. 20814
Benson, Paul E., California Department of Transportation, 5900 Folsom Boulevard, P.O. Box 19128, Sacramento, Calif. 95819
Bowlby, William, Vanderbilt University, Box 1537, Station B, Nashville, Tenn. 37235
Brisson, Raymond, Tennessee Department of Transportation, James K. Polk Building, Nashville, Tenn. 37219
Cohn, Louis F., Vanderbilt University, Box 1537, Station B, Nashville, Tenn. 37235
Gayk, Daniel P., Virginia Department of Highways and Transportation, 1401 East Broad Street, Richmond, Va. 23219
Haikalis, George, 1 Washington Square Village, New York, N.Y. 10012
Harris, Roswell A., Vanderbilt University, Box 1537, Station B, Nashville, Tenn. 37235
Hollenbeck, Kevin, Ecosometrics, Inc., 4715 Cordell Avenue, Bethesda, Md. 20814
Jordan, J. David, New York Metropolitan Transportation Council, One World Trade Center, 82nd Floor, New York, N.Y. 10048
Lago, Armando M., Ecosometrics, Inc., 4715 Cordell Avenue, Bethesda, Md. 20814
Lima, Peter M., Department of Civil Engineering, University of Nebraska, 60th and Dodge Streets, Omaha, Nebr. 68182-0178
McGeehan, Daniel D., Virginia Highway and Transportation Research Council, Box 3817, University Station, Charlottesville, Va. 22903-0817
Mehra, Joe, Ecosometrics, Inc., 4715 Cordell Avenue, Bethesda, Md. 20814
Siddique, Saud, Ecosometrics, Inc., 4715 Cordell Avenue, Bethesda, Md. 20814
Tate, Albert L., Georgia Department of Transportation, 2 Capitol Square, Atlanta, Ga. 30334
Waller, Bogue, Vanderbilt University, Box 1537, Station B, Nashville, Tenn. 37235

FHWA Procedure for Estimating Highway User Costs, Fuel Consumption, and Air Pollution: A Microcomputer Approach

PETER M. LIMA

ABSTRACT

A procedure has been developed by FHWA to estimate highway user costs, fuel consumption, and air pollution for traffic engineering projects. Basically, the procedure requires two steps. First the engineer collects field data on various measures of effectiveness such as speed, number of stops, number of speed changes, and number of idling hours. Second the engineer uses a set of figures and tables to look up values from the tables and figures. The FHWA procedure is outlined, the microcomputer program design is discussed, a comparison of the hand computations and computer output for a sample intersection is presented, future revisions to the program are indicated, and the implications of such programs for the evaluation of traffic engineering projects are discussed.

Current economic pressures have challenged the transportation professional to increase transport productivity and optimize resources. Phrases like "getting the most for our dollar" and "making the best of what we have" may become the public works mottos of the 1980s. Dollar-in dollar-out is often the bottom line when choosing one alternative over another. The ever-present money shortage has highlighted the importance of carefully setting priorities for all projects, small projects as well as large. As a professional, the traffic engineer has been keenly aware of the money shortage and the importance of getting the most for the money. But how does the traffic engineer know that he has obtained the best improvement for his money? How does he measure the effectiveness of the improvement? How does he compare traffic impacts before and after the improvement? Not only must the traffic engineer ask these questions but he must ask how he can evaluate his improvements within his budget. Where does the money come from to evaluate? The engineer is already faced with a tight budget for implementing projects; money for analysis and field evaluation is scarce. Moreover, how can the traffic engineer carry out time-consuming and sophisticated evaluations with limited staff?

The foregoing discussion leads to the conclusion that although one should get value for money spent, how can projects be evaluated within the given time, money, and staffing constraints? The answer to this dilemma may be to provide the practitioner with a straightforward evaluation procedure that can be carried out in the field and office within reasonable time and money limitations. Such an approach has been taken by FHWA in the development of a procedure for estimating highway user costs, fuel consumption, and air pollution (1). Designed for the practitioner, the procedure incorporates available data on user costs, fuel consumption, and air pollutants in a step-by-step method to compare traffic engineering projects. The FHWA report includes all the tables, forms, and figures that the traffic engineer needs to carry out an evaluation. This procedure has clearly simplified the evaluation process.

The procedure developed by FHWA can be simplified further by programming the procedure for use on a microcomputer. The traffic engineer would then be required only to collect field data to be input into the computer program. The intermediate step of looking up tables and figures and filling out forms would be eliminated. This procedure could be simplified even further by using a microprocessor-based data collector. The field data would be tabulated on the microprocessor unit and directly input into the microcomputer program. The entire process would be reduced to two steps: collecting field data on a microprocessor-based unit and entering the data to run the computer program.

A computer program based on the FHWA procedure is described that is designed to run on the Hewlett-Packard 85 (HP-85) microcomputer. This program is a step in the two-step evaluation procedure mentioned earlier. Work on the second step, collecting field data on a microprocessor unit, is currently under way. The remainder of this paper includes a description of the FHWA procedure, a description of the computer program, a sample analysis, and a discussion of future program and procedural revisions.

DESCRIPTION OF PROCEDURE

FHWA has identified the following four primary objectives for comparing one traffic engineering project with another:

1. To reduce highway user costs,
2. To reduce fuel consumption,
3. To reduce travel time, and
4. To reduce air pollution.

Each alternative project is compared with other alternatives with respect to the reduction or increase in the attributes of user costs, fuel consumption, and air pollution. The magnitude of each attribute is determined by estimating various measures of effectiveness (MOEs) (Table 1). Highway user costs, for instance, are measured by estimating the vehicle running costs, vehicle stopping costs, vehicle idling costs, and travel time costs due to vehicles crossing a particular project. Fuel consumption is measured by estimating the gallons of fuel consumed by vehicles traversing the project. Air pollution impacts are measured by estimating the amount of carbon monoxide (CO), hydrocarbon (HC), and nitrogen oxide (NOX) emitted by the vehicles crossing the project. A further discussion of these MOEs is presented in the following.

TABLE 1 Measures of Effectiveness (*1*, Table 3)

MOE	Computation Technique	Unit of Annual Output
User costs		
Running	Dollars per 1,000 vehicle miles times annual vehicle miles	Dollars
Delay		
Stopping	Dollars per 1,000 stops times annual stops	Dollars
Idling	Dollars per 1,000 vehicle-hr times annual idling hours	Dollars
Slowdown	Dollars per 1,000 cycles times annual slowdowns	Dollars
Travel time		
Point to point	Annual vehicle miles per mile per hour	Vehicle hours
Delay		
Stopping	Vehicle hours per 1,000 stops times annual stops	Vehicle hours
Idling	Vehicle hours per 1,000 stops times annual stops	Vehicle hours
Slowdown	Vehicle hours per 1,000 cycles times annual slowdowns	Vehicle hours
Fuel consumption		
Uniform speed	Gallons per 1,000 vehicle miles times annual vehicle miles	Gallons
Delay		
Stopping	Gallons per 1,000 stops times annual stops	Gallons
Idling	Gallons per 1,000 vehicle-hr times annual idling hours	Gallons
Slowdown	Gallons per 1,000 cycles times annual slowdowns	Gallons
Air pollution (CO, HC, NOX)		
Uniform speed	Pounds per 1,000 vehicle miles times annual vehicle miles	Pounds
Delay		
Stopping	Pounds per 1,000 stops times annual stops	Pounds
Idling	Pounds per 1,000 vehicle-hr times annual idling hours	Pounds
Slowdown	Pounds per 1,000 cycles times annual slowdowns	Pounds

Highway User Costs

Highway user costs are defined as the sum of vehicle operating costs, travel time costs, and accident costs (1). Vehicle operating costs can be further divided into running costs and delay costs. Running costs are those vehicle operating costs incurred at a uniform speed that are affected by the design and traffic characteristics. Delay costs are those additional operating costs due to vehicle idling and stopping and speed changes. Travel time cost is the monetary value placed on the highway user's time to travel a given project. Total travel time cost is the sum of the travel time costs due to delay (speed changes, idling, and stopping). Total accident costs are the sum of property, personal injury, and fatality costs associated with a given project.

Travel Time

Travel time is the sum of the point-to-point travel time to cross the length of the project at a uniform speed plus the added travel time due to stopping, idling, and slowing down.

Fuel Consumption

Although fuel consumption is a key factor in determining highway user costs, this attribute is also considered separately because of the need to conserve this vital resource. The total fuel consumed is the sum of the fuel consumed by a vehicle in the cruising, stopping, slowing, and idling modes.

Air Pollution

The improvement of traffic flow conditions can reduce air pollution significantly. Air pollution is measured by estimating the levels of CO, HC, and NOX generated by a traffic engineering project. The amount of pollutants generated is a function of the cruising, stopping, slowing, and idling modes.

Methodology

Each one of the project attributes discussed earlier can be expressed as a function of four traffic characteristics or MOEs: uniform speed, number of vehicles stopping, number of vehicle hours of idling, and number of speed changes. That is,

$$\text{Attribute} = f(\text{uniform speed, stops, idling, speed changes}) \quad (1)$$

The functional relationships between each attribute and the four MOEs are given as additive functions. The functions for the four attributes can be expressed as follows:

$$\text{User costs} = f1(\text{uniform speed}) + f2(\text{stops}) + f3(\text{idling}) + f4(\text{speed changes}) \quad (2)$$

$$\text{Travel time} = g1(\text{uniform speed}) + g2(\text{stops}) + g3(\text{idling}) + g4(\text{speed changes}) \quad (3)$$

$$\text{Fuel consumption} = h1(\text{uniform speed}) + h2(\text{stops}) + h3(\text{idling}) + h4(\text{speed changes}) \quad (4)$$

$$\text{Air pollution} = i1(\text{uniform speed}) + i2(\text{stops}) + i3(\text{idling}) + i4(\text{speed changes}) \quad (5)$$

To find the value of each attribute for a project, the traffic engineer first measures speed, number of stops, number of idling hours, and number of speed changes in the field for a given time period. He then evaluates the functional relationship between the MOEs and the attributes. Usually the attribute values are expressed as generation rates (Table 1). For instance, the generation rate for highway user costs due to vehicles stopping is expressed as dollars per 1,000 stops. Similarly, fuel consumption due to stops is expressed as gallons per 1,000 stops. Functional relationships between all the attributes and MOEs are included in the FHWA report on this procedure and are also available from other sources (2-5). The generation rates for each attribute are then converted to annual values. As indicated in Table 1, the annual cost due to stopping is found by multiplying dollars per 1,000 stops by the number of annual stops. The annual output for all the attributes is computed in a similar manner.

The procedure is summarized as follows:

1. Collect field data on the MOEs (volume, speed, number of stops, number of hours of idling, and number of speed changes),
2. Find the generation rates for each MOE (e.g., dollars per 1,000 stops),
3. Multiply the generation rate by the appropriate annual value of the MOE, and
4. Sum the appropriate MOE to find the total annual output of each attribute.

PROGRAM DESIGN

Based on the procedure outlined earlier, an interactive computer program was designed in the BASIC language to run on the HP-85 microcomputer. This computer's memory includes 32K of read-only memory (ROM) and a 16K internal random-access memory (RAM). The HP-85 is an integrated personal computer that includes an internal cartridge tape drive for mass storage and a built-in thermal printer. As noted earlier, the computer was programmed in BASIC, which for the HP-85 is an enhanced version of BASIC.

In Figure 1 the generalized steps designed for the program are shown. To run the program the user must collect the following field data for conditions both before and after a traffic engineering project and enter it into the program:

1. Approach speed (mph),
2. Approach slowdown speed (mph),
3. Approach grade (percentage of grade),
4. Volume of vehicles slowing down,
5. Approach volumes for a.m. and p.m. peak and off-peak periods, and
6. Average vehicle delay times (seconds per vehicle) for a.m. and p.m. peak and off-peak periods.

The user also has the option of selecting the desired analysis year. Because the internal tables are based on 1980 price levels, the output can be updated to the desired year by entering the appropriate consumer price index.

Given the approach speed, the program first searches a set of look-up tables (data arrays or data matrices) for the appropriate value of an MOE. For example, given an approach speed of 35 mph and a grade of zero, the program searches the matrix of vehicle running costs for the corresponding cost of $70.81 per 1,000 vehicle miles (1975 cost). The program then searches the separate data arrays for the travel time, fuel consumption, and amount of CO, HC, and NOX that corresponds to a uniform speed of 35 mph. Separate data matrices are searched to find the value of each MOE as a function of speed change. Given a cycle change of 35 to 15 to 35 mph, the program searches the appropriate row (15 mph) and column (35 mph) of the cost matix to find an added cost of $8.24 per 1,000 vehicle miles (1975 cost). Other data matrices are searched to find the added travel time, fuel consumption, and amount of CO, HC, and NOX due to speed changes. All the look-up tables within the program are based on data obtained from the FHWA report (1).

After the program searches the look-up tables, daily values for each MOE are computed. Daily values are a function of peak and off-peak traffic volumes, the number of daily speed changes, the number of daily stops, and the average vehicle delay time. Based on the cost update factor input by the user and 365 operating days per year, the program outputs annual values for each MOE for a given analysis year. Annual values are output for traffic conditions both before and after a traffic engineering project.

COMPARISON BETWEEN MANUAL AND COMPUTER METHODS

The following comparison is made between the manual and the computer techniques for estimating the project attributes. This comparison is based on the sample analysis of a before-and-after traffic situation presented in the FHWA report (1). This particular example is based on an evaluation carried out by Dale (6) on a traffic engineering improvement project implemented in 1972 by the city of Wichita, Kansas. The condition before the improvement consisted of the intersection of two four-lane undivided streets controlled by a fixed timed traffic signal. The intersection was upgraded to provide two through lanes and separate left-turn and right-turn lanes. The signalization was also upgraded to provide full traffic-actuated control and separate left-turn phases. The speed limit on all approaches was 35 mph before and after the improvement. Data collection included peak-hour turning-movement counts, 24-hr counts, and vehicular stopped delay measurements before and after the improvement. The delay studies were carried out only for the p.m.

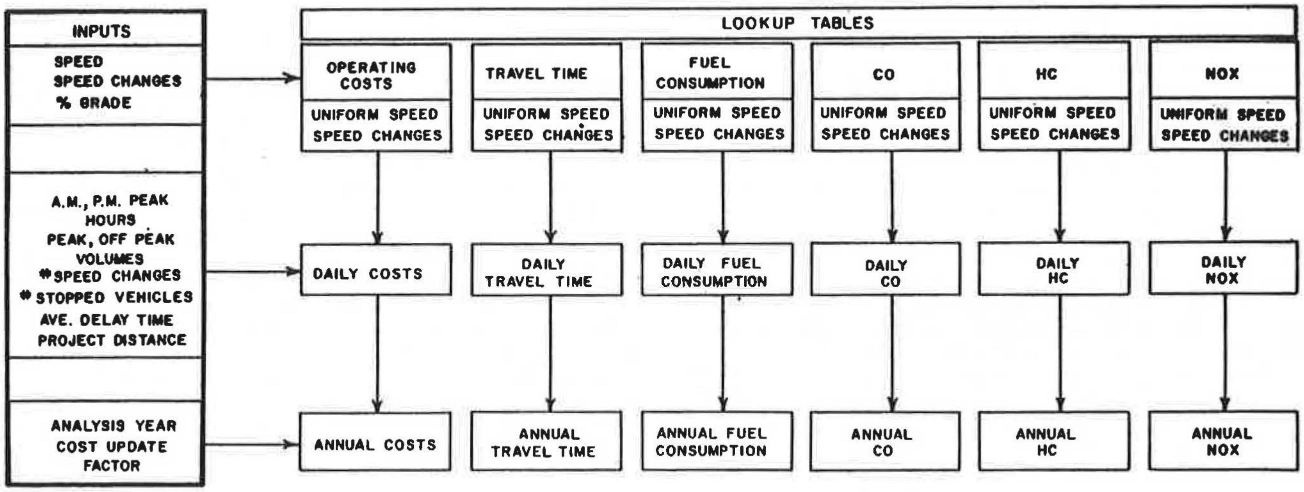


FIGURE 1 Microcomputer flowchart.

peak periods and vehicle delay was derived for the a.m. peak and off-peak hours.

The basic traffic parameters for the conditions before and after the improvement are given in Tables 2 and 3. Daily approach volumes were approximately 3,000 and 4,700 vehicles during the morning and afternoon peak hours, respectively, and 22,100 vehicles for the remaining hours of the day. Of the 29,900 vehicles per day before the improvement was made, 72 percent stopped during the morning peak hours, 87 percent stopped during the evening peak hours, and 64 percent stopped during the remaining hours. However, during the same periods after the improvement only 57 percent stopped during the morning peak, 68 percent stopped during the evening peak, and 51 percent stopped during the remaining hours. Reduction in the average delay per stopped vehicle corresponded to this reduction in the number of stops. For example, the average delay per stopped vehicle in the evening peak decreased from approximately 51 to 36 sec after the improvement. The decreased stopping delay resulted in an annual reduction of 39,000 vehicle idling hours. The improvement also resulted in a reduction of 1.1 million vehicle slowdowns from an initial speed of 35 to 15 mph.

TABLE 2 Traffic Volumes and Vehicle Delays Before and After an Improvement *(1)*

		Volume Stopped (%)		Vehicle Delay (sec)	
Time Period	Daily Volume	Before	After	Before	After
2-hr a.m. peak	3,019	72	57	37.1	21.3
3-hr p.m. peak	4,731	87	68	50.9	35.9
Other hours	22,140	64	51	36.5	24.0

TABLE 3 Annual Number of Vehicle Stops and Slowdowns and Vehicle Stopped Delay Before and After an Improvement *(1)*

Parameter	Before	After	Reduction
No. of vehicle stops	7,468,000	5,924,000	1,544,000
No. of vehicle 20-mph slowdowns	1,091,000	—	1,091,000
Vehicle stopped (idling) delay (hr)	81,800	42,900	38,900

Table 4 was prepared to help the reader follow the manual computations for the traffic condition before the improvement. All the generation rates for the project attributes were taken from the figures and tables included in the FHWA report (1). Note that because the speed limits before and after the improvement remain the same (35 mph), the impacts due to uniform speed cancelled each other out. Therefore, only the stopping, idling, and slowdown modes are considered in this example. To illustrate the manual computations, consider fuel consumption. The respective generation rates for the stopping, idling, and slowdown modes are 11.2 gal per 1,000 stops, 650 gal per 1,000 vehicle-hr, and 6.6 gal per 1,000 cycles. Based on the annual stops, idling hours, and slowdowns given in Table 3, the total annual fuel consumption is approximately 144,000 gal. The total annual output was found for the other attributes in Table 4 in the same manner.

Figure 2 shows the screen image of the input to the computer program. The input included the traffic parameters given in Table 2 plus the approach speed, slowdown cycle, and percentage of grade. The attribute values computed manually for the conditions both before and after the improvement are compared with the computer values in Table 5 (note that the internal 1975 operating costs have been inflated to 1980 price levels.) An examination of Table 5 indicates that the computer program reproduces the manual computations very well. Only slight differences occur, apparently because of the increased accuracy of the computer in reading the look-up tables rather than manual interpretation of the data in the report.

COMMENTS ON THE PROGRAM

As noted earlier, the computer program reproduces the manual computations well and is also much faster than the manual technique. For a typical problem the user can enter and print the output in a matter of minutes, whereas the same problem might require 30 min or more to complete manually. Moreover, the program produces consistent results between computer runs and between users. The guesswork in reading the figures in the report is completely removed. It is hoped that the increased ease in carrying out an otherwise time-consuming process will encourage traffic engineers to conduct more evaluations. In order to streamline the process even further, the program is being revised to take the input data directly from a microprocessor traffic board. Once the data have been collected on the counter board, it will be down-loaded into the computer via an RS-232C port. However, the HP-85 microcomputer is not equipped with such a port. Therefore, the program is being converted to the Apple II microcomputer, which is equipped with the RS-232C port. The Apple II will then be programmed to accept the input data on vehicle delay directly from the counter board. This additional capability will again greatly reduce the time needed to carry out the entire evaluation process for a given traffic engineering improvement.

Other revisions will be made to the program. The 1975 cost data will be updated to 1980 values by using the data provided in the most recent study of vehicle operating costs (2). Also, the current look-up tables are for light-duty vehicles only. Therefore, data will be added to include a complete traffic mix of passenger cars, single-unit trucks, and semitrailers. One other addition will be the inclusion of accident data in the program.

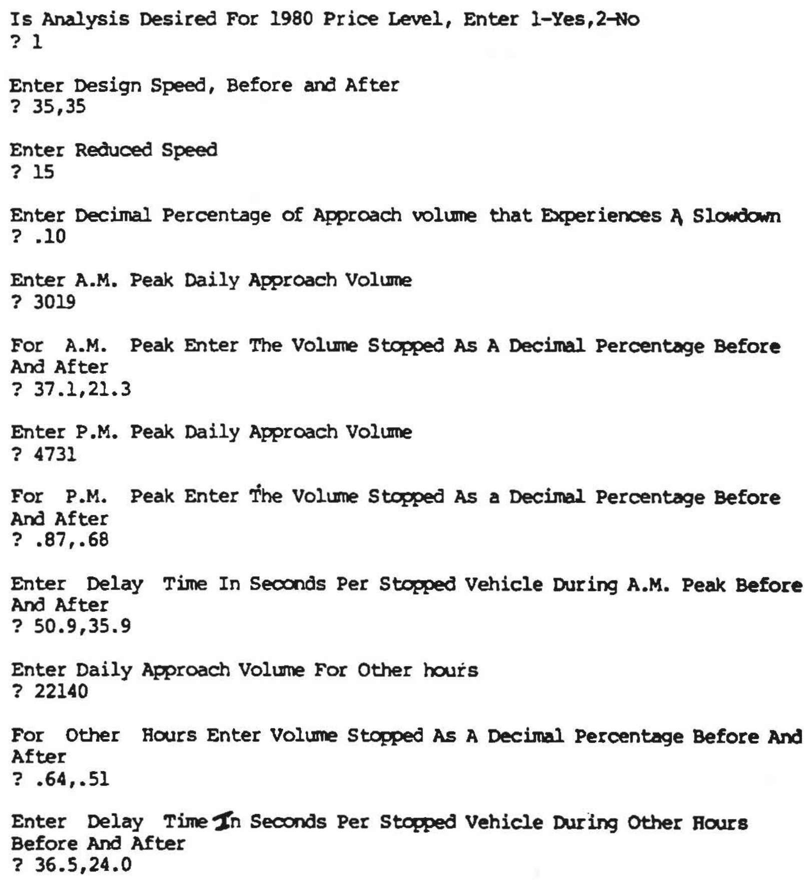
IMPLICATIONS FOR EVALUATION

Evaluation appears to be one of those functions that are needed but for which there is little time or money. The age of the microcomputer, however, is making evaluation easier to carry out. Not only can the engineer collect data in the field quickly and cheaply, but he can now carry out sophisticated analyses by using a desk-top microcomputer. In the near future such desk-top computers will be a common tool for the traffic engineer. Also, most cities today use one or more trained technicians to conduct traffic studies on a routine basis. The FHWA procedure to estimate highway user costs, fuel consumption, and air pollution can easily be integrated within these routine traffic studies. Moreover, the microcomputer program discussed here based on the FHWA procedure combined with the use of a microprocessor traffic counter board will turn the entire evaluation process into a routine procedure. The program could then be used on a daily basis to evaluate conditions before and after improvements and to compare different types of existing projects or be used to evaluate proposed projects. The program can be also be adapted to other microcomputers and can be easily expanded to include different variables or more internal data.

TABLE 4 Sample Computation (Condition Before Improvement) *(1)*

MOE	Computation Technique	Annual Output
User costs		
Stopping	$17.75/1,000 stops x 7,468,000 stops	$132,557
Idling	$312.64/1,000 vehicle-hr x 81,800 idling hr	$ 25,574
Slowdown	$8.24/1,000 cycles x 1,091,000 cycles	$ 8,990
Total		$167,121
Travel time		
Stopping	3.94 vehicle-hr/1,000 stops x 7,468,000 stops	29,424 vehicle-hr
Idling	10.95 vehicle-hr/1,000 stops x 7,468,000 stops	81,800 vehicle-hr
Slowdown	1.69 vehicle-hr/1,000 cycles x 1,091,000 cycles	1,844 vehicle-hr
Total		113,068 vehicle-hr
Fuel consumption		
Stopping	11.2 gal/1,000 stops x 7,468,000 stops	83,642 gal
Idling	650 gal/1,000 vehicle-hr x 81,800 idling hr	53,170 gal
Slowdown	6.6 gal/1,000 cycles x 1,091,000 cycles	7,201 gal
Total		144,013 gal
Air pollution		
Carbon monoxide		
Stopping	25 lb/1,000 stops x 7,468,000 stops	186,700 lb
Idling	2,430 lb/1,000 hr x 81,800 idling hr	198,774 lb
Slowdown	19 lb/1,000 cycles x 1,091,000 cycles	20,729 lb
Total		406,203 lb
Hydrocarbon		
Stopping	1.72 lb/1,000 stops x 7,468,000 stops	12,845 lb
Idling	160 lb/1,000 hr x 81,800 idling hr	13,088 lb
Slowdown	1.37 lb/1,000 cycles x 1,091,000 cycles	1,495 lb
Total		27,428 lb
Nitrogen oxide		
Stopping	1.90 lb/1,000 stops x 7,468,000 stops	14,189 lb
Idling	50 lb/1,000 hr x 81,800 idling hr	4,090 lb
Slowdown	1.67 lb/1,000 cycles x 1,091,000 cycles	1,822 lb
Total		20,101 lb

Note: Costs are 1975 costs.



```
Is Analysis Desired For 1980 Price Level, Enter 1-Yes,2-No
? 1

Enter Design Speed, Before and After
? 35,35

Enter Reduced Speed
? 15

Enter Decimal Percentage of Approach volume that Experiences A Slowdown
? .10

Enter A.M. Peak Daily Approach Volume
? 3019

For  A.M.  Peak Enter The Volume Stopped As A Decimal Percentage Before
And After
? 37.1,21.3

Enter P.M. Peak Daily Approach Volume
? 4731

For  P.M.  Peak Enter The Volume Stopped As a Decimal Percentage Before
And After
? .87,.68

Enter  Delay  Time In Seconds Per Stopped Vehicle During A.M. Peak Before
And After
? 50.9,35.9

Enter Daily Approach Volume For Other hours
? 22140

For  Other  Hours Enter Volume Stopped As A Decimal Percentage Before And
After
? .64,.51

Enter  Delay  Time In Seconds Per Stopped Vehicle During Other Hours
Before And After
? 36.5,24.0
```

FIGURE 2 Screen image of program input.

TABLE 5 Comparison of Computer and Manual Results

	Computer Results			Manual Results		
MOE	Before	After	Reduction	Before	After	Reduction
Operating costs ($)						
Stopping	216,057	171,387	44,670	216,067	171,396	44,671
Slowdown	14,653		14,653	14,654		14,654
Idling	51,617	27,053	24,564	41,696	21,862	19,824
Total	282,327	198,441	83,886	272,417	193,258	79,149
Travel time (hr)						
Stopping	29,422	23,339	6,083	29,424	23,241	6,083
Slowdown	1,844		1,844	1,844		1,844
Idling	81,855	42,902	38,953	81,800	42,900	38,900
Total	113,121	66,241	46,880	113,068	66,241	46,827
Fuel consumption (gal)						
Stopping	82,144	65,161	16,983	83,642	66,349	17,293
Slowdown	6,906		6,906	7,201		7,201
Idling	53,206	27,886	25,320	53,170	27,885	25,285
Total	142,256	93,047	49,209	144,013	94,234	49,779
Air pollution						
Carbon monoxide (lb)						
Stopping	173,622	127,726	35,895	186,700	148,100	38,600
Slowdown	19,092		1,407	20,729		20,729
Idling	198,908	104,251	94,656	198,774	104,247	94,527
Total	391,622	241,977	149,645	406,203	252,347	153,856
Hydrocarbon (lb)						
Stopping	12,695	10,070	2,625	12,845	10,189	2,656
Slowdown	1,407		1,407	1,495		1,495
Idling	13,097	6,864	6,233	13,088	6,864	6,224
Total	27,199	16,935	10,265	27,428	17,053	10,375
Nitrogen oxide (lb)						
Stopping	13,591	10,781	2,810	14,189	11,256	2,933
Slowdown	1,669		1,669	1,822		1,822
Idling	4,093	2,145	1,948	4,090	2,145	1,945
Total	19,353	12,926	6,427	20,101	13,401	6,700

Note: Costs are 1980 costs.

ACKNOWLEDGMENT

The author would like to extend his thanks to Linda Jenks and Ibrahim Sabbidine, students at the University of Nebraska, for their work in programming the HP-85.

REFERENCES

1. Procedure for Estimating Highway User Costs, Fuel Consumption, and Air Pollution. FHWA, U.S. Department of Transportation, 1981.
2. J. P. Zaniewski. Vehicle Operating Costs, Fuel Consumption, and Pavement Type and Condition Factors. FHWA, U.S. Department of Transportation, 1982.
3. A Manual on User Benefit Analysis of Highway and Bus Transit Improvements. AASHTO, Washington, D.C., 1977.
4. A. Curry and D. G. Anderson. Procedures for Estimating Highway User Costs, Air Pollution, and Noise Effects. NCHRP Report 133. TRB, National Research Council, Washington, D.C., 1972.
5. P. Claffey. Running Costs of Motor Vehicles as Affected by Road Design and Traffic. NCHRP Report 111. TRB, National Research Council, Washington, D.C., 1971.
6. C. W. Dale. Evaluation of a Traffic Engineering Improvement. In Transportation Research Record 528, TRB, National Research Council, Washington, D.C., 1974, pp. 15-19.

Publication of this paper sponsored by Committee on Environmental Analysis in Transportation

Analysis of Ambient Carbon Monoxide Data

PAUL E. BENSON

ABSTRACT

Several current methods for estimating worst-case ambient carbon monoxide levels are critically reviewed. The distributions by month, day, and hour of seasonal maximum ambient levels measured at 12 California stations are presented. These distributions are used to develop an observed maximum method for estimating the second annual maximum concentration from limited field measurements. The method is based on the combined use of the binomial distribution and combinatorial analysis. The binomial distribution is used to generate the expected number of occurrences of ambient concentrations within the top six ranks of the seasonal statistics given scheduling and duration of sampling. Combinatorial analysis is used to predict the distribution of seasonal maximums among these top six ranks. The resulting models are verified both separately and together by using the California data. A table is produced that can be used to design sampling plans that will yield observed maximum concentrations equal to or close to the second annual maximum.

The determination of second annual maximum 1-hr and 8-hr ambient carbon monoxide (CO) concentrations from limited field-monitoring data is an important component in transportation air quality impact studies. Because the significance of an air quality impact is judged on the basis of comparison with an absolute standard rather than between alternatives, accurate estimation of the ambient or background concentration is critical. It can often mean the difference between the finding of an acceptable or unacceptable impact. This is particularly true when project-related impacts are small relative to background concentrations. Many highway improvement projects in urban areas fall into this category.

In this paper the problems underlying the current method used by the California Department of Transportation (Caltrans) for extrapolating second annual maximum concentrations from field measurements are examined. A simpler, more accurate scheme is developed in which scheduling and duration of sampling are used to yield a high probability of sampling a value equal to or close to the second annual maximum. Data analysis is reduced by using the maximum value sampled as a direct estimate of the second annual maximum. The new method eliminates overly conservative assumptions and time-consuming analytical procedures.

LITERATURE REVIEW

The method currently used by Caltrans to estimate second annual maximum 1-hr and 8-hr CO concentrations was first introduced by R. I. Larsen in 1971 (1). It was developed empirically from aerometric data collected at eight urban sites from 1962 through 1968. A two-parameter lognormal distribution was used by Larsen to extrapolate expected maximum values from random field measurements. A computerized version of Larsen's model was developed by Caltrans in 1976 (2).

Since its introduction, Larsen's two-parameter lognormal model has been studied and in some ways improved on. The weaknesses of the original model primarily involve three areas:

1. The suitability of the two-parameter lognormal distribution.
2. The implicit assumption that sequential aerometric measurements are independent and evolve from a stationary process, and
3. The requirement that a random sampling scheme be followed.

Several authors, including Larsen, recognized that the two-parameter lognormal distribution was not appropriate for all cases. In 1977 Larsen proposed a three-parameter lognormal distribution for use on data collected at urban and source-affected sites (3). Mage and Ott recommended use of a censored three-parameter lognormal distribution in 1978 (4). In 1975 Curran and Frank proposed the use of a one- or two-parameter exponential distribution fit exclusively to the highest observed concentrations (5).

In 1973, Patel objected to the implicit assumption of independence between sequential aerometric measurements contained in Larsen's model (6). Neustadter and Sidik later showed that the assumption of independence was reasonable for successive measurements made 3 to 6 days apart (7). Horowitz and Barakat concluded that serial correlation between sequential measurements would not seriously limit the usefulness of Larsen's model but that deviations from the implicit assumption of stationarity could (8).

A survey conducted by Meisel and Dushane (9) showed that continuous aerometric sampling over a period of 3 weeks to 3 months was the normal field practice. Random sampling by day or by hour was characterized by respondents as inconsistent with efficient field operations. Respondents found it more efficient to site a sampler for a fixed block of time and sample on a 3- to 5-day weekly schedule. Meisel and Dushane developed an analytical methodology consistent with this type of quasi-continuous sampling plan. Their project, funded by NCHRP, was published as NCHRP Report 200 in 1979 (9).

NCHRP 200 METHOD

The NCHRP methodology is designed to amplify limited project-specific CO data by the use of an auxiliary data set collected concurrently at a nearby, year-round monitoring station. The method assumes a significant temporal correlation between the two sets of data. The auxiliary station data set is used to estimate the number of adverse days sampled at the project site target station. An adverse day is defined as a day containing an 8-hr daily maximum ranking in the upper 20 percent for the year.

The target station data may be analyzed in one of three ways: the distribution, observed maximum, or combination methods. The last is simply a weighted average of results from the first two methods. In the distribution method, an exponential distribution is fitted by least squares to the 8-hr daily maximums measured at the target station during adverse days. The second annual maximum is extrapolated from this distribution. In the observed maximum method, the number of adverse days occurring during the sampling period is used as a prequalification. If there are at least 6 adverse days in a 1-month period or 10 in a 2-month period, the highest 8-hr daily maximum observed during the period is used as an estimate of the second annual maximum. In cases where no auxiliary data are available, NCHRP 200 recommends that sampling periods be prequalified on the basis of nationwide or statewide monthly distributions of adverse days.

During implementation of NCHRP 200 by Caltrans, it became clear that acquiring and processing auxiliary data required an inordinate amount of time and effort. It was decided that the method for determining adverse days from statewide monthly distributions should be followed. However, this approach also presented a problem. The distribution of adverse days by months given in NCHRP 200 contained data from only two regions in California. In addition, possible differences between the monthly distributions of adverse days and second annual maximums had not been investigated. The lack of temporal resolution in the final result also had to be considered. For example, an observed 8-hr maximum that occurred late in the evening might be used as representative of a morning commute-hour ambient. Without organizing the analysis by time of day, similar examples of data mismatching might occur.

These problems and others were addressed by examining data from a number of California monitoring stations and developing several modifications to the original NCHRP 200 method.

ANALYSIS OF AMBIENT CO DATA FROM SELECTED CALIFORNIA STATIONS

In order to help develop and verify the intended modifications to NCHRP 200, a large representative data set was required. Fortunately, historical data from a comprehensive network of air quality monitoring stations throughout California were readily available from the California Air Resources Board in an edited, machine-readable form. Twelve stations with relatively complete records over a period of years were chosen from this data base. They represented a variety of geographic and demographic settings typical of California.

The selected data set was composed of daily records of 1-hr averaged CO concentrations. In cases where missing data were encountered, the NCHRP 200 interpolation method was used. If gaps within a 31-hr period (midnight to 7:00 a.m. of the following day) exceeded the size and frequency criteria set down in NCHRP 200, the entire day was dropped from the data set. After being edited for missing values, the data set was stratified by CO season, starting July 1 and ending June 30 of the following year. The seasonal stratification was made in lieu of a calendar year division so that the monthly distribution of maximums would accurately represent the distribution encountered when sampling was done within a season. Seasons with more than 10 days missing in any single month from October through February or more than 25 days missing over this entire 5-month wintertime period were deleted from the data set. This left a total of 112 station-seasons in the data set, each composed of an average of 349 days' worth of twenty-four 1-hr CO concentrations.

Peak 8-hr averages were determined for each day. Calculations were made by crossing midnight with the start hour of the 8-hr period to determine the date of the maximum. Overlapping 8-hr daily maximums were not permitted. The daily maximums within each station-season were then ranked. Dates and start hours of the top six ranks were retained in the final version of the data set. Tied values were assigned the same rank, making multiple occurrences of seasonal maximums possible. A similar treatment was given to 1-hr maximums, with the exception that multiple annual maximums within the same day were allowed. A description of the final data set is given in Table 1.

The distributions of the seasonal high 8-hr daily maximums by month, day of week, and hour of day were key elements in development of the modified sampling procedure. Instead of using the top 20 percent of the data, as in NCHRP 200, the modified method focused on the probabilities of encountering maximums within the top six ranks of the seasonal statistics. Study was limited to these seasonal maximums rather than adverse days because their temporal distributions were expected to follow the distribution of second annual maximums more closely.

The modified method assumes that the monthly distribution of seasonal maximums is independent of averaging time and rank. A categorical analysis of variance performed on the 12-station data set showed no significant differences between monthly distributions of 1-hr and 8-hr maximum and first- through sixth-ranked seasonal high 8-hr maximums. There was a significant difference in the distribution of maximums by station. However, this was slight enough to justify the aggregation of results over the 12 stations as representative of a composite California location. The final sampling plan was specified by using the aggregated monthly distribution of the proportion of days containing 8-hr seasonal maximums shown in Figure 1.

The distribution of seasonal maximums by day of week, shown in Figure 2, was also important in the development of the modified method. For weekdays the fraction of 1-hr seasonal maximums is somewhat greater than 8-hr maximums. For weekends this difference is reversed. The relatively short duration of weekday traffic peaks and the broader temporal distribution of traffic volumes on weekends is consistent with this pattern. The day-to-day trends in Figure 2 are roughly similar for both 1-hr and 8-hr averaging times. There are gradually more seasonal maximums occurring through the week until a peak is reached on Friday. The number of seasonal maximums then drops significantly for Saturday and reaches a minimum on Sunday. Cross-stratification of the data by time of day and day of week revealed that the additional Friday occurrences, as well as many of the Saturday occurrences, take place in the late evening hours. The few occurrences of Sunday maximums also take place in the evening about 1 hr later than weekday commute peaks.

These temporal patterns exhibited by the seasonal maximums closely follow expected traffic distributions reported by Shirley (10). A composite version of the 1-hr and 8-hr day-of-week distributions was used to determine the probabilities of encountering seasonal maximums associated with different day-of-week sampling plans.

The distributions of 1-hr and 8-hr seasonal maximums by start hour are shown in Figure 3. The distributions are quite dissimilar, particularly regarding the occurrence of morning maximums. The most concentrated number of 1-hr maximums occurs between

TABLE 1 California Ambient CO Data Set

1980 Metropolitan Population (000s)	Station	Area/Site Code	Years Studied	Total Seasons	Second Maximum, 1981-1982 (ppm)	
					1-Hr	8-Hr
<100	Pittsburg	700/430	1969-1982	12	8	4.9
	Lancaster	7000/82	1971-1982	10	9	4.9
	Escondido	8000/115	1975-1982	7	12	8.0
	Santa Barbara	4200/355	1974-1982	7	15	8.1
	Salinas	2700/544	1976-1982	5	4	2.9
100 to 500	Bakersfield	1500/203	1972,1973,1976-1979,1981-1982	5	14	10.1
	Stockton	3900/252	1965-1967,1979-1982	5	14	7.5
	Redwood City	4100/541	1968-1982	13	10	5.5
	Sacramento	3400/282	1972-1980	7	11[a]	7.4[a]
	Pomona	7000/75	1966-1982	14	12	9.6
>500	San Diego	8000/120	1973-1982	8	12	8.6
	Burbank (L.A.)	7000/69	1963-1982	19	25	20.1

[a] 1979-1980 season.

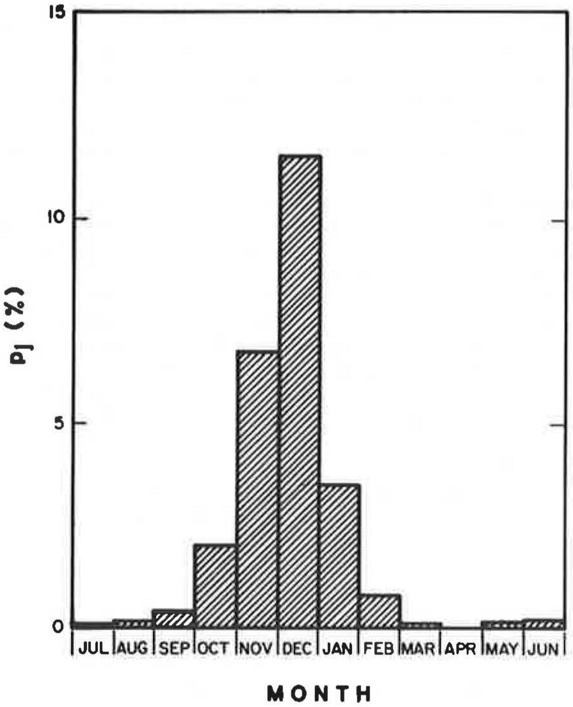


FIGURE 1 Monthly distribution of proportion of days (p_j) containing 8-hr daily maximums within top six seasonal ranks.

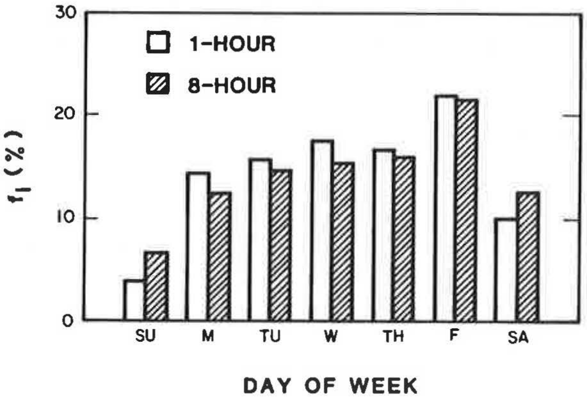


FIGURE 2 Fraction of 1-hr and 8-hr seasonal maximums (f_i) distributed by day of week.

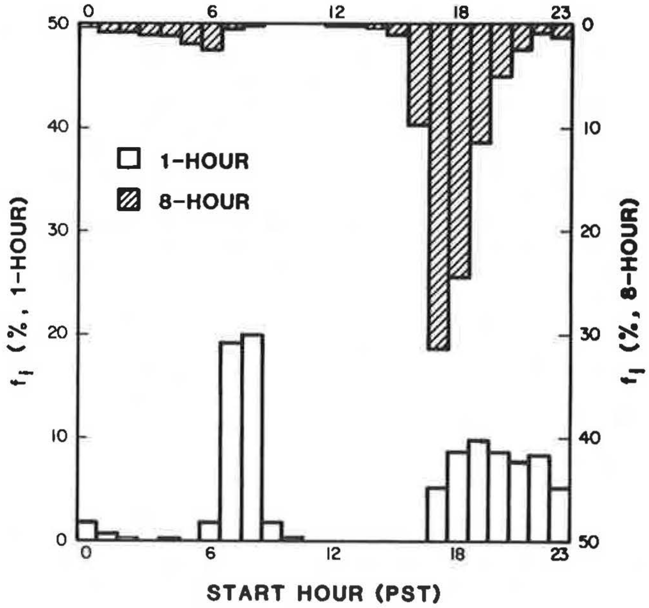


FIGURE 3 Fraction of 1-hr and 8-hr seasonal maximums (f_i) distributed by start hour.

the morning commute hours of 7:00 and 9:00 a.m. Approximately 40 percent of the 1-hr maximums and 10 percent of the 8-hr maximums occur during this period. The explanation for this difference lies in the combined temporal distributions of traffic and meteorology. During the evening hours, these two factors combine over sufficiently long periods to yield the bulk of the 8-hr daily maximums. In the morning hours, a pronounced morning commute and stable meteorological conditions lead to a substantial number of 1-hr seasonal maximums. However, the short duration of the morning commute peak and the rapid shift to unstable meteorological conditions typically following this peak limit the number of morning 8-hr seasonal maximums to a small percentage of the total.

The time-of-day distributions were used to determine an appropriate division of the modified observed maximum analysis into four time periods: morning, midday, evening, and nocturnal (Table 2).

DEVELOPMENT OF A MODIFIED SAMPLING PROGRAM

The fundamental difference between the NCHRP 200 method and the modified method developed in this

TABLE 2 Time Periods for Analysis of Ambient CO Concentrations

	Start Hour		Occurrence of Seasonal Maximum (%)	
Time Period	1-Hr Maximum	8-Hr Maximum	1-Hr	8-Hr
Morning	6:00	1:00	43	10
Midday	10:00	8:00	1	>1
Evening	5:00	11:00	32	80
Nocturnal	9:00	8:00	24	10

paper involves the procedure for determining the duration of sampling. Instead of sampling for a fixed 30 days with a minimum of 6 adverse days required, the modified procedure calls for a sampling program the duration of which varies with the month or months sampled. The duration of sampling is chosen so as to yield an extremely high probability of attaining as an observed maximum an unbiased estimate of the expected second annual maximum. This is achieved through the combined application of the binomial distribution and combinatorial analysis. The specific sampling intervals recommended in this paper are based on the California data set. However, the principles can be extended to any comparable data set.

A distribution of randomly chosen, independent events characterized by two mutually exclusive outcomes can be described by the binomial expansion $(q + p)^n$, where q and p represent the probabilities of occurrence attached to each outcome. The rth term of the expansion equals the probability that the outcome, the underlying probability of which is denoted by p, will occur r times in n samples. This can be stated as follows:

$$P(r|p,n) = [n!/r!(n - r)!]\ p^r q^{n-r} \qquad (1)$$

The binomial expansion was used to generate expected monthly probabilities of encountering r seasonal maximums (defined as daily 8-hr maximums within the top six ranks for the season) in an n-day sampling period based on the underlying probabilities shown in Figure 1. Thus, for a full-month sample taken during the jth month,

$$P(r|j) = P(r|p_j,n_j) \qquad (2)$$

where p_j and n_j equal, respectively for the jth month, the probability of encountering seasonal maximums and the number of days in the month. Equation 2 was used to predict the distribution of occurrences of seasonal maximums for the full-month sampling periods of October through February. These are compared in Table 3 with the observed distributions taken from the California data set. Probabilities are rounded to the nearest whole percent, so totals may not exactly equal 100 percent.

Use of the binomial distribution assumes that the 8-hr daily maximums are randomly chosen, independent events. In fact, they are a set of sequentially sampled, autocorrelated events. The assumption of randomness is not seriously violated provided sampling is of sufficient duration to incorporate a majority of winter meteorological conditions. The assumption of independence between daily maximums presents a more serious problem, however. Examination of the California data set showed that clusters of consecutive seasonal maximums occur with greater frequency than would be expected from a series of independent events. This was most evident for small clusters of two to three seasonal maximums; 26 percent of the paired values and 8 percent of the groups of 3 occurred on successive days.

Clustering of seasonal maximums is caused by short periods of calm, stable meteorological conditions between winter storms. The effect of clustering on the overall distribution of seasonal maximums is apparent in Table 3. There is a consistently higher percentage of months with no occurrences of seasonal maximums than would be expected from a truly independent distribution. This higher percentage is caused by the clustering of maximums in other months. By the same token, the overestimation of months with only one occurrence can be attributed to the likelihood that seasonal maximums will occur in clusters rather than as isolated events.

The binomial distribution does reasonably well at predicting the observed pattern for months having two or more occurrences as well as for the entire distribution for November. Therefore, the assumptions of independence and randomness, although not entirely valid, were considered satisfactory for purposes of approximating the number of seasonal maximums (r) within a given sampling interval.

The probability that an observed maximum equals the mth-ranked seasonal maximum, given a sample containing r seasonal maximums, can be stated as follows:

$$P(m|r) = [{}_{(\ell + 1)}C_r - {}_{\ell}C_r]/{}_6C_r \qquad (3)$$

where ℓ is the number of ranks less than the mth rank (6 - m) for the r seasonal maximums and

$${}_nC_r = \begin{cases} n!/r!(n - r)! & n \geq r \\ 0 & n < r \end{cases}$$

This formulation assumes that there are no multiple occurrences of seasonal maximums. For the California data set there were tied ranks, however, yielding an average of eight maximums within the top six ranks

TABLE 3 Observed and Predicted Probabilities of Encountering r Seasonal Maximums by Month

	Probability of Occurrence (%) by Month									
	Oct.		Nov.		Dec.		Jan.		Feb.	
No. of Seasonal Maximums (r)	Observed	Predicted	Observed	Predicted	Observed	Predicted	Observed	Predicted	Observed	Predicted
0	64	52	14	12	9	2	45	33	82	79
1	19	34	26	27	6	9	24	37	14	19
2	10	11	26	28	13	18	15	20	2	2
3	4	2	21	19	22	22	11	7	1	0
4	3	0	7	9	17	20	5	2	1	0
5	1	0	4	3	15	14	1	0		
6			2	1	10	8				
7			1	0	5	4				
8					2	1				
9					1	0				

per season. The following modification to Equation 3 was derived to account for this:

$$
\begin{aligned}
P(m|r) = {} & (1/{}_{8}C_{r})\ \{(q^2/36)[{}_{(\ell+1)}C_r - {}_{\ell}C_r] \\
& + (q/18)[{}_{(\ell+2)}C_r - {}_{\ell}C_r] + (q\ell/18)[{}_{(\ell+2)}C_r \\
& - {}_{(\ell+1)}C_r] + (1/36)[{}_{(\ell+3)}C_r - {}_{\ell}C_r] \\
& + (\ell/18)[{}_{(\ell+3)}C_r - {}_{(\ell+1)}C_r] \\
& + (\ell^2/36)[{}_{(\ell+3)}C_r - {}_{(\ell+2)}C_r]\} \qquad (4)
\end{aligned}
$$

where g is the number of ranks greater than the mth rank (m − 1).

Equation 4 is based on the assumption that the two extra seasonal maximums are randomly distributed among the top six ranks. Overall, there is a slight increase with descending rank of the number of ties in the California data set. However, for months containing three or more seasonal maximums, the distribution of tied ranks is approximately uniform among the top six ranks.

Equation 4 was used to model the distribution of observed maximums among the top six ranks as a function of the number of occurrences of seasonal maximums. These values can be compared in Table 4 to the rank distribution of monthly observed maximums categorized by number of occurrences (r). The discrepancies between observed and predicted probabilities are primarily due to the nonuniform distribution of tied ranks and the tendency for first and second seasonal maximums to be associated with clustered results.

To test the validity of the combined use of the binomial distribution and Equation 4, the modeled distributions of observed maximums by rank for the months October through February were generated by the following:

$$
P(m|j) = \sum_{r=1}^{7} [P(r|j) \cdot P(m|r)] + [P(r \geq 8|j) \cdot P(m|r=8)] \qquad (5)
$$

where P(m|j) equals the probability of the observed maximum during the jth month coming from the mth rank. The second term in Equation 5 relates the diminishing probabilities generated by the bionomial distribution for $r \geq 8$ to the fixed probability for r = 8 derived from the combinatorial analysis. The predictions generated by Equation 5 compare favorably with the observed distributions obtained from the California data set (Table 5).

In general terms, the combined model can be expressed as follows:

$$
P(m|p_j,n) = \sum_{r=1}^{n} [P(r|p_j,n) \cdot P(m|r)] \qquad (6)
$$

where n is the number of days sampled in the jth month and P(m|r) = P(m|r = 8) for all $r \geq 8$. Given known values for p_j and the average differences between concentrations by rank from the California data set, Equation 6 can be used to approximate an unbiased sampling program. The values for p_j are given in Figure 1, whereas the distribution of differences between the second seasonal maximum (m = 2) and the first through sixth seasonal maximums for the California data set are summarized in Table 6. The maximum and overall average differences are given as follows:

Seasonal Maximum (r)	$\lvert d_{m-2} \rvert_{max}$ (ppm)	$\lvert \bar{d}_{m-2} \rvert$ (ppm)
1	8.6	1.27
3	7.2	0.69
4	7.7	1.15
5	7.9	1.52
6	8.4	1.85

TABLE 4 Observed and Predicted Probabilities That Observed Maximum Will Equal mth Seasonal Maximum Given r Occurrences

Rank (m)	Probability of Occurrence (%) by No. of Seasonal Maximums (r)															
	1		2		3		4		5		6		7		8+	
	Observed	Predicted	Observed	Predicted	Observed	Predicted	Observed	Predicted	Observed	Predicted	Observed	Predicted	Observed	Predicted	Observed	Predicted
1	14	17	23	32	44	46	56	59	74	71	77	82	100	91	100	100
2	14	17	20	26	25	29	25	28	17	23	15	17	0	9		
3	11	17	27	20	18	16	17	10	9	5	0	2				
4	23	17	13	14	9	7	3	2	0	0	8	0				
5	19	17	13	7	4	2	0	0								
6	19	17	4	1	0	0										

Because there was no significant difference between the monthly distributions of 1-hr and 8-hr seasonal maximums, a sampling program based on 8-hr values was assumed equally valid for 1-hr estimates.

The sampling program was designed so that the duration of sampling would be sufficient to guarantee a fixed probability (P_c) of obtaining one or

TABLE 5 Observed and Predicted Probabilities by Month That Observed Maximum Will Equal mth Seasonal Maximum

Rank (m)	Probability of Occurrence (%) by Month									
	Oct.		Nov.		Dec.		Jan.		Feb.	
	Observed	Predicted	Observed	Predicted	Observed	Predicted	Observed	Predicted	Observed	Predicted
1	9	10	27	31	51	50	16	17	3	4
2	4	9	25	21	15	23	7	14	3	4
3	5	8	13	14	13	12	11	12	3	4
4	8	7	9	10	8	6	9	10	3	4
5	6	7	6	7	4	3	8	8	3	3
6	4	6	6	5	1	2	5	6	5	3

TABLE 6 Distribution of Differences Between Second and mth Seasonal Maximums

$\|d_{m-2}\|$(ppm)	Probability of Occurrence (%) by No. of Seasonal Maximums (r)				
	1	3	4	5	6
≤0.5	38	62	30	14	6
0.6-1.0	22	21	29	29	25
1.1-1.5	17	10	22	20	21
1.6-2.0	6	2	7	17	17
2.1-2.5	6	1	4	5	11
2.6-3.0	2	2	3	4	6
>3.0	9	3	5	11	14

more seasonal maximums. To select a proper value for P_c, the probabilities described by Equation 6 were used in combination with the average differences ($\bar{d}_{m-2}$) given earlier. Because the binomial distribution turned out to be relatively insensitive to values of p_j ranging from 0.01 to 0.10 given a fixed value of P_c, an averaged value ($\bar{p}$) of 0.05 was used in the following final design equation:

$$B = \sum_{r=1}^{7} \left\{ P(r|\bar{p},P_c) \cdot \sum_{m=1}^{6} [P(m|r) \cdot \bar{d}_{m-2}] \right\} + [P(r \geqslant 8|\bar{p},P_c) \cdot \bar{d}_{1-2}] + [(1 - P_c) \cdot \bar{d}_o] \qquad (7)$$

In this equation, B equals the expected bias in parts per million given P_c, and $\bar{d}_o$ represents an estimate of the average difference between the second seasonal maximum and observed maximums occurring outside the top six-rank interval. In cases where a seasonal maximum is not encountered during the sampling period, there is still a high probability (P_c') that a daily maximum within the top 12 ranks will be found. It can be shown that

$$P_c' = 1 - \exp [\ell n(1 - P_c)\ell n(1 - 2\bar{p})/\ell n(1 - \bar{p})] \qquad (8)$$

assuming that the average underlying probability of encountering a daily maximum within the top 12 ranks is twice the probability of encountering a maximum in the top 6 ranks. Thus, the selection of the design probability (P_c) was based on B approaching zero in Equation 7 and P_c approaching 1 in Equation 8. The value for $\bar{d}_o$ was determined by extrapolating values of $\bar{d}_{m-2}$ for m = 7 to 12 by using the average differences given earlier and compositing these values as follows:

$$\bar{d}_o = \sum_{r=1}^{7} \left\{ [P(r|\bar{p},P_c)/P_c] \cdot \sum_{m=7}^{12} [P(m-6|r) \cdot \bar{d}_{m-2}] \right\} + \left\{ [P(r \geqslant 8|\bar{p},P_c)/P_c] \cdot \bar{d}_{7-2} \right\} \qquad (9)$$

Equation 9 deals essentially with the small probability ($P_c' - P_c$) that an observed maximum will fall outside the top 6 ranks but within the top 12 ranks for the season. The same combined probabilities used to model the distribution of the top 6 ranks are used to weight the values of $\bar{d}_{m-2}$ for m = 7 to 12 when the composite result ($\bar{d}_o$) is developed.

By trial and error, a design value for P_c of 0.93 was derived. This yields a value of 0.995 for P_c'. Simply stated, this means that given a sampling period of sufficient duration to assure a 93 percent chance of encountering at least one seasonal maximum, one can be 99.5 percent confident that the observed maximum is an unbiased estimate of the expected second annual maximum.

The distribution of differences given in Table 6 represents a wide range of exposures. The average differences were used in this paper strictly for the purpose of approximating an unbiased sampling program. It was assumed that

$$\bar{d}_{1-2}/\bar{d}_{m-2} = \text{constant} \qquad (10)$$

for each value of m regardless of location, season, or averaging time. The absolute random error that one can expect in terms of parts per million for any given location will depend on the magnitude of the seasonal maximums at that location, not the average differences derived from the California data set.

RECOMMENDED SAMPLING PLAN

Scheduling and duration of sampling are the key elements in the modified observed maximum method. They are used to minimize bias and to assure a reasonable probability of encountering a maximum value equal to or near the second seasonal maximum. Sample scheduling determines the probability (p_{jk}) of encountering a seasonal maximum given the jth month and the kth day-of-week sampling plan. Sampling duration determines the probability of encountering one or more seasonal maximums given p_{jk}. If the probability $[P(r \geq 1|p_{jk})]$ equals the design probability (P_c), the observed maximum represents an unbiased estimate of the expected second seasonal maximum.

To facilitate selection and design of sampling plans, a table listing values of $P(r=0|p_{jk}) = 1 - P(r \geq 1|p_{jk})$ for 1-week periods as a function of month and days sampled during the week was constructed. The following simplified form of the binomial distribution for r = 0 was used to compute these probabilities:

$$P(r=0|p_{jk},n_k) = (1 - p_{jk})^{n_k} \qquad (11)$$

where n_k is the number of days sampled per week.

Values of p_j taken from Figure 1 were modified according to the following equation:

$$p_{jk} = p_j \cdot \left[7 \sum_{i=1}^{7} (D_{ik} \cdot \bar{f}_i) / \sum_{i=1}^{7} D_{ik} \right] \qquad (12)$$

where $\bar{f_i}$ equals the average probability from Figure 2 of encountering a seasonal maximum on the ith day, and D_{ik} = 1 if the ith day is included in the kth day-of-week sampling plan or D_{ik} = 0 if it is not. Equation 12 is simply a means of accounting for the significant difference in the distribution of seasonal maximums by day of week shown in Figure 2. Eight day-of-week sampling plans were considered. The results are given in Table 7.

TABLE 7 Probability of Encountering Zero Seasonal Maximums in a 1-Week Sampling Period by Month and Day-of-Week Sampling Plan

Days Sampled	$P(r=0 \mid p_{jk})$				
	Oct.	Nov.	Dec.	Jan.	Feb.
M–W	0.94	0.80	0.68	0.89	0.97
Tu–Th	0.93	0.79	0.66	0.89	0.97
W–F	0.92	0.76	0.62	0.87	0.97
M–Th	0.91	0.74	0.59	0.86	0.96
Tu–F	0.90	0.71	0.55	0.84	0.96
M–F	0.88	0.66	0.49	0.81	0.95
M–Sa	0.87	0.63	0.44	0.79	0.94
M–Su	0.86	0.61	0.43	0.78	0.94

To use Table 7, one simply selects the entry or entries for the month or months and day-of-week sampling plan or plans being considered. Treating each probability as independent, the combined probability of encountering zero seasonal maximums over a given sampling period will be the product of the individual probabilities taken from Table 7. For instance, if a proposed sampling plan calls for three weeks of M-F sampling in December followed by two weeks of Tu-F sampling and one week of M-Sa sampling in January, the combined probability of encountering zero seasonal maximums would be given by

$$P(r=0) = (0.49)^3 \cdot (0.84)^2 \cdot (0.79) = 0.07.$$

The criterion for accepting a proposed sampling plan is

$$\prod_{j,k} P(r=0 \mid p_{jk})^{w_{jk}} \simeq 1 - P_c \qquad (13)$$

where w_{jk} equals the number of weeks the kth day-of-week sampling plan will be repeated in the jth month. Because P_c = 0.93, the sample plan cited earlier meets this criterion.

By using Table 7 and Equation 13, a field supervisor can choose a sampling plan that will yield as an observed maximum a relatively unbiased estimate of the expected second seasonal maximum. If the need arises, a prearranged plan can even be changed midstream and still meet the criterion stated in Equation 13. After sampling is concluded and the data checked for outliers, the 1-hr and 8-hr observed maximums by time period can be considered accurate estimates of their respective second annual maximums.

CONCLUSION

Development of the sampling criterion specified by Table 7 and Equation 13 was presented in general form so that it might be applied to a variety of situations. For locations where the monthly distribution of seasonal maximums differs significantly from the 12-station California data set, a more appropriate version of Table 7 could be constructed from local aerometric data by using the same design equations. In cases where the duration of sampling falls short of the recommended period because of time, funding, or staff limitations, the probability of encountering the second or higher seasonal maximum can still be determined by using Equation 6. Proposed revisions to the National Ambient Air Quality Standards for CO by increasing the allowable number of exceedances to five per year (11) can also be accommodated by shifting the reference rank in Equation 7 from the second to the sixth seasonal maximum and modifying Equation 4 for use with either the second or third observed maximum. If the proposed revisions are adopted, sampling-duration requirements would probably be reduced.

The observed-maximum method recommended in NCHRP 200 and the modified sampling procedure developed in this paper will soon be implemented by Caltrans. It is anticipated that the new procedures will save considerable time in the collection and analysis of aerometric data for project-level transportation air quality studies. In addition, more accurate estimates of ambient maximums are expected.

ACKNOWLEDGMENT

This report was produced as part of a research project funded by FHWA. The author would like to express his appreciation to Gary Honcoop of the California Air Resources Board for providing the 12-station California data base, Jim Quittmeyer for performing numerous analyses of the data on the computer, and Earl Shirley for his review and interest in the final document.

REFERENCES

1. R. I. Larsen. A Mathematical Model for Relating Air Quality Measurements to Air Quality Standards. Report AP-89. U.S. Environmental Protection Agency, Nov. 1971.
2. P. D. Allen, A. J. Ranzieri, and E. C. Shirley. Application of Larsen's Mathematical Model for Air Quality Studies. Report TL-7082-12-76-25. Transportation Laboratory, California Department of Transportation, Sacramento, 1976.
3. R. I. Larsen. An Air Quality Data Analysis System for Interrelating Effects, Standards, and Needed Source Reductions, Part 4: A Three-Parameter Averaging-Time Model. Journal of the Air Pollution Control Association, Vol. 27, May 1977, pp. 454-459.
4. D. T. Mage and W. R. Ott. Refinements of the Lognormal Model for Analysis of Aerometric Data. Journal of the Air Pollution Control Association, Vol. 28, Aug. 1978, pp. 796-798.
5. T. C. Curran and N. H. Frank. Assessing the Validity of the Lognormal Model When Predicting Maximum Air Pollution Concentrations. Presented at the 68th Annual Meeting of the Air Pollution Control Association, Boston, Mass., 1975.
6. N. R. Patel. Comment on a New Mathematical Model of Air Pollution Concentration. Journal of the Air Pollution Control Association, Vol. 23, April 1973, pp. 291-292.
7. H. E. Neustadter and S. M. Sidik. On Evaluating Compliance with Air Pollution Levels Not to be Exceeded More Than Once a Year. Journal of the Air Pollution Control Association, Vol. 24, June 1974, pp. 559-563.
8. J. Horowitz and S. Barakat. Statistical Analysis of the Maximum Concentration of an Air Pollutant: Effects of Autocorrelation and Non-Stationarity. Atmospheric Environment, Vol. 13, 1979, pp. 811-818.
9. W. S. Meisel and T. E. Dushane. Monitoring

Carbon Monoxide Concentrations in Urban Areas. NCHRP Report 200. TRB, National Research Council, Washington, D.C., April 1979.
10. E. C. Shirley. Traffic Information Requirements for Estimates of Highway Impact on Air Quality. Report MR657082S(3)-72-09. California Division of Highways, Sacramento, 1972.
11. A. Samberg and J. Elston. The Proposed Revision to the NAAQS for Carbon Monoxide and Its Effect on State Designation. Journal of the Air Pollution Control Association, Vol. 32, Dec. 1982, pp. 1228-1230.

Publication of this paper sponsored by Committee on Transportation and Air Quality.

Cost-Effectiveness Model for the Analysis of Trade-Offs Between Stationary and Transportation Emission Controls in Baltimore

ARMANDO M. LAGO, SALVATORE BELLOMO, KEVIN HOLLENBECK, SAUD SIDDIQUE, and JOE MEHRA

ABSTRACT

The application of a cost-effectiveness model for the attainment of ozone standards in Baltimore is described. Cost-effectiveness programs for Baltimore are designed taking into account direct implementation costs and user costs. The mix of controls in the cost-effective solution varies when either direct implementation costs or social costs are considered. The economic and social impacts of the cost-effective solutions are discussed. Finally, the results of the Baltimore application are contrasted with the results of an earlier study in Philadelphia.

Under the provisions of the Clean Air Act (40 CFR 50, revised July 1, 1980) each state must prepare a state implementation plan (SIP) for meeting air quality goals. The SIP, which is usually prepared by a designated metropolitan planning organization (MPO), contains programs for control of mobile sources of air pollution [including transportation control measures (TCMs)] and stationary sources to meet the air quality emission goals. However, the plan may also consider other important socioeconomic, mobility, and environmental factors in the design and choice of pollution abatement and control strategies. A review of SIPs conducted by BKI Associates, Inc. (1) found that the SIP planning methodologies were applied separately to control of transportation sources and to stationary sources, a procedure that limited the opportunities for coordination and trade-off of mobile-source and stationary-source controls with the concomitant loss of information and opportunities for optimization of the strategies contained in the SIPs. The results of the development and application of a cost-effectiveness model for the analysis of trade-offs between controls of stationary sources and transportation sources for hydrocarbons in the Baltimore standard metropolitan statistical area (SMSA) are summarized.

BASIC COST-EFFECTIVENESS CONCEPTS

Cost-effectiveness analysis provides an efficient method for coordinating and trading off stationary-source and mobile-source control options. The method consists of defining a measure of effectiveness (MOE), in this case the reduction of hydrocarbon (HC) emissions, and then estimating costs of abatement control per unit of HC removed. Abatement strategies in specific pollutant-emitting industries are next ranked in terms of cost-effectiveness ratios (i.e., dollar costs divided by units of HC removed). Then, given an objective of total HC reductions derived from air quality standards for the region, the least-cost package of abatement strategies for meeting the standard is selected by picking those strategies with lowest cost per unit of HC removed and avoiding the higher-cost strategies and alternatives. Designing the least-cost package, sometimes called the cost-effective package, enables environmental planners to consider and trade off abatement strategies, such as those for stationary point sources versus those for mobile sources, an important feature sometimes lacking in the methodology used in developing the SIPs.

At the outset it should be noted that cost-effectiveness analysis per se is neutral with respect to the definition of the target level of emission reductions. In addition, cost-effectiveness analysis assumes that the effectiveness target is valuable in the sense that the benefits from its accomplishment exceed its costs. If the effectiveness target of HC reductions is not valuable, successively lower targets must be considered until one of these targets is deemed valuable. In this respect, cost-effectiveness analysis is a more restricted tool than benefit-cost analysis, which determines whether the benefits of the air quality standard are greater than its costs. However, although benefits from air pollution control have been quantified in terms of impacts on health (2), land values (3), and cleaning costs (4), among others, it is safe to state that controversy surrounds the estimation of these benefit impacts, so cost-effectiveness analysis is a more appropriate analysis technique.

Performing a cost-effectiveness analysis of air pollution control entails five major analytical operations, which are described in the following in the context of an application of the cost-effectiveness methodology to the planning of control of HC emissions in the Baltimore SMSA.

PROJECTION OF EMISSION INVENTORIES

The first step in the analysis is to project the emission inventories. The inventory of point sources (industrial processes and power plants) and area sources (residences, institutions, laundries, and gas stations) is usually contained in the National Emissions Data Systems (NEDS) (5) data base by type of pollutant. The point-source emissions inventories can be projected by assigned retirement rates to the existing sources and on the basis of new industrial growth rates expected by the industrial sectors. Value-added growth rates by industry sector provide the next most reasonable proxy if retirement rates are unavailable. Some area source emissions (e.g., dry cleaning and solvent evaporation) may be projected on the basis of general population growth rates, whereas others (e.g., fuel handling and asphalt paving) may be projected on the basis of vehicle miles of travel (VMT).

Mobile-source inventories, which include highway and off-highway vehicles, are developed by political jurisdiction, taking into account data on VMT, average speed, vehicle trip ends, and emission rates from the MOBILE I (6) and II (7) computer programs of the U.S. Environmental Protection Agency (EPA). The mobile-source inventories are projected on the basis of VMT growth rates and the effects of the Federal Motor Vehicle Emission Control Program. The projection data for mobile sources are available through the continuing, cooperative, and comprehensive (3c) transportation planning process. In the Baltimore SMSA application described here, projections of the emission inventories were available from local governmental sources. Projections of point and area HC emissions were available from the Maryland Department of Health and Mental Hygiene, and mobile-source emissions were available from the Baltimore Regional Planning Council (BRPC). These projections are presented in Table 1.

TABLE 1 1987 Projections of HC Emissions in the Baltimore SMSA

	Reactive HC Emission (short tons/yr)	
Source	1980	1987
Point	39,963	42,863
Area	38,842	40,667
Mobile	64,383	34,088
Total	143,188	117,618

Note: All the estimates come from BRPC and the Office of Environmental Programs of the Maryland Department of Health and Mental Hygiene.

DETERMINATION OF TARGET LEVEL OF EMISSION CONTROL REQUIREMENTS

The next analytical operation is to estimate the regionwide emission reductions needed to attain ambient air quality standards. The degree of HC emission control needed can be computed from an approved photochemical dispersion model, such as the Empirical Kinetic Modeling Approach (EKMA). The EKMA (city-specific level III) model produces a more realistic estimate of required emission reductions than the previously used rollback methods because (a) it is based on the chemical kinetics of O_3 production in smog chamber experiments and (b) it can be adjusted to reflect the existing mix of ambient HC and NO_x in the study region. EPA does not accept nonattainment plans for ozone that are based on linear or proportional rollback methods. There was no need for the researchers to apply the EKMA model to the Baltimore SMSA, because the target level of HC emission reductions had been estimated by the Maryland Department of Health and Mental Hygiene at 40,000 short tons per year of reactive HC by using similar methods to the one described earlier. The 40,000 short tons of reactive HC per year became then the target of the air pollution control efforts.

ESTIMATION OF COSTS AND EFFICIENCY OF AIR POLLUTION CONTROL OPTIONS

The control options for point sources of HC emission (8) include flares, thermal and catalytic incineration, carbon adsorption, Venturi scrubbers, floating roofs, and so on. As the regulatory agency, EPA has developed reasonably available control technologies (RACTs) for existing sources. For new sources, technologies corresponding to the lowest achievable emission rates (LAERs) are recommended. The area-source control technologies include carbon adsorption for dry cleaning, water coating for solvent evaporation, vapor balance and vacuum assist for fuel-handling sources, and emulsified asphalt for asphalt paving. Most of the area-source emission control options correspond to RACTs.

The estimation of costs of HC control options for point sources is complex because of the many industries involved and the wide variation in industrial processes. For point sources, the capital costs of controlling air emissions discharged through smokestacks are a function of the size (air flow) of the stack, whereas the operating and maintenance (O&M) costs are the product of control equipment size and operating time. Because data on the characteristics of air flow are not always available, a useful surrogate for estimating capital costs found in most emission inventories is the production or operating capacity (e.g., tons of fuel burned or chemical products) of the sources vented to the stack. Similarly, annual O&M costs can be estimated from information on the total amount of fuel used or output per year. The costs of each control operation include two functions, namely, one for capital costs and another for O&M costs. Total capital costs are defined as the sum of the cost of equipment, taxes and freight, installation, engineering, and contingencies. O&M costs include labor, parts, materials, utilities, waste disposal, energy penalties or credits, and by-product recovery credits, if any. In order to reflect economies of scale the HC emission control cost functions estimated are nonlinear functions of the following type:

Capital cost:

$$C_C = A(X_D)^{\alpha + 1} \tag{1}$$

O&M cost:

$$C_{OM} = B(X_0)^{\gamma + 1} \tag{2}$$

where

C_C = total capital costs in 1976 dollars;
X_D = maximum design rate for the point source in Source Classification Code (SSC) units per year;
A, α = empirical constants;
C_{OM} = annual O&M costs in 1976 dollars;
X_0 = annual operating rate, usually defined as amount of material produced (in some instances material consumed) in a given time, which may be used to compute emission factors, in SSC units per year; and
V, γ = empirical constants.

The design and operating rates of the foregoing cost functions are expressed in terms of the industrial units used in the NEDS system (the SCC units) (9). These SCC units may be tons, gallons, cubic feet, and other units appropriate to each industry. The cost functions were estimated by Energy and Environmental Analysis, Inc. (10), fitting a line to the costs for different scales of application reported in the literature. The capital costs are annualized by using capital recovery factors and added to the O&M costs to develop annual costs of abatement control for a given control option (RACT or LAER). The capital recovery factors used 10 percent discount rates and economic life of 10 years for the equipment.

For area sources the estimation of the costs and the HC emission reduction is accomplished on a more aggregate basis. The generalized cost functions are linear and the cost driving variable is now defined as annual tons of current emissions. Detail on the specifications of these functions has been presented by BKI Associates, Inc. (1) and Ecosometrics (11).

The methodology for estimating the TCMs is straightforward. Costs may be estimated for each of the TCMs by using unit costs in the literature or specific engineering estimates. Specific unit costs for TCMs are a function of the individual project, its location, and also the size of the urban area. However, generic unit costs can be developed (1,12) as a function of the size of the urban area, transit level of service, and the highway level of service. Annual recurring costs of operation, administration, maintenance, and enforcement make up the bulk of the costs incurred.

With respect to emission reduction estimates for mobile-source controls, these are obtained through sketch-planning techniques (13,14) or through the application of the Urban Transportation Planning System (UTPS). Essentially, mobile-source controls are translated into reductions in factors influencing emissions (vehicle trip ends, VMT, vehicle hours of travel, network speed). Once the transportation effects have been determined, the motor vehicle emissions can be estimated by using EPA's MOBILE I or II computer models.

With regard to the application of mobile controls for HC in the Baltimore SMSA, the analysis began with a list of initial transportation controls and their costs and impacts on HC reductions, developed by JHK and Associates (15) for BRPC. This study developed implementation costs and HC reduction impacts for the major corridors of the Baltimore metropolitan region.

The costs of the transportation control program for the Baltimore SMSA are presented in Table 2. These costs were developed by expanding to the metropolitan region the transportation control programs proposed by BRPC for the major corridors noted earlier (15). Economies of scale were assumed to be negligible. Equivalent annualized capital costs and operating costs were calculated by using a 10 percent discount rate (same as stationary sources) and reasonable assumptions of service life (for example, 10 years for traffic control systems, 15 years for buses, and 30 years for highway construction). Some of the TCMs were not expanded to the region because they involve spot improvements (such as SCC 954, 964, and 965). An important assumption made in developing costs of the inspection and maintenance program was that they would be borne by the users, who would pay through inspection fees for the costs incurred by the private sector (e.g., at gasoline stations and motor vehicle repair shops) and the program administration costs incurred by the Maryland Department of Motor Vehicles (DMV).

In addition to the direct implementation costs, user cost savings were also estimated for the TCMs. The user cost savings estimated included vehicle operating costs, travel time costs, and transit fares, whenever applicable. Accident costs were not estimated to correspond to the analytical procedures used by BRPC. The user unit cost estimates were derived by updating the 1975 AASHTO (16) estimates by using changes in the consumer price index (CPI). The demand projections used in the estimation of user cost savings made extensive use of the analysis of changes in VMT induced by the TCMs available from a previous study in Baltimore (15).

DESIGNING THE LEAST-COST POLLUTION CONTROL PROGRAM

The next analytical step is to select the mix of control options required to obtain air quality standards at minimum costs. Essentially the problem is one of selecting the least expensive set of control strategies that bring the total emissions in the region below a maximum emission level (E_{max}). The problem solution is formulated as an integer program as follows:

Minimize

$$\sum_{i=1}^{j} f_i(X_i)$$

Subject to

$$\sum_{i=1}^{j} g_i(X_i) \geqslant b \qquad X_i = 0, 1, \ldots, N_i$$

where

X_i = level of control on source category i,
$f_i(X)$ = cost of control level X on source category i,
$G_i(X)$ = tons reduced by control level X on source category i (this function is assumed to be an increasing function of X),
N_i = maximum level of control available for source category i, and
b = emission reduction needed ($b = E_{max}$) to obtain ozone standard.

TABLE 2 Direct and User Costs and Emission Reductions of Transportation Controls in the Baltimore SMSA

		Direct Costs ($ 1980)						
SCC	Action	Capital	Annual O&M	Annualized Capital	Total Annualized	Nonmethane HC Change (%)	Annual User Costs[a] ($ 1980)	Net Annual Costs (direct and user) ($ 1980)
950	Inspection and maintenance[b]	20,000,000	7,710,000	3,540,000	11,250,000	-23.460	787,500	12,037,500
951	Signal retiming, rephasing, and interconnection	427,200	21,600	76,660	98,260	-1.880	-2,019,410	-1,921,150
952	Remove signal or switch to flashing at nighttime	85,800	-61,800	14,760	-47,040	-0.227	-1,514,800	-1,561,840
953	Modify transit route, schedules, frequency, bus stops	3,666,000	-911,760	647,040	-264,720	-0.123	153,000	-111,720
954	Feeder service	1,713,000	371,500	293,200	664,700	-0.011	41,280	705,980
955	Improve transit marketing, information, amenities	2,444,580	166,460	430,390	596,850	-0.134	-229,270	367,580
956	Residential-based ridesharing	0	122,470[c]	0	122,470	-0.683	-15,756,620	-15,634,150
957	Employer-based ridesharing	0	1,597,240[c]	0	1,597,240	-3.116	-73,110,580	-71,513,340
958	Parking management	441,600	0	78,120	78,120	-0.010	-157,090	-78,970
959	Commuter park-and-ride lots[d]	17,794,800	116,640	3,070,920	3,187,560	-0.097	-2,185,270	1,002,290
960	Multiple use of parking facilities	489,600	47,400	86,660	134,060	-0.076	-684,300	-550,240
961	Improve bicycle facilities	4,657,200	52,800	822,600	875,400	-0.009	-296,390	579,010
962	Institute or extend turn lanes	12,638,400	2,400	2,241,480	2,243,880	-0.157	-2,966,940	-723,060
963	Improve roadways (geometrics and signing)	19,981,200	5,000	3,536,670	3,541,670	-0.183	-5,127,780	-1,586,110
964	Contraflow bus lanes	150,000	-24,000	27,000	3,000	-0.001	22,060	25,060
965	New signals[e]	312,000	36,000	55,200	91,200	+0.050	1,436,260[f]	1,527,460
966	One-way streets[e]	250,000	0	44,250	44,250	+0.001	58,680	102,930

[a] Negative figures denote savings or net benefits.

[b] These costs include $20 million of capital costs of investments by the private-sector operators, $1,875 million of annual administration costs by the Maryland Department of Motor Vehicles, $5,835 million of annual operation of the program by the private-sector operators, $11.25 million of inspections paid annually by the users, $5.25 million of annual repair costs of vehicles, and $4.462 million of annual fuel savings by the users.

[c] These figures refer to annual costs of a 6-year ridesharing program. To calculate the costs of the program in its entirety these costs must be multiplied by 6.

[d] The capital costs of commuter park-and-ride lots represent mostly right-of-way (35 percent) and construction (53 percent) expenses, the residual comprising shelters, signs, etc.

[e] These measures result in Increased nonmethane HC emissions.

[f] Excludes safety and accident cost savings.

The inputs to the least-cost model are the costs and emission reductions estimated in the previous steps and the estimated regionwide emission reductions needed to attain ambient air quality standards. Because the least-cost model has been described elsewhere (1) only its highlights are presented here. The workings of the least-cost model are as follows. Based on the available control options, the model selects sources for additional emission control by using the criteria of cost-effectiveness. Each control option is ranked according to its annualized cost per ton of emission reduction. The control option with the lowest cost per ton reduced is chosen first, the second-lowest cost per ton reduced next, and so on, up to the required emission reduction (specified by the user). The required emission reduction is based on the amount of HC emissions needed to attain a given annual ozone standard. If the available control options do not provide sufficient emission control to meet the specified HC reduction, the standard cannot be met and maximum control of all controllable sources in the inventory has been reached.

The least-cost model was then applied to design an HC pollution control program for the Baltimore SMSA. The control program selected was to be the one that achieved the target reduction of 40,000 tons per year at minimum social costs, which were defined to include the direct implementation costs plus the user costs with adjustments to remove double counting. A sensitivity analysis was also conducted to examine how the least-cost program would change if only direct implementation costs (no user costs) were considered. Of particular interest in the least-cost model simulations were the trade-offs between stationary-source and mobile-source controls in reaching the target level of emissions.

The application of all the control programs--stationary and mobile--results in controlling close to 840 HC pollution sources out of a possible total of 1,300 sources in the NEDS files. The sources subject to controls account for 81,700 reactive HC tons, and the emission control programs, if applied in their entirety, would result in reductions of 48,200 reactive HC tons, exceeding the 40,000-ton target. This results in opportunities for trading off strategies for control of stationary versus mobile sources.

As shown in Table 3, the transportation control options account for only 15 percent of the HC emission reductions in the cost-effective program package. Moreover, a large number of the transportation control options are cost effective if their user cost savings are considered. Inclusion of user cost considerations provides the correct basis for comparison because the sum of direct plus user costs renders the true social costs (public plus private) of each respective option. The stationary-source and area-source control options account for 86 percent of the HC reductions, but these reductions are achieved at the expense of greater costs. Not all the transportation control options are selected in the least-cost program. Some of them, such as SCC 965 (new signals) and SCC 966 (one-way streets) lead to increases in HC emissions and are therefore correctly excluded from the least-cost program package.

The results of the least-cost model considering only direct costs are presented in Table 4, in which the exclusion of user costs works to the disadvantage of the transportation control options whose cost-effectiveness ratios increase by the lack of consideration of the user cost savings. The relative small contribution of the TCMs in improving air quality and the political and institutional factors involved in selecting the TCMs often make cost effectiveness a secondary issue. Indeed, the TCMs will assume a smaller role in the future as new car control programs and vehicle inspection and maintenance programs continue to reduce vehicle emissions.

In this application of the cost-effectiveness model to the Baltimore SMSA, the HC emission control program achieves the target level of HC reductions and it is possible to trade off programs for stationary-source versus mobile-source control. However, this may not be typical of other areas. The reader should remember that the transportation control program postulated here has a broader metropolitan scope than the major corridor options developed by BRPC.

The total-cost curves of HC emission control in

TABLE 3 Summary of Cost-Effectiveness Model Results: Direct and User Costs

SCC Emission Source	Reactive HC Emission Reduction (tons/year)	Total Annualized Costs ($ 1987 000,000s)	Cost per Ton of HC Removed ($ 1987 000s)
Included in cost-effectiveness program package			
Mobile-source controls			
957 Employer-based ridesharing	608.0	-132.0	-217.0
956 Residential-based ridesharing	133.0	-28.90	-217.0
963 Improve roadways	35.7	-2.930	-82.1
958 Parking management	1.95	-0.146	-74.8
960 Multiple use of parking facilities	14.8	-1.020	-68.6
952 Remove signal or switch to flashing	44.3	-2.89	-65.2
962 Institute turn lanes	30.7	-1.34	-43.6
951 Signal retiming or rephasing	367.0	-3.55	-9.68
953 Modify transit routes and schedules	24.0	-0.207	-8.61
950 Inspection and maintenance	4,580.0	22.3	4.86
	5,839.45	-150.683	-25.80
Stationary-source controls (point and area)	34,160.55	41.68	1.22
Total	40,000.0	-109.00	-2.72
Not included in cost-effectiveness program package			
955 Improve transit marketing	26.20	0.680	26.0
959 Commuter park-and-ride lots	18.90	1.85	97.9
964 Contraflow bus lanes	0.195	0.046	237.0
954 Feeder service	2.15	0.31	608.0
961 Bicycle facilities	1.76	1.070	609.0
	49.205	4.956	100.721
All stationary-source controls (point and area)	8,150.795	5.63 x 10^6	690,730.2
Total	8,200.00	5.63 x 10^6	686,585.4

Note: Mobile-source controls SCC 965 (new signals) and SCC 966 (one-way streets) are not included because these measures result in increased nonmethane HC emissions.

TABLE 4 Summary of Cost-Effectiveness Model Results: Direct Costs Only

SCC Emission Source	Reactive HC Emission Reduction (tons/year)	Total Annualized Costs ($ 1987 000,000s)	Cost per Ton of HC Removed ($ 1987 000s)
Included in cost-effectiveness program package			
Mobile-source controls			
953 Modify transit routes and schedules	24.0	-0.490	-20.4
952 Remove signal or switch to flashing	44.3	-0.087	-2.0
951 Signal retiming or rephasing	367.0	0.182	0.495
956 Residential-based ridesharing	133.0	0.227	1.7
950 Inspection and maintenance	4,580.0	20.8	4.54
957 Employer-based ridesharing	608.0	2.95	4.86
	5,756.3	23.582	4.097
Stationary-source controls (point and area)	34,243.7	48.118	1.405
Total	40,000.0	71.70	1.793
Not included in cost-effectiveness program package			
960 Multiple use of parking facilities	14.8	0.248	16.7
964 Contraflow bus lanes	0.195	0.006	28.4
955 Improve transit marketing	26.2	1.10	42.2
958 Parking management	1.95	0.145	74.0
965 Institute turn lanes	30.7	4.15	135.0
963 Improve roadways	35.7	6.55	183.0
959 Commuter park-and-ride lots	18.9	5.90	311.0
954 Feeder service	2.15	1.23	572.0
961 Bicycle facilities	1.76	1.62	921.0
	132.355	20.949	158.279
All stationary-source controls (point and area)	8,067.645	5.63 x 10^6	697,849.2
Total	8,200.00	5.63 x 10^6	686,585.4

Note: Mobile-source controls SCC 965 (new signals) and SCC 966 (one-way streets) are not included because these measures result in increased nonmethane HC emissions.

Baltimore are presented in Figure 1. The total-cost curves with user costs (which represent the social costs) show that the user cost savings generated by the transportation control programs enable emission reductions of approximately 45,000 tons of reactive HC through stationary-source and mobile-source controls at negligible social costs. However, the distributional considerations cannot be ignored because the affected industrial plans would have to bear a huge control cost, whereas the transportation users enjoy significant benefits. Regarding solely the stationary-source controls, the total-cost curves show diminishing returns after reaching 33,000 short tons of reductions of reactive HC through stationary-source controls. Approximately 33,600 HC tons are reduced through stationary-source controls at an annual cost of $23 million of annualized total costs, and 37,700 tons cost $78 million, whereas 41,000 reactive HC tons from stationary sources cost $739 million in 1987 dollars. As may be seen from Table 4, the presence of user cost savings in the mobile-control options diminishes the social costs of HC reductions to negligible amounts.

Figure 1 also shows the direct costs of HC emission control in the Baltimore SMSA. As shown, it is possible to reduce as much as 24,000 short tons per

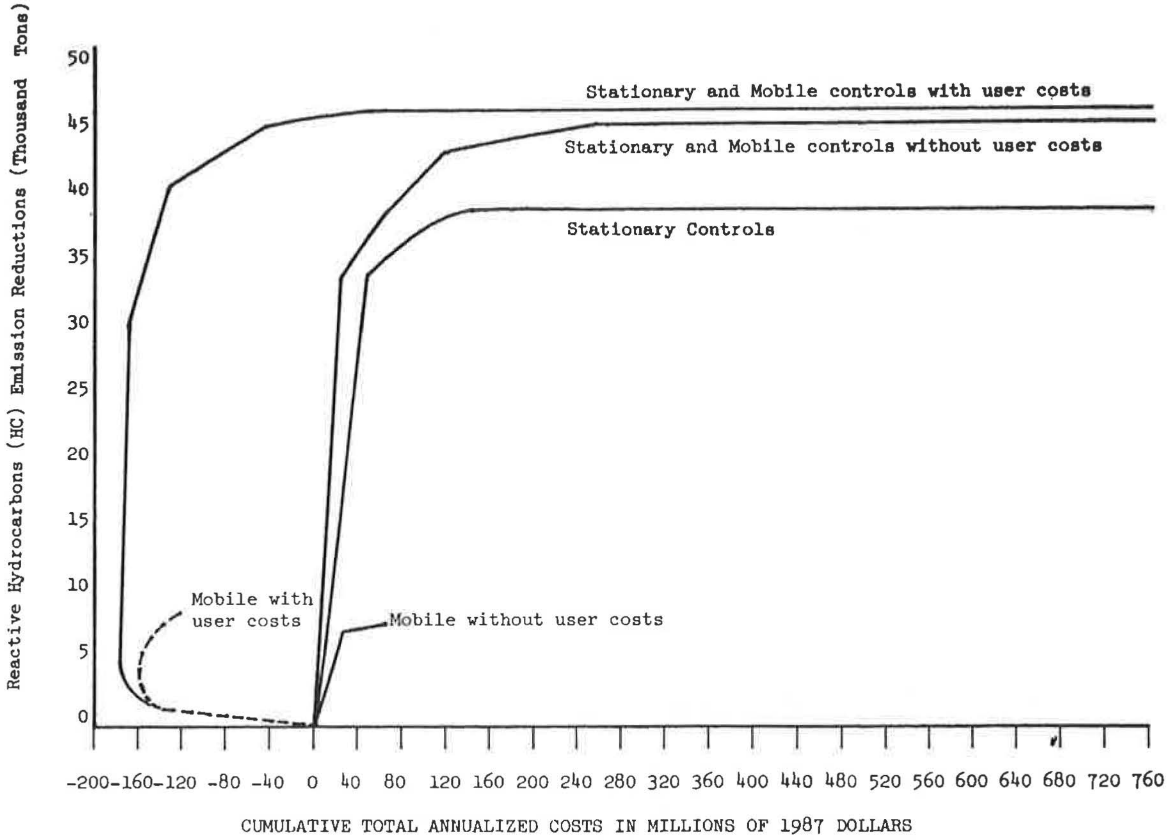


FIGURE 1 Cumulative total annualized costs of HC emission control in the Baltimore SMSA.

year of reactive HC at the moderate annual direct cost of $4.85 million in 1987 dollars. Reduction of 30,000 short tons costs $9.8 million in 1987 dollars every year. For the target of HC emission reductions in Baltimore of 40,000 short tons, the annual direct costs of implementation would be $71.7 million in 1987 dollars. However, it is costly to set the target level of emission reductions above 40,000 tons because reduction of reactive HC from 40,000 to 43,500 short tons costs an extra $32 million in direct costs annually. It may be concluded that reductions up to 40,000 tons of reactive HC are achieved at moderate costs, but that above this figure, the extra reductions are achieved at significantly higher costs.

The HC control cost functions of the Philadelphia Air Quality Control Region (AQCR) (1) and the Baltimore SMSA are contrasted in Figure 2. The direct-cost functions (which include the annual O&M costs and the annualized capital costs) are similar in shape in both areas except that the Baltimore cost curves become flatter much earlier than the Philadelphia curves, denoting that the costs per ton are cheaper in Philadelphia because of an economic base heavy with petrochemical concerns. In Baltimore the relatively lesser importance of petrochemicals affords less opportunities for point-source controls. As shown earlier, emission reductions greater than 40,000 tons are very expensive in Baltimore because less cost-effective methods must be employed after this level of emission reduction. Identical conclusions may be reached by focusing on the cost functions with user costs, except that in Baltimore large user cost savings accrue because of the transportation control program. With these considerations, the least-cost solutions differ in both areas, as follows:

Area	Least-Cost Solutions of Reductions in Reactive HC (short tons 000s) Stationary Source	Mobile Source
Baltimore SMSA (reactive HC)	34.2	5.8
Philadelphia AQCR (nonmethane HC)	150.0	15.0

In the Philadelphia AQCR stationary-source controls are relatively more cost effective; therefore its least-cost strategy concentrates less relative effort on mobile-source controls.

ECONOMIC AND SOCIAL CONSEQUENCES OF COST-EFFECTIVE PROGRAM

The final step in the analysis is to assess the economic, social, mobility, and environmental impacts of the control options in the least-cost set and their evaluations in the light of local preferences and policies. Because of their importance, only the economic and social impacts are discussed here. The reader is referred to the consultants' report (11) for a review of the mobility, energy, and other environmental impacts.

Economic Impacts

The estimation of economic and social effects is important because the costs of pollution abatement and control may adversely affect some of the industries in the region. This would be true partic-

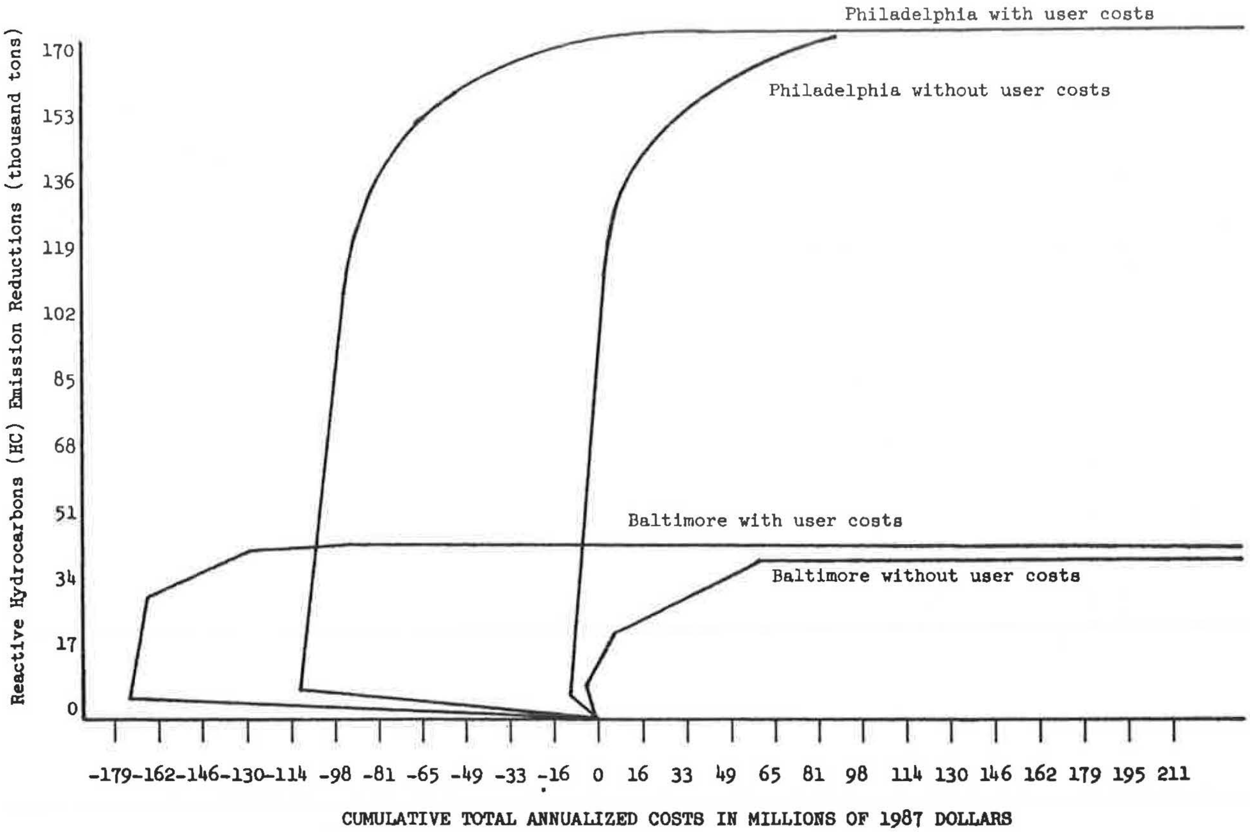


FIGURE 2 Comparison of annual costs of HC control in Baltimore SMSA and Philadephia AQCR.

ularly of regions without manufacturers that practice pollution abatement. In three case studies (Twin Cities, Ohio River Valley, and the New York metropolitan area) of impacts of air pollution control measures reviewed by the National Commission on Air Quality (17), relatively little impact of pollution control programs was noted. Depending on the industrial structure of the regional economy, pollution abatement expenditures need not result in regional losses in employment and output. Employment and output losses may not result if the regional economy possesses a manufacturing sector that practices pollution abatement or if the industries sensitive to economic dislocation are excluded from the control program. In some instances the pollution control technology results in more efficient processes that produce net cost savings. However, these cost savings in selected processes will not by themselves be large enough to offset cost increases in other sectors unless there is either a pollution-abatement manufacturing sector or an efficient set of transportation controls that generate enough employment through user benefits to offset job losses in other stationary sources.

The economic impacts of air pollution control in the Baltimore SMSA were researched by using the 1972 input-output matrix of the Baltimore SMSA economy, which was projected to 1987 for this study. The input-output impact analysis assumed that all air pollution control costs were shifted forward to consumers in the form of higher prices and that HC emission controls were uniformly implemented throughout the nation, so that competing plants in other regions were also subjected to controls. In addition, because of the peculiarities of the input-output approach, it was assumed that the household's user cost savings from the TCMs would be reallocated proportionally between increased consumer expenditures and other savings. The reader will recognize that the input-output approach followed in this study has elements in common with the input-output studies conducted by the Rice Center in Houston (18) and in St. Louis (19). The input-output analysis was complemented by a simple regional allocation model of population, employment, personal income, and fiscal impacts to distribute impacts on a county basis.

In Table 5 estimates of the economic and employment impact of HC emission control programs on the Baltimore SMSA economy are presented, assuming national implementation of ozone standards elsewhere in the United States. One advantage of using cost-effectiveness techniques for designing abatement strategies is that high-cost options are avoided and control programs result that have generally less adverse effects on the local economy. In the Baltimore case, the economic impact of control strategies is negligible. Slight increases in employment and regional income occur because of the employment increases generated by the transportation control programs, which exceed the reductions in employment due to the emission controls on stationary sources.

The negligible economic impacts of HC emission controls in Baltimore are due to the exclusion in the cost-effective or least-cost solution presented in Table 3 of some of the basic industries most sensitive to dislocation if subjected to HC control technologies. These industries include the Bethlehem Steel plant at Sparrows Point, some of the larger chemical plants, and some of the industrial processes at the General Motors plant in Baltimore City. The least-cost solution does not include these plants and facilities because their control options are more expensive in terms of cost per ton of HC

TABLE 5 Annual Changes in 1987 Baltimore SMSA Economy Induced by HC Emission Control Programs

	Area						
Characteristic Changed	Anne Arundel County	Baltimore County	Carroll County	Harford County	Howard County	Baltimore City	Total SMSA
Population (000,000s)	571	1,227	228	246	531	2,139	4,942
Employment (000,000s)	290	523	93	77	147	1,381	2,511
Personal income ($000,000s)	8.53	16.76	2.97	2.66	4.78	24.31	60.51
Regional output ($000,000s)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	113.51
Tax revenue	0.29	0.59	0.10	0.11	0.21	0.94	2.24
Income and sales taxes ($000,000s)	0.17	0.34	0.06	0.05	0.10	0.50	1.22
Property tax ($000,000s)	0.06	0.13	0.02	0.03	0.06	0.23	0.53
Miscellaneous charges ($000,000s)	0.06	0.12	0.02	0.03	0.05	0.21	0.49

Note: These impacts refer to the changes induced by HC emission control programs from the 1987 projection of the economic performance of the Baltimore SMSA economy without these emission controls, that is, comparisons of the Baltimore SMSA 1987 economy with versus without emission control programs.

removed; therefore this is an abatement program that does not place any burden on the regional and local economies of the counties in the SMSA. However, simulations of the economic impact conducted with the input-output model also revealed large adverse effects (i.e., employment losses of 10,000 and up) if these large basic industries were subjected to control programs.

Social Impacts

Two of the TCMs have a potential for adverse social effects. One-way streets (SCC 966), if located in the central business district and on retail strip locations, may have an adverse effect on some merchants (losses to some merchants compensated by gains to others) and although no net social impacts may occur over the metropolitan area, some redistribution effects may be present. The most important program in terms of its adverse effect on households is the vehicle inspection and maintenance program (SCC 950), which will generate as much as $11.25 million (in 1980 dollars) annually from inspection fees paid by households in addition to the $0.78 million in extra vehicle operating costs that the households must bear.

CONCLUSIONS

The results of the Baltimore application show the usefulness of the joint consideration and trade-off of stationary-source and mobile-source controls in the development of control strategies for attaining air quality and other goals. Separate consideration of stationary-source and mobile-source controls, such as those practiced in most SIPs, may not result in least-cost solutions with their concomitant less-adverse impact on local economies. This separate consideration of stationary-source and mobile-source controls should be abandoned in favor of the cost-effectiveness framework demonstrated in Philadelphia and Baltimore.

In summary, cost-effectiveness analysis provides a working methodology of relative easy application in other settings and an internally consistent framework for analyzing trade-offs between stationary-source and mobile-source controls. However, caution should be exercised in extending the results of the application to other sites. Not only are the TCM strategies and their costs sensitive to local conditions but also the costs of the stationary-source controls used in this study represent average generic costs, which may not properly reflect local features. However, it should also be recognized that there are areas that, in order to meet the air quality standards, require implementation of most of the pollution control programs, allowing little flexibility for selecting strategies and programs based on cost effectiveness. Each site should be encouraged to conduct its own application of cost-effectiveness analysis by using local costs and representing unique local conditions.

ACKNOWLEDGMENT

This research was funded by the U.S. Department of Transportation. The study was prepared for the Office of Environment and Safety of the Office of the Secretary.

REFERENCES

1. BKI Associates, Inc. Study of the Cost Effectiveness of Stationary Source, Mobile Source, and Transportation Controls to Improve Air Quality. U.S. Department of Transportation, Nov. 1981.
2. L. B. Lave. Air Pollution Damages: Some Difficulties in Estimating the Value of Abatement. In Environmental Quality Analysis (A. V. Kneese and B. T. Bower, eds.), Johns Hopkins Press, Baltimore, Md., 1972.
3. J. P. Nelson. The Effect of Mobile-Source Air and Noise Pollution on Residential Property Values. Report DOT-TST-75-76. Pennsylvania State University, University Park, 1975.
4. R. G. Ridker. Economic Costs of Air Pollution. Praeger, New York, 1967.
5. NEDS: National Emissions Data System Information. Report EPA-450/4-80-013. U.S. Environmental Protection Agency, July 1980.
6. User's Guide to MOBILE I: Mobile Source Emission Model. U.S. Environmental Protection Agency, 1979.
7. User's Guide to MOBILE II. Report EPA-460/3-81-006. U.S. Environmental Protection Agency, 1981.
8. Air Pollution Control Technology Applicable to 26 Sources of Volatile Organic Compounds. U.S. Environmental Protection Agency, May 1977.
9. Aeros Manual Series, Vol. 5: Aeros Manual of Codes. Report EPA-450/2-76-005-4. U.S. Environmental Protection Agency, Aug. 1981.
10. Energy and Environmental Analysis, Inc. Analytical Procedures to Estimate Pollution Costs and to Simulate Markets in Emissions and Air Quality Offsets in Non-Attainment Areas. U.S. Environmental Protection Agency, April 1979.
11. Study of Alternative Methodologies for Apportionment of Air Quality Control Requirements. Final Report RR-158. Ecosometrics, Inc., Bethesda, Md., Feb. 1983.
12. TSM: An Assessment of Impacts. Alan M. Voorhees

and Associates, McLean, Va.; U.S. Environmental Protection Agency, Nov. 1978.
13. Evaluating Options in Statewide Transportation Planning: Programming, Techniques, and Applications. NCHRP Report 199. TRB, National Research Council, Washington, D.C., March 1979.
14. Cambridge Systematics, Inc. Transportation Air Quality Analysis: Sketch Planning Methods, Vols. 1 and 2. Report EPA-400/1-800-001a. U.S. Environmental Protection Agency, Dec. 1979.
15. D. R. Samdahl, J. Reightler, and S. S. Lippman. Getting Results from TSM Planning: Baltimore's Corridor Study Approach. In Transportation Research Record 906, TRB, National Research Council, Washington, D.C., 1983, pp. 18-26.
16. Manual on User Benefit Analysis of Highway and Bus Transit Improvements. AASHTO, Washington, D.C., 1977.
17. To Breathe Clean Air. National Commission on Air Quality, Washington, D.C., March 1981.
18. Socio-Economic Impact Analysis of Selected Air Pollution Controls in the Houston-Galveston Region. Technical Report. Rice Center, Houston, Tex., March 1979.
19. Socio-Economic Impact Analysis of Selected Air Pollution Controls in the St. Louis Region. Technical Report. Rice Center, Houston, Tex., March 1979.

Publication of this paper sponsored by Committee on Transportation and Air Quality.

The Feasibility of Using Computer Graphics in Environmental Evaluations

DANIEL D. McGEEHAN and DANIEL P. GAYK

ABSTRACT

The purpose of this study was to develop a procedure that could be used to distinguish quickly between proposed transportation projects that would have an effect on the environment, and thus require special approval, and those that would not. It is intended that this procedure be used as a basis for agreements between the Virginia Department of Highways and Transportation and other state and federal agencies to expedite evaluations of environmental impact. Data collection, program selection, and retrieval and update procedures are described.

The Environmental Quality Division of the Virginia Department of Highways and Transportation (VDHT) is directed to assess the probable benefits and damages that will result from the construction of all the department's proposed projects. For state-funded projects, these assessments result in informal reports used as decision-making tools within the department. For federally funded projects, they result in some form of environmental impact statement (EIS).

Revisions to the National Environmental Policy Act (NEPA) have been made by the federal government with the intent of shortening the overall EIS process; however, the effects have been realized more at the reporting phase than at the data-collection and analysis phase. For example, the scoping process (Section 1501.7 of the regulations of the Council on Environmental Quality) requires that an agency, as soon as possible after deciding to write an EIS on a proposed project, publish a notice of intent in the Federal Register. Among other objectives, this notice is aimed at assuring that all parties affected by or interested in the proposed action be invited to participate in determining the scope of the EIS, which includes establishing the significant issues to be studied, eliminating from study those issues considered insignificant, identifying and coordinating related EISs being written, and establishing the length of the final EIS. To prepare for and conduct the scoping process, initial data must be collected on all potentially significant variables, such as historic site locations, within the project area.

PROBLEM STATEMENT

Requests for environmental surveys needed to comply with federal regulations are sent to the Environmental Quality Division of VDHT from the Location and Design Division and from the district environmental coordinators. In response, the Environmental Quality Division staff either performs the survey or contacts federal agencies and other state agencies to obtain information to satisfy the request. In most cases the information is manually maintained or must be collected for the first time, and where the department is dependent on other agencies for information, it cannot expedite retrieval.

It would be extremely rare for a project to affect all variables that must be considered in an environmental impact assessment. Some of the more complex projects involve several variables, but the majority of all projects have no environmentally adverse effects. Consequently, a great deal of time is spent surveying projects to determine which of the variables require study.

OBJECTIVE

The objective of this study was to develop a procedure that could be used by VDHT to quickly distinguish between proposed transportation projects that would have an effect on the environment, and thus require special approval, and those that would not. It was intended that this procedure would be used as the basis for agreements between VDHT and other state and federal agencies to expedite evaluations of environmental impact.

DEVELOPMENT OF THE PROCEDURE

The procedure developed consists of selecting an appropriate computer program, developing a data base, and selecting a means of accessing and updating the information. A suggested agreement for implementing the procedure was devised. These steps are discussed under the subheadings that follow. Although the procedure can be applied for locating many different types of variables, the historic-landmark data base is used in the illustration presented here.

Program Selection

Two computer programs were evaluated: SYMAP, a program obtained from Harvard University that is designed to produce graphic output on a line printer, and the landmark data and list program (LDLP) developed by VDHT from a base program obtained from FHWA and having the capability of producing graphic output on a pen plotter.

SYMAP Program

The SYMAP program, obtained from Harvard University's Laboratory for Computer Graphics and Spatial Analysis in Cambridge, Massachusetts, was selected because of its proven reputation. It was developed at Harvard during the 1960s and is currently the most widely distributed general-purpose computer mapping software package. It can produce maps containing point, line, or area data or combinations of these. By electing certain built-in program options, SYMAP users can manipulate the size and scale of the maps produced and the symbols used to distinguish map features. The program can enlarge portions of a map, can be programmed to include only certain data features, and can produce cosmetic features such as legends and directional arrows within the map border. The output is produced by a standard line printer on standard computer paper (Figure 1). SYMAP was evaluated by using data obtained from the U.S. Geological Survey (USGS) series of maps of land use and land cover. Land cover maps describe natural land features such as vegetation, wetlands, rock outcropping, and glaciers. Land use maps show man's use of the land for facilities such as highways, bridges, buildings, and dams.

These maps are being developed by the USGS at a scale of 1:25,000 [1 in. (25.4 mm) on the map equals approximately 4 miles (6.4 km)]. The land use and land cover classification system uses 9 general level 1 categories further subdivided into 37 level 2 categories. This evaluation revealed the following information:

1. The SYMAP program is an excellent tool for comparing data by using an overlay technique. For example, by graphically overlaying variables usually related to archaeological sites, areas of land on which a site may exist will be identified by a dark shading (Figure 2).
2. SYMAP is a reliable canned program and can easily be implemented on VDHT's IBM 370 computer.
3. SYMAP data can be transmitted from terminal to terminal by using equipment already available in VDHT's district offices.
4. SYMAP is not as accurate for point location as a program that uses a pen plotter for graphic output.
5. SYMAP is best used for representing continuous data on land use and land cover rather than point or line data.
6. In most cases the collection and reduction of data for SYMAP requires may man-hours. The work required is often in the form of digitizing, which in VDHT is performed without viewing the results and results in downtime for corrections.

LDLP

Several programs available within VDHT were consolidated to test the applicability of data graphically produced on a pen plotter. Although the resulting program, LDLP, does not provide the convenience of a canned program, the immediate availability of the component programs and the programming expertise make it an economical and tailored system.

The program was evaluated by using data obtained from the files of the Virginia Historic Landmarks Commission. These files contain approximately 20,000 historic locations identified in a survey of Virginia. Of these, 1,000 representing locations listed on or nominated for the National Register and those listed on the Virginia Register were selected.

The following findings are relevant to both the computer program and the historic site location data used:

1. The pen plotter is accurate for locating site-specific data;
2. The best results were obtained when data were overlaid on a USGS quadrangle map;
3. Data in this form could not be transmitted to other locations because of the need for specialized equipment;
4. Using the programs available within VDHT, data could be retrieved on a statewide basis to coincide with the state map, county map, or USGS quadrangle map;
5. By collecting only location data and limited descriptive data, a useful data base could be established;
6. The overlay method of depicting data is sufficient, given the time limitations of an environmental evaluation; and
7. The transmittal of information by mail is sufficient for environmental evaluations.

Conclusions

The findings from the two evaluations led to the selection of the LDLP for use in establishing the

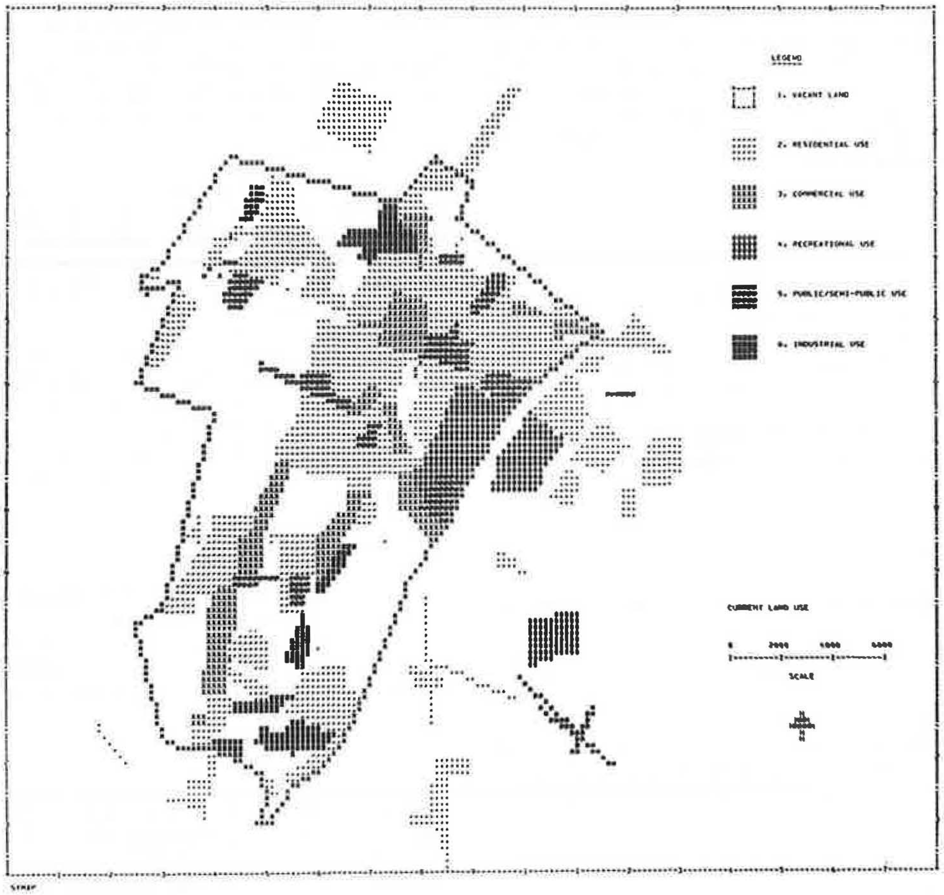


FIGURE 1 SYMAP-produced land use map of Winchester, Virginia.

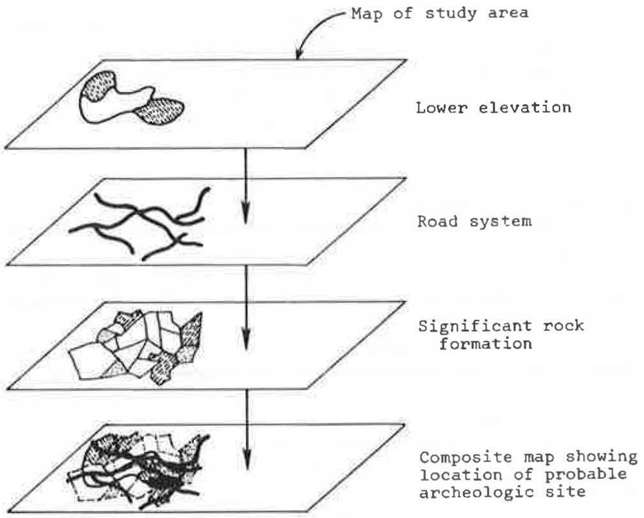


FIGURE 2 Sample overlays.

environmental data base. Program SYMAP could be used, it was decided, for some specific studies on a quadrangle level.

Development of a Data Base

Types of Data

For this illustration of the establishment of a data bank using historic site information, representatives of VDHT, the Virginia Historic Landmarks Commission, FHWA, and the registrar from the National Register of Historic Places were involved in deciding what types of data would be collected.

In addition to collecting the historic site information mentioned previously, information of interest to agencies other than VDHT was also collected. It was believed that to the extent that other agencies are interested in a specific data bank, they will aid in updating the data.

An effort was made to collect enough data to make the program useful to the Historic Landmarks Commission while at the same time not so complex that the time required to complete the data bank and the effort needed for updating would be unreasonable.

Data Input

The information selected for use was limited to that contained on the coding and input data sheets shown in Figures 3 and 4, respectively. Certain information on these sheets is applicable to all variables. Other information items are to be modified or the

Category (Column 7-46)

1. District
2. Building
3. Structure
4. Site
5. Object
6. Public
7. Private

Significance (Column 48-61)

1. Archeology — prehistoric
2. Archeology — historic
3. agriculture
4. architecture
5. art
6. commerce
7. communications
8. community planning
9. conservation
10. economics
11. education
12. engineering
13. exploration/settlement
14. industry
15. invention
16. landscape architecture
17. law
18. literature
19. military
20. music
21. philosophy
22. politics/government
23. religion
24. science
25. sculpture
26. social/humanitarian
27. theater
28. transportation
29. local history
30. scenic
31. medicine
32. presidential birthplace
33. animal husbandry
34. folklife
35. decorative arts
36. 19th century townscape
37. revolutionary history
38. afro-american
39. fire fighting
40. civil war
41. printing
42. resort
43. stone structure
44. presidential home site
45. equestrian
46. labor
47. funerary art
48. park planning
49. health
50. maritime
51. colonial settlement
52. nautical
53. biological
54. esthetic
55. depth
56. geological
57. hydrological
58. paleontological
59. length
60. recreational
61. building
62. bridge
63. mill
64. tavern
65. church
66. canal
67. historic district
68. archeological district
69. house
70. courthouse
71. glebe
72.
73.
74.
75.
76.
77.
78. FUTURE EXPANSION
79.
80.
81.
82.
83.
84.
85. urban and built-up land
86. urban commercial
87. urban industrial
88. urban institutional
89. urban mixed
90. cropland and pasture
91. orchards, groves, vineyards, horticultural
92. rangeland
93. forestland
94. streams and waterways
95. lakes
96. reservoirs
97. bays and estuaries
98. nonforest and wetland
99. barren land

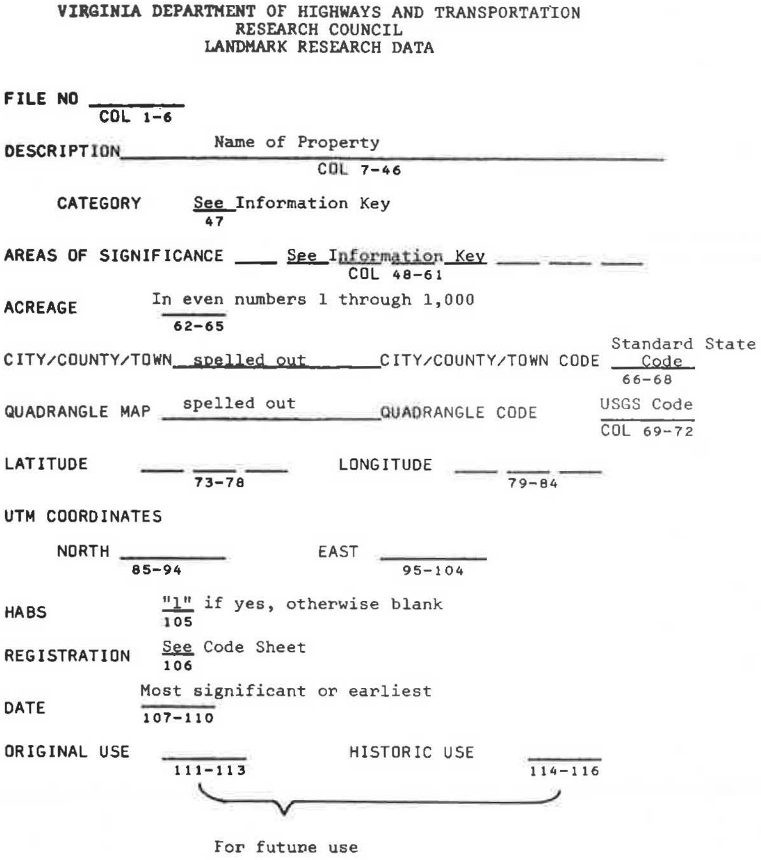
Registration (Column 106)

1. National Register of Historic Places
2. National Historic Landmark
3. Virginia Landmark Register
4. Determination of Eligibility
5. Virginia Historic Landmark Commission Inventory
6. Protected
7. Unprotected

FIGURE 3 Historic sites coding sheet.

data translated in order to be used. The items on the information sheet are explained in the following, and in cases where these items may need interpretation, examples are given. The following explanations are correlated with the data sheet items in Figure 4:

- File number: A six-digit number. The first three digits represent the geographic location of the site; the remaining three identify the specific site within that location. This variable is necessary for retrieval.
- Description: The preferred name of the location. This is not necessary and can be left blank.
- Category: A one-digit number that identifies the location as a district, a building, a structure, a site, or an object. This item can be used to designate privately or publicly owned properties.
- Area of significance: A two-digit number that identifies the reason or reasons that the site is significant (e.g., architecture, art, commerce, or transportation). This item is used to describe the data and to identify the specific site or area to be recalled (searched). Some of the significance items are close in meaning in an attempt to accommodate subtle but significant differences in meaning between disciplines supplying the data. A maximum of seven codes can be used to describe and identify a particular item; the more exact the coding, the better the chances for a comprehensive retrieval.
- Acreage: The amount of acreage surrounding the site. This number may be an overestimate of the property involved. For example, if the record shows that the property is less than 1 acre, 1



VIRGINIA DEPARTMENT OF HIGHWAYS AND TRANSPORTATION
RESEARCH COUNCIL
LANDMARK RESEARCH DATA

FILE NO ______ COL 1-6

DESCRIPTION ______ Name of Property ______ COL 7-46

CATEGORY See Information Key 47

AREAS OF SIGNIFICANCE ___ See Information Key ___ ___ ___ COL 48-61

ACREAGE In even numbers 1 through 1,000 62-65

CITY/COUNTY/TOWN spelled out CITY/COUNTY/TOWN CODE Standard State Code 66-68

QUADRANGLE MAP spelled out QUADRANGLE CODE USGS Code COL 69-72

LATITUDE ___ ___ ___ 73-78 LONGITUDE ___ ___ ___ 79-84

UTM COORDINATES

NORTH ______ 85-94 EAST ______ 95-104

HABS "1" if yes, otherwise blank 105

REGISTRATION See Code Sheet 106

DATE Most significant or earliest 107-110

ORIGINAL USE ______ 111-113 HISTORIC USE ______ 114-116

For future use

FIGURE 4 Input sheet.

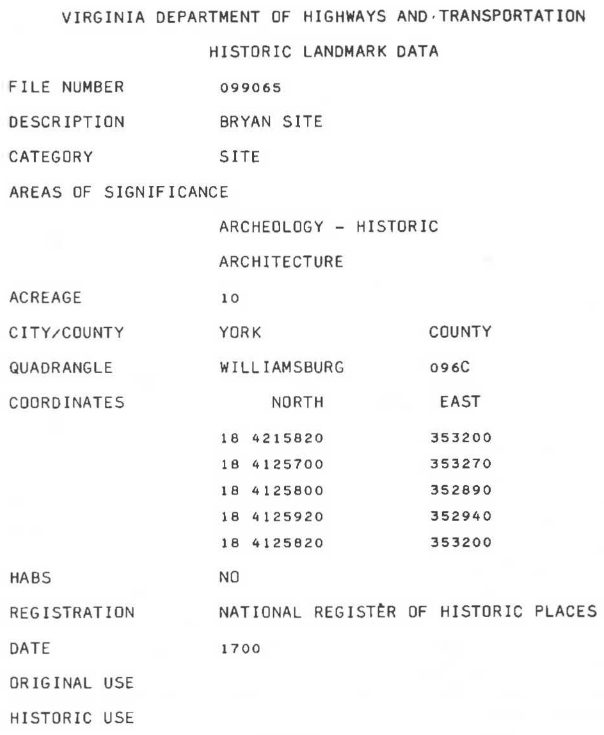
acre will be the amount recorded; in other words, if the property is described as consisting of a fraction of a measurement, the next whole number will be recorded.

- City/County/Town: The name and a three-digit code assigned by the state, used to identify the geographic location of the site.
- Quadrangle map: The name and quadrangle number assigned by the USGS, used for location.
- Latitude and longitude: One system used to locate sites. The coordinate system was used to gather historic data before 1966; consequently these data must be gathered and translated into state plane coordinates (SPC) for use by VDHT. (A program obtained from the USGS is used to make these conversions.) Either this system or the Universal Transverse Mercator (UTM) system should be used, not both.
- UTM coordinates: System now used to locate historic sites. These are translated into SPC for use in the program. Either the UTM system or the latitude-longitude system should be used, not both.
- HABS: Refers to the Historic American Building Survey. A 1 is used to indicate that the historic site was a part of this survey. This item is used only with historic data.
- Registration: Indication of formal registration of a landmark; 1-5 are used to indicate that the landmark is on the National Register, is a National Historic Landmark, has been nominated to the National Register, is on the Virginia Landmark Register, or is registered by the Virginia Historic Landmark Commission; 6 and 7 apply to cave data. This item does not have to be used.
- Date: The most significant date of the property or a date that has been established for the origin of the property. It is important for description and identification.
- Original use: The use for which the landmark was originally constructed (e.g., the Alamo was originally a church; in Virginia, the Sutherland Mansion was originally a private residence), used exclusively for historic data.
- Historic use: The use for which the landmark is known and because of which it is deemed historically significant (e.g., the Alamo was originally a church but is historically noted as a fortress; the Sutherland Mansion was the last capitol of the Confederacy), used exclusively for historic data.

Data Access and Update

Information from the data bank established can be obtained on request from the Data Processing Division. Because the process is designed to be easily used by various agencies, the information can be retrieved by identifying the code number of the county or quadrangle for which it is desired. The information can also be retrieved by identifying the latitude and longitude, UTM, or state lane coordinates that encompass the area for which it is desired. By requesting a search of the data bank, the retrieval can be limited to any of the words under the significance coding or any date within a ± 25-year interval.

The retrieval process produces a series of standard printouts (Figure 5) and, on request, graphic representations. As previously noted, the scale can



```
      VIRGINIA DEPARTMENT OF HIGHWAYS AND TRANSPORTATION

                     HISTORIC LANDMARK DATA

FILE NUMBER          099065

DESCRIPTION          BRYAN SITE

CATEGORY             SITE

AREAS OF SIGNIFICANCE

                     ARCHEOLOGY - HISTORIC

                     ARCHITECTURE

ACREAGE              10

CITY/COUNTY          YORK                 COUNTY

QUADRANGLE           WILLIAMSBURG         096C

COORDINATES              NORTH             EAST

                     18 4215820           353200
                     18 4125700           353270
                     18 4125800           352890
                     18 4125920           352940
                     18 4125820           353200

HABS                 NO

REGISTRATION         NATIONAL REGISTER OF HISTORIC PLACES

DATE                 1700

ORIGINAL USE

HISTORIC USE
```

FIGURE 5 Typical printout of information contained in historic data bank.

be varied to enable displays at the state, the county, or the quadrangle level.

Information can be added to the data bank with the authorization of the manager of the Data Processing Division. Although the frequency of updating information will vary from variable to variable, information stored in the data bank can be changed by submitting it on a form to the Data Processing Division.

Agreement for Implementing System

To implement the procedure illustrated here, VDHT must obtain the agreement of any concerned agencies. Such an agreement is now being negotiated between the Environmental Quality Division and the Virginia Historic Landmarks Commission. The elements of the agreement that must be worked out are discussed in the following.

Type and Accuracy of Data to be Used

In the trial use of the procedure developed, the information used was taken from the Virginia Historic Landmarks Commission files. Most important were the coordinates designating the location of an historic site. These could be obtained either by copying those in the files or by interpreting the positions of landmarks located on maps. The accuracy of these data depends on the expertise of those who originally located the sites and the accuracy of those who then transcribed the information for the files.

Method of Data Reduction

In mapping, VDHT uses the SPC system. However, the files in the Virginia Historic Landmarks Commission contain information located both by latitude and longitude for the period before 1966 and by UTM since that time.

Accuracy of Graphic Displays

To ensure that the data displayed on the computer-produced overlays were accurate, several random samples were checked against data transcribed on maps at the Virginia Historic Landmarks Commission. Several of these overlays were field checked as well. It is important that all data produced by the computer accurately represent data in the files. A breakdown could result in a lack of confidence that would invalidate any agreement between VDHT and a concerned agency.

Method of Updating Data

Personnel of the Virginia Historic Landmarks Commission agreed to fill out the computer input sheets for those properties placed on the Virginia register at their monthly meeting and for all newly surveyed properties.

Method of Notification

Once the questions relating to data are resolved, a method of notification must be devised. This method should (a) stipulate how VDHT is to give the other party to the agreement prior notice of any planned action and (b) specify a time period within which the other party is to make any desired response.

COST OF DATA BANK

The cost of establishing a data bank depends on such factors as the hardware and software available, the programming service needed, and the desired precision of the data. However, once the data base has been established, updating and maintenance are relatively inexpensive.

VDHT has the expertise to maintain a given data bank, and with other agencies participating in the updating procedures, the costs would be limited to those for storing and retrieving data and processing the updated information. For maintaining the historic site location data, the annual cost is estimated to be $33.

RECOMMENDATIONS

Recommendations resulting from this study are stated in the following. They are all predicted on the implementation by VDHT of the procedure for distinguishing projects likely to have an undesirable environmental impact.

1. It is recommended that the historic landmarks data bank established in this study be maintained and updated as a routine operation.
2. It is recommended that the LDLP developed by the Data Processing Division of VDHT be used to store data on a statewide basis when the data are relatively easy to collect and reduce. The SYMAP program should be used on a limited basis, for example, for analyzing data in an area of the size represented by a USGS quadrangle map.
3. Because data collection is the most expensive aspect of this procedure, an effort must be made to

gather only information that will (a) aid in determining whether a project area is environmentally sensitive and (b) be of sufficient interest to encourage other state agencies to aid in maintaining and updating the data bases. Therefore, it is recommended that the authorization for establishing data banks within the system be obtained through the Environmental Quality Division or the Data Processing Division.

4. If data are needed and must be digitized for entry into the system, it is recommended that the Mapping Section of the Location and Design Division be consulted for assistance.

5. It is recommended that an agreement be made between VDHT and the Virginia Historic Landmarks Commission to the following effect:

   a. The data available for the procedure to be implemented are sufficient to determine whether there is a question of impact;

   b. The demonstrated procedure for data collection, interpretation, and method of display gives an accurate representation of the project area;

   c. VDHT can assume that a project is clear of any adverse impact on a historical site when data in the system support this decision;

   d. In each instance a memo will be sent to the director of the Virginia Historic Landmarks Commission informing him of action to be taken; and

   e. If no reply is received within a stated time period, the action outlined by VDHT would be authorized.

This agreement is appropriate with the information now in the historic landmarks data base and could serve as an example for agreements with other agencies.

ACKNOWLEDGMENT

The research reported in this paper was sponsored by VDHT in cooperation with FHWA. The development of the system, including the computer hardware and software, and the collection and reduction of data required the efforts of personnel from VDHT, the Virginia Highway and Transportation Research Council, and the Virginia Historic Landmarks Commission.

The Environmental Division of VDHT, headed by Robert Hundley, initiated the research. Earl Robb, assistant environmental quality engineer, identified the problem and requested the research. Gene Wray, environmental coordinator, provided the liaison with other agencies, and Lyle Browning, archeologist, gave technical assistance.

The Information Systems Division provided the hardware and developed the software for the system; Harris Allen was instrumental in coordinating and guiding the available personnel.

Personnel of the Location and Design Division reduced the data required to produce the desired graphics. Fred Bales, George Habel, and Kermit Wood directed the manpower efforts to provide digitizing and acquire information from various maps and aerial photographs.

Special appreciation is extended to Tom Slayton, digitizer, and Bill Ross, electronics technician, for their efforts. Especially appreciated was their tolerance in working with the researchers through many trial-and-error attempts to coordinate the equipment required to reduce the data.

Calder Loth, architectural historian, and Cory Hudgins, registrar, interpreted the information contained in the files of the Virginia Historic Landmarks Commission. C. Vernon March III, the environmental review officer, aided in reducing the information to that which was essential for environmental documentation. Bob Carter, historian and head of the Survey and Registration Division, is responsible for updating the information and the continued use of the program so that the benefits from the research can be realized. Randy Turner, prehistoric archeologist, and John Broadwater, nautical archeologist of the Research Center for Archeology, a satellite of the Historic Landmarks Commission, interpreted and classified the archeological data.

Bill Kelsh, research scientist, of the Virginia Highway and Transportation Research Council, was coauthor and technical advisor on a previous study that was used to test program options and select those most applicable for the research reported here.

Publication of this paper sponsored by Committee on Environmental Analysis in Transportation.

Transportation Impacts on the Environment in 2003

LOUIS F. COHN

ABSTRACT

The year 2003 is a generation away. Yet the transportation system that will be in place to serve the United States at that time is basically in place in 1983. Many billions of dollars have been spent in the last 150 years to create the transportation infrastructure of today, and billions more need to be spent to solve immediate problems and to maintain the system already in place. The status of transportation impacts on the environment in 2003 is examined by first discussing the evolution and condition of the transportation system of 1983. Conclusions are drawn concerning the system in 2003, and predictions are made concerning the likely situations to be encountered 20 years in the future. For example, noise levels are expected to be higher, air quality to be better, and water quality to be no worse than today.

How difficult is it to predict the future? Who knows what anything will be like in 20 years, much less the status of transportation impacts on the environment? Fortunately, the transportation engineering community has committed itself to at least attempting the prediction of future events and conditions through the subdisciplines of transportation planning and environmental planning. Combining these two fields should provide the means to assess transportation impacts on the environment in the year 2003.

Before charging off into the future with confidence based on naiveté, one should be aware of the limitations of planning. For example, the author and two colleagues at Vanderbilt were recently employed to do a traffic planning study for a proposed 2,200-acre research park in Huntsville, Alabama. One question posed to the clients was, "What development rate do you expect for the park?" They replied, "Between 35 and 100 acres per year." Assuming that development begins in 1985, the park will be fully developed sometime between 2007 and 2048, thus providing a "window" of 41 years. Several different methods were used, including ITE and NCHRP procedures, to determine the number of peak-hour trips that could be expected to go to the park at whatever year it reached full development. These different methods gave numbers ranging from 8,000 to 17,500 trips per hour. Working with exact information like this, the client wanted to know when to build entrances, how many lanes to make them, and so on.

What does all this have to do with transportation impacts on the environment in 2003? Nothing really, except that it must always be remembered that whatever else the future holds, it holds change. Some change can be anticipated but some change cannot. Given this premise as the foundation for discussion, a framework for the assessment of the future of transportation must be established. In so doing, it should

1. Define where we have been,
2. Define where we are,
3. Speculate on why we got here, and
4. Speculate on where we are going.

"We" in the foregoing points and the pages to follow should be defined as the aggregate mobile society in the United States. Other definitions might include transportation consumers or system users.

WHERE HAVE WE BEEN?

Wilfred Owen of the Brookings Institution has categorized (1) the evolution of transportation into five stages:

1. Immobility and isolation (before 1830),
2. Mechanization and regional trade (1830-1900),
3. Motorization and aviation (1900-1950),
4. International transport and global economy (1950-?), and
5. Unified global economic system (?-?).

Keeping in mind that the topic concerns the environmental impacts of transportation, these phases should not be belabored. It is apparent, however, that we are currently in the fourth phase, international transport and global economy. The international aspects of this phase are such that they greatly favor free rights-of-way, that is, the water, the air, and the air waves. In 1950, for example, a large cargo ship had a dead-weight capacity of about 35,000 tons. Today's container ships, by contrast, have capacities up to 500,000 tons. In the late 1960s, there were 1.2 million overseas telephone calls made each year, but in the early 1980s, the yearly average was 176 million. World trade today is increasing at twice the rate of the gross world product. In the United States, 20 percent of the industrial workforce is filling foreign orders.

What is it that is causing this astonishing increase in trade and economic interdependence? Obviously there are many answers to that question, but certainly they would include evolution of air transportation, evolution of goods movement, and telecommunications. If we ever get into the final phase, the unified global economic system, we will be thrust there by that new but ubiquitous form of transportation, telecommunications. The electronic revolution spawned by advances in microprocessor technology is quite simply changing the way we live our lives, fulfill our travel needs, and conduct our business.

Again, what does this have to do with transportation impacts on the environment in 2003? This time the answer is: a great deal. What is seen when considering the five phases of transportation evolution is actually exponential development. It happens that we are now in the part of the curve where the rate of change in development rate is wildly increasing, as in Figure 1. To get to this point, however, a lot of development, and therefore transportation inventory, has been generated over a long period of time, hence the problem of infrastructure obsolescence. Members of the ASCE are well aware that there is a rising concern over the crisis in infrastruc-

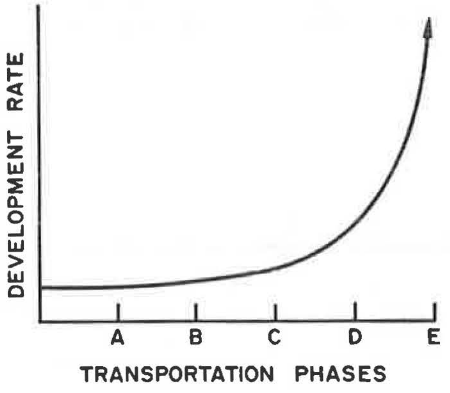


FIGURE 1 Transportation evolution.

ture decay in the United States. Thus, we arrive at the second point in the establishment of our framework.

WHERE ARE WE?

We can establish our location, or where we are in the development process, by reviewing a catalogue of facts.

The United States has nearly 4 million miles of highways, streets, and roads, including 42,944 miles on the nearly completed Interstate system. Nearly 8,000 miles on the Interstate system are in immediate need of resurfacing or reconstruction, and 2,000 more miles are added to that list each year. The U.S. Department of Transportation reports that the cost to remove all highway deficiencies, not counting bridges and non-federal-aid road networks, is more than $360 billion in 1980 dollars and that it would take 15 years (2). The 1980 National Transportation Policy Study Commission reported that the total of national highway capital needs through the year 2000 is more than $1 trillion in 1980 dollars, yet under existing policies, total highway revenue generated at all levels of government would be only $750 billion (3).

Concerning bridges, FHWA reported to Congress in 1982 that 248,357 bridges out of 557,516 inventoried under its Highway Bridge Replacement and Rehabilitation Program were either structurally deficient or functionally obsolete and in need of major work. This represents nearly 45 percent of U.S. bridges. From 1972 to 1982, 8,658 bridges were replaced or rehabilitated under this program. At that rate, 866 bridges per year, it will take 287 years to correct all the bridges that need it now. The current price tag for this work is $47.6 billion (4). To confirm that the U.S. transportation network has been established for a significant time period, it should be noted that nearly 40 percent of the 557,516 bridges inventoried are at least 45 years old.

The American Public Transit Association reports that $16 billion will be needed in the next 10 years to modernize and improve fixed rail systems and bus facilities. This is in addition to more than $20 billion in established needs for extensions, completions, and new starts (3).

The financial condition of America's railroads is such that there has been no regular program of railroad tie replacement in the last 30 years. Therefore, just to maintain current levels of track use and speed, 50 percent of all ties should be replaced by 1988. In addition, a large number of rail facilities are in urgent and immediate need of capital-intensive work because of obsolescence and deferred maintenance. The American Association of Railroads estimates the costs of these improvements to be about $90 billion over a 10-year period (3).

The FAA expects an annual growth rate of 4.6 percent well into the 1990s. If this projection is accurate, the number of passengers will more than double by 2003. To accommodate this increased demand, as well as similar growth in general aviation, the FAA National Airport System Plan identifies $13.5 billion in airport development requirements by 1993 (5). The 1982 Airport and Airways Improvement Act, however, provides less than $1 billion per year over a 5-year period in airport development aid.

So where are we, at least with respect to the physical inventory of our transportation system? We are the owners of a multi-billion-dollar collection of facilities that is wearing out at a rate outstripping our ability to maintain it.

Given the system now in place and the expected growth in travel, is the system adequate? Probably not, at least for urban highways. As indicated in Figure 2, peak-hour congestion will significantly deteriorate in the next 15 years. It appears that about two-thirds of the urban peak-hour travel will take place under conditions of volume to capacity (V/C) ratio of 0.8 or greater. This constitutes level of service C or worse. The solution to congestion has traditionally been increasing capacity through widening projects; however, the FHWA 1981 Status Report indicates that nearly 50 percent of the roads and streets on the current system cannot be widened because of adjacent development. For these, only traffic engineering and use management projects are feasible to increase capacity (2).

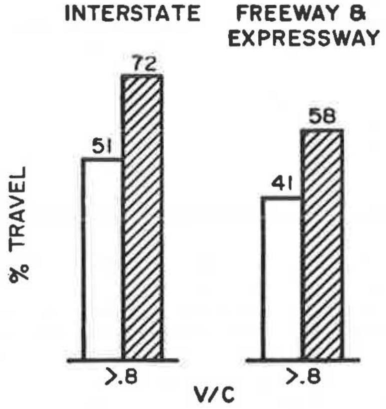


FIGURE 2 Impact of 15 years of travel on peak-hour V/C (unshaded bars, 1980; shaded bars, 1995).

In summary, the U.S. transportation system is inventory intense, underfunded, and not complete. It is inventory intense in the sense that it represents many billions of dollars of facilities put in place in the last 100 years or so. It is underfunded in the sense that maintenance needs alone now appear to demand more capital than is available through existing funding policies. And it is not complete in the sense that current and projected problems and needs demand transportation solutions that have yet to be implemented.

Where are we in terms of environmental laws and regulations affecting transportation? Table 1 and Figure 3 show that the past 20 years have witnessed the adoption of a significant number of laws. The 25 laws and executive orders shown were judged to be

TABLE 1 Federal Environmental Legislation Influencing Transportation

Date	Legislation
Pre-1960	The Rivers and Harbors Act of 1899
	Fish and Wildlife Coordination Act of 1958
1960	Federal Aid Highway Act of 1962
	Clean Air Act of 1963
1965	Housing and Urban Development Act of 1965
	Department of Transportation Act of 1966
	Air Quality Act of 1967
	Control and Abatement of Aircraft Noise and Sonic Boom Act of 1968
	Wild and Scenic Rivers Act of 1968
	National Flood Insurance Act of 1968
	National Environmental Policy Act of 1969 (NEPA)
1970	Federal Aid Highway Act of 1970
	Executive Order 11514, Protection and Enhancement of Environmental Quality, 1970
	Environmental Quality Improvement Act of 1970
	Airport and Airway Development Act of 1970
	Noise Control Act of 1972
	Federal Water Pollution Control Act of 1972
	Coastal Zone Management Act of 1972
1975	Coastal Zone Management Act Amendments of 1976
	Executive Order 11988, Floodplain Management, 1977
	Executive Order 11990, Protection of Wetlands, 1977
	Clean Air Act Amendments of 1977
	Clean Water Act Amendments of 1977
	Executive Order 11991, Protection and Enhancement of Environmental Quality (amended), 1977
	Quiet Communities Act of 1978
1980	

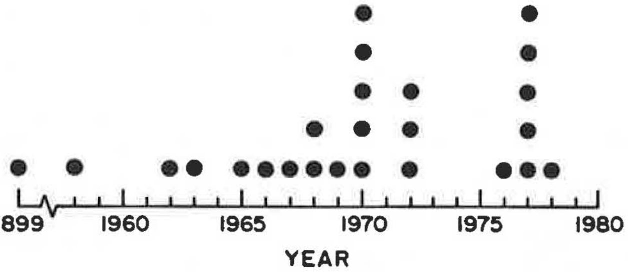


FIGURE 3 Distribution of 25 environmental laws influencing transportation.

most important with regard to their influence on transportation. It is not to be argued that this list is all inclusive or otherwise perfect; however, the 25 actions listed certainly merit consideration as consequential.

In reviewing the list, it becomes obvious that there have been no significant laws enacted in the last 5 years, although some are currently under major revision. There are several political reasons for this recent lack of activity, but definitely a fundamental reason is that the 25 laws already in place constitute a solid and relatively complete framework for considering transportation impacts on the environment. Certainly some adjustments, additions, and even deletions are in order and may be implemented, but the question could be posed, "Does the United States need any additional environmental laws affecting transportation project development?" This writer thinks not.

Where are we in terms of the analytical tools and techniques necessary to quantify transportation impacts on the environment? The answer is that we are in fairly good shape. The last 15 years have seen a phenomenal growth in predictive modeling for air quality, noise, and ecological impacts. The noise models STAMINA 2/OPTIMA (6) and INM (7) and the air quality models CALINE 3 (8) and HIWAY-2 (9) give sufficiently accurate results for decision-making purposes. Habitat evaluation procedures are also quite adequate. In addition, FHWA has recently settled on methods to determine the functional values of wetlands, which represents a major step forward. Obviously improvements to all the models will evolve, but generally it can be said with confidence that engineers have the tools needed to quantify most environmental impacts and in many cases design mitigation strategies.

HOW DID WE GET HERE?

How did the United States come to have an inventory-intense, underfunded, incomplete transportation system? The answer to this question must relate to the natural evolutionary growth patterns that are in place for a dynamic society such as exists in this country. These growth patterns have been driven by increasing population and advancing technology, and as a result, transportation development has been forced to lag. The further problem of limited monetary resources exacerbates this lag. Transportation engineers have been building for years but still have not solved the nation's transportation problems. Solving the problems is analogous to the old saying, "Every time I almost make ends meet they move the ends." Every time the transportation problems are almost solved, the problems change. The airline industry is a good example. In the mid- to late 1960s the problem was that anticipated growth rates in passenger travel meant that not enough airplanes were available. The solution was to buy more airplanes. Then the economy turned sour, and one of the problems was that many of the airlines were too heavily inventoried; that is, they had bought too many airplanes. Compounding the problem was the fact that energy costs were skyrocketing, and many of the airplanes purchased in the 1960s were not fuel efficient and also were officially designated [Control and Abatement of Aircraft Noise and Sonic Boom Act of 1968 (U.S.C., Title 49, Sections 1421-1430)] as being noise incompatible and in need of engine retrofit. Thus, the solutions to the 1960s problems became the 1970s problems, given the new emphases on energy conservation and environmental compatibility and a different economic climate.

Thus the U.S. transportation system in 1983 is old, worn out, and beset with problems. Nevertheless, it functions, to the point that the economic recovery now under way is not currently threatened. In fact, the great maintenance and rehabilitation needs mentioned earlier are providing opportunities to reduce unemployment in the hard-pressed construction industry. The nickel-per-gallon gasoline tax that took effect earlier in early 1983 was passed in large part on the basis of its being an economic stimulant. And stimulate it has. The Tennessee Department of Transportation (TDOT), for example, now has more than 400 highway projects under construction, with $224 million committed, which is tops in the nation. More than $75 million has been attributed by TDOT directly to the tax increase. The TDOT construction program for 1983 is 380 percent greater than it was in 1982 (10).

WHERE ARE WE GOING?

A status check on several key issues may be the best way to answer the question of where we are going. A check will be made on the 2003 status of

1. The system,

2. The laws,
3. The pollutants, and
4. The methodologies.

To assist in providing answers to these 20-year status queries, the members of TRB Committee A1F02, Environmental Analysis in Transportation, were asked for input. Their responses are included in the discussion to follow but without individual identification.

The System

The year 2003 will present a transportation system similar to that in 1983 but worse. In fact, more than 99 percent of it will be identical to that in 1983, only 20 years older. As a result, maintenance and rehabilitation will receive the greater share of emphasis. One committee member said, "On an overall basis, transportation improvement programs seem to be headed more toward '4R' type activities and away from new construction." (Note, 4R means resurfacing, restoring, rehabilitating, and reconstructing, from the 1982 Surface Transportation Assistance Act.)

In addition to the ever-present headaches of infrastructure decay, 2003 will also bring about projects designed to reduce worsening urban congestion. Recall the earlier comment that two-thirds of the urban peak-hour travel will face level of service C or worse in 15 years. Several major cities are also actively engaged in major urban redevelopment efforts that could serve to worsen urban congestion problems. Three such cities that come to mind are Louisville, Memphis, and Nashville. An A1F02 committee member from the urbanized Northeast commented:

> There will be a substantial increase in transportation projects which are involved with urban revitalization, joint development. This will include rail stations, ports, and urban road network improvements. Preservation of historic and culturally significant buildings and other facilities will be an important environmental component of this work.

The system will be forced to become more responsive to those new forms of transportation like telecommunications. This will enhance diversity and possibly lighten the load on the existing traditional system.

Last, the system will also be forced to accommodate more exotic freight as technologies and needs evolve. A committee member notes:

> The movement by various transportation modes of hazardous cargoes will become an increasingly more significant issue and there will be undoubtedly much tighter regulation on the movements of these cargoes. This would also include hazardous waste.
>
> On the inland waterways and coastal waterways of the country the barges and tows are likely to increase in size thereby resulting in more significant aquatic habitat impacts. Also it is likely that new locks and dams and new deep draft ports will have to be built and there will be serious environmental issues related to these activities.

The Laws

In 2003 there will surely be some new environmental laws in place, and some existing laws will have been modified or deleted. However, just as the last 5 years have not brought much that is really new, the next 20 years most likely will not either. Significant changes and additions will only be to accommodate significant technological advances, like deep-draft ports, nuclear waste movement, high-speed rail, and so on. If there are other significant changes, they will likely be as a result of economics. According to the President's Council on Environmental Quality (CEQ), current environmental and natural resource policy has "fallen out of touch with the basic economic premise that costs incurred by any requirement should be commensurate with benefits received" (11). This line of reasoning is perfectly acceptable as long as it is not used as a basis for retreating from the commitment to environmental protection, which CEQ says is still strong.

An A1F02 committee member from the Southwest observes:

> People will have to become more sophisticated and knowledgeable in environmental matters. Engineers must take the lead in this effort. Otherwise, well meaning, but frequently ill-informed individuals will lead society into tragic errors, both environmentally and economically.

A friend of the committee who works for the federal government in intermodal policy and planning suggested by telephone that the best way to consider environmental impacts in 2003 is to study the environmental laws in place in 1983. This makes sense, given the 15- to 20-year period to complete a major transportation project from conception to construction.

One can never be sure of what will happen in the legislative bodies of the United States. One committee member wrote of an educational TV show he watched concerning the possible Shin-Kansen between Los Angeles and San Diego. (Shin-Kansen is Japanese for Bullet Train.) This concept obviously has great potential to reduce automobile congestion and air pollution and to save energy. Yet the Japanese interviewed on the program complained about vibration and noise problems relating to the train's operations. First-hand observations indicate that Japan is spending millions on environmental controls on its bullet train lines, both for new and existing lines. What has the California legislature done? According to the TV program, it has waived environmental assessment requirements for the high-speed rail project.

The Pollutants

Will the problems of noise, air, and water pollution be worse in 20 years? The answer is yes, to the extent that political and economic pressures result in delays or setbacks in the implementation of control measures.

Recent federal highway law, for example, eliminated separate funding for noise barrier retrofit projects and made that program part of the 4R project set. This is tantamount to ending the retrofit program, even though there are hundreds of miles of barrier needs identified on the existing system.

Given normal traffic growth, roadway surface deterioration, and so on, these identified noise problems will only get worse. Also, the truck noise reduction requirements from the 1972 Noise Control Act have been rendered useless by the elimination of the U.S. Environmental Protection Agency noise program. This will certainly result in higher noise levels in 2003.

Air quality should improve in the next 20 years, provided that the Clean Air Act is not diluted and vehicle emission limits are not further delayed. The mix of the fleet is critical, and energy costs will continue to have a dominating impact on mix. The real question may be whether the U.S. automobile industry will start producing competitive, fuel-efficient, nonpolluting passenger cars that will compete with the imports.

An overriding issue for both air quality and noise levels in 2003 is the increased urban congestion projected by FHWA. Fortunately, level-of-service E and F traffic conditions do not generate much noise. Nevertheless, increased congestion will lead to more noise and worse air quality.

Water quality and other ecology-related impacts will be lessened to some degree by 2003. This is because most intracity high- and medium-service facilities are already in place, and the emphasis has shifted to maintenance and rehabilitation. One factor that could affect the quantity and quality of rural roads is whether this or a future administration will be successful in turning the primary and secondary road systems back to the states.

Possibly the best way to anticipate the status of the pollutants, and even environmental impacts in general, for the year 2003 is to examine other nations where population densities are greater and cities older. A committee member commented, "Transportation impacts in 2003, in this country, will be similar to impacts experienced now in highly developed and densely populated areas like central Europe and Japan." When traveling in either of these regions, one cannot help but be impressed with the number of noise barriers, many of which are absorptive, the relative quiet of the trucks and buses, and the fuel efficiency of the passenger vehicles. Yet the need for further attention to environmental concerns seems to precipitate a higher degree of concern among Japanese and European transportation officials than among their American counterparts. This leads to the conclusion that the problems are at least perceived to be worse abroad. Bluntly stated, environmental problems resulting from transportation facilities will not just go away if ignored. Those governments genuinely concerned with the quality of life for their citizens must build environmental thinking into the project development process.

The Methodologies

Serious research and development in noise, air quality, and ecology modeling has been under way for at least 20 years and has brought the state of the art a long way. Federal transportation research administrators have indicated that by 2003 assessment techniques should be fully adequate. Even today, noise and air quality models are felt to be sufficiently accurate for most applications. Other methods, including those for wetlands and habitat assessment, will be significantly improved by 2003. Of course, there will always be room for improvements, but it is predicted that the basic modeling techniques for virtually all environmental issues will be in place and properly functioning by 2003.

CONCLUSION

The impact of transportation on the environment in 2003 will most likely be worse than in 1983. Fortunately, as a nation the United States will have the wherewithal to adequately deal with the situation, provided that the entire transportation infrastructure does not mortally damage the economic system first, because regardless of how accustomed Americans have become to a deficit-based society, the provision of transportation services is ultimately a bottom-line venture.

REFERENCES

1. W. Owen. Perspective: Transportation's Past and Future. Transportation Quarterly (Eno Foundation), Vol. 37, No. 2, 1983.
2. The Status of the Nation's Highways: Conditions and Performance. FHWA, U.S. Department of Transportation, 1981.
3. Our Fractured Framework: Why America Must Rebuild. Construction, Nov. 1982.
4. Highway Bridge Replacement and Rehabilitation Program. Third Annual Report to Congress. FHWA, U.S. Department of Transportation, 1982.
5. National Airport System Plan. FAA, U.S. Department of Transportation, 1982.
6. W. Bowlby, J. Higgins, and J. Reagan (eds.). Noise Barrier Cost Reduction Procedure, STAMINA 2.0/OPTIMA: User's Manual. Report FHWA-DP-58-1. FHWA, U.S. Department of Transportation, 1982.
7. M. C. Flythe. INM, Integrated Noise Model Version 3: User's Guide. Report FAA-EE-81-17. FAA, U.S. Department of Transportation, 1982.
8. P. E. Benson. CALINE 3--A Versatile Dispersion Model for Predicting Air Pollutant Levels Near Highways and Arterial Streets. Report FHWA/CA/TL-70/23. California Department of Transportation, Sacramento, 1979.
9. W. B. Petersen. User's Guide for HIWAY-2, a Highway Air Pollution Model. Report EPA-600/8-80-018. U.S. Environmental Protection Agency, 1980.
10. M. Collins. Road Construction a Record for State. The Tennessean, June 27, 1983, p. 1.
11. Thirteenth Annual Report. Council on Environmental Quality, Federal Council on Science and Technology, Washington, D.C., 1982.

Publication of this paper sponsored by Committee on Environmental Analysis in Transportation.

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

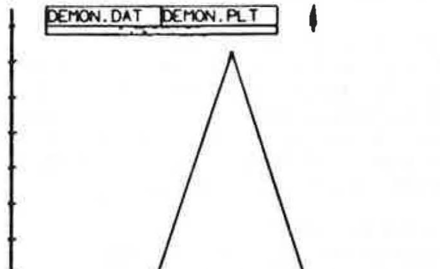


FIGURE 1 Miscoded point in data.

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 different 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 completed 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 coding forms or both and in keypunching them into the computer is saved. In addition, the time spent correcting 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, however, 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 accuracy 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 process 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 calculates the origin and the orientation of the axes of the plans on the table, it can accurately calculate 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-coordinates 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 initialization 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 initialized. 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

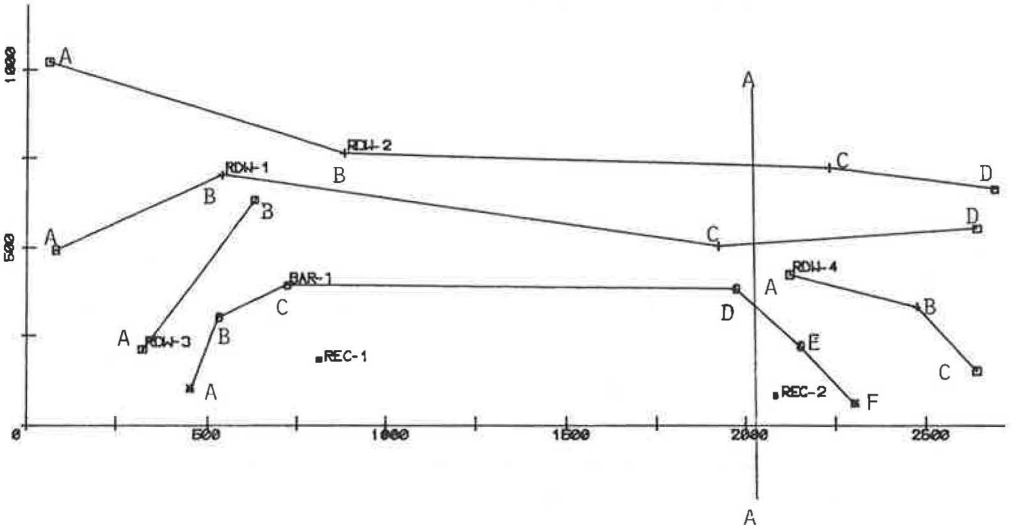


FIGURE 2 Typical roadway scenario.

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 completely 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 CON-
TINUE? 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

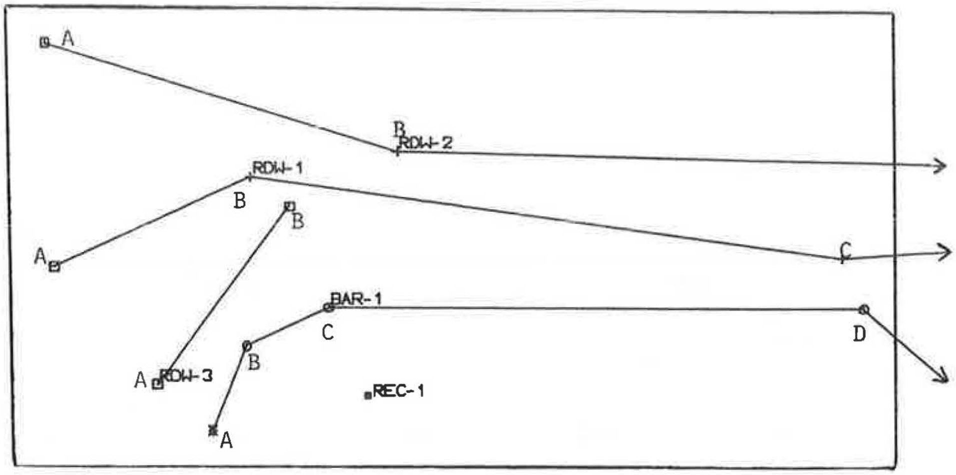


FIGURE 3 Segments extend past edge of table.

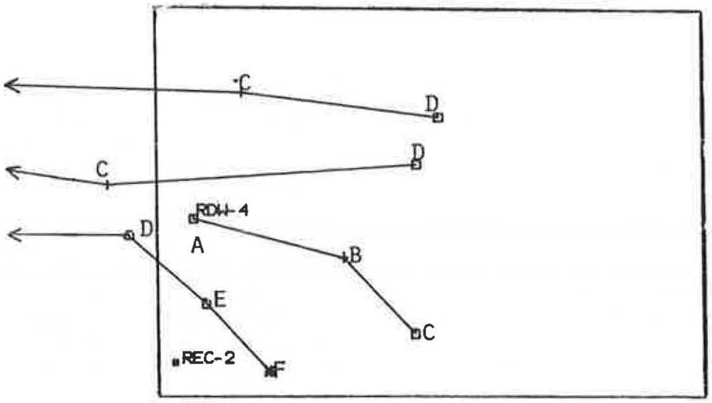


FIGURE 4 Reorientation of plans on digitizing table.

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-

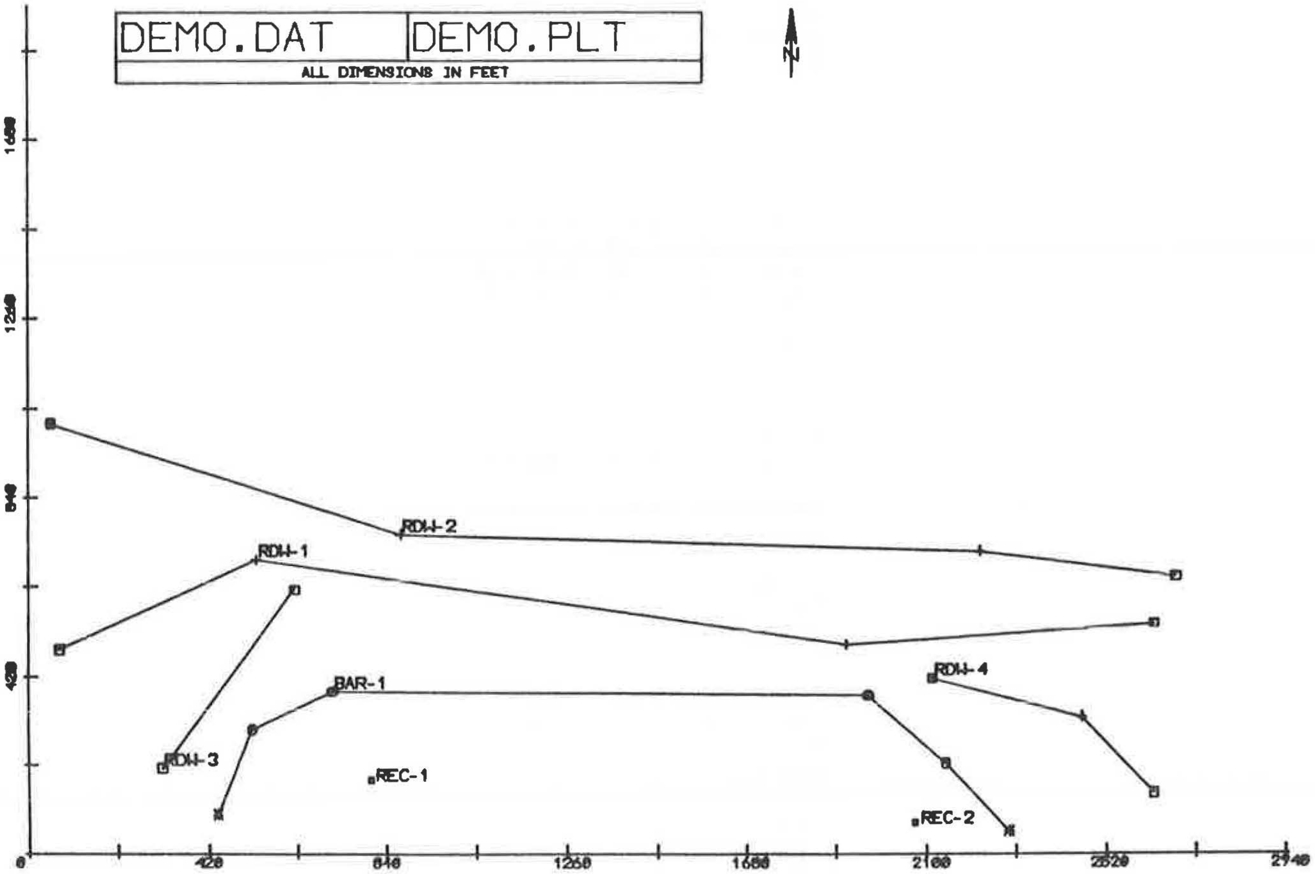


FIGURE 6 Plot of file in Figure 5 as seen by ST2PLT program.

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.

REFERENCES

1. G. J. Sisson. Coding Forms and Instructions for STAMINA 1.0 Highway Traffic Noise Prediction Model Program. Report FHWA-DP-45-5. FHWA, U.S. Department of Transportation, 1980.
2. Noise Prediction Model: Level II, STAMINA 1.0. Report M 22-28 (HR). Washington State Department of Transportation, Olympia, 1979.
3. W. Bowlby. SNAP 1.1: A Revised Program and User's Manual for the FHWA Level I Highway Traffic Noise Prediction Computer Program. Report FHWA-DP-45-4. FHWA, U.S. Department of Transportation, 1980.
4. G. H. Grove. Traffic Noise Level Predictor Computer Program. Research Report R-890. Michigan Department of State Highways, Lansing, 1973.
5. C. G. Gordon, W. J. Galloway, B. A. Kugler, and D. L. Nelson. Highway Noise: A Design Guide for Highway Engineers. NCHRP Report 117. TRB, National Research Council, Washington, D.C., 1971.
6. G. Morgan. CAL3: An Interactive Form of CALINE 3. Presented at 60th Annual Meeting of the Transportation Research Board, Washington, D.C., 1981.
7. P. E. Benson. CALINE 3: A Versatile Dispersion Model for Predicting Air Pollutant Levels Near Highways and Streets. Report FHWA-CA-TL-79/23. California Department of Transportation, Sacramento, 1979.
8. D. Wood and R. Hendriks. User Instructions for

SOUND3. California Department of Transportation, Sacramento, 1980.

9. W. Bowlby, J. Higgins, and J. Reagan (eds.). Noise Barrier Cost Reduction Procedure, STAMINA 2.0/OPTIMA: User's Manual. Report FHWA-DP-58-1. FHWA, U.S. Department of Transportation, 1982.
10. W. Bowlby and L. F. Cohn. Highway Construction Noise: Environmental Assessment and Abatement, Vol. 4--User's Manual for FHWA Highway Construction Noise Computer Program, HICNOM. Vanderbilt University Report VTR 81-2. FHWA, U.S. Department of Transportation, 1982.
11. K. J. Plotkin. A Model for the Prediction of Highway Construction Noise. Wyle Research Report WR 80-58. FHWA, U.S. Department of Transportation, 1980.
12. E. J. Rickley, D. W. Ford, and R. W. Quinn. Highway Noise Measurements for Verification of Prediction Models. Report DOT-TSC-OST-78-2 (DOT-TSC-FHWA-78-1). Transportation Systems Center, U.S. Department of Transportation, Cambridge, Mass., 1978.
13. Y. Y. Ma and F. F. Rudder, Jr. Statistical Analysis of FHWA Traffic Noise Data. Report FHWA-RD-78-64. FHWA, U.S. Department of Transportation, 1978.
14. FHWA. Procedures for Abatement of Highway Traffic Noise and Construction Noise. 23 C.F.R. Part 772, 1982.
15. W. Bowlby (ed.). Sound Procedures for Measuring Highway Noise: Final Report. Report FHWA-DP-45-1. FHWA, U.S. Department of Transportation, 1981.
16. W. Bowlby, K. R. Agent, T. A. Fuca, D. F. Fuca, D. F. Noble, and J. R. O'Connor. Environmental Noise Measurements. NCHRP Synthesis of Highway Practice. TRB, National Research Council, Washington, D.C., 1984 (to be published).
17. R. A. Harris. Determination of the Reference Energy Mean Emission Level in Georgia. In Transportation Research Record, TRB, National Research Council, Washington, D.C., 1984 (to be published).
18. A. A. Prahl and M. A. Miller. Noise Model for Slow-Speed Truck on Baltimore City Streets. Report 3217. Interstate Division for Baltimore City, Baltimore, Md., 1975.
19. L. F. Cohn. Bus Noise Levels in New York City and Albany Metropolitan Areas. Journal of Noise Control Engineering, Vol. 14, No. 1, 1980, pp. 38-42.
20. W. Bowlby. Transit Vehicle Noise Emission Levels in Yosemite National Park. Proc., 1982 International Noise Control Engineering Conference, Institute of Noise Control Engineers, Poughkeepsie, New York, 1982.
21. J. E. Wesler. Manual for Highway Noise Prediction. Report DOT-TSC-FHWA-72-1. Transportation Systems Center, U.S. Department of Transportation, Cambridge, Mass., 1972.
22. B. A. Kugler and A. G. Piersol. Highway Noise: A Field Evaluation of Traffic Noise Reduction Measures. NCHRP Report 144. TRB, National Research Council, Washington, D.C., 1973.
23. B. A. Kugler, D. E. Commins, and W. J. Galloway. Highway Noise: A Design Guide for Prediction and Control. NCHRP Report 174. TRB, National Research Council, Washington, D.C., 1976.
24. F. F. Rudder, Jr., and P. Lam. User's Manual: TSC Highway Noise Prediction Code: MOD-04. Report RD-77-18. FHWA, U.S. Department of Transportation, 1977.
25. T. M. Barry and J. A. Reagan. FHWA Highway Traffic Noise Prediction Model. Report FHWA-RD-77-108. FHWA, U.S. Department of Transportation, 1978.
26. F. F. Rudder, Jr., and D. F. Lam. User's Manual: FHWA Highway Traffic Noise Prediction Model, SNAP 1.0. FHWA, U.S. Department of Transportation, 1979.
27. F. F. Rudder, Jr., D. F. Lam, and P. Chueng. User's Manual: FHWA Level II HIghway Traffic Noise Prediction Model, STAMINA 1.0. Report FHWA-RD-78-138. FHWA, U.S. Department of Transportation, 1979.
28. J. M. Lawther and S. I. Hayek. A Noise Barrier Parameter Study. Unpublished Report 10. TRB, National Research Council, Washington, D.C., 1979, pp. 147-156.
29. W. Bowlby and L. F. Cohn. IMAGE-3: Computer-Aided Design for Parallel Highway Noise Barriers. In Transportation Research Record 937, TRB, National Research Council, Washington, D.C., 1983, pp. 52-62.
30. S. Slutsky, W. R. McShane, Jose M. Ulerio, S. H. Lee, and P. J. Grealy. Stop and Go Urban Intersection Noise. In Transportation Research Record 937, TRB, National Research Council, Washington, D.C., 1983, pp. 15-23.
31. User's Guide to MOBILE-2 (Mobile Source Emissions Model). Report EPA-460/13-81-006. U.S. Environmental Protection Agency, 1981.
32. User's Guide to MOBILE-1 (Mobile Source Emissions Model). Report EPA-400/9-78-007. U.S. Environmental Protection Agency, Aug. 1978.
33. W. B. Petersen. User's Guide for HIWAY-2: A Highway Air Pollution Model. Report EPA-600/8-80-018. U.S. Environmental Protection Agency, May 1980.
34. F. Benesh. Carbon Monoxide Hot Spot Guidelines, Vol. 5: User's Manual for the Intersection Midblock Model. Report EPA-450/3-78-037. GCA/Technology Division, Bedford, Mass.; U.S. Environmental Protection Agency, 1978.
35. T. Midurski. Carbon Monoxide Hot Spot Guidelines, Vol. 3: Workbook. Report EPA-450/3-78-035. GCA/Technology Division, Bedford, Mass.; U.S. Environmental Protection Agency, Aug. 1978.
36. Guidelines for Air Quality Maintenance Planning and Analysis, Vol. 9. Report EPA-450/4-78-001. U.S. Environmental Protection Agency, 1975.
37. A. D. Messina, J. A. Bullin, J. P. Nelli, and R. D. Moe. Estimates of Air Pollution Near Signalized Intersections. FHWA, U.S. Department of Transportation, 1983.
38. L. F. Cohn, L. W. Casson, and W. Bowlby. Enhancement of Highway Noise Modeling Through Computer Graphics. In Transportation Research Record 865, TRB, National Research Council, Washington, D.C., 1982, pp. 39-43.
39. W. Bowlby and L. F. Cohn. Applications of Interactive Computer Graphics in Modeling Traffic Impacts Upon Environment. In Compendium of Technical Papers, Institute of Transportation Engineers, Washington, D.C., 1983.

Publication of this paper sponsored by Committee on Environmental Analysis in Transportation.

Mitigating Construction Impacts on Rural and Urban Highways

ROSWELL A. HARRIS, LOUIS F. COHN, WILLIAM BOWLBY, ALBERT L. TATE, and RAYMOND BRISSON

ABSTRACT

The image of the typical state transportation agency has evolved from that of an organization that cared little for environmental impacts to one that has integrated mitigation of impacts on the environment into the project development process. Three examples are documented of how two state transportation agencies are implementing mitigative steps in historic preservation, noise abatement, and preservation of the natural environment during the construction phase of project development.

In the not too distant past, the typical state highway agency was viewed by the general public as an organization intent on building more highways, with little or no regard for the environmental cost. This image, however, has been slowly reversing itself during the last 10 years. Obviously the passage of the 1969 National Environmental Policy Act (NEPA), through its legal mandates, has played a major role in this reversal. Subsequent related legislation has also been a factor. More important, the citizens of the United States have demanded a greater role in the project development process.

It is inevitable that construction of transportation facilities will cause changes in the existing environment. However, adverse impacts resulting from these changes can be minimized if reasonable precautions and mitigation techniques are incorporated into the normal project development process. Thus, today's highway design engineer must function as a member of an interdisciplinary team for which environmental awareness is as important as pavement design or structural analysis.

The purpose of this paper is to present examples of how two state transportation agencies have handled the mitigation of impacts on the environment during the construction phase. Specific examples include historical resources, noise levels, and the natural environment.

PROTECTING HISTORICAL RESOURCES

The Federal Bridge Replacement Program is a plan authorized by the 1978 Surface Transportation Act to aid in upgrading and maintaining the U.S. infrastructure. Under this program, many of the bridges identified for replacement are characterized as potentially historic because they represent design techniques of a past era. By nature, most of the bridges marked for replacement are the oldest and thus have the highest potential for being historically significant. As a consequence, many historic structures are subject to physical destruction if preventive steps are not taken. In the following paragraphs one case is discussed in which the Tennessee Department of Transportation (TDOT) was able to preserve a portion of a locally significant bridge.

On May 10, 1979, the Anderson County Superintendent of Roads notified the Tennessee Commissioner of Transportation that the Massengill Bridge had been identified as the first priority for replacement among off-system bridges in the county. This bridge had been assigned a sufficiency rating of 23.4 points on a scale where 100 points is considered a perfect structure (1). To close the bridge without replacement would have left local residents without convenient access to nearby cities.

The Massengill Bridge is located on Coal Creek Road in a rural area in northeast Anderson County between Lake City and Norris, Tennessee. It was erected in 1916 by the Virginia Bridge and Iron Company of Tennessee, which was headquartered in Roanoke, Virginia. In 1915 Anderson County officials decided to improve the county's road system by replacing four ferries with bridges, which were funded and constructed in 1916. The Massengill Bridge is the only one of these bridges remaining.

The bridge derives its primary significance from engineering merits. Each of its four steel trusses is significant as a representative example of a specific truss design (the Pratt through, two through camelbacks, and the Pratt pony). In addition, the pony truss is also constructed with splayed or tapered vertical members, an unusual design often used by the Virginia Bridge and Iron Company (1).

Having determined the historical significance of the bridge, TDOT officials submitted appropriate documentation to the National Register of Historic Places for a determination of its eligibility for listing in the Register. The bridge was subsequently determined eligible for inclusion in the Register on August 14, 1981 (1).

Because the bridge was eligible for inclusion in the National Register, its removal was governed by Section 106 of the National Historic Preservation Act of 1966 and Section 4(f) of the Department of Transportation Act of 1966. As mitigation required by these laws, archivally stable photographs were made, and the bridge design was documented by drawings made to Historic American Engineering Record (HAER) standards (1).

In addition, cost estimates were made for relocating the individual trusses for reuse in some other capacity. It was determined that it would be economically feasible to relocate only the Pratt pony truss. Because this was the most significant part of the bridge, the decision was made that it would be preserved. It was then moved to a campground near Lake City, Tennessee, where it is being stored until the city can relocate it in a city park. A TDOT estimate placed the cost of moving, cleaning, painting, redecking, and placing the truss on new abutments at $16,000 (1). It is significant to note that federal funds were available to aid in the moving, cleaning, and painting. Without these funds, physical preservation of the bridge likely would not have been deemed economically feasible. As it now stands, the local government will only be responsible for the cost of providing new abutments for the truss and then moving it into place.

This is but one example of how federal, state, and local governments can work together to preserve a locally significant historical resource. It is also indicative of what can be accomplished when all parties involved work together in a conscientious effort toward a common goal.

MITIGATING CONSTRUCTION NOISE IMPACTS

The construction or reconstruction of a major highway in an urban area will invariably cause some disruption to an established community. If the affected community is located in the immediate vicinity of the proposed highway, noise generated by the construction of the highway itself is likely to be an issue. Because there are no federal criteria for construction noise and because construction activity is generally perceived as a temporary inconvenience, an in-depth analysis of the effects of construction noise is seldom performed on highway projects.

However, there are cases when a cursory analysis and specification of simple abatement strategies are simply not adequate. TDOT recently began construction on such a project, a new 7.5-mile Interstate (I-440) across south Nashville. Even though the proposed alignment followed an abandoned railroad right-of-way, the surrounding land use was largely residential. As would be expected, considerable public concern was expressed over the effects of constructing a major transportation facility in this area.

One of the problems faced by TDOT officials was the issue of construction noise. Given the high concentration of noise-sensitive land use adjacent to the proposed alignment, extensive noise abatement measures were planned to mitigate noise impacts generated by operation of the new highway. Because construction of this project would last several years, a logical extension of the overall noise abatement plan was to also provide abatement for construction noise where it was determined practical.

The proper analysis of a problem as complex as construction noise requires the use of a computer model. FHWA, in its leadership role of providing guidance and analysis tools to the state highway agencies, sponsored (through Vanderbilt University) the development of a comprehensive analytical model for predicting highway construction noise levels. This model permits detailed analysis of construction noise impact and effectiveness of subsequent mitigation strategy (2).

Noise barriers for line and area construction sources are analyzed in the same manner as highway noise barriers. In effect, a point source is moved along the line (roadway) and its insertion loss (IL) is computed at each point along the line. These ILs are then combined to obtain the total IL for the line source.

Specific application of the model to the proposed I-440 construction required a multiple-step process. First, construction plans for the project were thoroughly reviewed. Areas of potential impact were tentatively located in addition to areas of specific construction activities, such as rock drilling, earthwork, and hauling. Second, a detailed field review of the project was made to clarify questions raised during the plan review and to familiarize the engineer with potential abatement strategies. After the plan and field reviews had been completed, the list of potentially affected areas was made final.

At this point the highway construction noise computer program (HICNOM) was used to calculate typical noise levels in the impacted areas based on the major types of activities expected. Three main scenarios were tested: rock drilling, scraper earthwork, and truck hauling. It was determined that the highest noise levels would be generated by the rock-drilling operations. Generally the scraper and truck-hauling activities produced lower levels because of the time-varying nature of the levels (intermittent passbys versus continuous drill or compressor operations). Based on these results, several abatement strategies were developed. Two major considerations in the choice of strategies were cost and ease of implementation.

One strategy that is both economical and easy to implement is the use of earth stockpiles as noise barriers. Contractors typically store topsoil in mounds for future use in such tasks as landscaping. Strategic placement of these mounds can offer substantial noise protection. Because there were four locations on the project where earth berms were to be constructed as permanent noise barriers, TDOT officials elected to construct those berms at the beginning of the construction contract. This action not only provides a significant reduction in construction noise levels (3 to 10 dBA) at the affected receptors but costs significantly less in the beginning than at the originally scheduled construction time.

Another noise abatement strategy applicable to the I-440 project is the use of quiet air compressors in the rock-drilling operations. These compressors are manufactured to meet the 1976 U.S. Environmental Protection Agency (EPA) Portable Air Compressor Emission Standards and are 10 to 20 dBA quieter than older units.

Assuming that the compressors run full time and the rock drills are in operation about half of the time, the 8-hr L_{eq} would be reduced 3 to 5 dBA because of the shorter-term, but louder, drill noise. However, the affected areas would have periods of relative quiet while the drills were being reset as compared with a continuous high background level set by the older compressors.

There are numerous other methods of mitigating construction noise impacts. Some that were considered for the I-440 project include the following:

1. Constructing temporary noise barriers (a wall 8 ft high and approximately 240 ft long would reduce construction noise levels by 10 dBA at three residences located adjacent to the I-440 right-of-way),
2. Prohibiting the contractor from working on Sunday,
3. Positioning stationary equipment to take advantage of a material stockpile or some other obstacle to act as a noise barrier,
4. Locating haul roads as far away from noise-sensitive areas as possible,
5. Locating equipment parking and maintenance in remote areas, and
6. Using some type of warning device to alert residents of an impending blast.

As suggested by the preceding discussion, the noise impacts associated with building a major highway in an urban environment can be mitigated. The mitigation techniques recommended for the I-440 construction demonstrate some easily implemented strategies, analyzed through computer modeling, for reducing unwanted high noise levels.

PRESERVATION OF THE NATURAL ENVIRONMENT

Any highway construction activity will nearly always have an effect on the surrounding natural environment. Effects normally associated with the construction of a transportation facility include the loss of natural habitat, the impacts of erosion and sedimentation on streams and wetlands, and the potential threat to rare species. Although these concerns are real, steps can be taken to minimize harm caused by construction. Reclamation of marshland, modification of drainage structures to accommodate stream life systems, containment of silt, and erosion control are but a few of the methods available for mitigating disruption to the natural environment.

A common problem that is often overlooked is the effect of placing a drainage structure in an undisturbed stream. From an engineering standpoint, culverts are designed to accommodate a given water flow based on a desired flood recurrence interval, with little regard to minimum flow conditions. However, the typical stream rarely experiences maximum flow levels, and bankfull levels occur only about once every 1.5 years and then for only short periods of time (3). Even the mean annual flow is equaled or exceeded only about 25 percent of the time (3). Thus most forms of stream life are adapted to low flow conditions.

To avoid creating a barrier to the movement of fish and other aquatic life, culvert design should also consider the low flow characteristics of a stream. In larger streams, the streambed configuration is such that, even during long periods of low discharge, the stream bottom is usually covered with water. However, with low flow conditions in smaller streams, the water coverage is contracted so that half or less of the stream bottom remains covered. When this happens, the flat bottom of a conventionally designed culvert creates a sheet flow condition that provides inadequate depth and bottom roughness for many aquatic species and thus forms a barrier to passage.

The Georgia Department of Transportation (GDOT) uses two alternative culvert designs to mitigate this type of impact. One is a bottomless design in which the normal floor is simply eliminated. The other is a conventional design, but the culvert is constructed with the floor 1 ft or more below the normal stream bottom. In the latter case, the stream then fills the culvert with sand and rock material, making a natural stream bottom contour.

Another common concern associated with steam crossings is that of realigning the stream channel to a more perpendicular crossing of the highway. Small channel changes (up to several hundred feet) are not uncommon in highway construction. If proper steps are not taken, scars can be seen for several years in the form of a straight ditch covered with little or no vegetation.

Mitigation of such impacts can be accomplished with little difficulty. GDOT routinely builds a slight curve into the new stream channel and then lines the channel bottom and sides with stone riprap. Soil from the old streambank is then excavated to a depth of about 1 ft and dumped into the riprap along the new channel banks. This technique serves to rapidly restore the streambank vegetation along the new channel. The riprap placed in the bottom of the new channel provides roughness to the new stream contour and greatly enhances stream bottom habitat.

The preceding examples illustrate what can be accomplished in minimizing construction impacts to the natural environment. GDOT has managed to combine good engineering design and the preservation of the natural environment into a single objective: cost-effective highway construction that minimizes environmental impacts.

SUMMARY AND CONCLUSIONS

The examples offered in this paper provide evidence that the negative effects of highway construction on the environment can be minimized or eliminated. Cultural resources can be preserved, the quality of urban life can be aided through the abatement of construction noise, and the natural environment can even be enhanced with innovative construction techniques.

REFERENCES

1. Pub. L. 89-670, Department of Transportation Act. 80 Stat. 931. Section 4(f): Protection of Public Lands (Replacement of the Massengill Bridge, Anderson County, Tennessee, Nov. 1981).
2. W. Bowlby and L. F. Cohn. Highway Construction Noise: Environmental Assessment and Abatement, Vol. 4: User's Manual for FHWA Highway Construction Noise Computer Program, HICNOM. Vanderbilt University Report VTR81-2. FHWA, U.S. Department of Transportation, 1982.
3. H. B. N. Hynes. The Ecology of Running Waters. University of Waterloo, Ontario, Canada, 1970.

Publication of this paper sponsored by Committee on Environmental Analysis in Transportation.

Stringent Transportation Measures to Reduce Vehicular Emissions in the New York City Metropolitan Area

GEORGE HAIKALIS and J. DAVID JORDAN

ABSTRACT

The analysis performed for the revised 1982 state air quality plans for New York and New Jersey revealed that significant reductions in pollutant emissions would be achieved as newer cars that cause less pollution replaced older cars that cause more pollution. Inspection and maintenance of vehicles would sustain and further induce reductions. Modest traffic engineering and local transit improvements would produce only small additional gains. More stringent transportation measures would be required to achieve clean air. Impacts of measures such as higher bridge and tunnel tolls, parking surcharges, and major transit service improvements were analyzed by using an iterative, elasticity-based sketch-planning model (SPIZZIE). The analysis suggests that although generally not justifiable on pollution reduction merits alone, these measures when packaged together may achieve multiple regional objectives. Pricing measures and service improvements that are most effective in achieving an efficient balance among modes while providing a source of revenue for maintaining and operating the transportation system are recommended for further consideration and implementation.

Controlling air pollution from motor vehicles and stationary sources is an especially challenging task in the New York City metropolitan region (Figure 1). In spite of declining population and jobs, New York, the largest, most populated city in the United States, continues to draw more than 650,000 vehicles daily to its business district from an 8,000-mile^2 area covering significant portions of three states.

Air quality concerns have spurred a concerted effort on the part of federal, state, and local governments to increase mass transit use and decrease the excessive pollutant emissions from vehicles and stationary sources that prevail in many portions of this region. Although these efforts have provided significant contributions toward cleaner air, it is recognized that if all national air quality standards are to be met, these efforts will have to be continued and expanded because vehicles are the source of approximately 90 percent of the carbon monoxide pollution in the New York metropolitan region. In addition, vehicles and gasoline handling account for approximately half of the hydrocarbon emissions, a major cause of the ozone pollution that spreads over most of the East Coast.

Analysis performed for revised 1982 state air quality plans revealed that federal new-car standards supported by a program of inspection and maintenance of control devices would achieve significant reductions in pollutant emissions. Although further small reductions are possible through conventional traffic engineering and local transit improvements, more stringent measures are required to achieve clean air.

In this paper the evaluation of alternative stringent measures to achieve multiple transportation, fiscal, and environmental objectives in the New York City metropolitan area is summarized. Stringent measures to reduce pollutant emissions in the metropolitan area through pricing and automobile restrictions were first proposed in the 1973 air quality plan for New York City (1). Later many of these measures were considered politically infeasible and were not implemented. However, opinion surveys continue to reflect strong public support for environmental control. In 1981 more than 85 percent of those questioned favored maintaining clean air regulations at least at current levels (2). This relatively strong backing exists even with growing awareness of the cost associated with such controls (3).

A more comprehensive analysis of these measures performed for the revised 1982 state air quality plans for New York and New Jersey revealed a wide range of benefits to the public and might warrant reconsideration.

REVISED SIP REQUIREMENT

The Clean Air Act, as amended in August 1977, required the revision of air quality state implementation plans (SIPs) in areas that exceeded the National Ambient Air Quality Standards (NAAQS) for specific pollutants. Under provisions of the amended act, revised plans demonstrating attainment of ozone and carbon monoxide standards by the end of 1987 by using reasonably available measures were to be submitted to the U.S. Environmental Protection Agency (EPA) by July 1, 1982.

Most of New York City, portions of suburban New York, and the central business districts (CBDs) of several older cities in northeastern New Jersey were designated nonattainment areas for carbon monoxide (CO) (Figure 1). All of New Jersey and New York State were designated nonattainment areas for ozone.

The amended act and subsequent EPA guidelines suggested that the revised plans be based on a comprehensive technical analysis of alternative transportation strategies performed by local, regional, state, and operating agencies with the participation of local elected officials and the public. Such an analysis was performed. In this paper the evaluation is described of measures generally perceived by officials to be stringent, that is, measures not readily accepted by the public.

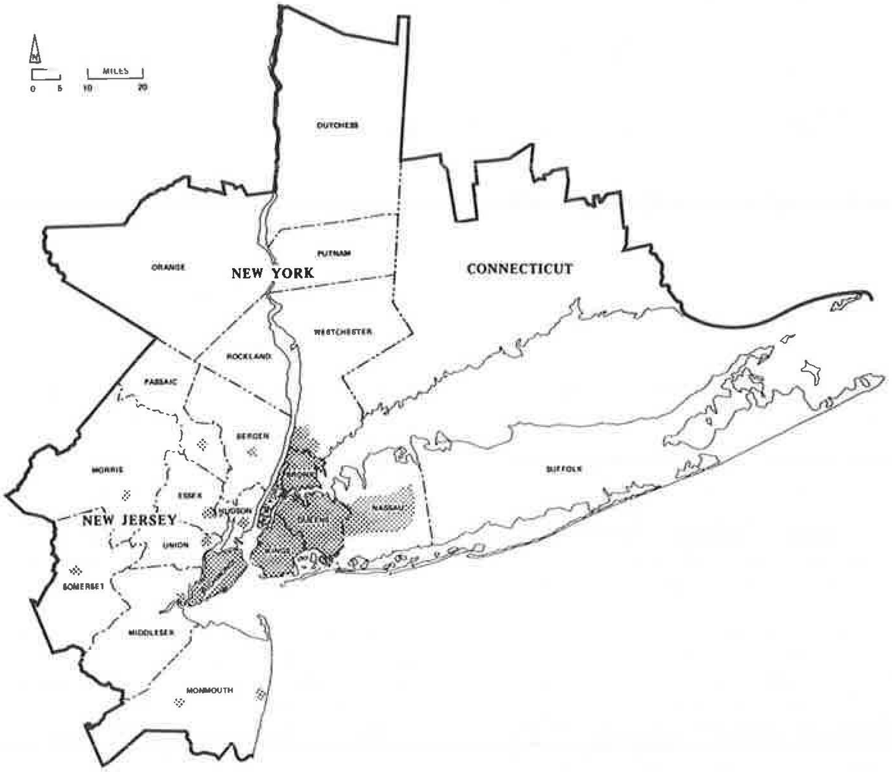


FIGURE 1 Nonattainment areas for carbon monoxide: New York City metropolitan area.

GROWING TRAFFIC VOLUMES

Population in the three-state metropolitan area peaked in 1971 and has declined each year since then to about 18 million in 1980. The major loss took place in New York City and other older urban centers and was partially offset by minor growth in the outer suburban areas (4). Automobile ownership continued to grow faster than population; 20 percent more cars were registered in the suburbs in 1981 than in 1971 (5). Personal travel increased 11 percent regionwide between 1970 and 1980, but the bulk of this was inter- and intrasuburban travel by automobile, which increased 19 percent during this period; small increases registered on certain facilities following the gasoline shortages of 1974 and 1979 (5). Slightly more than three-quarters of all daily trips in the region are now by automobile.

This increasing reliance on the automobile strains the available capacity of the street system, particularly as daily work and business trips converge on older employment centers. About 36 percent of the urban highway system experiences severe congestion during both peak work-travel periods (6). This mismatch of demand and capacity appears to contribute to two distinct pollution problems: high levels of CO caused by accumulations of slow-moving vehicles in congested business districts and high levels of ozone recorded late in the day in Long Island and Connecticut caused partially by hydrocarbon and nitrogen oxide emissions from large volumes of congested morning peak traffic.

CARBON MONOXIDE, A CBD PROBLEM

CO monitors continue to show a steady decline in background levels of this traffic-generated pollutant in the densely developed business districts of both New Jersey and New York. Reduction in CO is particularly noticeable in New Jersey where the federal motor vehicle control program has been made more effective through an inspection and maintenance program initiated in 1974. In Manhattan, however, the 8-hr CO standard continues to be exceeded several times daily and there are insufficient valid data to establish a trend. It is estimated that although the federal new-car program and annual inspection and maintenance may bring CO to healthy levels by 1987 in most areas, the Manhattan business district and other locations of chronic traffic congestion may be exceptions.

Although jobs in Manhattan have decreased over the past 20 years, it continues to be an area of intense economic and cultural activity. Of the almost 3 million who enter the business district below 60th Street daily, 2 million enter by public transport and 930,000 by motor vehicle.

Automobile trips into the CBD have continued to increase since systematic traffic counts became available in the 1920s (5). More than 650,000 motor vehicles entered the 9-mile² area on a typical workday in 1980. It is estimated that up to 400,000 vehicle miles of travel per square mile occur in the most active portions of Manhattan; about half are generated by taxis and a quarter each by trucks and private automobiles. The large volume of trucks and buses compounds the problem by slowing traffic so that vehicles pollute at even higher rates. The risk to health is particularly severe for thousands of pedestrians and outdoor workers who are directly exposed daily to the pollutants present in vehicular exhaust.

Several traffic engineering measures have been implemented during the past few years to improve traffic flow in the CBD. These include stricter enforcement of traffic regulations, fewer on-street parking slots, introduction of exclusive bus lanes, and channelization. Although these measures produce local improvements and begin to address the problem of allocation of scarce street space, they might be more effective if integrated with available mechanisms to control travel demand and produce revenue for transportation system improvements. Some of these mechanisms were explored through an analysis of alternatives performed as a basis for actions in the revised 1982 state air quality plans of New York (7) and New Jersey (8).

OZONE, A REGIONWIDE PROBLEM

Pollutants emitted by motor vehicles and industry in Pennsylvania, New Jersey, and New York appear to contribute to high ozone readings in eastern Long Island and New England. As the phenomenon of long-range transport of pollutants in the northeastern United States becomes better understood and more accurately defined, more efficient and cost-effective strategies to alleviate the problem will emerge. Continuous monitoring during the 1979-1981 base period showed that all state measurement sites but one exceeded the federal ozone standard and there was no discernible downward trend. Based on a crude simulation, it is estimated that a regionwide reduction of nonmethane hydrocarbon emissions in excess of 60 percent will be necessary if the national ozone standard is to be met by 1987. A reduction of this magnitude requires measures of major scope and impact on travel, commerce, and industry.

In the New York metropolitan area automobiles, taxis, and trucks generated about half of the nonmethane hydrocarbons emitted in 1980. The remainder came from industrial and other stationary sources. It is estimated that existing controls will reduce emissions from stationary sources 13 percent by 1987.

Federal emissions standards for new cars, if reinforced with a program of annual inspection and maintenance of pollution control devices, could reduce reactive hydrocarbon emissions from mobile sources 58 percent by 1987, far short of the amount required for attainment of the standard. The states are reluctant to impose more stringent technically feasible controls on industry for fear of the economic consequences. More stringent measures affecting personal travel are also viewed by state and local agencies as politically and economically unacceptable.

Further investigation of these stringent transportation measures revealed that they may contribute to more efficient personal mobility, lower fuel consumption, and also lower emissions. Although generally not economically justifiable because of pollution reduction alone, their apparent contribution to the achievement of multiple regional objectives makes them worthy of consideration, evaluation, and implementation, where feasible.

REGIONAL TRANSPORTATION SOLUTIONS FOR CLEANER AIR

In a time of scarce resources, it is imperative to preserve the existing transportation system and develop a permanent source of funds for maintaining the system and operating it efficiently. Efficient operation implies maximum use of public transit wherever feasible and better management of street space in more automobile-dependent parts of the region. By moving more persons per vehicle at a faster rate, such improvements lower emission levels and conserve fuel.

In particular, the demand for transportation facilities can be managed through varying the cost of using the system. Pricing, skillfully applied, is a potentially powerful tool for achieving

1. A more efficient transportation system in which the demand for a facility is adjusted to match available capacity or service,
2. A source of revenue that can be dedicated for maintenance and operation of the transportation system, and
3. A more equitable means for financing the system.

Pricing is particularly applicable in the New York metropolitan area because the physical and administrative mechanism for charging fees for the use of the transportation system is already in place. Manhattan-bound trips can be controlled by varying the tolls on the river crossings, altering parking charges, and changing the transit fare. More widespread management of travel can be achieved through imposing additional gasoline taxes and tolls on suburban facilities and at selected cordons.

More than 1.4 million vehicles enter and leave Manhattan daily via 18 bridges and 4 tunnels (Figure 2). Drivers from New Jersey pay a uniform toll on all crossings into New York City, whereas drivers from New York City, Long Island, and the northern suburbs have a choice of paying a toll or entering free. It is estimated that half of all drivers park free and the others pay a substantial amount to park in garages and lots.

The 3.37 million daily subway riders currently pay a flat fare of 75 cents, whereas 586,000 daily commuters from the suburbs of New Jersey and New York pay a fare based roughly on distance traveled. Revenue generated at the fare-box pays for about 60 percent of the cost of operating the subway system and about 40 percent of the daily expenses of the various commuter lines.

TRANSPORTATION PRICING MEASURES

Several regional schemes to manage travel demand more efficiently through pricing measures were analyzed. Travel, environmental, energy, and economic impacts of alternative travel cost and service levels were quantified by using models that simulate the regional transportation system and the travel characteristics of its users.

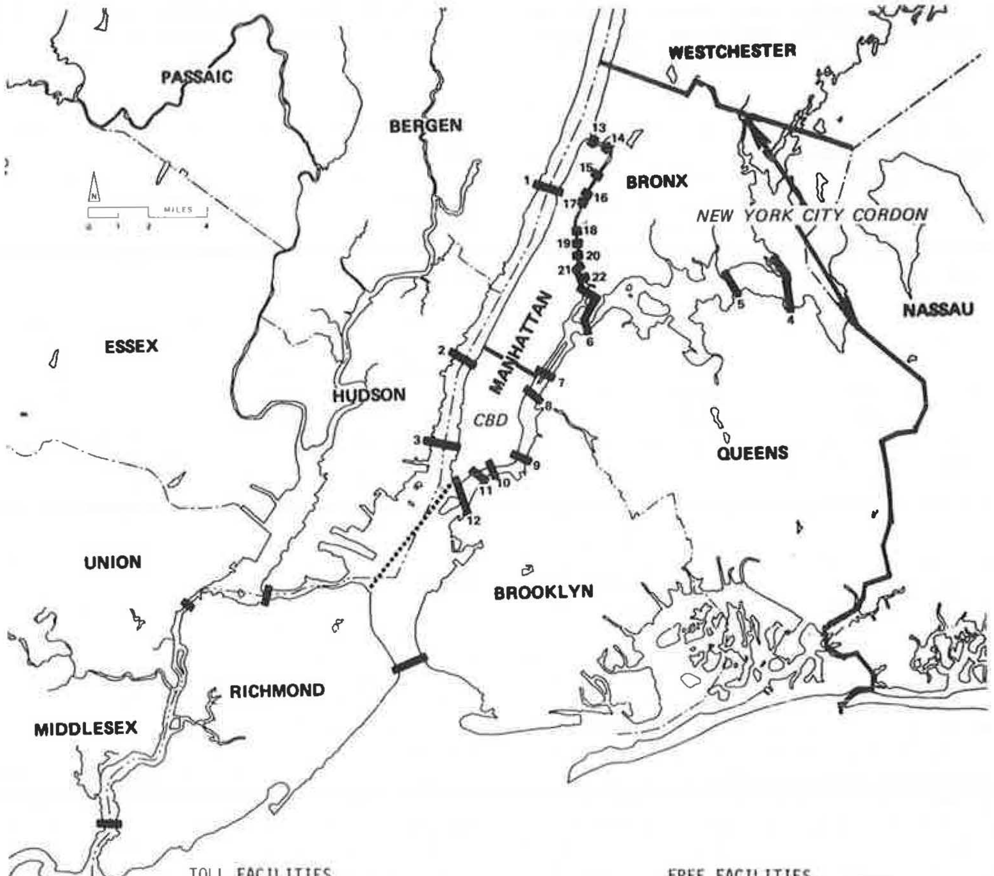
Specifically the following strategies were explored singly and in combination:

1. Controlling automobiles entering Manhattan through river-crossing tolls and parking fees,
2. Controlling automobiles entering New York City through tolls at the city line,
3. Controlling automobile use regionwide through a gasoline tax,
4. Raising the transit fare to increase revenue,
5. Improving transit service, and
6. Allowing the transit system to continue to deteriorate.

Each of these measures would affect vehicular pollutant emissions in varying degrees depending on the pricing level and the geography affected. Thus the first measure would primarily affect CO in Manhattan, whereas the third could produce areawide ozone reductions.

MEASURES OF EFFECTIVENESS

The policy packages were evaluated on the basis of five measures, expressed as changes from the base case:



TOLL FACILITIES

Port Authority of New York and New Jersey (PANYNJ)

- George Washington Bridge (1)
- Lincoln Tunnel (2)
- Holland Tunnel (3)

Triborough Bridge and Tunnel Authority (TBTA)

- Throgs Neck Bridge (4)
- Bronx-Whitestone Bridge (5)
- Triborough Bridge (6)
- Queens Midtown Tunnel (8)
- Brooklyn Battery Tunnel (12)

- Henry Hudson Bridge (13)

FREE FACILITIES

New York City Department of Transportation (East and Harlem Rivers)

- Queensboro Bridge (7)
- Williamsburg Bridge (9)
- Manhattan Bridge (10)
- Brooklyn Bridge (11)
- Broadway Bridge (14)
- University Heights Bridge (15)
- Washington Bridge (181st. St.)(16)
- Alexander Hamilton Bridge (17)
- Macombs Dam Bridge (18)
- 145th St. Bridge (19)
- Madison Ave. Bridge (20)
- Third Ave. Bridge (21)
- Willis Ave. Bridge (22)

FIGURE 2 River crossing locations.

1. The effect on economic activity in the CBD as expressed by the change in travel to that area,
2. The effect on CO emissions in the Manhattan CBD (this is also an indication of the amount and speed of traffic in the CBD),
3. The effect on regionwide highway travel and hydrocarbon emissions as expressed by changes in vehicle miles of travel (VMT), and
4. Savings to tripmakers in travel costs expressed as the dollar value of changes in travel time and fuel consumed.

A sketch-planning travel demand model was used to simulate stringent measures and to derive the measure of effectiveness.

SPIZZIE: AN EVALUATION TOOL

The Sketch-Planning Iterative Zone-to-Zone Impedance Elasticity Model (SPIZZIE) is a program that estimates changes in automobile and transit trips caused by policies affecting travel costs or times in the New York metropolitan area (9). The model does this by applying empirically derived elasticities to a model of travel demand and highway supply consisting of a zone-to-zone modal trip table the automobile component of which is loaded onto a spider network that determines zonal and interzonal mileages, speeds, and costs. Highway level of service varies with vehicular volumes, so equilibrium of demand and supply is approximated through iteration. The program is written in FORTRAN and stored in disk packs.

SPIZZIE's 38 zones are whole or subdivided counties, depending on intracounty variance in structure and density. Paths are simulated in the model as a series of zones traversed in the current minimum friction path between each zonal pair. The paths are fixed, are the same for work and nonwork trips, and are used to calculate origin-destination automobile mileages, times, costs, and VMT. Trips among the 38 zones are disaggregated by mode (automobile driver, automobile passenger, transit) and by purpose (work and nonwork). Travel times can be entered as an externally estimated matrix for all modes or can be calculated by SPIZZIE by using its paths of through zones for automobiles. Zonal congestion values vary by time period (peak, off peak) and class of facility (expressway, other). Access times are added at the origin and destination and vary by time of day, type of trip end (origin or destination), and zone. Travel costs either are entered exogenously or are calculated for automobiles by SPIZZIE based on mileage-related costs modified at the zone level by congestion and road type, to which are added applicable tolls and parking costs. Direct elasticities vary with mode (automobile, transit), transit-mode-share category, type of friction (time, money), and purpose (work, nonwork). The share of each direct trip change going to or coming from competing trip categories is varied according to purpose (work, nonwork), by transit-mode-share category, by mode of original trip change (automobile, transit), by type of friction (time, money), and according to whether the original trip change was an increase or decrease.

SPIZZIE starts out with base-year zone-to-zone trips, times, and costs. Next it either accepts as input or calculates a new set of interzonal impedances based on the policy to be modeled. It then estimates the change in the affected mode's zone-to-zone trips by applying the relevant elasticity to each friction change. Some of this trip change is allocated to or from other modes and destinations by using cross-elasticities. When all new zone-to-zone trips are sorted out, the model converts the new automobile driver trips into zonal VMT, which alters highway level of service by changing congestion levels. The new values are used to calculate new interzonal automobile costs and times, and the entire process converges toward equilibrium through a series of iterations. Finally, changes in VMT and speed provide changes in pollutant emissions and fuel consumption through a modified version of MOBILE 2 (10).

ALTERNATIVE SCENARIOS

Fifteen pricing and service-level policy alternatives were simulated and compared through SPIZZIE. Each simulation is described along with the underlying rationale in Table 1.

Table 2 gives a summary of the 15 sets of policies simulated and analyzed. In Table 3 travel, emission, and fuel-use impacts of each set of policies are given, and in Table 4 the resulting economic and financial consequences are quantified. A detailed discussion of the evaluation of the alternative policies follows.

Transit Fare Increase

Simulation 1 demonstrated a 3 percent increase in CO emissions in the Manhattan CBD caused by the 25 percent transit fare increase that went into effect July 1, 1981. There is a net loss in trips to the CBD of 1.7 percent with an associated decline in economic activity. Regionwide, the impact of the fare increase is a 0.2 percent increase in VMT, a 0.7 percent increase in vehicular hydrocarbon emissions, and almost $100,000 per day lost in additional travel-time and fuel costs.

Transit Fare Increase with River Crossing Tolls

When the fare increase is accompanied by a round-trip toll of $2.00 on all East and Harlem River crossings, the net loss in trips to the CBD is slightly higher (1.8 percent), but CO emissions in the CBD drop by 0.3 percent and there is virtually no change in regionwide motor vehicle travel (simulation 3). When the round-trip toll on the currently free river crossings is raised to $3.00 and TBTA tolls are raised by 50 percent, there is still a net loss in trips to the CBD with a resulting 2.3 percent decrease in CO emissions in the CBD. Regionwide, there is a small decrease in VMT with a savings of $27 million in travel time, partially offset by $12 million more spent on gasoline. These tolls would net more then $600 million a year in revenue (simulation 4).

Tolls

If a part of the revenue generated through the toll increases described earlier was allocated to operation of the transit system without the 25 percent fare increase, considerable travel and environmental benefits would result (simulation 5). There would be a 4.6 percent reduction in CBD CO emissions and a 0.3 percent vehicular hydrocarbon emission reduction regionwide. Trips to the CBD would decrease by only 0.1 percent, and travelers would save $87 million in travel time and fuel costs annually.

Doubling Transit Fare

If the transit fare were doubled to cover system operating expenses, as in simulation 6, there would be a 5 percent loss in CBD trips and a 9 percent increase in CO in the business district. Vehicular hydrocarbon emissions regionwide would increase by 1.4 percent, and users of the transportation system would pay $251 million more annually in extra travel time and fuel costs.

Tolls on All River Crossings

Doubling all PANYNJ river crossing tolls, increasing all TBTA tolls by 50 percent, and placing a $3.00 round-trip toll on all East and Harlem River crossings would produce a 5.5 percent reduction in CO in the CBD and a 0.4 percent reduction in regionwide vehicular hydrocarbon emissions (simulation 7). Additional annual revenue of $875 million would result, with a $134 million savings in annual travel-related costs.

Gasoline Tax Increase

A statewide tax of $0.15 per gallon of gasoline produces major areawide impacts on highway travel (simulation 8). Both regional VMT and vehicular hydrocarbon emissions decrease by more than 3 percent when the $0.15 fuel tax is superimposed on the toll structure of simulation 7. Total travel to the CBD decreases by 0.2 percent with a 6.3 percent drop in CO emissions. There are major annual savings in travel time and fuel costs of $444 million along with more than $900 million generated yearly by the gasoline tax surcharge.

CBD Parking Surcharge

A sizable decrease in CBD pollutant emissions is achieved with a $1.45 surcharge on those who park in the CBD. The parking fee, when added to the toll structure and gasoline tax of simulation 8, produces a 9 percent reduction in CO in the Manhattan busi-

TABLE 1 Pricing and Service-Level Policy Alternatives

Simulated Scenario	Rationale
1. Citywide 25 percent transit fare increase	The fare was raised 25 percent in July 1, 1981, to offset transit system operating expenses
2. Citywide 25 percent transit fare increase and $1.00 East and Harlem River round-trip tolls	Increasing tolls on currently free crossings into Manhattan to offset the negative effects of the transit fare increase
3. Citywide 25 percent transit fare increase and $2.00 East and Harlem River round-trip tolls	
4. Citywide 25 percent transit fare increase, $3.00 East and Harlem River round-trip tolls, and 50 percent increase in TBTA tolls (to Manhattan)	
5. 50 percent increase in TBTA tolls (to Manhattan) and $3.00 East and Harlem River round-trip tolls	Tolls on free crossings (without a fare increase) to manage demand and raise revenue for transit operating expenses
6. Citywide 100 percent transit fare increase	Doubling the transit fare to generate funds to operate the system
7. 50 percent increase on all TBTA facilities, 100 percent PANYNJ toll increase, and $3.00 East and Harlem River tound-trip tolls	
8. 50 percent increase on all TBTA facilities, 100 percent PANYNJ toll increase $3.00 East and Harlem River round-trip tolls, and gasoline tax increase of $0.15 per gallon	
9. 50 percent increase on all TBTA facilities, 100 percent PANYNJ toll increase, $3.00 East and Harlem River round-trip tolls, gasoline tax increase of $0.15 per gallon, and $1.45 CBD parking surcharge	Major increases in tolls on all entry facilities, a gasoline surcharge, and a parking surcharge to manage demand and generate revenue to maintain and operate the transportation system
10. 10 percent decrease in transit service	To quantify the impacts of a deteriorating transit system
11. 5 percent increase in transit service	To quantify the impacts of an improved transit system
12. 25 percent increase on all TBTA facilities and 25 percent PANYNJ toll increase	Modest increase in tolls on currently tolled facilities
13. 100 percent increase on all TBTA facilities and 100 percent PANYNJ toll increase	Doubling tolls on currently tolled facilities
14. 50 percent increase on all TBTA facilities, 100 percent PANYNJ toll increase, $3.00 East and Harlem River round-trip tolls, and $1.50 city-line round trip tolls	Disincentives to automobiles entering New York City in addition to tolls into Manhattan
15. 50 percent increase on all TBTA facilities, 100 percent PANYNJ toll increase, $6.00 East and Harlem River round-trip tolls, and $3.00 city-line round-trip tolls	

TABLE 2 Scenario Characteristics

Scenario	Fare Increase (%)	TBTA Toll Increase (%)		PANYNJ Toll Increase (%)		East and Harlem River Round-Trip Toll ($)	Gasoline Tax Increase per Gallon ($)	CBD Parking Surcharge ($)	Transit Service Change (%)	City-Line Round-Trip Toll ($)
		Manhattan	Other	Manhattan	Other					
1	25	–	–	–	–	–	–	–	–	–
2	25	–	–	–	–	1.00	–	–	–	–
3	25	–	–	–	–	2.00	–	–	–	–
4	25	50	–	–	–	3.00	–	–	–	–
5	–	50	–	–	–	3.00	–	–	–	–
6	100	–	–	–	–	–	–	–	–	–
7	–	50	50	100	100	3.00	–	–	–	–
8	–	50	50	100	100	3.00	0.15	–	–	–
9	–	50	50	100	100	3.00	0.15	1.45	–	–
10	–	–	–	–	–	–	–	–	−10	–
11	–	–	–	–	–	–	–	–	+5	–
12	–	25	25	25	25	–	–	–	–	–
13	–	100	100	100	100	–	–	–	–	–
14	–	50	50	100	100	3.00	–	–	–	1.50
15	–	50	50	100	100	6.00	–	–	–	3.00

Note: Dashes indicate category not applicable.

TABLE 3 Scenario Results

Scenario	Change in CBD Trips (%)			Change in CBD Street Use (%)			Change Regionwide (%)		Regionwide Avg Weekday Measures			Change Screen Line (%)	
	Transit	Driver	Total	VMT	Avg Speed	CO Emissions	VMT	HC Emissions	Mileage Savings (miles)	Fuel Savings (gal)	Transit Time Savings (hr)	Manhattan	City Line
1	−2.44	+1.35	−1.72	+1.42	−2.66	+3.10	+0.21	+0.65	−16,800	−81,000	–	–	–
2	−2.42	+0.84	−1.80	+0.47	−0.90	+1.32	+0.12	+0.49	−8,800	−65,500	–	–	–
3	−2.35	+0.30	−1.83	−0.45	+0.80	−0.29	+0.02	+0.33	−1,200	−47,800	–	–	–
4	−2.23	−0.49	−1.88	−1.67	+3.04	−2.33	−0.10	+0.16	+7,600	−28,600	–	–	–
5	+0.23	−1.80	−0.14	−3.01	+5.54	−4.62	−0.32	−0.18	+23,400	+12,700	–	–	–
6	−7.35	+4.19	−5.16	+4.30	−8.00	+8.74	+0.66	+1.40	−51,100	−170,900	–	–	–
7	+0.25	−2.05	−0.16	−3.52	+6.48	−5.50	−0.63	−0.43	+32,200	+51,100	–	–	–
8	+0.29	−2.36	−0.19	−4.02	+7.38	−6.28	−3.41	−3.10	+66,700	+502,300	–	–	–
9	+0.58	−4.95	−0.46	−4.71	+10.51	−8.96	−3.47	−3.22	+72,900	+515,700	–	–	–
10	−4.38	+2.00	−3.19	+1.86	−3.55	+3.96	+0.25	+0.74	−23,500	−90,900	−170,500	–	
11	+2.47	−2.17	+1.63	−1.96	+3.88	−3.14	−0.23	−0.12	+25,100	+8,300	+85,200	–	–
12	+0.03	−0.27	−0.03	−0.41	+0.76	−0.36	−0.12	−0.18	+5,400	+22,300	–	–	–
13	+0.11	−1.01	−0.10	−1.48	+2.73	−2.16	−0.44	−0.15	+19,100	+21,400	–	–	–
14	+0.26	−2.09	−0.16	−3.82	+3.04	−5.86	−0.87	−1.05	+46,700	+136,300	–	−2.00	−7.00
15	+0.51	−4.39	−0.45	−7.37	+6.10	−10.48	−1.56	−1.84	+81,100	+241,700	–	−4.00	−14.00

TABLE 4 Financial and Economic Impacts

	Annual Savings ($000,000s)			Annual Revenue Change ($000,000s)						Transit Operating Cost Increase ($000,000s)	City-Line Toll Revenue ($000,000s)
Scenario	Automobile Time	Transit Time	Fuel	TBTA	PANYNJ	East and Harlem Rivers	Transit	Gasoline Tax Surcharge	CBD Parking Surcharge		
1	-59	-	-34	+3	+1	-	+351	-	-	-	-
2	-31	-	-28	+2	+1	+202	+351	-	-	-	-
3	-4	-	-20	+1	-	+401	+351	-	-	-	-
4	+27	-	-12	+48	-1	+597	+351	-	-	-	-
5	+82	-	+5	+48	-3	+589	+4	-	-	-	-
6	-179	-	-72	+11	+6	-	+1,332	-	-	-	-
7	+113	-	+21	+134	+149	+588	+4	-	-	-	-
8	+233	-	+211	+134	+149	+586	+4	+903	-	-	-
9	+255	-	+217	+134	+149	+570	+8	+902	+114	-	-
10	-82	-256	-38	+5	+3	-	-63	-	-	-	-
11	+88	+128	+3	-6	-3	-	+36	-	-	+45	-
12	+19	-	+9	+69	+37	-	-	-	-	-	-
13	+67	-	+9	+265	+146	-	+2	-	-	-	-
14	+163	-	+57	+134	+149	+588	+4	-	-	-	260
15	+284	-	+102	+134	+149	+570	+8	-	-	-	480

ness district (simulation 9). The parking surcharge produces an annual revenue of $114 million.

Transit Service Changes

Deterioration of the transit system would depress the economy of the metropolitan area and the CBD. If trips by public transportation took 10 percent longer because of service costs, travel to the CBD would decrease by more than 3 percent, and there would be 4 percent more CO emissions (simulation 10). Regionwide VMT would increase 0.25 percent and $376 million more would be expended annually in travel and fuel costs.

Improvements to public transportation service resulting in a 5 percent shorter journey time would bring 1.6 percent more trips to the CBD and would lower CO emissions by more than 3 percent (simulation 11). Regionwide VMT would decrease by 0.2 percent, and travelers would save $219 million annually in travel and fuel costs.

Increased Tolls on Currently Tolled Facilities

A modest 25 percent increase in tolls on all TBTA and PANYNJ toll facilities would produce small but generally positive changes: stable trips to the CBD, small decreases in emissions, $28 million saved annually in travel and fuel costs, and $106 million generated in additional revenue (simulation 12).

Doubling tolls on the TBTA and Port Authority crossings produces more substantial changes with positive impacts. There would be a 2 percent decrease in CO emissions in the CBD, a 0.4 percent reduction in regionwide VMT, $76 million saved annually in travel and fuel costs, and more than $400 million in annual revenue generated (simulation 13).

Controlling Automobiles Entering New York City

Automobile entries into New York City could be controlled through a charge on all cars crossing the city line. A $1.50 city-line cordon charge in addition to increased Manhattan entry charges would reduce areawide vehicular hydrocarbon emissions by 1 percent and CBD CO emissions by almost 6 percent (simulation 14). In addition, this policy would generate $220 million in travel-time and fuel cost savings and more than $1.1 billion in revenue.

A $3.00 city-line charge in addition to a $6.00 round-trip toll on the East and Harlem Rivers, doubled Port Authority facility tolls, and 50 percent TBTA toll increases would lower regionwide vehicular hydrocarbons by almost 2 percent and central area CO emissions by more than 10 percent (simulation 15). There would be $386 million saved in travel-time and fuel costs with more than $1.3 billion generated in added revenue.

SUMMARY OF RESULTS

Impacts of six of the simulated pricing policy proposals are highlighted in Table 5. The relative effectiveness of various road-pricing measures, transit service improvements, and transit fare increases in achieving certain key objectives related to travel, the environment, the economy, and generated revenue is shown. The conclusions and recommendations that follow are based on the policy impacts shown in Tables 2-4 and highlighted in Table 5.

Fuel taxes and cordon charges are effective in reducing areawide VMT and vehicular hydrocarbon emissions. Substantial user savings and revenue accrue (simulations 8, 14, 15, and particularly simulation 9). CO emissions in the CBD can be lowered substantially by restructuring the price of automobile entry into Manhattan and New York City and through better management of parking controls. Substantial savings to travelers and revenues are also generated (simulations 5, 7, 9, 14, and especially simulation 15). Improved public transit service to the business district produces increased economic activity and less pollution in the CBD (simulation 11). A sharp increase in the public transit fare produces a substantial increase in pollutant emissions and a decline in economic activity in the CBD (simulation 6). Negative impacts of smaller increases in the transit fare can be partially offset with automobile-entry controls and transit service improvements (simulation 4). Deterioration of the public transit system and substandard service produce a less efficient transportation system, more pollutant emissions, increased fuel use, and losses in travel time, revenue, and economic activity (simulation 10).

Based on these findings, a number of strategies are recommended for more detailed study and implementation. To obtain areawide vehicular nonmethane hydrocarbon emission reductions, the following combination of policies is recommended:

1. A restructured system of tolls on all New York City river crossings;
2. A statewide gasoline tax surcharge;

TABLE 5 Impacts of Selected Policies

	Change from Base (%)			Change from Base ($000,000s/year)	
Simulation	CO in CBD	CBD Activity	Regionwide VMT	Savings in Travel Cost	Revenue Generated
9. Toll increases, gasoline tax, and parking surcharge (50 percent increase on all TBRA facilities, 100 percent PANYNJ toll increase, $3.00 East and Harlem River round-trip toll, gasoline tax increase of $0.15 per gallon, and $1.45 CBD parking surcharge)	-9.0	-0.5	-3.5	472	1,877
15. Toll increases and city-line tolls (50 percent increase on all TBTA facilities, 100 percent PANYNJ toll increase, $6.00 East and Harlem River round-trip tolls, and $3.00 city-line round-trip tolls)	-10.5	-0.5	-1.6	386	1,341
5. Tolls on free crossings [50 percent increase in TBTA tolls (to Manhattan) and $3.00 East and Harlem River round-trip tolls]	-4.6	-0.1	-0.3	87	638
13. Doubled tolls on currently tolled facilities (100 percent increase on all TBTA facilities and 100 percent PANYNJ toll increase)	-2.2	-0.1	-0.4	76	403
11. Improved transit service (5 percent increase in transit service)	-3.1	+1.6	-0.2	219	(-18)
6. Doubled transit fare (citywide 100 percent transit fare increase)	+8.7	-5.2	+0.7	(-251)	1,349

Note: Adverse impacts are underlined.

3. A transit fare level that rises no faster than the cost of living;
4. Improved transit service financed with a portion of the revenue generated from tolls, the gasoline tax, and fare-box proceeds; and
5. Maintenance of the highway network with a portion of the revenue generated from tolls and the gasoline tax.

In addition, policies recommended to lower CO levels in the CBD are

6. Better management of parking in the CBD through restrictions and charges, and
7. Pedestrian and transit malls along with other amenities to make the CBD more attractive.

Future studies should further examine these policies:

1. Variation of the transit fare by time of day to optimize the use of available off-peak system capacity (11),
2. Variation of the transit fare according to trip length,
3. Variation of highway facility tolls and parking charges (according to available street capacity) by time of day, and
4. A network of automobile-free zones in Manhattan (12).

Although commitments to implement stringent measures were not obtained, the analysis and recommendations described in the foregoing were included in the 1982 New York SIP (7). A similar analysis was included in the 1982 New Jersey SIP (8).

ACKNOWLEDGMENT

This paper is dedicated to the memory of Allen Wasserman, who developed SPIZZIE.

The contributions of several members of the staff of the Tri-State Regional Planning Commission to this analysis of alternatives are gratefully acknowledged. The Commission was dissolved in 1982 and reorganized, with modified goals and functions, into the New York Metropolitan Transportation Council. This work was partially funded with EPA Section 175 funds.

REFERENCES

1. New York City Metropolitan Area Air Quality Implementation Plan: Transportation Controls. New York State Department of Environmental Conservation, Albany, April 1973.
2. National Public Opinion Survey. Louis Harris and Associates, New York City, May 6-10, 1981.
3. Public Opinion on Environmental Issues: Results of a National Public Opinion Survey. U.S. Government Printing Office, Washington, D.C., 1980.
4. Annual Demographic Report. Tri-State Regional Planning Commission, New York City, June 1982.
5. Annual Transportation Report. Tri-State Regional Planning Commission, New York City, June 1982.
6. Regional Highway Performance Report 1980. Skycomp Data Corporation, Princeton, N.J., June 1981.
7. New York State Air Quality Implementation Plan: Appendix F. New York State Department of Environmental Conservation, Albany, June 1982.
8. Transportation/Air Quality Plan for the New Jersey Portion of the New York-New Jersey-Connecticut Air Quality Control Region: Appendix D. Tri-State Regional Planning Commission, New York City, March 1982.
9. A. Wasserman. SPIZZIE, Tri-State's Sketch Planning Model. Interim Technical Report 2803/P-117. Tri-State Regional Planning Commission, New York City, June 1981.
10. A Procedure for Estimating Pollutant Emissions and Fuel Consumption. Urban Systems, Inc., Chicago, Ill., May 1981.
11. G. Haikalis. The B-5 Strategy: An Analysis of Short-Range Transit Improvements That Would Reduce Auto Use to the Manhattan CBD. Interim Technical Report 2121. Tri-State Regional Planning Commission, New York City, June 1977.
12. G. Haikalis. Auto-Free Zones in CBDs and an Example for Lower Manhattan. Interim Technical Report 2128. Tri-State Regional Planning Commission, New York City, June 1979.

Publication of this paper sponsored by Committee on Transportation and Air Quality.