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

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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.

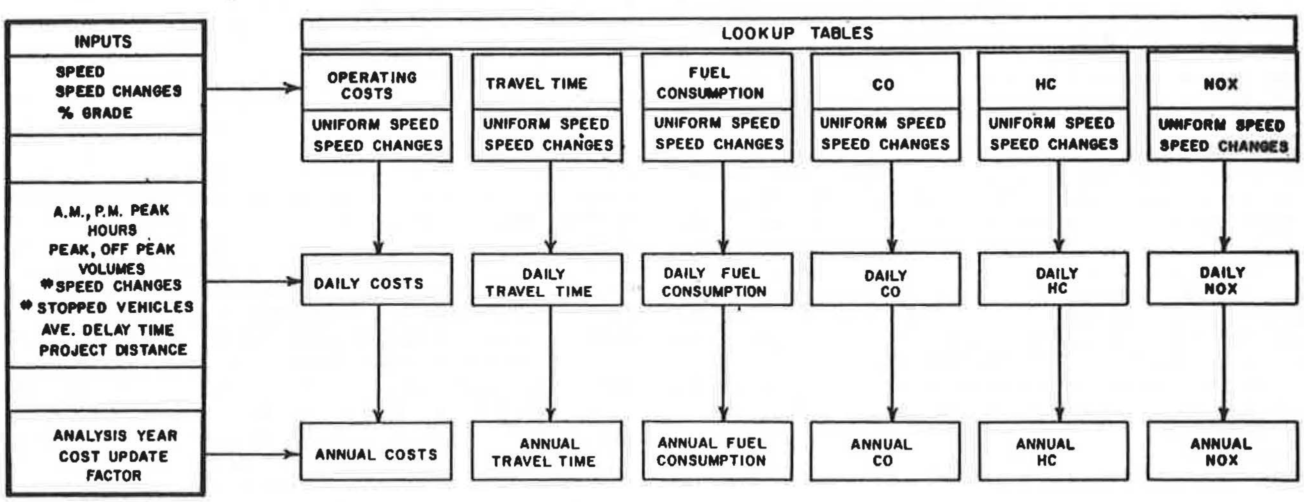


FIGURE 1 Microcomputer flowchart.

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)***

| Time Period | Daily Volume | Volume Stopped (%) Before | Volume Stopped (%) After | Vehicle Delay (sec) Before | Vehicle Delay (sec) 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**

| MOE | Computer Results Before | Computer Results After | Computer Results Reduction | Manual Results Before | Manual Results After | Manual Results 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

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