An economic analysis computer program (ECOANA) was developed in FORTRAN to generate economic measures from included rate tables and stored traffic operation data. The traffic data used are stored by the modified FREQ3CP freeway simulation program. The measures include monetary costs for travel time, vehicle operation and accidents as well as fuel consumption and pollution emission quantities. The derivation of each economic measure is discussed by listing how the simulated traffic data are used to manipulate the appropriate cost or usage table. A discussion of how to set up the program cards for the ECOANA program is given along with a listing, sample printout and flowchart of the program. The engineer can now have realistic data from which benefit-to-cost figures can be developed.
AN ECONOMIC AND ENVIRONMENTAL ANALYSIS PROGRAM
USING THE RESULTS FOR THE FREQ3CP MODEL

by

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Research Report 210-5
Evaluation of Urban Freeway Modifications

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ABSTRACT

An economic analysis computer program (ECOANA) was developed in FORTRAN to generate economic measures from included rate tables and stored traffic operation data. The traffic data used are stored by the modified FREQ3CP freeway simulation program. The measures include monetary costs for travel time, vehicle operation and accidents as well as fuel consumption and pollution emission quantities. The derivation of each economic measure is discussed by listing how the simulated traffic data are used to manipulate the appropriate cost or usage table. A discussion of how to set up the program cards for the ECOANA program is given along with a listing, sample printout and flowchart of the program. The engineer can now have realistic data from which benefit-to-cost figures can be developed.
SUMMARY

The development of an economic analysis (ECOANA) computer program that provides economic measures based on FREQ3CP simulated traffic operations has been developed. The data requirements and assumptions necessary to perform the calculation of the measures were outlined in Research Report 210-3, "Analyzing the FREQ3CP Freeway Operations Simulation Model". In each of the five economic areas in which quantitative measures were determined, a discussion is given concerning the data required from the FREQ3CP simulation and the manipulation of the appropriate economic rate tables. The five economic measures include monetary costs for travel time, vehicle operation, and accidents, as well as the quantitative measures of fuel consumed and pollution emissions.

The economic rate tables generally provide for four vehicle types with the user supplying the percentage of each vehicle type in the traffic stream. All of the economic tables utilized by the ECOANA program are permanently stored on a remote computer tape. As the simulation data are calculated, they are stored on a unique file. After the user has determined that reasonable FREQ3CP simulation results were obtained, then ECOANA can be executed independent of the simulation program. Unlike FREQ3CP, there is not a calibration sequence to follow in the ECOANA program. If the FREQ3CP simulation results are invalid, the ECOANA results will likewise be invalid. The merit of the FREQ3CP simulation program is that the engineer can compare before and after control measures to determine the most advantageous control scheme. In this manner, the engineer can now be provided with economic measures, which provides a more realistic data base for a benefit-to-cost evaluation which is explained in more detail in this report.
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INTRODUCTION

One of the objectives of the research study entitled "Evaluation of Urban Freeway Modifications," being conducted by the Texas Transportation Institute and sponsored by the State Department of Highways and Public Transportation (SDHPT) in cooperation with the Federal Highway Administration, calls for examining and applying techniques, such as the FREQ3CP Freeway Operations Simulation Model designed for evaluating proposed freeway improvement projects before and after implementation. One of the tasks of this objective calls for adapting, calibrating, and testing the FREQ3CP simulation model to a specific freeway problem. Another task calls for the development of an economic analysis program to provide economic measures based on FREQ3CP simulated traffic operations.

The I.H. 10 West (Katy) Freeway in Houston, Texas was chosen as a site on which the FREQ3CP simulation model could be tested for calibration. Traffic volume data were collected and converted to useable form by a separate computer program called SYNODM. In the attempt to calibrate the FREQ3CP computer program, it became evident that the user of the program can distort the program results by the choice of subsectional capacities and Origin-Destination (O-D) input data. The SYNODM program provides a method by which actual demand data at each entry and exit point along a freeway system can be synthesized in such a way that the total inputs and outputs of the O-D matrix are equal.

The output data of the SYNODM program can be used as direct inputs into the FREQ3CP program. In turn, the output of the FREQ3CP program becomes part of the input data for the economic analysis program, ECOANA, which is described in this report. The data requirements and assumptions necessary to use ECOANA are outlined in Research Report 210-3. They are repeated in this report, and the unit cost data are presented in tabular form. Also, procedures to update the unit costs are presented in this report.
ECOANA uses peak period FREQ3CP output data collected from each subsection of the project by 15-minute time slice intervals as well as data summarized over all subsections and time slices to simulate before and after construction traffic conditions. The peak period assumed in the FREQ3CP program is specified by the user. The sample output data used for the trial run analysis of ECOANA is based on a peak period, beginning at 6:00 a.m. and ending at 9:30 a.m. on the Southwest Freeway.

ECOANA enables the engineer to compare before and after economic measures and provides realistic data for a benefit-to-cost evaluation. The possible alternative uses of the ECOANA output are discussed in the next section of this report.
FREQ3CP output data, the economic data and assumptions used in the economic analysis program, ECOANA, are covered here. The program determines peak period time costs, vehicle operating costs, fuel consumed, pollution emissions, and accident costs. More specifically, ECOANA determines time costs, vehicle operating costs, etc. for simulated traffic on the freeway's main lanes, on the entrance ramps, and on the diversion route. ECOANA provides for separate calculations on four vehicle types, as described in Table 1. These vehicle types are those customarily used in user benefit analyses (1, 2) and represent the major vehicle types using freeways and highways. Further, these vehicle types represent significant differences in vehicle operating costs. The unit costs, fuel consumption rates, and pollution emission factors used in ECOANA are based on the more recent information found in the literature. The time and vehicle operating unit costs are those reported in the Texas Transportation Institute (TTI) Research Report 202-2 (3), except that they are combined into four vehicle types and updated to represent January 1980 costs. The unit values of time recommended in the ASSHTO Redbook (1) are not too different from those recommended in the TTI 202 report. Since the values of time recommended in the TTI report are based on truck and driver costs prevailing in the Southwest, they are preferred over those recommended in the Redbook for evaluation of Texas Freeway improvement.
projects. The vehicle operating unit costs recommended in the TTI report are given in tabular form, and hence, are easier to computerize than those recommended in graphic form in the Redbook. Also, the unit costs of the TTI report are more responsive to Level of Service F speeds and speed changes than those of the Redbook. Unit costs of the TTI report increase consistently as vehicle speeds decrease, whereas, those of the Redbook increase and decrease alternately with vehicle speeds. Finally, the unit costs of the TTI report are especially adapted to analyzing freeway modification projects. The fuel consumption rates are based on the unit costs reported in the TTI 202-2 report and the fuel costs reported by Winfrey (4) and the ASSHTO Redbook (1). The data source for fuel consumption rates is more or less dictated by the choice of vehicle operating unit costs used. Since the unit costs of the TTI report are used in ECOANA, fuel consumption rates based on these costs are also used. The pollution rates are predicted 1977 rates and are based on a 1975 Environmental Protection Agency (EPA) report (5). The accident unit costs are based on those reported in the ASSHTO Redbook (1) and updated to represent January 1980 costs. The accident unit costs used in ECOANA represent the most complete accounting of costs that might be incurred as a result of an accident. The accident unit costs in the TTI 202 report are not recommended primarily because corresponding accident rates are not available in up-to-date form. The accident rates are based on 1978 accident information obtained from the SDHPT files.

The unit costs used in ECOANA represent estimated January 1980 prices. The unit costs chosen from a particular data source were updated by using
the appropriate component of the National Consumer Price Index (CPI) of or the Producer Price Index (PPI) and the appropriate updating formulas, where applicable, that are recommended in the ASSHTO Redbook (1). The PPI replaces the old Wholesale Price Index (WPI). The same procedure can be used to update ECOANA's unit costs beyond the January 1980 base, but a less detailed procedure, as presented in this section, can be used to account for changes in appropriate components of the above price indexes.

A discussion of the possible uses of the ECOANA output data is presented later in this section of the report.
Time Costs

The portion of the economic package described here pertains to time costs. The FREQ3CP output (simulation) data, economic data (values of time), assumptions and calculations required to determine the total time cost for estimating time cost for on freeway, on ramp, and diversion route travel are covered below.

On Freeway Travel Time Costs

The FREQ3CP output required to calculate travel time costs on the freeway proper is the cumulative sum of on freeway travel times for all subsections for the entire peak period in the form of:

- Total vehicle-hours and
- Total passenger-hours

The economic data required are the values of time by vehicle type for moving vehicles, as presented in Table 2. These data are presented in dollars ($) per hour for the driver and the passenger, because they are different for each vehicle type, except Vehicle Type 1.

The assumptions and given data required to generate time costs are as follows:

- Percentage distribution of the four vehicle types (TABLE 1),
- Number of passengers per vehicle for Vehicle Types 1 and 4,
- Percentage distribution of vehicles and number of passengers are the same for all subsections over all time slices,
- Total passenger-hours generated by the FREQ3CP program includes trucks driver-hours, and
- FREQ3CP output data takes into account the time required for speed changes and stops.
<table>
<thead>
<tr>
<th>Vehicle Type Number</th>
<th>Vehicle Type Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Automobiles, pickups, and panel trucks (2-axle, 4-tire)</td>
</tr>
<tr>
<td>2</td>
<td>Single-unit trucks (other than 2-axle, 4-tire)</td>
</tr>
<tr>
<td>3</td>
<td>Truck-tractor-semi-trailer or trailer combinations</td>
</tr>
<tr>
<td>4</td>
<td>Buses</td>
</tr>
</tbody>
</table>

Note: A decimal value for each is entered via card entry at program execution time. The sum of all four values must equal 1.
Table 2. Value of Time, by Vehicle Type and Driving Mode

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>In Moving Vehicle&lt;sup&gt;a&lt;/sup&gt;</th>
<th>In Stopped Vehicle&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Driver</td>
<td>Passenger</td>
</tr>
<tr>
<td>1</td>
<td>6.31</td>
<td>6.31</td>
</tr>
<tr>
<td>2</td>
<td>11.72</td>
<td>6.31</td>
</tr>
<tr>
<td>3</td>
<td>16.36</td>
<td>6.31</td>
</tr>
<tr>
<td>4</td>
<td>17.66</td>
<td>6.31</td>
</tr>
</tbody>
</table>

<sup>a</sup>Update of values of time reported by Buffington and McFarland in Texas Transportation Institute Research Report 202-2.

<sup>b</sup>Represents 1.5 times the in stopped vehicle values of time, and is based on waiting data reported in the 1977 ASSHTO Redbook.
The calculations required to arrive at the total driver time cost are as follows:

1. Multiply the total vehicle-hours by the vehicle type (TABLE 1) percentage distribution to arrive at the total driver-hours per vehicle type.

2. Multiply the total driver-hours per vehicle type by the moving vehicle values of time for the corresponding vehicle types presented in Table 2 to obtain the time costs for drivers of each vehicle type.

3. Sum the driver-time costs for the four vehicle types.

The calculations required to arrive at the total passenger-time cost are as follows:

1. Subtract the total passenger-hours from the total driver-hours to obtain the total net passenger-hours.

2. Multiply the total net passenger-hours by the moving vehicle passenger time value presented in Table 2 to obtain the total passenger time costs.

Finally, the total driver-time cost is added to the total passenger-time cost to arrive at the total on freeway time cost per peak period.

**On Ramp Travel Time Costs**

To calculate on ramp travel time costs resulting from input or on ramp delay, the cumulated total input delay in vehicle-hours and passenger-hours for all time slices must be obtained as output from the FREQ3CP program.
The economic data required for the calculation are the values of time for drivers and passengers waiting in stopped vehicles by vehicle type. These values are presented in Table 2 in dollars per hour.

The assumptions and given data are the same as those required for the on freeway calculations, except for the following:

- Time while vehicles are moving on the ramp is not calculated and
- Value of time while waiting in vehicle is worth more than the value of time in a moving vehicle due to increased mental anguish and patience required.

The calculations required to arrive at the total on ramp time cost are the same as those enumerated above to arrive at the total on freeway time cost.

**Diversion Route Travel Time Cost**

Travel time costs for persons voluntarily or involuntarily diverted from the freeway's main lanes during the peak period can be calculated from the cumulative data for all time slices combined. The assumption is made that the diverted vehicles will travel the same distance as would be traveled on the main lanes. (While this assumption is conservative and does not account for backtracking, it does provide a means of comparing the before and after conditions of a control scheme or geometric change to the freeway facility.) The following FREQ3CP output or given data are needed to make such calculations.
• Number of vehicle-miles and passenger-miles traveled by vehicles diverted from the freeway's main lanes, and
• Average speed (mph) on the diversion route.

The economic data required for calculating diversion travel time costs are the values of time for drivers and passengers in moving vehicles. These values are shown in Table 2 in dollars per hour.

The same assumptions required for freeway and ramp travel time costs apply in the calculation of diversion travel time costs, except for the following:

• Average diversion speed takes into account the time required for speed changes and stops, and
• Average diversion speed is the same for all subsections and time slices.

The following calculations are required to arrive at the diversion travel time costs:

1. Divide the number of vehicle-miles and passenger-miles by the average miles per hour to obtain total vehicle-hours and total-passenger-hours.
2. Using vehicle-hours and passenger-hours, proceed in the same manner as enumerated above in calculating "on freeway" time costs to arrive at the total diversion travel time cost.

To arrive at the overall total travel time cost for one peak period, sum the time costs for on freeway, on ramps and diversion route.
Vehicle Operating Costs

Vehicle operating costs during peak periods can be estimated for simulated freeway travel on freeway's main lanes, the on ramps, and the diversion route using the FREQ3CP outputs, economic data, assumptions, and calculations indicated below. Vehicle operating costs are the mileage dependent costs of running motor vehicles on freeways and city streets, including fuel, tire, engine oil, maintenance, and depreciation costs.

On Freeway Vehicle Operating Costs

The FREQ3CP output required to calculate the on freeway vehicle operating costs consist of the following individual subsection data per time slice:

- Average speed (mph)
- Volume-to-capacity ratio (v/c)
- Total vehicle-miles of travel.

The economic or given data required are the vehicle operating unit costs by average speed, vehicle type, and level of service, as shown in Tables 3, 4, and 5. Also, the v/c ratios (range) applicable for each level of service must be given, as shown in Table 6. The v/c ratio ranges vary somewhat depending upon the number of lanes of capacity.

The following assumptions apply to the vehicle operating cost calculations:

- The unit costs in the above tables account for speed changes and stops that are normally experienced by vehicles on freeways, and
- The percentage of vehicles by type must be assumed by the user.
Table 3. Running Costs for Vehicle Type 1 on Freeways, by Level of Service and Average Speed

<table>
<thead>
<tr>
<th>Miles Per Hour&lt;sup&gt;b&lt;/sup&gt;</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
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<tr>
<td>5</td>
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<td>10</td>
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<td>17.360</td>
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<td>14.725</td>
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<td>25</td>
<td>13.189</td>
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<tr>
<td>30</td>
<td>9.571</td>
<td>12.413</td>
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<td>35</td>
<td>9.512</td>
<td>9.708</td>
<td>9.758</td>
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<td>40</td>
<td>9.694</td>
<td>9.787</td>
<td>9.977</td>
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<tr>
<td>45</td>
<td>9.713</td>
<td>10.033</td>
<td>10.200</td>
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<tr>
<td>50</td>
<td>9.706</td>
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<td>10.451</td>
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<td>55</td>
<td>10.647</td>
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<tr>
<td>60</td>
<td>10.563</td>
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<td>65</td>
<td>11.268</td>
<td></td>
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</table>

<sup>a</sup>Update of costs reported by Buffington and McFarland in Texas Transportation Institute Research Report 202-2.

<sup>b</sup>To convert from miles per hour to kilometers per hour, multiply by 1.609344.

<sup>c</sup>To convert from cents per miles to cents per kilometer, multiply by 0.6214.
Table 4. Running Costs of Vehicle Types 2 and 4 on Freeways, by Level of Service and Average Speed\textsuperscript{a}

<table>
<thead>
<tr>
<th>Average Speed</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miles Per Hour\textsuperscript{b}</td>
<td>Cents Per Vehicle Mile\textsuperscript{c}</td>
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</tr>
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</table>

\textsuperscript{a}Update of costs reported by Buffington and McFarland in Texas Transportation Institute Research Report 202-2.

\textsuperscript{b}To convert from miles per hour to kilometers per hour, multiply by 1.609344.

\textsuperscript{c}To convert from costs per mile to cents per kilometer, multiply by 0.6214.
Table 5. Running Costs for Vehicle Type 3 on Freeways, by Level of Service and Running Speed\(^a\)

<table>
<thead>
<tr>
<th>Average Speed</th>
<th>Level of Service</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miles Per Hour(^b)</td>
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<td>306.167</td>
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<td>49.283</td>
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</tbody>
</table>

\(^a\)Update of costs reported by Buffington and McFarland in Texas Transportation Institute Research Report 202-2.

\(^b\)To convert from miles per hour to kilometers per hour, multiply by 1.609344.

\(^c\)To convert from cents per mile to cents per kilometer, multiply by 0.6214.
Table 6. Freeway Volume to Capacity Ratios, by Number of Lanes and Level of Service

<table>
<thead>
<tr>
<th>Number Of Lanes</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>0.00-0.35</td>
<td>0.36-0.50</td>
<td>0.51-0.75</td>
<td>0.75-0.90</td>
<td>0.91-1.00</td>
<td>1.00-0.00</td>
</tr>
<tr>
<td>6</td>
<td>0.00-0.40</td>
<td>0.41-0.58</td>
<td>0.59-0.80</td>
<td>0.81-0.90</td>
<td>0.91-1.00</td>
<td>1.00-0.00</td>
</tr>
<tr>
<td>8</td>
<td>0.00-0.42</td>
<td>0.43-0.63</td>
<td>0.64-0.83</td>
<td>0.84-0.90</td>
<td>0.91-1.00</td>
<td>1.00-0.00</td>
</tr>
</tbody>
</table>

\(^a\)Volume to capacity ratios based on 70 miles per hour design speeds, ignoring the peak-hour factor. These \(v/c\) limits are assumed to be acceptable for other design speeds.

\(^b\)The Level of Service \(F\) is considered independent of \(v/c\) values.

The calculations required to arrive at the total vehicle operating costs for each subsection per time slice are as follows:

1. Multiply the total vehicle-miles of travel in the subsection by the vehicle type percentage distribution (Table 1) to arrive at the total vehicle-miles by vehicle type.

2. Select the appropriate unit cost for each vehicle type by taking the following steps:
   a. Determine the level of service corresponding to the v/c ratio and number of lanes by referring to Table 6. Note: Level of Service F designations are considered independent of the v/c ratios.
   b. Look up the unit cost (cents per mile) for each vehicle type corresponding to the designated level of service and average speed of the subsection by referring to the appropriate unit cost table (Table 3, 4, or 5). Note: Since unit costs are given only in five-miles-hour increments for each level of service, the unit cost representing a speed in between these incremental speeds must be computed by: (1) subtracting the lower unit cost from the higher unit cost bracketing the subsection speed; (2) dividing that difference by five to determine the additional cost for each additional mile per hour; (3) subtracting the subsection speed from the lower of the bracketed incremental speeds to determine the additional miles per hour; (4) multiplying the additional miles per hour by the additional cost per mile per hour, and (5) adding the extra unit cost to the lower of the two bracketed unit cost.
3. Multiply the selected unit cost of each vehicle type found in Tables 3, 4, and 5 by the corresponding total vehicle-miles of each vehicle type.

4. Sum the vehicle operating costs of each vehicle type.

To calculate the total on freeway vehicle operating cost for all time slices (peak period), sum the total vehicle operating cost for each time slice.

**On Ramp Vehicle Operating Costs**

To calculate on ramp vehicle operating costs resulting from input or on ramp delay, the cumulated total input delay in vehicle-hours for all time slices must be obtained as output from the FREQ3CP program.

The economic data required for calculating vehicle operating cost resulting from on ramp delay are the idling costs by vehicle type obtained from Table 7.

The assumptions and given data required for the on ramp vehicle operating costs are as follows:

- Percentage distribution by vehicle type is given and is the same over all subsections and time slices.
- Vehicle operating costs while the vehicle is moving is not calculated.

The calculations required to arrive at the total on ramp vehicle operating costs are as follows:

1. Multiply the total vehicle-hours by the percentage distribution of vehicles to arrive at the total idling vehicle-hours per vehicle type.

2. Multiply the appropriate idling cost (cents per hour) of each vehicle type by the corresponding total idling vehicle-hours of each vehicle-type.
Table 7. Idling Costs, by Type of Vehicle\textsuperscript{a}

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Idling Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cents per Hour</td>
</tr>
<tr>
<td>1</td>
<td>37.540</td>
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<tr>
<td>2 &amp; 4</td>
<td>78.214</td>
</tr>
<tr>
<td>3</td>
<td>80.218</td>
</tr>
</tbody>
</table>

\textsuperscript{a}Update of Costs reported by Buffington and McFarland in Texas Transportation Institute Research Report 202-2.
3. Sum the idling vehicle operating costs of each vehicle type to arrive at the total on ramp idling vehicle operating cost for the peak period.

**Diversion Route Vehicle Operating Costs**

Vehicle operating costs of vehicles diverted from the freeway on to a service road or another parallel street during the peak period can be calculated from data for all subsections and time slices combined. The following FREQ3CP output or given data are needed to make such calculations:

- Number of vehicle-miles traveled by vehicles diverted from the freeway's main lanes,
- The uniform (approach) speed (mph) between intersections on the diversion route,
- Number of stops per vehicle-mile at intersections,
- Average vehicle-hours per stop,
- Number of speed changes (including stops) per vehicle mile, and
- Average speed (mph) reduction caused by speed change.

The economic data required for calculating diverted vehicle operating costs are as follows:

- Running unit costs on city streets by vehicle type and uniform speed, as shown in Table 8.
- Excess running unit costs of speed cycle changes on city streets by vehicle type and initial speed, as shown in Tables 9, 10, and 11.
- Idling Costs, by vehicle type, as shown in Table 7.
Table 8. Running Costs on City Streets, by Vehicle Type and Uniform Speed

<table>
<thead>
<tr>
<th>Uniform Speed Miles Per Hour</th>
<th>Vehicle Type 1</th>
<th>2 &amp; 4</th>
<th>3</th>
</tr>
</thead>
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<td>66.960</td>
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<td>46.590</td>
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<td>12.866</td>
<td>25.627</td>
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<td>50</td>
<td>11.858</td>
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<td>41.951</td>
</tr>
</tbody>
</table>

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aUpdate of Costs reported by Buffington and McFarland in Texas Transportation Institute Research Report 202-2.

bTo convert from miles per hour to kilometers per hour, multiply by 1.609344.

cTo convert from cents per mile to cents per kilometer, multiply by 0.6214.
Table 9. Excess Running Costs of Speed Cycle Changes on City Streets for Vehicle Type 1, by Initial Speed

<table>
<thead>
<tr>
<th>Initial Speed</th>
<th>Speed Reduced to and Returned From (MPH)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stop</td>
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<tr>
<td>Miles Per Hour</td>
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<td>5</td>
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<tr>
<td>20</td>
<td>1.457</td>
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<tr>
<td>25</td>
<td>2.031</td>
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</table>

\(^{a}\)Update of Costs reported by Buffington and McFarland in Texas Transportation Institute Research Report 202-2.

\(^{b}\)To convert from miles per hour to kilometers per hour, multiply by 1.609344.
Table 10. Excess Running Costs of Speed Cycle Changes on City Streets for Vehicle Type 2 & 4, by Initial Speed\(^a\)

<table>
<thead>
<tr>
<th>Initial Speed</th>
<th>Speed Reduced to and Returned from (MPH)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stop</td>
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<tr>
<td>Miles Per Hour(^b)</td>
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<td></td>
<td>10</td>
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<tr>
<td></td>
<td>15</td>
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</table>

\(^a\) Update of Costs reported by Buffington and McFarland in Texas Transportation Institute Research Report 202-2.

\(^b\) To convert from miles per hour to kilometers per hour, multiply by 1.609344.
Table 11. Excess Running Costs of Speed Cycle Changes on City Streets for Vehicle Type 3, by Initial Speed

<table>
<thead>
<tr>
<th>Initial Speed</th>
<th>Speed Reduced to and Returned from (MPH)</th>
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</thead>
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<td>Miles Per Hour</td>
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<td>95.601</td>
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</tbody>
</table>

aUpdate of Costs reported by Buffington and McFarland in Texas Transportation Institute Research Report 202-2.

bTo convert from miles per hour to kilometers per hour, multiply by 1.609344.
The assumptions required for calculating diverted vehicle operating costs are as follows:

- The uniform or initial speed, average vehicle-hours per stop, and the average speed reduction due to speed changes are the same for all subsections and time slices, and
- The percentage distribution by vehicle type is given by the user, and is the same over all subsections and time slices.

The following calculations are required to arrive at the diverted vehicle operating costs resulting from the uniform speed:

1. Multiply the total diverted vehicle-miles of travel by the vehicle type percentage distribution (Table 1) to arrive at the total vehicle-miles per vehicle type.
2. Multiply the appropriate unit cost of each vehicle type found in Table 8 by the corresponding total vehicle-miles of each vehicle type.
3. Sum the uniform vehicle operating costs per vehicle type to obtain the total uniform vehicle operating costs.

The following calculations are required to arrive at the speed change costs for diverted vehicles:

1. Multiply the number of speed changes by the vehicle type percentage distribution (Table 1) to arrive at the total number of speed changes by vehicle type.
2. Multiply the number of speed changes for each vehicle type by the appropriate excess running cost (cents per cycle change) for the given average initial speed and average speed reduction.
3. Sum the excess running costs per vehicle type to obtain the total running costs due to speed changes.
The following calculations are required to arrive at the total idling vehicle operating costs of diverted vehicles:

1. Multiply the total vehicle hours of idling time at intersections by the vehicle type percentage distribution (Table 1) to obtain the total idling hours by vehicle type.

2. Multiply the total idling hours per vehicle type by the appropriate idling unit costs found in Table 7.

3. Sum the idling costs per vehicle type to obtain the total idling cost of diverted vehicles.

The total peak hour operating cost for diverted vehicles is the sum of the uniform, speed change, and idling costs.
Fuel Consumption Costs

Vehicle fuel consumption during peak periods can be estimated for simulated freeway travel on the freeway's main lanes, the on ramps, and the diversion route using the FREQ3CP outputs, economic data, assumptions, and calculations indicated below. For the vehicle fuel consumption calculations, Vehicle Types 2 and 4 are combined.

On Freeway Fuel Consumption

The FREQ3CP output required to calculate the on freeway vehicle fuel consumption consist of the following individual subsection data per time slice:

- Average speed (mph)
- Volume-to-capacity ratio (v/c)
- Total vehicle-miles of travel.

The economic or given data required are the vehicle fuel consumption costs by average speed, vehicle type, and level of service, as shown in Table 12, 13, and 14. Also, the v/c ratios (range) applicable for each level of service must be given, as shown in Table 6. The v/c ratio ranges vary somewhat depending upon the number of lanes of capacity.

The following assumptions apply to the fuel consumption calculations:

- The unit consumption in the above account for speed changes and stops that are normally experienced by vehicles on freeways, and
- The percentage of vehicles by type must be assumed by the user.

The calculations required to arrive at the total fuel consumption for each subsection per time slice are as follows:
1. Multiply the total vehicle-miles of travel in each subsection by the vehicle type percentage distribution (Table 1) to arrive at the total vehicle-miles by vehicle type.

2. Select the appropriate unit rates for each vehicle type by taking the following steps:
   a. Determine the level of service corresponding to the v/c ratio and number of lanes of subsection by referring to Table 6.
   b. Look up the unit rate (gallons per vehicle mile) for each vehicle type corresponding to the designated level of service and average speed of the subsection by referring to the appropriate unit rate table (Table 12, 13, or 14). Note: Since unit rates are given only in five-miles-hour increments for each level of service, the rate representing a speed in between these incremental speeds can be computed in a similar fashion to that method described in the earlier operating cost methodology.

3. Multiply the selected unit rate of each vehicle type found in Tables 12, 13 and 14 by the corresponding total vehicle-miles of each vehicle type.

4. Sum the vehicle fuel consumption of each vehicle type.

To calculate the total on freeway vehicle fuel consumption for all time slices (peak period), sum the total vehicle fuel consumption for each time slice.
Table 12. Fuel Consumption Rates for Vehicle Type 1 on Freeways, by Level of Service and Average Speeda

<table>
<thead>
<tr>
<th>Average Speed Miles Per Hourb</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
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<td>60</td>
<td>.0494</td>
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<td>65</td>
<td>.0567</td>
<td></td>
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</tr>
</tbody>
</table>

aBased on proportion of fuel cost to total cost at various speeds as reported in the 1977 AASHTO Redbook and applied to total costs as reported in the Texas Transportation Research Institute Report 202-2 for vehicle types 1 and 2 in .97 and .03 proportions, and then converted to fuel consumption rates by using the appropriate cost per gallon. The fuel costs of the latter report were originally based on the fuel consumption rates reported in NCHRP Report 111, Highway Research Board, 1971 by Paul Claffey and associates and in "Economics Analysis for Highways," International Textbook Company, Scranton, Pennsylvania, 1969 by Robley Winfrey.

bTo convert from miles per hour to kilometers per hour, multiply by 1.609344.
Table 13. Fuel Consumption Rates for Vehicle Types 2 & 4 on Freeways, by Level of Service and Average Speed\textsuperscript{a}

<table>
<thead>
<tr>
<th>Average Speed</th>
<th>Level of Service</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miles Per Hour\textsuperscript{b}</td>
<td>A</td>
</tr>
<tr>
<td>5</td>
<td>-</td>
</tr>
<tr>
<td>10</td>
<td>-</td>
</tr>
<tr>
<td>15</td>
<td>-</td>
</tr>
<tr>
<td>20</td>
<td>-</td>
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<tr>
<td>25</td>
<td>-</td>
</tr>
<tr>
<td>30</td>
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<td>.1486</td>
</tr>
<tr>
<td>55</td>
<td>.1613</td>
</tr>
<tr>
<td>60</td>
<td>.1782</td>
</tr>
<tr>
<td>65</td>
<td>.1981</td>
</tr>
</tbody>
</table>

\textsuperscript{a}Based on Fuel Consumption rates and fuel costs as a proportion of total costs as reported in the 1977 ASSHTO Redbook and on total costs reported by Buffington and McFarland in Texas Transportation Research Report 202-2 for Vehicle Types 3 and 6.

\textsuperscript{b}To convert from miles per hour to kilometers per hour, multiply by 1.609344.
Table 14. Fuel Consumption Rates for Vehicle Type 3 on Freeways, by Level of Service and Average Speeda

<table>
<thead>
<tr>
<th>Average Speed (Miles Per Hour)</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
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<tbody>
<tr>
<td>5</td>
<td></td>
<td></td>
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<td>3.1346</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>1.055</td>
</tr>
<tr>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.5660</td>
</tr>
<tr>
<td>20</td>
<td></td>
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<td>.3784</td>
</tr>
<tr>
<td>25</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>.2963</td>
</tr>
<tr>
<td>30</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.1567</td>
<td>.2445</td>
</tr>
<tr>
<td>35</td>
<td></td>
<td></td>
<td>.1503</td>
<td>.1552</td>
<td>.1613</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td></td>
<td>.1529</td>
<td>.1566</td>
<td>.1646</td>
<td></td>
<td></td>
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<td>45</td>
<td>.1613</td>
<td>.1676</td>
<td>.1722</td>
<td>.1745</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>.1778</td>
<td>.1860</td>
<td>.1951</td>
<td>.2026</td>
<td></td>
<td></td>
</tr>
<tr>
<td>55</td>
<td>.1928</td>
<td>.2041</td>
<td>.2167</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>.2017</td>
<td>.2128</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>65</td>
<td>.2208</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

aBased on Fuel Consumption rates and fuel costs as a proportion of total costs as reported in the 1977 ASSHTO Redbook and on total costs reported by Buffington and McFarland in Texas Transportation Research Report 202-2 after combining vehicle types 4 and 5 in .26 and .74 proportions, respectively.

bTo convert from miles per hour to kilometers per hour, multiply by 1.609344.
On Ramp Fuel Consumption

To calculate on ramp vehicle fuel consumption resulting from input or on ramp delay, the cumulated total input delay in vehicle-hours for all time slices must be obtained as output from the FREQ3CP program.

The economic data required for calculating vehicle fuel consumption resulting from on ramp delay are the idling fuel consumption by vehicle type obtained from Table 15.

The assumptions and given data required for the on ramp vehicle fuel consumption are as follows:

- Percentage distribution by vehicle type is given and is the same over all subsections and time slices.
- Vehicle fuel consumption while the vehicle is moving is not calculated.

The calculations required to arrive at the total on ramp vehicle fuel consumption are as follows:

1. Multiply the total vehicle-hours by the percentage distribution of vehicles (Table 1) to arrive at the total idling vehicle-hours per vehicle type.

2. Multiply the appropriate idling fuel rate (gallons per hour) of each vehicle type by the corresponding total idling vehicle-hours of each vehicle-type.

3. Sum the idling vehicle fuel consumption of each vehicle type to arrive at the total on ramp idling vehicle fuel consumption for the peak period.
Table 15. Idling Fuel Consumption, by Vehicle Type

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Idling Fuel Consumption Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gallons Per Hour&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>1</td>
<td>.370</td>
</tr>
<tr>
<td>2 &amp; 4</td>
<td>.650</td>
</tr>
<tr>
<td>3</td>
<td>.400</td>
</tr>
</tbody>
</table>

<sup>a</sup>To convert gallons per hour to liters per hour, multiply by 3.7854.

Diversion Route Vehicle Fuel Consumption

Fuel consumption of vehicles diverted from the freeway on to a service road on another parallel street during the peak period can be calculated from data for all subsections and time slices combined. The following FREQ3CP output or given data are needed to make such calculations:

- Number of vehicle-miles traveled by vehicles diverted from the freeway's main lanes,
- The uniform (approach) speed (mph) between intersections on the diversion route,
- Number of stops per vehicle-mile at intersections,
- Average vehicle-hours per stop,
- Number of speed changes (including stops) per vehicle mile, and
- Average speed (mph) reduction caused by speed change.

The economic data required for calculating diverted vehicle fuel consumption are as follows:

- Fuel consumption rate on city streets by vehicle type and uniform speed, as shown in Table 16.
- Excess fuel consumption rates of speed cycle changes on city streets by vehicle type and initial speed, as shown in Tables 17, 18, and 19.
- Idling fuel rates, by vehicle type, as shown in Table 15.

The assumptions required for calculating diverted vehicle fuel consumption are as follows:

- The uniform or initial speed, average vehicle-hours per stops, and the average speed reduction due to speed changes are the same for all subsection and time slices, and
- The percentage distribution by vehicle type is given by the user, and is the same over all subsections and time slices.
The following calculations are required to arrive at the diverted vehicle fuel consumption resulting from the uniform speed:

1. Multiply the total diverted vehicle-miles of travel by the vehicle type percentage distribution (Table 1) to arrive at the total vehicle-miles per vehicle type.

2. Multiply the appropriate fuel usage of each vehicle type found in Table 16 by the corresponding total vehicle-miles of each vehicle type.

3. Sum the uniform vehicle fuel consumption per vehicle type to obtain the total uniform vehicle fuel consumption.

The following calculations are required to arrive at the speed change usage for diverted vehicles:

1. Multiply the number of speed changes per vehicle-mile by the vehicle type percentage distribution (Table 1) to arrive at the total number of speed changes by vehicle type.

2. Multiply the number of speed changes for each vehicle type by the appropriate excess fuel usage (gallons per cycle change) for the given average initial speed and average speed reduction.

3. Sum the excess fuel use per vehicle type to obtain the total fuel use due to speed changes.

The following calculations are required to arrive at the total idling vehicle fuel used of diverted vehicles:

1. Multiply the total vehicle hours of idling time at intersections by the vehicle type percentage distribution to obtain the total idling hours by vehicle type.

2. Multiply the total idling hours per vehicle type by the appropriate idling unit costs found in Table 15.
3. Sum the idling fuel per vehicle type to obtain the total idling fuel used of diverted vehicles.

The total peak hour fuel consumption for diverted vehicles is the sum of the uniform, speed change, and idling fuel use. Also, the fuel consumption tables that correspond to vehicle operating cost tables are shown in Table 20.
Table 16. Fuel Consumption Rates on City Streets, by Vehicle Type and Uniform Speed

<table>
<thead>
<tr>
<th>Uniform Speed</th>
<th>Vehicle Type</th>
<th>Miles Per Hour</th>
<th>Type 1</th>
<th>Types 2&amp;4</th>
<th>Type 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miles Per Hour</td>
<td>---</td>
<td>Gallons Per Mile</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>.1025</td>
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</tr>
<tr>
<td>10</td>
<td>.0634</td>
<td>.1273</td>
<td>.2648</td>
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</tr>
<tr>
<td>15</td>
<td>.0511</td>
<td>.1075</td>
<td>.1861</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>.0460</td>
<td>.0988</td>
<td>.1558</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
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<td>.0434</td>
<td>.0936</td>
<td>.1125</td>
<td></td>
<td></td>
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<tr>
<td>40</td>
<td>.0449</td>
<td>.0954</td>
<td>.1195</td>
<td></td>
<td></td>
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<tr>
<td>45</td>
<td>.0460</td>
<td>.0988</td>
<td>.1271</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>.0499</td>
<td>.1040</td>
<td>.1452</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

aTo convert miles per hour to kilometers per hour, multiply by 1.609344.

bTo convert gallons per mile to liters per kilometer, multiply by 2.351.

cFuel consumption rates are based on those reported in Winfrey, Robley, Economic Analysis for Highways, Internation Textbook Co., Scranton, Pennsylvania, 1969. Passenger cars and commercial vehicles, in proportions of .97 and .03 respectively, make up Type 1 vehicles. The 2-S2 gasoline trucks and 3-S2 diesel trucks, in proportions of .26 and .74 respectively, make up Type 3 vehicles.
Table 17. Excess Fuel Consumption Rates for Speed Cycle Changes of Vehicle Type 1 on City Streets, by Initial Speed

<table>
<thead>
<tr>
<th>Initial Speed Miles Per Hour&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Speed Reduced to and Returned from (MPH)</th>
<th>Stop</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>.00025</td>
<td>------</td>
<td>------</td>
<td>------</td>
<td>------</td>
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</tr>
<tr>
<td>10</td>
<td>.00101</td>
<td>------</td>
<td>------</td>
<td>------</td>
<td>------</td>
<td>------</td>
</tr>
<tr>
<td>15</td>
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<td>------</td>
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<tr>
<td>25</td>
<td>.00613 .00378 .00135</td>
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<td>------</td>
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<tr>
<td>30</td>
<td>.00792 .00565 .00311</td>
<td>------</td>
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<td>35</td>
<td>.00980 .00766 .00524 .00198</td>
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<tr>
<td>40</td>
<td>.01180 .00986 .00753 .00474</td>
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<td>------</td>
<td>------</td>
<td>------</td>
<td>------</td>
</tr>
<tr>
<td>45</td>
<td>.01399 .01228 .01005 .00750 .00277</td>
<td>------</td>
<td>------</td>
<td>------</td>
<td>------</td>
<td>------</td>
</tr>
<tr>
<td>50</td>
<td>.01647 .01511 .01287 .01046 .00601</td>
<td>------</td>
<td>------</td>
<td>------</td>
<td>------</td>
<td>------</td>
</tr>
</tbody>
</table>

<sup>a</sup>To convert from miles per hour to kilometers per hour, multiply by 1.609344.

<sup>b</sup>To convert from gallons per cycle to liters per cycle, multiply by 3.7854.

<sup>c</sup>Fuel consumption rates are based on those reported in Winfrey, Robley, Economic Analysis for Highways, Internation Textbook Co., Scranton, Pennsylvania, 1969. Passenger cars and commercial vehicles, in proportions of .97 and .03 respectively make up Type 1 vehicles.
Table 18. Excess Fuel Consumption Rates for Speed Cycle Changes of Vehicle Types 2 and 4 on City Streets, by Initial Speed

<table>
<thead>
<tr>
<th>Initial Speed Miles Per Hour&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Speed Reduced to and Returned from Stop (MPH)</th>
<th>Gallons Per Cycle Change&lt;sup&gt;bc&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>5</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>10</td>
<td>.00333</td>
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<td>15</td>
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<td>.01179</td>
<td>.00554</td>
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<td>.02220</td>
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<td>.03294</td>
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<tr>
<td>50</td>
<td>.03717</td>
<td>.03050</td>
</tr>
</tbody>
</table>

<sup>a</sup>To convert from miles per hour to kilometers per hour, multiply by 1.609344.

<sup>b</sup>To convert from gallons per cycle to liters per cycle, multiply by 3.7854.

Table 19. Excess Fuel Consumption Rates for Speed Cycle Changes of Vehicle Type 3 on City Streets, by Initial Speed

<table>
<thead>
<tr>
<th>Initial Speed (Miles Per Hour)</th>
<th>Speed Reduced to and Returned from (MPH)</th>
<th>Gallons Per Cycle Change&lt;sup&gt;bc&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stop</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>5</td>
<td>.00112</td>
<td></td>
</tr>
<tr>
<td>10</td>
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</tr>
<tr>
<td>15</td>
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<td>.00722</td>
</tr>
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<td>.02866</td>
<td>.01820</td>
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<tr>
<td>25</td>
<td>.04097</td>
<td>.03094</td>
</tr>
<tr>
<td>30</td>
<td>.05430</td>
<td>.04440</td>
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<tr>
<td>35</td>
<td>.06860</td>
<td>.05865</td>
</tr>
<tr>
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<td>45</td>
<td>.09990</td>
<td>.08821</td>
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<td>50</td>
<td>.11682</td>
<td>.10429</td>
</tr>
</tbody>
</table>

<sup>a</sup>To convert from miles per hour to kilometers per hour, multiply by 1.609344.

<sup>b</sup>To convert from gallons per cycle to liters per cycle, multiply by 3.7854.

<sup>c</sup>Fuel consumption rates are based on those reported in Winfrey, Robley, Economic Analysis of Highways, International Textbook Co., Scranton, Pennsylvania, 1969. Vehicle Type 3 rates represent 2-S2 gasoline trucks and 3-S2 diesel trucks combined in .26 and .74 proportions, respectively.
Table 20. Fuel Consumption Tables Which Correspond to the Operating Cost Tables, by Location of Vehicle Travel

<table>
<thead>
<tr>
<th>Location of Vehicle Travel</th>
<th>Corresponding Tables</th>
<th>Operating Costs</th>
<th>Fuel Consumption Rates</th>
</tr>
</thead>
<tbody>
<tr>
<td>On Freeway Travel</td>
<td>3, 4, and 5</td>
<td>12, 13, and 14</td>
<td></td>
</tr>
<tr>
<td>&quot;On&quot; Ramp Travel</td>
<td>7</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Diversion Route Travel</td>
<td>8, 9, 10, and 11</td>
<td>16, 17, 18, and 19</td>
<td></td>
</tr>
</tbody>
</table>
Vehicle Pollution Emissions

Vehicle pollution emissions can be calculated for simulated travel on the freeway's main lanes, on ramps, and diversion routes by using the appropriate FREQ3CP output data, pollution emission rates, and calculations detailed in this section.

The three principal pollutants emitted by motor vehicles are: (1) carbon monoxide, (2) hydrocarbons, and (3) nitrogen oxides. Table 21 shows the Federal pollution rate standards, as of March 1978, for the above pollutants. Particulates and sulfur oxides are pollutants of lesser importance but are also emitted by motor vehicles. Pollution rates are available for all five of these pollutants from an Environmental Protection Agency (EPA) study (5).

The pollution rates presented here are the projected 1977 rates based on the above EPA study and were adjusted to represent the temperature and altitude conditions in Texas. The fraction of in-user vehicles by model year (vehicle age) weighted on the basis of annual miles driven was developed from nationwide statistics and was used to adjust the pollution rates. Speed correction factors were used to generate the pollution rates for average speeds of 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, and 55 miles per hour. Actually, the pollution rates for speeds above 45 miles per hour are out of the range of the supporting data and should be used with caution. The speed correction factors are based on a composite of driving modes (idle, cruise, acceleration, deceleration) encountered at lower speeds in urban areas as well as at higher speeds in rural areas. The hot and cold correction factor varies according to vehicle type. For light-duty vehicles (automobiles, pick-ups and panel trucks), the pollution rates represent a 20 percent cold and 80 percent hot operation. For heavy-duty gasoline and diesel powered trucks, the pollution rates represent a 100 percent warmed-up operation.
Type 1 vehicles are represented by the EPA's light-duty vehicles (including pickups and panel trucks). Types 2 and 4 vehicles are represented by the EPA's heavy duty gasoline trucks and buses. Type 3 vehicles are represented by the EPA's heavy duty diesel trucks.

On Freeway Pollution Emissions

The FREQ3CP output data required to calculate on freeway pollution emissions per subsection and time slice are as follows:

- Total vehicle miles of travel, and
- Average speed.

Pollution rates have not been related to level of service or the v/c ratio. However, the pollution emissions for a particular level of service could be determined by identifying the v/c ratio which corresponds to the average speed and then referring to level of service Table 6.

The economic or given data required to calculate the emissions of the three primary pollutants are the pollution emission rates by vehicle type and average speed, as shown in Tables 22, 23 and 24. To calculate the particulate and sulfur oxide emissions, based only on total vehicle-miles, use the pollution rates given in Table 25.

The following assumptions apply to the vehicle emission calculations:

- The vehicle emission rates in Tables 22, 23 and 24 account for speed changes and stops normally experienced by vehicles on freeways in Texas, and
- The percentage of vehicles by type must be assumed by the user.

The calculations required to arrive at the total vehicle emissions for each subsection per time slice are as follows:

1. Multiply the total vehicle-miles of travel in each subsection by the vehicle type percentage distribution to arrive at the total vehicle-miles by vehicle type.
Table 21. Pollution Rate Standards by Vehicle Type, Model Year, and Type of Pollutanta

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Light Duty Gasoline Vehicles</td>
<td>Carbon Monoxide</td>
<td>23.0</td>
<td>39.0</td>
<td>39.0</td>
<td>15.0</td>
<td>15.0</td>
<td>7.0</td>
<td>3.4</td>
</tr>
<tr>
<td></td>
<td>Hydrocarbons</td>
<td>2.20</td>
<td>3.40</td>
<td>3.40</td>
<td>1.50</td>
<td>1.50</td>
<td>0.41</td>
<td>0.41</td>
</tr>
<tr>
<td></td>
<td>Nitrogen Oxide</td>
<td>none</td>
<td>none</td>
<td>3.00</td>
<td>3.00</td>
<td>2.00</td>
<td>2.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Heavy Duty Gasoline Vehicles</td>
<td>Carbon Monoxide</td>
<td>1.5%c</td>
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<tr>
<td></td>
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<td>140.0</td>
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</tr>
<tr>
<td></td>
<td>Nitrogen Oxide</td>
<td>none</td>
<td>12.40</td>
<td>3.20</td>
<td>2.85</td>
<td>2.85</td>
<td>5.35</td>
<td></td>
</tr>
<tr>
<td>Heavy Duty Diesel</td>
<td>Carbon Monoxide</td>
<td>1.5%c</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hydrocarbons</td>
<td>none</td>
<td>159.0</td>
<td>140.0</td>
<td>29.7</td>
<td>29.7</td>
<td>15.30</td>
<td>10.00</td>
</tr>
<tr>
<td></td>
<td>Nitrogen Oxide</td>
<td>none</td>
<td>12.40</td>
<td>5.00</td>
<td>2.85</td>
<td>2.85</td>
<td>5.35</td>
<td></td>
</tr>
</tbody>
</table>

aAs of March 1978.

bTo convert from grams per mile to grams per kilometer, multiply by 0.6214.

cPercent of molecular volume.

dParts per million.

Table 22. Pollution Emission Rates of Vehicle Type 1, by Type of Pollutant and Average Speed\(^a\)

<table>
<thead>
<tr>
<th>Average Speed</th>
<th>Type of Pollutant</th>
<th>Carbon Monoxide</th>
<th>Hydrocarbons</th>
<th>Nitrogen Oxides</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miles Per Hour(^b)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>176.37</td>
<td>12.07</td>
<td>4.46</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>95.29</td>
<td>7.07</td>
<td>4.06</td>
</tr>
<tr>
<td>15</td>
<td></td>
<td>59.96</td>
<td>5.35</td>
<td>3.80</td>
</tr>
<tr>
<td>20</td>
<td></td>
<td>46.40</td>
<td>4.38</td>
<td>3.95</td>
</tr>
<tr>
<td>25</td>
<td></td>
<td>36.84</td>
<td>3.69</td>
<td>4.10</td>
</tr>
<tr>
<td>30</td>
<td></td>
<td>30.35</td>
<td>3.21</td>
<td>4.25</td>
</tr>
<tr>
<td>35</td>
<td></td>
<td>25.80</td>
<td>2.86</td>
<td>4.41</td>
</tr>
<tr>
<td>40</td>
<td></td>
<td>22.62</td>
<td>2.63</td>
<td>4.57</td>
</tr>
<tr>
<td>45</td>
<td></td>
<td>20.46</td>
<td>2.48</td>
<td>4.72</td>
</tr>
<tr>
<td>50</td>
<td></td>
<td>19.10</td>
<td>2.42</td>
<td>4.77</td>
</tr>
<tr>
<td>55</td>
<td></td>
<td>18.40</td>
<td>2.42</td>
<td>5.02</td>
</tr>
<tr>
<td>60</td>
<td></td>
<td>18.23</td>
<td>2.49</td>
<td>5.18</td>
</tr>
</tbody>
</table>

\(^a\)Derived from pollution emission and speed correction factors published in U.S. Environmental Protection Agency, Supplement No. 5 for Compilation of Air Pollutant Emission Factors, Second Edition, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina, December 1975. Light duty gasoline automobiles and trucks are combined in .97 and .03 proportions, respectively.

\(^b\)To convert from miles per hour to kilometers per hour, multiply by 1.609344.

\(^c\)To convert from grams per mile to grams per kilometer, multiply by 0.6214.
Table 23. Pollution Emission Rates of Vehicle Types 2 and 4, by Type of Pollutant and Average Speed\(^a\)

<table>
<thead>
<tr>
<th>Average Speed</th>
<th>Type of Pollutant</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Carbon Monoxide</td>
</tr>
<tr>
<td>Miles Per Hour(^b)</td>
<td>--------</td>
</tr>
<tr>
<td>5</td>
<td>571.82</td>
</tr>
<tr>
<td>10</td>
<td>328.02</td>
</tr>
<tr>
<td>15</td>
<td>237.16</td>
</tr>
<tr>
<td>20</td>
<td>191.42</td>
</tr>
<tr>
<td>25</td>
<td>159.16</td>
</tr>
<tr>
<td>30</td>
<td>136.32</td>
</tr>
<tr>
<td>35</td>
<td>120.28</td>
</tr>
<tr>
<td>40</td>
<td>109.32</td>
</tr>
<tr>
<td>45</td>
<td>102.36</td>
</tr>
<tr>
<td>50</td>
<td>98.72</td>
</tr>
<tr>
<td>55</td>
<td>98.07</td>
</tr>
<tr>
<td>60</td>
<td>100.37</td>
</tr>
</tbody>
</table>


\(^b\)To convert from miles per hour to kilometers per hour, multiply by 1.609344.

\(^c\)To convert from grams per mile to grams per kilometer, multiply by 0.6214.
Table 24. Pollution Emission Rates of Vehicle Type 3, by Type of Pollutant and Average Speeda

<table>
<thead>
<tr>
<th>Average Speed</th>
<th>Type of Pollutant</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Carbon Monoxide</td>
<td>Hydro-Carbons</td>
<td>Nitrogen Oxides</td>
</tr>
<tr>
<td>Miles Per Hourb</td>
<td>----------</td>
<td>----------</td>
<td>----------</td>
</tr>
<tr>
<td>5</td>
<td>34.25</td>
<td>7.37</td>
<td>29.83</td>
</tr>
<tr>
<td>10</td>
<td>30.41</td>
<td>5.45</td>
<td>23.65</td>
</tr>
<tr>
<td>15</td>
<td>29.13</td>
<td>4.81</td>
<td>21.59</td>
</tr>
<tr>
<td>20</td>
<td>25.37</td>
<td>4.26</td>
<td>21.92</td>
</tr>
<tr>
<td>25</td>
<td>19.38</td>
<td>3.66</td>
<td>23.85</td>
</tr>
<tr>
<td>30</td>
<td>15.39</td>
<td>3.26</td>
<td>25.14</td>
</tr>
<tr>
<td>35</td>
<td>12.53</td>
<td>2.97</td>
<td>26.03</td>
</tr>
<tr>
<td>40</td>
<td>10.40</td>
<td>2.76</td>
<td>26.70</td>
</tr>
<tr>
<td>45</td>
<td>8.73</td>
<td>2.59</td>
<td>27.23</td>
</tr>
<tr>
<td>50</td>
<td>7.40</td>
<td>2.45</td>
<td>27.66</td>
</tr>
<tr>
<td>55</td>
<td>6.31</td>
<td>2.34</td>
<td>28.00</td>
</tr>
<tr>
<td>60</td>
<td>5.40</td>
<td>2.25</td>
<td>28.30</td>
</tr>
</tbody>
</table>


bTo convert from miles per hour to kilometers per hour, multiply by 1.609344.

cTo convert from grams per mile to grams per kilometer, multiply by 0.6214.
Table 25. Particulate and Sulfur Oxide Pollution Rates, by Vehicle Type\textsuperscript{a}

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Particulates</th>
<th>Sulfur Oxides</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>_________</td>
<td>_________</td>
</tr>
<tr>
<td>1\textsuperscript{c}</td>
<td>0.36</td>
<td>0.13</td>
</tr>
<tr>
<td>2 &amp; 4\textsuperscript{d}</td>
<td>1.31</td>
<td>0.36</td>
</tr>
<tr>
<td>3\textsuperscript{e}</td>
<td>2.20</td>
<td>2.80</td>
</tr>
</tbody>
</table>


\textsuperscript{b}To convert from grams per mile to grams per kilometer, multiply by 0.6214.

\textsuperscript{c}Based on light duty vehicle and light duty gasoline vehicle rates combined in proportions of .97 and .03, respectively.

\textsuperscript{d}Represents heavy duty gasoline trucks and buses.

\textsuperscript{e}Represents heavy duty diesel trucks and buses.
2. Look up or calculate the pollution rate for each vehicle type corresponding to the average speed of the subsection by referring to the appropriate pollution rate table. Note: For the three primary pollutants, use the same procedure as described in the vehicle operating cost calculations to compute the pollution rate for a speed between the incremental speeds listing in the tables.

3. Multiply the selected or calculated pollution rate of each vehicle type by the corresponding total vehicle-miles of each vehicle type.

4. Sum the vehicle pollution emissions (grams) of each vehicle type per time slice.

To calculate the total on freeway vehicle pollution emissions for a peak period, sum the emissions for all time slices.

**On Ramp Vehicle Pollution Emissions**

To calculate on ramp vehicle pollution emissions resulting from input or ramp delay, the same FREQ3CP output, economic data, assumptions or given data, and calculations as described earlier for estimating on ramp vehicle operating costs are used here. However, substitute the pollution rates in Table 26 for the unit idling costs in Table 7. Note: The idling pollution emissions for particulate and sulfur oxide are not available and, therefore, can not be calculated.

**Diversion Route Vehicle Pollution Emissions**

Pollution emissions resulting from diverting vehicles from the freeway's main lanes onto a service road or on another parallel street during the peak period can be calculated from data for all subsections and time slices combined.

The following FREQ3CP output or given data are needed to calculate total diverted vehicle pollution emissions:
Table 26. Idling Pollution Rates, by Vehicle Type and Type of Pollutant\(^a\)

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Type of Pollutant</th>
<th>Carbon Monoxide</th>
<th>Hydro-Carbons</th>
<th>Nitrogen Oxides</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>grams per</td>
<td></td>
<td>grams per</td>
</tr>
<tr>
<td></td>
<td></td>
<td>minute</td>
<td></td>
<td>minute</td>
</tr>
<tr>
<td>1(^b)</td>
<td></td>
<td>14.74</td>
<td>0.83</td>
<td>0.12</td>
</tr>
<tr>
<td>2(^c)</td>
<td></td>
<td>61.72</td>
<td>3.68</td>
<td>0.33</td>
</tr>
<tr>
<td>3(^d)</td>
<td></td>
<td>0.64</td>
<td>0.32</td>
<td>1.03</td>
</tr>
</tbody>
</table>


\(^b\) Based on light duty vehicles and light duty gasoline trucks combined in proportions of .97 and .03, respectively.

\(^c\) Represents heavy duty gasoline trucks and buses.

\(^d\) Represents heavy duty diesel trucks and buses.
• Number of vehicle-miles traveled by diverted vehicles, and
• Average speed

The economic data necessary to calculate diverted vehicle pollution emissions are the pollution rates found in Tables 22, 23, 24, and 25.

The assumptions applicable for calculating diverted vehicle pollution emissions are the same as those used for calculating on freeway vehicle pollution emissions.

The calculations required to arrive at the total diverted vehicle pollution emissions are the same as those used for calculating diverted vehicle operating costs resulting from a uniform speed, except that average speed is used instead.

**Accident Costs**

This portion of the economic package pertains to motor vehicle accident costs experienced by the persons and vehicles directly involved (in collision) in an accident. These costs include direct out-of-pocket costs as well as certain indirect costs such as the loss of future gross earnings of accident victims killed or permanently disabled and costs for loss of services to home and family, and cost of pain and suffering of victims partially disabled from the accident. Other costs resulting from an accident such as extra time costs, extra vehicle operating costs, additional fuel consumed and air pollution emissions are not covered here. The literature does contain procedures for estimating extra time costs due to accidents or bottlenecks on a freeway (6, 7), but considerable time would be required to implement them here. Also, procedures for estimating extra vehicle operating costs, extra fuel consumption, and air pollution emissions due to accidents have not been fully developed.
If the FREQ3CP Program has the capability of generating the output required to calculate such extra costs due to an accident, then the unit time costs, vehicle operating costs, etc. presented earlier in this package can be used essentially in the same form as previously described to make such estimates.

The FREQ3CP output data, economic data, assumption or given data, and calculations required to determine accident costs for on freeway, on ramp, and diversion route accidents are covered below.

On Freeway and On Ramp Accident Costs

Accident costs experienced by persons and vehicles directly involved in an accident on the freeway's main lanes and on the on ramps require the following FREQ3CP output:

- Number of vehicle-miles by highway type and accident location, i.e., number of lanes and whether rural, urban or metered urban for all subsections and time slices.

The economic data required to determine accident costs due to the accident vehicles and occupants are as follows:

- Motor vehicle accident unit costs by severity and location accident, as given in Table 27, and
- Motor vehicle accident rates by highway type and location of accident, as given in Table 28, if actual accident rate is not known.

The assumptions and given data required to generate such accident costs are as follows:

- Percentage distribution of accidents by severity of accident.

(The percentage distribution used in the Highway Economic Evaluation Model HEEM (6) for Texas urban freeways, particularly in
Table 27. Motor Vehicle Accident Unit Costs per Reported Accident by Severity and Location of Accident

<table>
<thead>
<tr>
<th>Severity of Accident</th>
<th>Location of Accident</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rural</td>
<td>Suburban</td>
<td>Urban</td>
<td>---------</td>
</tr>
<tr>
<td>Fatal</td>
<td>566,103</td>
<td>506,304</td>
<td>446,503</td>
<td>---------</td>
</tr>
<tr>
<td>Injury</td>
<td>27,709</td>
<td>24,630</td>
<td>21,551</td>
<td>---------</td>
</tr>
<tr>
<td>Property Damage Only</td>
<td>1,264</td>
<td>1,084</td>
<td>904</td>
<td>---------</td>
</tr>
</tbody>
</table>

\(^{a}\) Based on NHTSA accident costs adjusted for location using CALTRANS accident cost data and then updated to August 1979 using the automobile insurance component of the U.S. Consumer Price Index.

\(^{b}\) Includes direct accident costs and discounted gross future earnings which includes future maintenance costs of the decedent.

\(^{c}\) Includes direct accident costs as well as costs for pain and suffering, loss of earnings, and loss of services to home and family in partial or total disability accidents.

Table 28. Motor Vehicle Accident Rates, by Highway Type and Location of Accident

<table>
<thead>
<tr>
<th>Highway Type</th>
<th>Location of Accident</th>
<th>Rural</th>
<th>Urban</th>
<th>Urban Metered</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>--Per Million Vehicle Miles--</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Freeways**

<table>
<thead>
<tr>
<th>Highway Type</th>
<th>4-lane</th>
<th>6-lane</th>
<th>8-lane</th>
<th>10-lane</th>
<th>12-lane</th>
<th>14-lane</th>
<th>16-lane</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-lane</td>
<td>1.4</td>
<td>2.8</td>
<td>2.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6-lane</td>
<td>1.3</td>
<td>2.6</td>
<td>2.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8-lane</td>
<td>1.2</td>
<td>2.4</td>
<td>2.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10-lane</td>
<td>1.1</td>
<td>2.2</td>
<td>2.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12-lane</td>
<td>1.0</td>
<td>2.0</td>
<td>1.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14-lane</td>
<td>-</td>
<td>1.8</td>
<td>1.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16-lane</td>
<td>-</td>
<td>1.6</td>
<td>1.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Expressways**

<table>
<thead>
<tr>
<th>Highway Type</th>
<th>2-lane</th>
<th>4-lane</th>
<th>6-lane</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-lane</td>
<td>3.0</td>
<td>6.0</td>
<td>-</td>
</tr>
<tr>
<td>4-lane</td>
<td>2.8</td>
<td>5.6</td>
<td>-</td>
</tr>
<tr>
<td>6-lane</td>
<td>2.6</td>
<td>5.2</td>
<td>-</td>
</tr>
</tbody>
</table>

**Conventional Highways**

**Undivided**

<table>
<thead>
<tr>
<th>Highway Type</th>
<th>2-lane</th>
<th>4-lane</th>
<th>6-lane</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-lane</td>
<td>6.0</td>
<td>12.0</td>
<td>-</td>
</tr>
<tr>
<td>4-lane</td>
<td>5.6</td>
<td>11.2</td>
<td>-</td>
</tr>
<tr>
<td>6-lane</td>
<td>5.2</td>
<td>10.4</td>
<td>-</td>
</tr>
</tbody>
</table>

**Divided**

<table>
<thead>
<tr>
<th>Highway Type</th>
<th>4-lane</th>
<th>6-lane</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-lane</td>
<td>2.8</td>
<td>-</td>
</tr>
<tr>
<td>6-lane</td>
<td>2.6</td>
<td>-</td>
</tr>
</tbody>
</table>

**Source:** Texas Department of Highways and Public Transportation, Guide to the Highway Economic Evaluation Model, Austin, Texas, February 1976.
Houston, is 0.4% fatal accidents, 14.6% injury accidents, and 85.0% property damage only accidents.)

- The accident unit costs are not adjusted for unreported accidents.
- The accident unit costs are the same for wet and dry days.
- The accident unit costs are representative of actual accident costs in Texas.

The calculations required to estimate on freeway accident costs involving only the accident vehicles and occupants are as follows:

1. Multiply the total vehicle-miles (in millions) for each freeway segment (one of more subsections) separated according to number of lanes and location by the actual accident rate of each segment or by the appropriate rate found in Table 28 to arrive at the total number of accidents on each freeway segment for all time slices in peak period.

2. Multiply the total number of accidents on each freeway segment by the percentage distribution of accidents by severity of accident (Table 29) to arrive at the total number of fatal, injury and property damage only accidents for each freeway segment.

3. Sum the number of accidents by freeway segment to arrive at the overall total number of fatal, injury, and property damage accidents for all time slices in peak period.

4. Multiply the total number of accidents of each severity type by the appropriate accident unit cost found in Table 27 to arrive at the total accident cost by severity type.

5. Sum the accident costs by severity type to arrive at the grand total accident cost for all time slices in the peak period. This sum must be generated before and after the freeway improvement to determine the total on freeway accident savings, if any, resulting from such an improvement.
Diversion Route Accident Costs

Accident costs experienced by persons and vehicles directly involved in an accident on a diversion route can be estimated by using essentially the same FREQ3CP output, economic data, assumptions and given data, and calculations as outlined above with the following exceptions:

- The accident rates for a 2-lane undivided conventional highway, as shown in Table 28, would be the most appropriate for a diversion route.

- If the actual percentage distribution of accidents by severity of accident is not known, the urban 2-lane distribution based on California data (9), as presented in Table 29, might be more appropriate than that used in the HEEM Model (6).

The resulting accident cost estimate must be generated before and after the freeway improvement to determine the total diversion route savings (dissavings), if any, resulting from such an improvement. Then, the net savings of the freeway improvement can be generated by adding (subtracting) the diversion route accident savings (dissavings) to the on freeway accident savings.
Table 29. Percentage Distribution by Accident Severity

<table>
<thead>
<tr>
<th>Highway Type</th>
<th>Fatal</th>
<th>Injury</th>
<th>Fatal and Injury</th>
<th>Property Damage Only</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-lane</td>
<td>2.9</td>
<td>43.0</td>
<td>45.9</td>
<td>54.1</td>
<td>100.0</td>
</tr>
<tr>
<td>3-lane</td>
<td>3.4</td>
<td>38.7</td>
<td>42.1</td>
<td>57.9</td>
<td>100.0</td>
</tr>
<tr>
<td>4 or more lane</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>undivided</td>
<td>1.7</td>
<td>39.7</td>
<td>41.4</td>
<td>58.6</td>
<td>100.0</td>
</tr>
<tr>
<td>4 or more lane</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>divided</td>
<td>2.2</td>
<td>39.8</td>
<td>42.0</td>
<td>58.6</td>
<td>100.0</td>
</tr>
<tr>
<td>Divided expressway</td>
<td>3.2</td>
<td>42.0</td>
<td>45.2</td>
<td>54.8</td>
<td>100.0</td>
</tr>
<tr>
<td>Freeway</td>
<td>3.6</td>
<td>43.2</td>
<td>46.8</td>
<td>53.2</td>
<td>100.0</td>
</tr>
<tr>
<td>Urban</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-lane</td>
<td>0.7</td>
<td>31.0</td>
<td>31.7</td>
<td>68.3</td>
<td>100.0</td>
</tr>
<tr>
<td>3-lane</td>
<td>0.9</td>
<td>28.4</td>
<td>29.3</td>
<td>70.7</td>
<td>100.0</td>
</tr>
<tr>
<td>4 or more lane</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>undivided</td>
<td>0.6</td>
<td>33.8</td>
<td>34.4</td>
<td>65.6</td>
<td>100.0</td>
</tr>
<tr>
<td>4 or more lane</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>divided</td>
<td>0.6</td>
<td>31.5</td>
<td>32.1</td>
<td>67.9</td>
<td>100.0</td>
</tr>
<tr>
<td>Divided expressway</td>
<td>1.3</td>
<td>35.6</td>
<td>36.9</td>
<td>63.1</td>
<td>100.0</td>
</tr>
<tr>
<td>Freeway</td>
<td>1.1</td>
<td>40.7</td>
<td>41.8</td>
<td>58.2</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Procedures for Updating the ECOANA Unit Costs

The unit costs used by any benefit-cost procedure, such as ECOANA, should be updated in order to furnish accurate outputs. There are three reasons for updating unit costs:

(1) Correct for changes in the general price level (inflation),

(2) Correct for changes in relative prices of the specific elements determining each unit cost, and

(3) Correct for changes in the unit costs brought about by technological innovations.

Updating for changes in the general price level should be performed on a continuous basis. Updating for relative price changes between cost elements should be performed about every two or three years. Updating for technological changes should be performed about every 10 years. The updating procedures presented here are limited to changes in the general price level. These procedures are based on those presented in TTI Research Report 225-8 [10].

Values of Time

Values of time presented in Table 2 were updated to the January 1980 general price level, as reflected by the composite Consumer Price Index (CPI) and the composite Producer Price Index (PPI) for the United States (U.S.). The assumption is that the values of time will escalate with these indexes.

The CPI and PPI are more appropriate for use in adjusting for inflation or changes in the general price level, especially on a continuous basis, than a per capita or hourly income series. However, the appropriate
income series should be used periodically, every two or three years, to adjust the values of time to more nearly reflected actual income levels.

The use of the U.S. CPI and PPI does offer the advantage of being published (by the U.S. Bureau of Labor Statistics) more frequently than the personal or hourly income data. In fact, CPI and PPI are published monthly, and the unit values of time can be updated continuously, with only a month's lag required. Therefore, it is recommended that such indexes be used to keep all unit costs, including values of time, adjusted for inflation.

The formulas to use in obtaining the updating multipliers for each value of time are as follows:

1. Multiplier of passenger vehicle occupants = \( \frac{\text{CPI for all commodities at latest date reported}}{\text{CPI for January 1980}} \)

2. Multiplier for drivers of commercial vehicles and buses = \( \frac{\text{PPI for industrial commodities at latest date reported}}{\text{PPI for industrial commodities for January 1980}} \)

The CPI and PPI, based on 1967 = 100, for January 1980 were 233.2 and 260.0, respectively.

Updating unit values of time to reflect relative price changes or changes in technology will require new base studies similar to those conducted to derive the presently used values of time. This would be especially true in the case of unit values of time for drivers of commercial vehicles. This type of updating is overdue since over ten years have passed since these base studies were conducted.
Vehicle Operating Costs

To update the ECOANA's 1980 vehicle operating unit costs for changes in the general price level, one component of the national or local CPI and one component of the national or local PPI should be used. For updating operating costs for passenger cars (Vehicle Type 1), the private transportation component of the CPI is the most relevant index to use. For updating operating costs for trucks and large buses (Vehicle Types 2, 3 and 4), the industrial commodities component of the PPI should be used. The formulas to use in obtaining the general price level updating multipliers (factors) for each vehicle type are as follows:

(1) Multipliers for Passenger Cars (Vehicle Type 1) = \frac{\text{CPI for private transportation at latest date reported}}{\text{CPI for private transportation for January 1980}}

(2) Multipliers for Trucks and Buses (Vehicle Types 2, 3, and 4) = \frac{\text{PPI for industrial commodities at latest date reported}}{\text{PPI for industrial commodities for January 1980}}

Using a base of 1967 = 100, the private transportation component of the CPI was 233.5 in January 1980 and the industrial commodities component of the WPI was 260.0.

After two or three years have passed, the vehicle operating unit costs should be adjusted for relative price or nonproportional changes. Since the overall vehicle operating unit costs are made up of several components priced separately in the market place, such an adjustment is necessary. The components of vehicle operating unit costs used by the ECOANA are as follows: (1) fuel costs, (2) maintenance costs, and (3) depreciation. During a two-or three-year period, the cost of fuel components experience a greater percentage increase than the other cost components.
components. If such be the case, then each cost component should be adjusted separately, using the appropriate price index. Also, since each component represents a greater or lesser share of the total vehicle operating unit cost, an adjustment must be made to keep the correct proportions between the components before arriving at an overall updating multiplier for a particular driving condition and vehicle type.

TTI Research Report 225-8 [10] presents appropriate formulas for updating the separate components of unit vehicle operating costs. These formulas were adapted from those appearing in the new AASHTO Redbook [1]. Technological changes could bring about a significant shift in the proportion of vehicle operating costs among the separate component costs to the extent that the coefficients used in the formulas would be invalid. Therefore, new base studies should be conducted about every 10 years to update the assumed costs.

Accident Costs

The overall CPI is recommended for updating the ECOANA's 1980 accident unit costs for the first two to three years, at the most. After three years, they should be updated with relevant component indexes of the CPI. For fatal and injury unit costs, automobile insurance rates components should be used. For property damage unit costs, the automobile repairs and maintenance cost components should be used.

The formula for a general price level multiplier for all accident unit costs is as follows:
Multiplier for all types of accidents

\[ \text{Multiplier} = \frac{\text{CPI for all commodities at latest date reported}}{\text{CPI for all commodities for 1980 (annual index)}} \]

The latest available index should be used to calculate the above updating multiplier.

Like the other user unit costs used in the ECOANA, accident unit costs change not only due to inflation or general price level changes but also due to other factors, such as changes in the design of motor vehicles, design and condition of roads, and incomes of the vehicle occupants. Therefore, about every 10 years new accident cost base studies should be conducted to update accident unit costs for these factors. Some of the base studies still in use are already too old.

**Fuel Consumption Rates**

The fuel consumption rates used in the ECOANA should be updated to reflect changes in the fuel efficiency of vehicles making up the stream of traffic being analyzed. Changes in the overall fuel efficiency of vehicles in a stream of traffic can result from changes in type of fuel consumed, vehicle weight, engine design, etc. Starting with the 1978 models, the federal government has set fuel efficiency standards for passenger cars to be achieved annually through the 1985 model year [11]. Therefore, the fuel efficiency of automobiles must increase considerably above 1980's overall average fleet fuel consumption rate of 14.1 miles per gallon for Texas. During the next 10 years the fuel efficiency of the Texas automobile fleet is expected to increase to 18.2 miles per gallon. This is an increase of 29% over a 10
year period or 2.9% per year.

In lieu of developing a detailed and more accurate procedure (which needs to be done) for updating Type 1 vehicle consumption rates used in the ECOANA, the tabular rates can be updated by multiplying each rate by a derived factor. To calculate the updating factor, use the following formula:

\[
\text{Updating Factor} = 0.02816 \times \frac{\text{Number of Years since 1980}}{1.00000}
\]

Such an updating factor should be used only until a more reliable updating procedure is developed.

Arriving at a temporary updating factor for Vehicle Types 2, 3, and 4 fuel consumption rates used in ECOANA is even more difficult, due to data deficiencies. Historical series of vehicle-miles per gallon for each of these vehicle types appear in the U.S. Department of Transportation's "Highway Statistics" [12]. The data for single-unit trucks (Type 3) reveal very little change in vehicle miles per gallon between 1970 and 1978. On the other hand, the data for Vehicle Types 3 and 4 indicate that vehicle-mile per gallon have increased by about 12 percent between 1970 and 1978. This increase in fuel efficiency is primarily the result of switching from gasoline powered to diesel powered vehicle. As yet, there are no federal fuel efficiency standards in effect for trucks and buses.

Since Type 2 vehicles have experienced little change in fuel efficiency and Type 4 vehicle is designated to use the Type 2 vehicle consumption rates, no updating factor is given for Types 2 and 4 fuel consumption rates. In the case of Type 3 vehicles, the tabular fuel
consumption rates can be updated by multiplying each rate by a derived factor. To calculate the updating factor, use the following formula:

\[
\text{Updating Factor} = 0.01687 \times \text{Number of Years since 1980} - 1.00000.
\]

Again, this updating factor should only be used until a more accurate updating procedure can be developed.

**Pollution Emission Factors**

The 1977 pollution emission factors used in ECOANA should be updated at least every five years. Since the calculation of the 1977 factors, new base data for calculating pollution emissions have been published by the EPA [12]. Updating the ECOANA factors will require additional study of the new base data to develop appropriate updating multipliers. Considerable time and effort will be needed to perform this task.

**Uses of ECOANA Output Data**

The initial output of ECOANA is the total time costs, vehicle operating costs, accident costs, gallons of fuel consumed, and pounds of air pollutants generated from motor vehicles using the study facility during one peak period, computed separately before and after the proposed improvement. The difference in the before and after amounts of each of these measures of effectiveness represents the benefits (disbenefits) of the proposed improvement for one peak period of operation. Each differential quantity can be expanded to reflect the magnitude of benefits (disbenefits) for as many peak periods as might be relevant to study.

Although the magnitude of the indicated first year benefits (disbenefits)
can be used as one measure of the effectiveness of a proposed improvement, a better measure is one which compares the present value (in dollars) of a stream of annualized future benefits, if any, with the present value of the capital, maintenance, and operation costs of the facility improvement. The relevant period for this comparison is the expected life (economic, not only physical) of the improvement. If the present value of the stream of benefits is greater than the present value of the stream of improvement costs, then the improvement is justifiable from an economic point of view. This amount is a measure of the net benefits of the improvement. A benefit/cost ratio can be calculated to indicate the magnitude of the benefits to costs relationship. A benefit/cost ratio of one or more indicates that the proposed improvement is economically feasible.

Of the five measures of effectiveness used by ECOANA, three (time, vehicle operating, and accident costs) are measured in dollars. These costs can be combined to calculate the net dollar benefits and the benefit/cost ratio. The other two measures of effectiveness are measured in physical quantities, and thus have to be calculated separately from those in dollars. Then, the analyst has to consider all five measures together to make a valid decision.

The relevant assumptions that must be made to calculate net benefits and the benefit/cost ratio are listed below:

1. Life of the improvement. This is the economic life which takes into consideration physical life. The life of the improvement is the analysis period.

2. Traffic growth rate over the life of the project. Even though it is not very realistic, the simplest analysis assumes a constant growth rate.
3. Discount rate to apply to future benefits and costs and calculate the present value of benefits and costs. If inflation is assumed to be zero over the life of the improvement, allowing future benefits and costs to be calculated in constant dollars, a discount rate of 3 to 5 percent is recommended. If inflation is assumed to be 8 percent, a discount rate of 10 to 12 percent should be used. Again, the simplest analysis assumes that inflation is zero. As a note of caution, the initial capital costs of an improvement do not have to be discounted to arrive at the present value of improvement costs.

To calculate the present value (PV) of future benefits over the analysis period, a present worth factor (PWF) is used. The PWF depends on the length of the analysis period and the discount rate assumed. The PWF can be looked up in present worth tables in highway economy, financial, or real estate appraisal text books. The PWF is multiplied by the annual benefits (AB) of the improvement to arrive at the PV of the future benefits. PV of the annualized improvement costs (maintenance and operation costs, not including capital costs) is derived the same way. Only capital costs other than the initial year capital costs have to be discounted from the year of expenditure. Capital, maintenance, and operating costs of the facility improvement must be supplied by the user. All discounted costs plus initial capital costs are divided into the present value of the benefits to derive the benefit/cost ratio.

ECOANA furnished the output data to calculate vehicle user costs and benefits but furnished only air pollution data that can be used to evaluate nonuser costs and benefits. Such nonuser impacts as land use, property value, noise, etc, need evaluating to complete the impact evaluation of an improvement.
ECOANA USER'S NOTE

The ECOANA program was developed to operate on generated output measures from FREQ3CP (13). All concepts, assumptions and definitions as set forth in the FREQ3CP model are carried into the ECOANA program. The ECOANA user must be familiar with the FREQ3CP simulation model's assumptions and definitions to properly evaluate the economic measures.
The successful implementation of the ECOANA program was assured upon a detailed inspection of the FREQ3CP program. Traffic measures (speed, v/c ratios, travel, etc.) by time period are required for ECOANA calculations. Within the FREQ3CP program logic, definitive points exist where these necessary measures can be reserved for ECOANA's use without inhibiting the execution or integrity of the FREQ3CP operation. After the appropriate program steps were implemented into the FREQ3CP program, the traffic data to be utilized by ECOANA were placed, in an orderly fashion, on a remote storage tape. Upon completion of a FREQ3CP simulation program run, a decision can be made to execute the ECOANA program. If the simulation results from FREQ3CP are not satisfactory, it is not necessary to execute ECOANA. ECOANA depends upon the last data stored by the FREQ3CP program. Therefore, careful examination of the FREQ3CP simulation results should be accomplished before advancing to the next simulation run. If, at a later date, previous simulation results are needed for an ECOANA execution, the FREQ3CP data cards can be reassembled as in the previous configuration and executed. ECOANA can then be run on the newest data set. As previously described, the utility of ECOANA is not so much as to the accuracy or importance given to any one set of measurements (i.e. travel time costs, operating costs, etc.), but in the relative changes of these measurements between FREQ3CP runs where before and after conditions are simulated.

FREQ3CP Data Storage

The traffic data measures to be retained for use by ECOANA must be captured at the points in the execution steps of FREQ3CP where they are
encountered. FREQ3CP is two programs that have been merged; i.e. the simulation portion is FREQ3 (the third generation of freeway simulation) and the optimizing ramp metering control portion PREFLO (13). It is in the FREQ3 freeway simulation portion of FREQ3CP that the required freeway measures are generated. As set forth in the previous discussions, ECOANA must use measures from subsection by time slice units as well as data summarized over all subsections and time slices. FREQ3CP processes the simulation of freeway traffic by subsection and time slice. The individual measures for the subsections are unique only for that time slice. Before the next time slice is processed, these unique measures must be remotely stored for use by ECOANA. FREQ3 does accumulate summary information throughout all time slices. These accumulated measures are available at the conclusion of the FREQ3 simulation for retention for ECOANA use.

The first record of data stored by FREQ3CP pertains to the dimensionings of the overall freeway system. As shown in Table 30, the number of lanes in each subsection, the number of subsections and the ratio of persons per vehicle are given in Record 1. The number of diverted vehicle-miles of travel will contain valid information only if an after control simulation is conducted. In a before control simulation, vehicles may be diverted (due to excess queue waiting time or an overcapacity demand), but these vehicles were not observed to be processed in the same manner as were the diverted vehicles in the optimization routines. If valid information is not to be included in any of the information, all elements of the diverted vehicle-miles array are set to numeric zeros. Each record from 2 through the total number of time slices (ICT(2)value) contains identical information for each time slices. The measures by subsection are speed, the volume to
<table>
<thead>
<tr>
<th>RECORD</th>
<th>VARIABLES STORED</th>
<th>VARIABLE DEFINITION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>LANE(1-40)</td>
<td>LANE = Number of lanes per subsection 1 through subsection 40</td>
</tr>
<tr>
<td></td>
<td>DVM(1-40)</td>
<td>DVM = Diverted vehicle-miles travel by subsection 1 through subsection 40</td>
</tr>
<tr>
<td></td>
<td>NSEC</td>
<td>NSEC = Number of subsections</td>
</tr>
<tr>
<td></td>
<td>ICT(2)</td>
<td>ICT(2) = Total number of time slices</td>
</tr>
<tr>
<td></td>
<td>FAC(3)</td>
<td>FAC(3) = Average vehicle occupancy (pass/veh)</td>
</tr>
<tr>
<td>2</td>
<td>USP(1-40)</td>
<td>USP = Speed (MPH) per subsection</td>
</tr>
<tr>
<td></td>
<td>VOC(1-40)</td>
<td>VOC = Volume to capacity ratio per subsection</td>
</tr>
<tr>
<td></td>
<td>FVM(1-40)</td>
<td>FVM = Total vehicle-miles of freeway travel per subsection</td>
</tr>
</tbody>
</table>
|        | ICT(2)            | IQUE(1-40) = Queue status per freeway subsection  
|        |                  | = 0  No queue  
|        |                  | = -1 Partial queue  
|        |                  | = -2 Total queue  |
|        | CUM(1-10)         | CUM = Cumulative values per time slice  
|        |                  | CUM(1) = Freeway vehicle-hours of delay  
|        |                  | CUM(2) = Freeway passenger-hours of delay  
|        |                  | CUM(3) = Vehicular input delay at Entrance Ramps  
|        |                  | CUM(4) = Passenger input delay at Entrance Ramps  
|        |                  | CUM(5) = Vehicular output delay at Exit Ramps  
|        |                  | CUM(6) = Passenger output delay at Exit Ramps  
|        |                  | CUM(7) = Total travel time (veh-hrs)  
|        |                  | CUM(8) = Total travel time (Pass-hrs)  
|        |                  | CUM(9) = Total travel distance (veh-miles)  
|        |                  | CUM(10) = Total travel distance (Pass-miles)  |
capacity ratio, freeway travel and queueing status. Cumulative measures are routinely retained for future processing. Only in the last time slice period will the cumulative measures be meaningful to the present ECOANA logic.

ECOANA Program Input Tables

In the first half of this report, 29 tables of economics information were given. Twenty six of the tables are stored on a remote file for use by ECOANA. The other three tables are not needed. Many of the tables are combined into three dimensional arrays when accessed by ECOANA. Table 32 lists the three dimensional arrays and the included tables. The other economic tables are listed in the documentation and retain the same numeric number in the program. Table 28, for example, in the report is TAB28 array in the ECOANA program. Subroutine FIRST accesses the storage file and places all the economic data into the correct tables.

ECOANA Program Input Cards

There are a total of five data cards that must be created and used each time that ECOANA is executed. The cards must always be stacked in the following order:

CARD 1 - contains VTYPE values
CARD 2 - contains TABA through TABE values
CARD 3 - first line of page heading information
CARD 4 - second line of page heading information
CARD 5 - contains values for accident analysis of MROAD, NTYPE, MHIGHT, LSEVER, and IDVER

The user is urged to take note of the formats for these cards as shown in Table 31. If strict adherence to the order or format is not observed, a program error will unequivocally occur. All other information required by the ECOANA program will be taken from the stored FREQ results or the stored ECOANA input tables.

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Table 31. ECOANA Input Variables with Values and Description of Use

<table>
<thead>
<tr>
<th>VARIABLE NAME</th>
<th># ELEMENTS</th>
<th>FORMAT</th>
<th>VALUES</th>
<th>DESCRIPTION OF USE</th>
</tr>
</thead>
<tbody>
<tr>
<td>VTYPE</td>
<td>4</td>
<td>4F10.2</td>
<td>.915</td>
<td>Fractional number of each of 4 types of vehicles in traffic as denoted in Table 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>.070</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>.010</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>.055</td>
<td></td>
</tr>
<tr>
<td>TABA</td>
<td>4</td>
<td>4F3.0</td>
<td>35.</td>
<td>Uniform approach speed (MPH) on Diversion Route by Vehicle Type</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>35.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>35.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>35.</td>
<td></td>
</tr>
<tr>
<td>TABB</td>
<td>4</td>
<td>4F3.0</td>
<td>2.3</td>
<td>Number of stops per vehicle mile on Diversion Route by vehicle type due to intersections</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2.3</td>
<td></td>
</tr>
<tr>
<td>TABC</td>
<td>4</td>
<td>4F3.0</td>
<td>32.</td>
<td>Seconds per stop on Diversion Route by vehicle type</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>36.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>36.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>36.</td>
<td></td>
</tr>
<tr>
<td>TABD</td>
<td>4</td>
<td>4F3.0</td>
<td>3.6</td>
<td>Number of speed changes per mile on Diversion Route by vehicle type</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4.7</td>
<td></td>
</tr>
<tr>
<td>TABE</td>
<td>4</td>
<td>4F3.0</td>
<td>10.</td>
<td>Amount of speed change (MPH) on Diversion Route by vehicle type</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>10.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>10.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>10.</td>
<td></td>
</tr>
<tr>
<td>HEAD</td>
<td>20</td>
<td>20A4</td>
<td></td>
<td>First line of Page Heading</td>
</tr>
<tr>
<td>HEADB</td>
<td>20</td>
<td>20A4</td>
<td></td>
<td>Second line of Page Heading</td>
</tr>
<tr>
<td>MROAD</td>
<td>1</td>
<td>A2</td>
<td>b</td>
<td>Location of Accidents (Table 28) Urban by default</td>
</tr>
<tr>
<td>NTYPE</td>
<td>1</td>
<td>A2</td>
<td>b</td>
<td>Highway Type (Table 28) Freeway by default</td>
</tr>
<tr>
<td>MHIGHT</td>
<td>1</td>
<td>I2</td>
<td>b</td>
<td>Highway Type (Table 28) Urban Freeway by default</td>
</tr>
<tr>
<td>LSEVER</td>
<td>1</td>
<td>I2</td>
<td>b</td>
<td>Location of Accident (Table 27) Urban Freeway by default</td>
</tr>
<tr>
<td>IDVER</td>
<td>1</td>
<td>I2</td>
<td>b</td>
<td>Diversion Route (Table 28) Undivided 2 Lane by default</td>
</tr>
</tbody>
</table>
Table 32. Three Dimensional Array Assignment

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>DIMENSIONS</th>
<th>CONTAINS TABLES</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>RCOSTS</td>
<td>3,13,6</td>
<td>3,4,5</td>
<td>Running cost on freeways by vehicle type, speed and level of service (LS)</td>
</tr>
<tr>
<td>EXCOST</td>
<td>3,10,5</td>
<td>9,10,11</td>
<td>Excess running costs on City Streets by speed cycle change, VT, speed and LS</td>
</tr>
<tr>
<td>FRATES</td>
<td>3,13,6</td>
<td>12,13,14</td>
<td>Fuel consumption rates on Freeways by vehicle type, speed and LS</td>
</tr>
<tr>
<td>FUEL CN</td>
<td>3,10,5</td>
<td>17,18,19</td>
<td>Excess Fuel Consumption Rates on City Streets by speed cycle change, speed and LS</td>
</tr>
<tr>
<td>EMPOL</td>
<td>3,12,3</td>
<td>22,23,24</td>
<td>Pollution Emission Rates on Freeways by vehicle type and speed</td>
</tr>
</tbody>
</table>
Program Input Variables

A general objective in the development of the ECOANA program was to provide a minimum number of input variables (from cards) at execution time. The vast number of economic tables required by ECOANA are stored in discrete files separate from ECOANA. The tables can be updated on a yearly basis without accessing the ECOANA program. A description of the variables entered via cards are contained in Table 31. The variable, VTYPE, provides the fractional number of vehicles by type as defined in Table 1. This mix of vehicles can greatly influence the measures, such as operating costs. No provision was made to provide separate vehicle type percentages for on freeway and diversion routes.

The variables, TABA through TABE, provide a means for designating individuality by vehicle types for diversion route travel. The TABA variable is the uniform approach speed on the diversion route. Most frontage road facilities have 35 MPH speed limits and, as such, were the speed values used for all vehicles types. The units used for variable TABB were 2.3 stops per vehicle mile for type 1 and 3.3 for the remaining vehicle types. Correspondingly, there are fewer seconds used at each stop for Type 1 (32 seconds) and the other vehicle types (36 seconds) contained in TABC. The number of speed changes per mile are fewer with Vehicle Type 1 than the remaining vehicle types. There are 3.6 speed changes per mile by Type 1 vehicles and 4.7 for the rest as contained in variable TABD. TABE contains the magnitude of each speed change for each vehicle type. Ten miles per
hour was the value chosen in the scenario.

The values used in variables TABA through TABE were taken from travel run studies conducted along the frontage roads on the North Central Expressway in Dallas, Texas. The user may chose to use these values given in Table 31 or may choose to develop their own. The authors could not find a source other than the Dallas studies from which to draw values.

There are two variables (HEAD & HEADB) that are presently used as a means for the user to document each ECOANA run. The user may place any alphanumeric character from Column 1 through Column 80 on 2 consecutive cards. The information will be printed on each of the five pages of economic measures basically centered on a 132 column page.

The final input card to ECOANA contains selective units for utilizing the accident analysis tables. Table 28 has been divided into a matrix of fifteen horizontal rows by three vertical columns. The variable MROAD is used to select the vertical column of Table 28. Only the alpha characters "R" for rural or "M" for metered urban are used. By default, if no alpha character is present, the urban column is selected. Similarly, the horizontal rows are selected using variable NTYPE by "E" expressway, "U" undivided conventional or "D" divided conventional. By default, a blank character will cause freeways to be selected. The remaining three variables are all entered as integer values.

The MHIGHT variable is used to select the horizontal row of Table 29; an integer value from one to twelve. The freeway is selected by default if no value is entered. LSEVER, by default, will cause the urban column to be chosen in Table 27 unless another is selected. While the above variables are primarily used to select accident rates for freeways, the IDVER variable can be used to select a different accident rate for the diversion route. The default value is the undivided conventional urban roadway accident rate.
General Program Operation

The ECOANA program can be separated into three basic execution steps. At first, it is necessary to obtain card and file information. All FREQ data that has been stored is then accessed and processed. Finally, the summary information for the five economic measures is calculated and printed. The ECOANA program documentation in the Appendices contains information that will help the user in being able to follow the explanation that is to follow.

The five data cards are read by the ECOANA program and placed into the appropriate arrays. Subroutine FIRST brings the stored economic tables into dimensioned arrays from the remote file. The first record of data stored by FREQ3CP is read. From these data, the number of lanes per subsection, the total vehicle-miles of travel by time-slice on the diversion route, the number of subsections, the number of time slices and the passenger occupancy per vehicle are obtained. At this point, the processing of time slice data is ready to begin.

FREQ3CP can process a freeway system composed of a maximum of 40 subsections. All ECOANA variables were set up to process this same maximum. Records 2 through the total number of time slices are each read and processed in the same manner. Even though each array contains 40 elements (one per subsection) only the number of subsections read in from Record 1 are analyzed. The data read in each time slice is given in Table 30.

The first objective to be accomplished is to match speed and level of service in each subsection against Tables 3, 4, 5, and 12, 13, 14. A close inspection of these two groups of tables (Operating Costs and Fuel Consumption) will show that in each level of service column only a finite number of speeds will yield valid rates. For example, a speed of 53 mph and a level of service
D will not yield a valid rate. Therefore, there is a certain amount of logic that must be processed to enable factual rates to be selected. All speeds, from FREQ, are real numbers and the decimal places are removed for earlier limit checks. The maximum speed allowed in any of the economic tables is 65 mph. A limit check of the speed assures a maximum of 65 mph. The queue check is performed. If the queue extends throughout the subsections, a level of service F must be applied and the speed cannot be greater than 35 mph. A limited or non-existent queue causes the volume to capacity (v/c) ratio to be limited to two decimal places. The v/c by number of lanes is compared to Table 6. A Table 6 examination will find the appropriate level of service from A to E (1 to 5). At this point a search is conducted of Tables 3, 4, 5 (or 12, 13, 14) where the level of service selected above is used to assert that the speed is within the range of allowable rates. If the speed is below the range of acceptable rates, then the minimum speed is selected for the lowest rate. If speed is above, the maximum speed is chosen. There are two working variables (RATE and RAT) which are used to contain the operating costs and fuel consumption rates by vehicle type. These two arrays are used to calculate the total on freeway operating costs of travel (TFVM) and the total on freeway fuel consumption (TFCON) by vehicle types. The freeway vehicle miles of travel in this subsection (FVM), cost or consumption rate by vehicle type and vehicle type percentage all multiplied together yields the appropriate cost or consumption by vehicle type. When the pollutant emissions are to be accumulated, the highest speed range allowed is 60 mph so a maximum speed check is again performed. A working array (EMPOL) is used to hold the pollution rates for the speed and v/c values in the subsection. Once again the pollution rate, vehicle miles of travel and the fractional vehicle types multiplied together yields the quantity of pollutant (EMPOL).
by pollutant types in Table 22, 23, 24 and vehicle types. This processing concludes after subsections through all slices are accomplished.

When all time-slice processing within ECOANA has concluded there are three measures calculated; the operating cost, the fuel consumed and the quantity of pollutants all by vehicle types. The five measures tabulated by ECOANA will be printed in the order presented in the report; i.e., time costs, operating costs, fuel consumption, emissions and accidents. The remainder of the ECOANA program is directed towards building arrays best suited to output formatting. In the program the building of each measure's output is clearly evident because of the grouping of large output formats.

Travel time delays (vehicle-hours TVH and passenger-hours TPH) are accumulated by the FREQ program and stored in the last array in each time slice data record (CUM). Delay and cost for both driver and passenger are calculated for the freeway, entrance, exit and diversion route (for after control simulations). Horizontal and vertical sums are totalled as shown in Appendix B.

The operating costs and fuel consumption are calculated in a similar manner. During the calculation of the operating costs, the fuel consumed is also summarized whenever convenient. Operating costs are found for the freeway, entrance and exit ramps. The diversion route has three separate cost figures; operating costs due to uniform speeds, speed changes and idling time conditions. It is during the calculations of these diversion route costs that the program variables (TABA through TABE) read from data cards are utilized. All costs figures are totalled in a horizontal and vertical fashion as before.
The fuel consumption measures have, for the most part, already been calculated. The ramps are the only measures which must be calculated. Outputting the sum total through the appropriate formats is the final processing for this measure.

The pollution measures for the freeway traffic for carbon monoxides, hydrocarbons and nitrogen-oxides are calculated during the time slice calculations. The other locations (entrance, exit and diversion route) also must be calculated. Two additional pollutants (particulates and sulfur oxides) are also determined for the appropriate locations. Sum totals are outputted.

The accident costs are determined for only two locations; the freeway main lanes and the diversion route. The assumptions entered on card five of the program entry (Table 31) are used to select the desired accident rates, severities, and costs. Summary total are outputted as before.

**Speed Versus V/C Ratio Test**

During each time slice, calculations performed by FREQ3 provide a volume-to-capacity (V/C) ratio and a speed for each subsection. These values are stored for use by ECOANA. The V/C ratio is used in ECOANA to determine the level of service (L/S) from Table 6 based on the number of lanes in the subsection. This L/S value (1-6) is next combined with the speed for the subsection to select rate values for operating cost and fuel consumption. Inspection of the rates tables (3,4,5 or 12,13,14) indicates that not all choices of L/S and speed will yield valid rates. It is for this reason that limit checks are performed on the speed to insure that valid rates are chosen.
There is a question as to which value (V/C ratio or speed) should be assumed to be more correct. The V/C ratio is derived from the input-output and number of vehicles per subsection. Speed is computed from a program included or user installed speed and V/C curves. One of the tasks performed during the tuning of the freeway simulation model is to modify the parameters and input data to FREQ3CP until the freeway traffic queues and subsectional speeds reasonably match the field observations. The speed in each subsection is dependent upon the calculated V/C value. Also, the V/C value for the next time slice is dependent on the progression of the traffic stream which utilizes the speed for movement. Also, the speed can be adversely affected by the improper selection of the V/C-speed curve.

To justify the selection of the V/C as the more stable value from the FREQ3 program for the ECOANA calculations, a test was devised and conducted. The ECOANA computer program was constructed in two different versions. The first version assumed that the V/C ratio was correct as stored by FREQ. The speed from FREQ was then modified until valid rates could be found in the aforementioned rate tables. This ECOANA version was executed on before and after control FREQ3CP simulations. The second ECOANA version assumed speed was correct as stored by FREQ and the V/C was used as a variable. This second version was also executed on the identical before and after control FREQ3CP simulation results. The comparison of the ECOANA results are given in Table 33.

Inspection of Table 33 will indicate that the travel time and accident costs for both versions are the same. This is because these measures use only the total vehicle miles of travel for their calculations and do not depend on speed or the V/C ratio. The other ECOANA measures are affected by other the V/C ratio and speed. The operating cost, fuel consumption, and pollution emissions do show similar changes between before and after control simulations.
as shown in Table 34. The operating cost in the version that assumes V/C is correct indicates approximately the same relative change from the before to after condition as does the speed version. The fuel consumption and pollutants also show similar tendencies between versions. The V/C ratio assumption was chosen and included in the final ECOANA computer program. This version provides the more conservative costs, fuel consumed, and pollutants. Also, the user may change the speed vs. V/C ratio curves in the FREQ3CP program and effect only minor differences in the ECOANA analysis results.
Table 33. Speed and V/C versions of ECOANA based on Before and After Control FREQ3CP Simulation

<table>
<thead>
<tr>
<th>Version</th>
<th>Total Travel</th>
<th>Operating Fuel</th>
<th>Accident</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time Costs</td>
<td>Costs</td>
<td>Consumption</td>
</tr>
<tr>
<td>V/C Correct</td>
<td>$68020</td>
<td>$26166</td>
<td>14565 gals.</td>
</tr>
<tr>
<td>Before Control</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V/C Correct</td>
<td>$40415</td>
<td>$22159</td>
<td>10972 gals.</td>
</tr>
<tr>
<td>After Control</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed Correct</td>
<td>$68020</td>
<td>$30340</td>
<td>16362 gals.</td>
</tr>
<tr>
<td>Before Control</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed Correct</td>
<td>$40415</td>
<td>$26306</td>
<td>12750 gals.</td>
</tr>
<tr>
<td>After Control</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Version</td>
<td>Operating Costs</td>
<td>Fuel Consumption</td>
<td>Fuel Pollution Emissions</td>
</tr>
<tr>
<td>--------------------------</td>
<td>----------------</td>
<td>-----------------</td>
<td>-------------------------</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CO</td>
</tr>
<tr>
<td>V/C Assumed Correct-Speed Variable</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BEFORE Control</td>
<td>$26166</td>
<td>14565 gals.</td>
<td>8971 kg.</td>
</tr>
<tr>
<td>AFTER Control</td>
<td>-$22159</td>
<td>-10972 gals.</td>
<td>-5824 kg.</td>
</tr>
<tr>
<td>NET CHANGE</td>
<td>$ 4007</td>
<td>3593 gals.</td>
<td>3147 kg.</td>
</tr>
<tr>
<td>PERCENT Change from Before</td>
<td>15.3%</td>
<td>24.7%</td>
<td>35.1%</td>
</tr>
<tr>
<td>Speed Assumed Correct-V/C Variable</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BEFORE Control</td>
<td>$30340</td>
<td>16362 gals.</td>
<td>17911 kg.</td>
</tr>
<tr>
<td>AFTER Control</td>
<td>-$26306</td>
<td>-12750 gals.</td>
<td>-11643 kg.</td>
</tr>
<tr>
<td>NET CHANGE</td>
<td>$ 4034</td>
<td>3621 gals.</td>
<td>6334 kg.</td>
</tr>
<tr>
<td>PERCENT Change from Before</td>
<td>13.3%</td>
<td>22.1%</td>
<td>35.2%</td>
</tr>
</tbody>
</table>
CONCLUSIONS AND RECOMMENDATIONS

The ECOANA program provides a direct way of obtaining economic measures from the FREQ3CP freeway traffic simulation program. By using the economic measures in a before and after freeway improvement scenario, the user can develop benefits associated with the improvement. The benefits can, in turn, be compared to the costs of the improvement if the costs are known. The user can quickly develop a number of freeway improvements and obtain the economic measures of each. In this manner, the user can secure a complete inventory of proposed improvements and the relative benefits of each. The ECOANA program can provide decision makers with more complete information concerning proposed improvements.

There are three areas that are recommended for further development. At the inception of the research project, FREQ3CP was the current freeway simulation model. Since then, the simulation work has been updated to FREQ6PE. It would be beneficial for the SDHPT to keep (within the computer storage facilities) only one freeway simulation program instead of two. An inspection of FREQ6PE revealed that modifications can be made that will enable ECOANA to function based on FREQ6PE inputs instead of FREQ3CP inputs.

A portion of the FREQ6PE simulation outputs are two usage measures; fuel consumption and emissions. It would be of interest to execute ECOANA based on FREQ6PE outputs and compare the two methods of determination. This comparison could reveal differences in the methods used to quantify the measures. Analysis of the differences could be insignificant which would mean that the FREQ6PE measures were adequate. Significant differences could mean that ECOANA measures should continue to be used.
The third area concerns the modifications to the ECOANA program that would enable total "life-of-the-improvement" measures to be calculated. At present, to determine the economic measures throughout the life expectancy of the improvement, FREQ3CP must be executed for each year of the life of the improvement with a fixed growth applied. A 20 year life would require 20 FREQ3CP and ECOANA program executions. Modifying ECOANA would reduce the output to only one total summary output of the economic measures.
REFERENCES
REFERENCES


APPENDIX A

DESCRIPTION OF VARIABLES USED IN ECOANA
APPENDIX A
DESCRIPTION OF VARIABLES USED IN ECOANA

CUM(10) - CUMULATIVE MEASURES AT END OF EACH TIME SLICE
CUM(1) - FREEWAY VEHICLE-HOURS OF DELAY
CUM(2) - FREEWAY PASSENGER-HOURS OF DELAY
CUM(3) - VEHICULAR INPUT DELAY AT RAMPS
CUM(4) - PASSENGER INPUT DELAY AT RAMPS
CUM(5) - VEHICULAR OUTPUT DELAY AT RAMPS
CUM(6) - PASSENGER OUTPUT DELAY AT RAMPS
CUM(7) - TOTAL TRAVEL TIME (VEH-HRS)
CUM(8) - TOTAL TRAVEL TIME (PASS-HRS)
CUM(9) - TOTAL TRAVEL DISTANCE (VEH-MILES)
CUM(10) - TOTAL TRAVEL DISTANCE (PASS-MILES)

DVM(40) - NUMBER OF DIVERTED VEHICLE-MILES OF TRAVEL IN EACH SUBSECTION - STORED BY FREQ3CP

EMPOL(3,12,3) - POLLUTION EMISSION RATES (GRAMS PER MILE) BY VEHICLE TYPES (1 TO 3), SPEED RANGE (5 TO 60 MPH IN 5 MPH INCREMENTS), AND POLLUTANT (CARBON MONOXIDE = 1, HYDROCARBONS = 2, NITROGEN OXIDES = 3)

EPOL(3,3) - POLLUTANT RATES (GRAMS PER MILE) FOR CURRENT SPEED RANGE IN THIS SUBSECTION BY VEHICLE TYPE (1 TO 3) AND POLLUTANT (CO = 1, HC = 2, NO = 3)

EXCOST(3,10,5) - EXCESS RUNNING COSTS DUE TO SPEED CHANGES (¢ PER CYCLE CHANGE)
EXCOST(VEHICLE TYPE (1-3), SPEED RANGE (5-50 MPH IN 5 MPH INCREMENTS, SPEED REDUCTIONS (0-50 MPH IN 10 MPH INCREMENTS)

FAC - PASSENGER OCCUPANCY AS USED IN FREQ3CP

FRATES(3,13,6) - FUEL CONSUMPTIONS RATES ON FREEWAYS (GALLONS PER VEHICLE-MILE) BY VEHICLE TYPE, SPEED RANGE AND LEVEL OF SERVICE.
FRATES(I,J,K) - IDENTICAL TO RCOSTS ARRAY

FUEL CN(3,10,5) - EXCESS FUEL CONSUMPTION RATES (GALLONS PER CYCLE CHANGE) BY VEHICLE TYPE (1-3), SPEED RANGE (5-50 MPH IN 5 MPH INCREMENTS), SPEED REDUCTIONS (0-50 MPH IN 10 MPH INCREMENTS)

FVM(40) - VEHICLE-MILES OF TRAVEL ON THE FREEWAY IN EACH SUBSECTION

HEAD(20) - CONTAINS HEADING INFORMATION IN 20A4 FORMAT

HEADB(20) - CONTAINS HEADING INFORMATION IN 20A4 FORMAT

IA X(7,4) - SUMMARY INFORMATION FOR OPERATING COSTS
  IAX(1,1-4) - CONTAINS ON FREEWAY OPERATING COSTS
  IAX(2,1-4) - CONTAINS ON RAMP OPERATING COSTS
  IAX(3,1-4) - CONTAINS OFF RAMP OPERATING COSTS
  IAX(4,1-4) - CONTAINS DIVERSION - UNIFORM SPEED FOR OPERATING COSTS
  IAX(5,1-4) - CONTAINS DIVERSION - SPEED CHANGE FOR OPERATING COSTS
  IAX(6,1-4) - CONTAINS DIVERSION - IDLING COSTS FOR OPERATING COSTS
  IAX(7,1-4) - CONTAINS VERTICAL TOTALS FOR OPERATING COSTS

IDVER - HIGHWAY TYPE FOR ACCIDENT ANALYSIS

IQUE(40) - "*" IN EACH SUBSECTION IF FREEWAY QUEUE THROUGHOUT.

ITT(5,5) - SUMMARY INFORMATION FOR TRAVEL TIME COSTS

KAX(7,4) - SUMMARY INFORMATION FOR FUEL CONSUMPTION
  (SAME ASSIGNMENTS AS IAX(7,4))

LANE(40) - NUMBER OF LANES IN EACH SUBSECTION - STORED BY FREQ3CP
LOX(5,4,5) - SUMMARY POLLUTANT INFORMATION BY TRAVEL METHOD, VEHICLE TYPE AND POLLUTANTS
LOX(1,I,J) - ON FREEWAY
LOX(2,I,J) - ON RAMP
LOX(3,I,J) - OFF RAMP
LOX(4,I,J) - DIVERSION
LOX(5,I,J) - TOTALS
LOX(L,1,I) - VEHICLE TYPE 1
LOX(L,2,I) - VEHICLE TYPES 2 & 4
LOX(L,3,I) - VEHICLE TYPE 3
LOX(L,4,I) - TOTALS
LOX(L,I,1) - CARBON MONOXIDES (GRAMS PER MINUTE)
LOX(L,I,2) - HYDROCARBONS (GRAMS PER MINUTE)
LOX(L,I,3) - NITROGEN OXIDES (GRAMS PER MINUTE)
LOX(L,I,4) - PARTICULATES (GRAMS PER MILE)
LOX(L,I,4) - SULFUR OXIDES (GRAMS PER MILE)

LSEVER - LOCATION OF ROADWAY FOR ACCIDENT ANALYSIS
LX(15) - HEADING INFORMATION FOR SUMMARY REPORT
MHIGHT - ROADWAY TYPE FOR ACCIDENT ANALYSIS
MONEY(3,7) - SUMMARY INFORMATION ON ACCIDENTS AND COSTS BY TRAVEL METHOD
MR0AD - ROADWAY TYPE FOR ACCIDENT ANALYSIS
NSEC - NUMBER OF SUBSECTIONS - STORED BY FREQ3CP
NTS - NUMBER OF TIME SLICES - STORED BY FREQ3CP
NTYPE - ROAD TYPE AS INPUT PARAMETER TO ACCIDENT ANALYSIS
POLS(3,3) - SUMS POLLUTANTS BY VEHICLE TYPE (1-3) FOR ALL SUBSECTIONS AND TIME SLICES BY POLLUTANTS (1-3)
ØPLIST(196) - HEADING INFORMATION FOR SUMMARY PRINTOUTS IN 7A4 FORMAT

RAT(3) - CURRENT FUEL CONSUMPTION (GAL/V-M) BY VEHICLE TYPE BASED ON SPEED AND LEVEL SERVICE IN THIS SUBSECTION AND TIME SLICE

RATE(3) - CURRENT RUNNING COSTS (¢/V-M) BY VEHICLE TYPE BASED ON SPEED AND LEVEL SERVICE PER SUBSECTION AND TIME SLICE

RCOSTS(3,13,6) - RUNNING COSTS (¢ PER VEH-MI) ON FREEWAYS BY VEHICLE TYPE, SPEED RANGE, AND LEVEL OF SERVICE

RCOSTS(I,J,K) - I=1 FOR VEHICLE TYPE 1

I=2 FOR VEHICLE TYPES 2 AND 4

I=3 FOR VEHICLE TYPE 3

J=1-13 FOR SPEEDS RANGES IN 5 MPH INCREMENTS

K=1-6 FOR 6 LEVEL OF SERVICES A-F

SPED(40) - SPEED IN MPH FOR EACH SUBSECTION

NOTE: TABA - TABE FOR DIVERSION ROUTE

TABA(4) - AVERAGE INITIAL SPEED (MPH) BY VEHICLE TYPES (1-4)

TABB(4) - AVERAGE NUMBER OF STOPS PER VEHICLE-MILE AT INTERSECTIONS

TABC(4) - AVERAGE VEHICLE-HOURS PER STOP

TABD(4) - AVERAGE NUMBER OF SPEED CHANGES PER VEHICLE-MILE

TABE(4) - AVERAGE SPEED REDUCTION PER SPEED CHANGE

TAB2(4,4) - VALUES OF TIME ($) BY VEHICLE TYPE (1-4) AND DRIVING MODE (1-MOVING, 2-STopped)

TAB6(3,6) - V/C RATIOS GROUPED BY LEVEL OF SERVICE (L/S) AND NUMBER OF LANES

TAB7(3) - IDLING COSTS (¢/HR) BY VEHICLE TYPE
- RUNNING COSTS (¢/V-M) ON CITY STREETS BY (SPEED GROUP, VEHICLE TYPE)
- IDLING FUEL CONSUMPTION (GALS/HR) BY VEHICLE TYPE
- FUEL CONSUMPTION RATES (GAL/MI) ON CITY STREETS
- PARTICULATE AND SULFUR OXIDE POLLUTION (GRAMS/MILE) (VEHICLE TYPE, POLLUTANT)
- IDLING POLLUTION RATES (GRAMS/MINUTE) (VEHICLE TYPE, POLLUTANT)
- MOTOR VEHICLE ACCIDENT UNIT COSTS ($/ACCIDENT) PER REPORTED ACCIDENT (SEVERITY, LOCATION)
- MOTOR VEHICLE ACCIDENT RATES (PER 10^6 V-M) (HIGHWAY TYPE, LOCATION)
- PERCENTAGE DISTRIBUTION (HIGHWAY TYPE, ACCIDENT SEVERITY)
- SUMS THE FUEL CONSUMED BY VEHICLE TYPES (1-4) FOR ALL SUBSECTIONS AND TIME SLICES
- SUMS THE RUNNING COSTS BY VEHICLE TYPES (1-4) FOR ALL SUBSECTIONS AND TIME SLICES
- MIRROR COPY OF VTYPE ARRAY EXCEPT ELEMENT (4) IS ADDED TO ELEMENT (2) AND SANED IN (2)
- VOLUME TO CAPACITY RATIO FOR EACH SUBSECTION
- VEHICLE-MILES OF TRAVEL BY LANE
- FRACTION OF EACH TYPE VEHICLE IN TRAFFIC STREAM
APPENDIX B

ECOANA PROGRAM LISTING
INTEGER IJ:
REAL Journey(3,7)
DIMENSION CPLIST(45)
DIMENSION ITT(5,5), I/7(7,4), KAX(7,4)
DIMENSION VTYPE(4), TAE4(4), TAE6(4), TAE7(4), TAE8(4)
DIMENSION TFVM(4), TFCCN(4), EPCL(3,3), VMBLN(8)
DIMENSION LCI(5,4,5)
DIMENSION HEAC(20), HEACE(20), TRICK(4), DVM(40), FVM(40), CUM(10)
COMMON/IOATA/RCC1(3,13,6),FRATES(3,13,6), EXCST(3,10,5),
*TAB6(3,12), TAE8(10,3), TAB7(3), TAB15(3), TAB2(4,4),
*TAB16(10,3), TAE25(12,3), EMFCL(3,12,3), TAE28(15,3), TAE27(3,3),
*TAB26(3,3), TAE2(3,3), FUELCLN(3,10,5)

READ(5,1111) (VTYPE(I), I=1,4), ITABLE
1111 FORMAT(4F10.3,5X,11)

VTYPE = % OF EACH TYPE VEHICLE IN TRAFFIC STREAM
VTYPE(1) = ALTCS.PU & PANELS (2-AXLE, 4-TIRES)
VTYPE(2) = SL TRUCKS (OTHER THAN 2-AXLE, 4-TIRES)
VTYPE(3) = T.T. SEMI OR TRAILER COMBOS

READ(5,564)(TAE4(I), I=1,4), (TAE6(I), I=1,4), (TABC(I), I=1,4),
* (TABC(I), I=1,4), (TAE4(I), I=1,4)
564 FORMAT(4F3.0,4F3.0,4F3.0,4F3.0,4F3.0,4F3.0)

ITIME=0

READ(5,5357) READ
5357 FORMAT(20A4 )
READ(5,5357) READ
READ(5,5868) MFCAD, VTYPE, WEIGHT, LSEVER, IDVER
5868 FORMAT(2(IX,A2 ),312)

CALL FIRST

DO 355 I=1,4
355 TRICK(I) = VTYPE(I)
TRICK(2) = TRICK(2) + TRICK(4)
C
C OBTAIN GENERAL INFORMATION FROM FREG STORAGE
C
C TVM=0.
DO 7070 IKX=1,4
TFVM(IKX)=0.
TFCCN(IKX)=0.
VMBLN(IKX)=0.
    707C VMBLN(IKX+4)=0.
    DO 7071 IKX=1,3
    DO 7071 IKY=1,3
    7071 POLLS(IKX,IKY)=0.
REWIND 3
REAC(3) LANE,VM,NSEC,NTS,FAC
C LANE(40) = NUMBER OF LANES IN EACH SUBSECTION
C DVM(40) = DIVERTED VEH-MILES TRAVEL IN EACH TIME SLICE
C NSEC = NUMBER OF SUBSECTIONS
C NTS = NUMBER OF TIME SLICES
C FAC = PASSENGER OCCUPANCY USED IN FREG
C
C BEGIN TIME SLICE CALCULATIONS
C
C******************************************************************************
C******************************************************************************
    DO 100 I=1,NTS
    READ(3) SPED,VC,FVM,IQUE,CUM
    C SPED(40) = AVERAGE SPEED (MPH) PER SECTION
    C VC(40) = V/C RATIO PER SECTION
    C FVM(40) = CN FREEWAY VEH-MILES OF TRAVEL
    C IQUE(40) = PARTIAL QUEUE = 1 TOTAL QUEUE = 2
    C CUM = CUMULATIVE TOTALS DELAY AND TRAVEL FROM FREG
C******************************************************************************
C******************************************************************************
    DO 10 NS = 1, NSEC
    C
    C IP=SPED(NS)
    SPED(NS) = 1.*IF
        IF( IP .GT. 65) SPED(NS) = 65.
        IF( IQUE(NS) .LT. 2 ) GC TC 11
        IF( LANE(NS) .LE. 2 ) J=1
        IF( LANE(NS) .GE. 3 ) J=2
        IF( LANE(NS) .GE. 4 ) J=3
    C TAB6 CONTAINS LEVEL OF SERVICE BY V/C BY LANES
        JJ=0
        IP=VC(NS)*100.
        VC(NS) = (1.*IF)/100.
        DO 13 K=2,10,2
            IPA = 100.* TAB6(J,K-1)
            IPB = 100.* TAB6(J,K)
            IF( IP .GE. IFA .AND. IF .LE. IPE ) JJ= K/2
        13 CONTINUE
        IF( JJ .NE. 0 ) GC TC 14
        11 JJ = 6
        1193 IF(SPED(NS) .GE. 35.) GC TC 1192
        KK=SPED(NS) / 5.
        AI=(SPED(NS)-(5.*KK))/5.
GO TO 26
1152 KK=7
GO TO 25
C
C 115 KK= $FED(NS) / 5.0
   AI = ( SPED(NS) = ( 5.0 + KK ) ) / 5.0
C
115 IA = 5
1B = 6
1C = 5
DO 120 KA = 1,5
   IF( JJ * NE. IA ) CC TC 119
   IF( KK * LE. IE ) KK = IE
   IF( KK * GT. IC ) KK = IC
   GO TO 26
119 IA = IA + 1
IB = IE + 1
IC = IC + 1
120 CONTINUE
GO TO 29
C
25 DO 28 IA = 1,3
   RATE( IA ) = FRCST( IA,KK,JI )
28 RATE ( IA ) = FRATES( IA,KK,JI )
GO TO TC 29
C
RCCSTH( VTYPES,SPEED RANGE,L/S ) = RUNNING COSTS ON FREEWAYS
VTYPES( 1, 2 + 48 3
SPEEDS RANGED BY 5 MPH FROM 5 TO 65 MPH
LEVEL OF SERVICE ( L/S ) FROM AA TO F
C
RATE1 FOR RUNNING COSTS VEH-TYPE 1 AT SPEED AND L/S
RATE2 FOR RUNNING COSTS VEH-TYPE 2 $ 4 AT SPEED AND L/S
RATE3 FOR RUNNING COSTS VEH-TYPE 3 AT SPEED AND L/S
C
FRATES( VTYPES,SPEED RANGE, L/S ) = FUEL CONSUMED RATES ON FREEWAYS
GALS. PER VEH = MILE
C
R1 FUEL CONSUMPTION VEH-TYPE 1
C
R2 FUEL CONSUMPTION VEH-TYPE 2 $ 4
C
R3 FUEL CONSUMPTION VEH-TYPE 3
C
26 DO 27 IA = 1,3
   RATE( IA ) = FRCST( IA,KK,JI ) + AI * ( RCCSTH( IA,KK+1,JI ) =
*   RCCSTH( IA,KK ,JI ) )
   RATE ( IA ) = FRATES( IA,KK,JI ) + AI * ( FRATES( IA,KK+1,JI ) =
   FRATES( IA,KK ,JI ) )
27 CONTINUE
C
29 CONTINUE
C
SUM FOR THIS SECTION ON FREEWAY VEH-MILES BY VTYPE = OPERATING COST
TFVM( 1 = 4 ) = TOTAL ON FREEWAY OPERATING COST OF TRAVEL BY
VEH-TYPE

97
DO 32 IA = 1, 3
TFVM( IA ) = TFVM( IA ) + FVM( NS ) * RATE( IA ) * VTYPE( IA )
TFCCN( IA ) = TFCCN( IA ) + FVM( NS ) * RATE( IA ) * VTYPE( IA )
32 CONTINUE
TFVM( 4 ) = TFVM( 4 ) + FVM( NS ) * RATE( 2 ) * VTYPE( 4 )
TFCCN( 4 ) = TFCCN( 4 ) + FVM( NS ) * RATE( 2 ) * VTYPE( 4 )
C TOTAL CN FREEWAY FUEL CONSUMPTION BY VEH-TYPE
( GALLONS FUEL USED )
C
KP = KK
IF( KP .LE. 11 ) GC TO 30
DO 36 JA = 1, 3
DO 33 JB = 1, 3
33 EFCL( JA, JB ) = EMFCL( JA, 12, JE )
36 CONTINUE
GO TO 40
30 DO 35 JA = 1, 3
DO 34 JB = 1, 3
34 EPOL( JA, JB ) = EMFCL( JA, KP, JE ) + AI * ( EMFCL( JA, KP + 1, JB ) - EMFCL( JA, KP - 1, JB ) )
35 CONTINUE
40 CONTINUE
C JA FOR VEH-TYPE;
C JB FOR POLLUTANTS
C
DO 50 JA = 1, 3
DO 51 JB = 1, 3
POLLS( JA, JB ) = POLLS( JA, JB ) + EPOL( JA, JB ) * FVM( NS ) * TRICK( JA )
51 CONTINUE
50 CONTINUE
C ACCUMULATE CN FREEWAY VEH-NILES CF TRAVEL
C
TVM = TVM + FVM( NS )
C ACCUMULATE VEH-NILES TRAVELED BY LANE FOR ACCIDENT ANALYSIS
C
VMBLN( LANE( NS ) ) = VMBLN( LANE( NS ) ) + FVM( NS )
C
THIS POINT ENDS THE SECTION CALCULATIONS
10 CONTINUE
C
END OF ALL TIME SLICE SERVICING
**WRITE(6,5995)**

5995 FORMAT(1HI,"/",/21X,"****EEEEEEEEEEEECCCCCCCCCCD00000A

*AAAAA NNNN NNN AAAAAAAA*./21X,"****EEEEEEEEEEEECCCCCC
1C COCCCOOOGC AAAA**************NNNN NNN AAAAAAAAAA*./21X,*
2EEE*12X*CCCGCCCO COO AAAA AAAA NNNNNN NNN A
3AA AAA*./21X,"EEE*11X,"CCCG10X,"CCG COO AAAA AAA
4 NNNNNN NNN AAA AAA*./21X,"EEEEEEEEEECCCC*.10X,*CCG
5 CCC*11X,"CCCGAAAAAAA NNN NNN NNN AAAAAAAAAA
8NNN AAAAAAAAAA*./21X,"EEE*12X,"CCCGCC COO COO AAA
9A AAA AAA NNN AAA AAA A*/)

**WRITE(6,5998)**

5998 FORMAT(21X,"****EEEEEEEEEEEECCCCCOOOGC COO00000 AAA AAA

* NNN NNNN AAA AAA*./21X,"EEEEEEEEEECCCCCOOOGC
1 COCCCOOOGC AAA AAA AAA NNNN AAA AAA A*/)

**C SUM THE DIVERTEC VEH-WI, CF TRAVEL & PLACE IN DCVM**

**C DVDM( I-NTS ) MAY NOT HAVE VALUES UNLESS OPTIMIZATION HAS BEEN RUN IN FREQ**

**C FAC HAS PASS CCUPANCY AS USED IN LAST FREQUENCY SLICE ON FREEWAY**

**C PDVM CONTAINS PASS-WI. CF TRAVEL ON DIVERSION ROUTE**

**DDVM = 0.* DO 1117 K=1,NTS**

1117 DDVM = DDVM + DVDM( K )

**PDVM = DDVM + FAC**

**C**

**C PRINT CUMULATIVE VALUES FROM FREQ THAT USED BY ECOANA PROCESSING**

**C PRINT CUMULATIVE VALUES FROM FREQ THAT USED BY ECOANA PROCESSING**

**WRITE(6,5353) HEAD,FEAD**

5353 FORMAT(//,"",/21X,2CA4,/,/21X,20A4,/,/21X,*"THE FOLLOWING DATA WAS STORED BY FREQ3CF",/)

**WRITE(6,903C) CUM(I) , I=1,10), DDVM , FDVM**

903C FORMAT(41X,"VEH=FFS",11X,"FASS=HRS",/21X,"FREeway TRAVEL TIME",*

*2(F8.0,10X),/23X,"TOTAL TRAVEL TIME",2(F8.0,10X),/40X,*2"VEH=HI",10X,"FASS=H1",/19X,"TOTAL TRAVEL DISTANCE",2(F8.0,10X,**

30X),/15X,"DIVERSION TRAVEL DISTANCE",2(F8.0,10X)**

IF( ITABLE .NE. C ) GC TO 9671

**WRITE(6,566S)(( I,VTPE(I) ), I=1,2)**

566S FORMAT(1",/",/1C0),"VEHICLE TYPES AND PERCENTAGES USED IN THIS CCN"*

**TROL PERIOD",/EX,1HI,11(1H=),1HI,11(1H=),1HI,32(1H=),1HI,/6X,1HI**

1I,11X,1HI,11X,1HI,32X,1HI,/6X,1HI,3X,"VEHICLE I PERCENTAGE DES"**

2CRIPTI",18X,1HI,/6X,"TYPE I",11X,1HI,32X,1HI,/6X,1HI,3X,1HI**

3X,11X,1HI,32X,1HI,/6X,1HI,3X,1HI,11X,1HI,11(1H=),1HI,11(1H=),1HI**

4,6X,1HI,11X,1HI,11X,1HI,32X,1HI,/6X,1HI,3X,1HI,F7.3,4X,1HI,3

5X,AL105S,Pu (2-APLES,4 TIRES),3X,1HI,/6X,1HI,11X,1HI,11X,1HI,32X

6,1HI,/6X,1HI,16,5X,1HI,F7.9,4X,1HI,2X,"SU TRUCKS (OTHER THAN AECV**

7E) I"/6X,1HI,11X,1HI,11X,1HI,32X,1HI**

**WRITE(6,567C)(( I,VTPE(I) ), I=3,4)**

567C FORMAT(1",/",/1C0),"VEHICLE TYPES AND PERCENTAGES USED IN THIS CCN"*

**TROL PERIOD",/EX,1HI,16,5X,1HI,F7.9,4X,1HI,2X,"SEMI AND T.T TRUCKS",9X,1**

*HI,/6X,1HI,11X,1HI,11X,1HI,32X,1HI,/6X,1HI,16,5X,1HI,F7.9,4X,1HI**

1,3X,"EUSEES",24X,1HI,/6X,1HI,11X,1HI,11X,1HI,32X,1HI,/6X,1HI,11X,1HI**

2H=),1HI,11(1H=),1HI,32(1H=),1HI**

**9671 CONTINUE**

**WRITE(6,5358) HEAD**

5358 FORMAT(1",/",/2CA4,/)**

**WRITE(6,5356) HEAD**
DO 800  I=1,5
DO 600  J=1,5
CC ITT( I, J ) = 0
T = 0.
DO 801 I = 1,4
C1 T = T + ( TVH * VTYPE( I ) * TAB2( I,1 ) )
C TAB2( I,1 ) = VALUE OF TIME BY VEH TYPE AND DRIVER IN MOVING VEHICLE
ITT( I,1 ) = TVH
ITT( I,2 ) = TPH = TVH
ITT( I,3 ) = T
ITT( I,4 ) = ( TFH = TVH ) * TAB2( I,2 )
C TAB2( I,2 ) = VALUE OF PASS TIME BY VEH TYPE IN MOVING VEH
ITT( I,5 ) = ITT( I,3 ) + ITT( I,4 )
C C C
C ********* CN = RAMP TRAVEL TIME CCSTS *********
C T = 0.
DO 802 I=1,4
C2 T = T + ( TCRVH * VTYPE( I ) * TAB2( I,3 ) )
ITT( 2,1 ) = TCRVH
ITT( 2,2 ) = TOFFP = TCRVH
ITT( 2,3 ) = T
ITT( 2,4 ) = ( TCRPH = TCRVH ) * TAB2( I,4)
ITT( 2,5 ) = ITT( 2,3 ) + ITT( 2,4 )
C C C
C ********* CFF= RAMP TRAVEL TIME CCSTS *********
C T=0.
DO 808 I=1,4
C8 T=T+( CFFRV * VTYPE( I ) * TAB2( I,3 ) )
ITT( 3,1 ) = CFFRV
ITT( 3,2 ) = CFFFF = CFFRV
ITT( 3,3 ) = T
ITT( 3,4 ) = ITT( 3,2 ) * TAB2( I,4)
ITT( 3,5 ) = ITT( 3,3 ) + ITT( 3,4 )
C C C
C FIND DIVERSION ACUTE DELAY AND COSTS

100
CONVERT DVM INTO DH AND DH BY AVERAGE PASS OCCUPANCY AS ON FREEWAY

\[ \text{CPC} = \frac{\text{TPH}}{\text{TPH}} \]
\[ \text{DPM} = \text{APC} \times \text{CDH} \]
\[ A = \text{DVM} / \text{TAEA(1)} \]
\[ T = 0 \]

\[ \text{DO 803 I} = 1,4 \]

803 \[ T = T + (A \times \text{TYPE}(1) \times \text{TAB2(1,1)}) \]
\[ E = (\text{DPM} / \text{TAEA(1)}) \times A \]
\[ \text{ITT}(4.1) = A \]
\[ \text{ITT}(4.2) = E \]
\[ \text{ITT}(4.3) = T \]
\[ \text{ITT}(4.4) = E + \text{TAB2(1,2)} \]
\[ \text{ITT}(4.5) = \text{ITT}(4.3) + \text{ITT}(4.4) \]

C FIND TOTALS

\[ \text{DO 805 J} = 1,5 \]
\[ \text{DO 804 I} = 1,4 \]

804 \[ \text{ITT}(5.4) = \text{ITT}(5.4) + \text{ITT}(I.J) \]

805 CONTINUE

C THIS ENDS TRAVEL TIME CALCULATIONS

\[ \text{WRITE(6,6000)} \] (\[ \text{ITT(I.J)},J=1,5 \] = 1,5)

6000 \[ \text{WRITE(6,6001)} \] (\[ (\text{ITT(I.J)},I=1,5 \] = 1,2,4)

6001 \[ \text{WRITE(6,6002)} \] (\[ (\text{ITT(I.J)},J=1,5 \] = 1,5)

6002 \[ \text{WRITE(6,6003)} \]

C TFVM(1,4) = OPERATING COSTS CN FREEWAY BY VEHR-VEH
C TORVH = TOTAL CN FAMF DELAY IN VEHR-VEHS
C IAX(1,7,1,4) CONTAINS OPERATING COSTS

101
C KAX( 1, 1 - 4 ) CONTAINS CN FREEWAY OPERATING COSTS
C KAX( 2, 1 - 4 ) CONTAINS CN RAMP OPERATING COSTS
C KAX( 3, 1 - 4 ) CONTAINS CF RAMP OPERATING COSTS
C KAX( 4, 1 - 4 ) CONTAINS DIVERSION = UNIFORM SPEED FOR OPERATING COSTS
C KAX( 5, 1 - 4 ) CONTAINS DIVERSION = SPEED CHANGE FOR OPERATING COSTS
C KAX( 6, 1 - 4 ) CONTAINS DIVERSION = IDLING COSTS FOR OPERATING COSTS
C KAX( 7, 1 - 4 ) CONTAINS VERTICAL TOTALS FOR OPERATING COSTS
C
C KAX( 1=7, 1-4 ) CONTAINS VALUES IN FUEL USED
C
DO 995 I = 1,7
DO 995 J = 1,4
KAX( I, J ) = C
995 IAX( I, J ) = C
C
C COMBINE VM TRAVELED BY VEHICLE TYPES 2 + 4
TFVM( 2 ) = TFVM( 2 ) + TFVM( 4 )
DO 1000 I = 1,3
IAX( 1, I ) = TFVM( I ) / 100.
IAX( 2, I ) = ( TCFVM * TRICK( I ) * TAB7( I ) ) / 100.
IAX( 3, I ) = ( CFVM * TRICK( I ) * TAB7( I ) ) / 100.
C
C TABA( 4 ) = AVERAGE INITIAL SPEED (MPH) PER VEHICLE TYPE
C TABB( 4 ) = AVERAGE NUMBER OF STOPS PER VEHICLE MILE AT INTERSECTIONS
C TABC( 4 ) = AVERAGE VEHICLE HOURS PER STOP
C TABD( 4 ) = NUMBER OF SPEED CHANGES PER VEHICLE MILE
C TABE( 4 ) = AVERAGE SPEED REDUCTION PER SPEED CHANGE
C
J = TABA( I ) / 5.
C = DCFVM * TRICK( I )
IAX( 4, I ) = ( C * TAEE( J, I ) ) / 100.
KAX( 4, I ) = C * TAB( J, I )
C
C DIVERSION RULE OPERATING COSTS
C CALCULATE WHEN ALL TIME SLICES OPERATION ARE COMPLETE
C
B = TABA( I ) = TABE( I )
DO 1001 IY = 1,E
A = ( ( 10 * IV ) = 10 ) * 1.0
IF( B * EG( A ) ) GO TO 1005
IF( E * LT( A ) ) GO TO 1010
1001 CONTINUE
C
WRITE(6,31)
31 FORMAT( 'ERROR = INITIAL SPEED CN DIVERSION AND SPEED CHANGE GRE
*ATER THAN 50 MPH')
GO TO 1000
C
C EXCCST( 3,10,,E ) ARE TABLES FOR EXCESS RUNNING COSTS DUE TO SPEED CHANGES
C EXCCST( TYPE, SPEED RANGE, SPEED REDUCED ) CENTS / CYCLE CHANGE
C
1005 RT = EXCCST( I,J,IY )
RRT = FUEL( I,J,IY )
GO TO 1020
1010 R = ( A=E ) / 10.
RT = EXCCST( I,J,IY-1 ) - ( EXCCST( I,J,IY-1 ) - EXCCST( I,J,IY ) ) * R
RRT = FUEL( I,J,IY-1 ) = ( FUEL( I,J,IY-1 ) = FUEL( I,J,IY ) ) * R
C
102
1020 D = TABC( I ) * C
    IAX( E, I ) = ( D * RT ) / 100.
    KAX( E, I ) = C * RT

C

E = ( TABC( I ) * TABB( I ) * C ) / 3600.
    IAX( E, I ) = ( E * TAE7( I ) ) / 100.
    KAX( E, I ) = E * TAB15( I )

1000 CONTINUE

C

SUM HH AND VEH TOTALS
DO 1040 I = 1, E
    DO 1030 J = 1, 3
      IAX( I, J ) = IAX( I, J ) + IAX( I, J )
      IAX( 7, J ) = IAX( 7, J ) + IAX( I, J )
      IAX( 7, 4 ) = IAX( 7, 4 ) + IAX( I, J )
    1030 CONTINUE

1040 CONTINUE

C

THIS ENDS OPERATING CCSTSS ANALYSIS
WRITE(6, 6255) TITLE
WRITE(6, 6256) TITLE
WRITE(6, 6359)

6005 FORMAT(///,50X)*VEHICLE OPERATING COSTS*,//,58X)*( DOLLARS )*)
WRITE(6, 6101)

6010 FORMAT(///,6X,1HI,5E(1F=),1HI,/,2(6X,1HI,30X,1HI,4(16X,1HI))/)
       *6X,1HI,30X,1HI,* VEHICLE TYPE 1*,1HI,* VEHICLES 2 6 4 *,1HI,
       1* VEHICLE TYPE 2 *,1HI,6X,* TOTALS*,5X,1HI,/,2(6X,1HI,30X,1HI,4(16X
       2,1HI,/,6X,1HI,5E(1F=),1HI,/,6X,1HI,30X,1HI,16X,1HI,16X,1HI,16X,1HI
       3,1HI,16X,1HI,/,6X,1HI,30X,1HI,16X,1HI,16X,1HI,16X,1HI,16X,1HI)

DO 1060 I = 1, E
    IA = 7 * ( I = 1 ) + 1
    IB = 7 * I
    WRITE( 6, 6012 ) ( OPLIST( IC ), IC = IA, IE ), ( IAX( I, J ),
       *J = 1, 4 )

6012 FORMAT(6X,1HI,7A4,2X,1HI,4(5X,1HI$,I7,3X,1HI)/)
       *6X,1HI,30X,1HI,4(16X,1HI)/)

1060 CONTINUE

WRITE(6, 6014) ( OPLIST( IC ), IC = 43, 49 ), ( IAX( 7, J ), J = 1, 4)

6014 FORMAT(6X,1HI,5E(1H=),1HI,/,2(6X,1HI,30X,1HI,16X,1HI,16X,1HI,16X,1HI
       1,1HI,16X,1HI,/,6X,1HI,7A4,2X,1HI,4(5X,1HI$,I7,3X,1HI)/)
       *2(6X,1HI,30X
       1,1HI,16X,1HI,16X,1HI,16X,1HI,16X,1HI,16X,1HI,16X,1HI,16X,1HI,16X,1HI
       /),6X,1HI,98(1H=),1HI)

C

C

C

C

TFCCN(1-4) FUEL CONSUMPTION CN FREEWAY EY VEH-TYPE

FUELCN( 3,10, $ ) ARE TAELES FOR FUEL CONSUMPTION DUE TO SPEED CHANGES

FUELCN TYPF,REDCE,REDUF ) GALS / CYCLE CHANGE

C

TFCCN( 2 ) = TFCCN( 2 ) + TFCCN( 4 )

DO 1100 I = 1, 3

C

FUEL CONSUMPTION CN FREEWAY
KAX( 1, I ) = TFCCN( I )

C

CN RAMP FUEL CONSUMPTION
KAX( 2, I ) = TCRVF * TRICK( I ) * TAB15( I )

C

OFF RAMP FUEL CONSUMPTION
KAX( 3, I ) = ( CFFVF * TRICK( I ) * TAB15( I )

1100 CONTINUE

C
CO 1120  I = 1.6
DO 1110  J = 1.3
KAX( 1,4 ) = KAX( 1,4 ) + KAX( 1,J )
KAX( 7,4 ) = KAX( 7,4 ) + KAX( 1,J )
KAX( 7,J ) = KAX( 7,J ) + KAX( 1,J )
1110  CONTINUE
1120  CONTINUE
C
WRITE(6,5358)  HEAD
WRITE(6,5356)  HEADB
WRITE(6,6015)
5015  FORMAT(  /*50X,FUEL CONSUMPTION*/,,53X,'( GALLONS )',,,6X,14
*HI, 122(1H), 1HI, 1 J, 2(6X, 1HI, 30X, 1HI, 22X, 1HI, 22X, 1HI, 122(1H), 1HI,,6X,1HI,7A4
*J,2X,1HI,4(6X,11C,* GALS *,1HI),/6X,1HI,30X,1HI,4(22X,1HI))
1130  CONTINUE
WRITE(6,6030) (CFLIST(IC), IC=IA, IB), (KAX(I,J), J=1,4)
6030  FORMAT(6X,1HI,30X,1HI,22X,1HI,22X,1HI,22X,1HI,22X,1HI,6X,1HI,7A4
*J,2X,1HI,4(6X,11C,* GALS *,1HI),/6X,1HI,30X,1HI,4(22X,1HI))
1130  CONTINUE
WRITE(6,6031) (CFLIST(IC), IC=43,49) , (KAX(J,J), J=1,4)
6031  FORMAT(6X,1HI,30X,1HI,4(22X,1HI),/6X,1HI,122(1H),1HI,/6X,1HI,11A4
*J,2X,1HI,4(22X,1HI),/6X,1HI,7A4,2X,1HI,4(6X,11C,* GALS *,1HI),/6X,11HI,30X,1HI,4(22X,1HI),/6X,1HI,122(1H),1HI)
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C * 4 * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
CN FREEWAY POLLUTANTS, PARTICULATES & SULFUR OXIDES
C
C
LOX( 1,1,J ) = CN FREEWAY
LOX( 2,1,J ) = CN RAMP
LOX( 3,1,J ) = CFF RAMP
LOX( 4,1,J ) = DIVERSION
LOX( 5,1,J ) = T.CTALS
C
C
LOX( L,1,J ) = VEHICLE TYPE 1
LOX( L,2,J ) = VEHICLE TYPES 2 & 4
LOX( L,3,J ) = VEHICLE TYPE 3
LOX( L,4,J ) = T.CTALS
C
C
LOX( 5,3,5 ) CONTAINS POLLUTANTS BY VEHICLE TYPE & TRAVEL METHOD
C
C
LOX( L,1,1 ) = CARBON MONOXIDES
LOX( L,1,2 ) = HYDROCARBONS
LOX( L,1,3 ) = NITROGEN OXIDES
LOX( L,1,4 ) = PARTICULATES
LOX( L,1,5 ) = SULFUR OXIDES
C
C
CN FREEWAY 1 = 3
C
TVM = TOTAL VEHICLES ON FREEWAY
DO 101  I=1,3
DO 101  J=1,3
101  LOX( 1,1,J ) = FELLS( I,J ) / 1000.
C
CN FREEWAY 4 & 5
DO 102 I=1,3
D = ( TVM * TRICK( I ) ) / 1000.
LOX( 1,I,4 ) = D * TAE25( I,1 )
102 LOX( 1,I,5 ) = D * TAE25( I,2 )
A = 0.06
DO 103 I=1,3
D = TCRVH * TRICK( I )
DG 103 J=1,3
C
CN RAMP
LOX( 2,I,J ) = D * TAE26( I,J ) + A
C
CFF RAMP
103 LOX( 3,I,J ) = OFFRV * TRICK( I ) * TAE26( I,J ) * A
C
DIVERSECA
L = TASA( 1 ) / 5.
DO 104 I=1,3
D = ( CDVM * TRICK( I ) ) / 1000.
DO 105 J=1,3
105 LOX( 4,I,J ) = C * EMFCL( I,L,J )
LOX( 4,I,4 ) = C * TAE25( I,1 ) * 60.
104 LOX( 4,I,6 ) = D * TAE25( I,2 ) * 60.
C
TOTALS
DO 110 L=1,4
DO 110 I=1,3
DO 110 J=1,5
LOX( L,4,J ) = LCX( L,4,J ) + LOX( L,I,J )
LOX( 5,I,J ) = LCX( 5,I,J ) + LOX(L,I,J)
110 LOX( 1,4,J ) = LCX( 1,4,J ) + LOX( L,I,J )
WRITE(6,5358) TAD
WRITE(6,5356) TAECD
WRITE( 6,6050 )
6050 FORMAT(//,51X,'FCELLUTION EMISSIONS',//,54X,'( KILOGRAMS )',//,2H I
*,127(I=1),1HI,/,2H I,14X,1HI,3(26X,1HI),31X,1HI,/,2H I,14X,1HI,5X,
1*VEHICLE TYPE 1*,7X,1HI,4X,*VEHICLE TYPES 2 & 4*,7X,1HI,5X,*VEHICL
2E TYPE 3*,7X,1HI,9X,* TOTALS',15X,1HI,/, 2H I,14X,1HI,26X,1HI,26X
3,1HI,26X,1HI,31X,1HI,/,2H I,127(I=1),1HI,/,2H I,14X,1HI,3(26X,1HI
4),31X,1HI)
WRITE(6,6056)
6056 FORMAT(2H I,14X,1HI,3(', CC HC NO PR SC I)',', CC HC
* NC PR SC I','/,2H I,14X,1HI,3(26X,1HI),31X,1HI)
IB=1
IC=3
DO 112 L=1,4
WRITE( 6,6051 ) ( LX( IA ),IA=IB,IC ),(( LCX( L,I,J ) ),J=1,5),I=1,4)
6051 FORMAT(2H I,14X,1HI,3(26X,1HI),31X,1HI,/,2H I,14X,1HI,3(26X,1HI)
*,1HI),1EI,1X,1HI,/,2H I,14X,1HI,3(26X,1HI))
IC=IC+3
112 IB=IB+3
WRITE(6,6052) ( LX(IA),IA=13,15 ),(( LOX( 5,I,J ) ),J=1,5),I=1,4)
6052 FORMAT(2H I,14X,1HI,3(26X,1HI),31X,1HI,/,2H I,127(I=1),1HI,/,2H I
*,14X,1HI,3(26X,1HI),31X,1HI,/,2H I,14X,1HI,3(26X,1HI),5I6,1X,
11HI,/,2H I,14X,1HI,3(26X,1HI),31X,1HI,/,2H I,127(I=1),1HI)
WRITE(6,6053)
6053 FORMAT(//,,
# 10X,'CC = CARENC MONOXIDE',/,,10X,'HC = HYDROCARBONS',/,,10X,
* NO = NITROGEN C)IDES',/,,10X,'PR = PARTICULATES',/,,10X,'SO = SULFU
1R CXICES')
105
C 404C CONTINUE
C MROAD = (BLANK) CR *F* CR *M*
C NTYPE = (BLANK) CR *E* CR *U* CR *D*
C C MROAD V (BLANK) CR *R* CR *M*
C NTYPE = (BLANK) CR *E* CR *U* CR *D*
C C URBAN FREEWAY BY DEFAULT
N = 2
C RURAL FCR TAE28 WILL HAVE *R* FCR MROAD
C IF( MROAD * EG. IFURAL ) M = 1
C METERED URBAN FCR TAE28 WILL HAVE *M*
IF( MROAD * EG. MLEAF ) M = 3
C C LANE ASSIGNMENT HAS FREEWAYS BY DEFAULT
N = 0
C EXPRESSWAYS WILL HAVE *E*
IF( NTYPE * EG. IMEXY ) N = 7
C UNDIVIDED CONVENTIONAL WILL HAVE *U*
IF( NTYPE * EG. IMU ) N = 10
C DIVIDED CONVENTIONAL WILL HAVE *D*
IF( NTYPE * EG. NM ) N = 13
C C FREEWAYS BY DEFAULT IN TAE29
NODE = 12
IF( MHEIGHT * EG. ( ) GO TO 300
NODE = MHEIGHT
C DD 3C6 I = 1,6
IF( VMBLN( I ) * LE. 0. ) GO TO 3C8
VMBLN( I ) = ( VMBLN( I ) * TAE28( N+1,M ) ) / 1000000.
C 3C8 CONTINUE
C FATAL = 0.
TINJUR = 0.
PD = 0.
DD 302 I = 1,6
IF( VMBLN( I ) * LE. 0. ) GO TO 3C2
FATAL = FATAL +(VMBLN( I ) * TAE29( NODE,1 ))/100.
TINJUR = TINJUR +(VMBLN( I ) * TAE29( NODE,2 ))/100.
PD = PD +(VMBLN( I ) * TAE29( NODE,3 ))/100.
C 3C2 CONTINUE
C C MCNEY( 3,7 ) (CONTAINS ACCIDENTS & COSTS
DD 303 I=1,3
DD 302 J=1,7
C 3C2 MCNEY(I,J) = (.
MCNEY( 1,1 ) = FATAL
MCNEY( 1,3 ) = TINJUR
MCNEY( 1,5 ) = PD
C C ACCIDENT COST CR URBAN FREEWAYS BY DEFAULT IN TAE27
C
IACC = 3
IF( LSEVER * NE. ( ) IACC = LSEVER
FATAL = FATAL * TAB27( 1, IACC )
TINJUF = TINJUR * TAE27( 2, IACC )
PD = DF * TAE27( 3, IACC )

C
MCNEY( 1.2 ) = FATAL
MCNEY( 1.4 ) = TINJUR
MCNEY( 1.6 ) = DF

330 CONTINUE
NN = 11
MM = 2
IF( JTERV * NE. ( ) NA = IDVER
NA = 7
MB = 3
ACCS = ( CCVM + TAB28( NN, MM ) ) / 1000000.
C
ACCS HAS # OF ACCIDENTS PER WKM
FATS = ACCS * TAE29( NA, 1 ) / 100.
TINS = ACCS * TAE29( NA, 2 ) / 100.
TPD = ACCS * TAE29( NA, 3 ) / 100.

C
MCNEY( 2.1 ) = FATS
MCNEY( 2.3 ) = TINS
MCNEY( 2.5 ) = TPD

C
FATS = FATS * TAE27( 1, MB )
TINS = TINS * TAE27( 2, ME )
TPD = TPD * TAE27( 3, ME )
MCNEY( 2.2 ) = FATS
MCNEY( 2.4 ) = TINS
MCNEY( 2.6 ) = TPD
DO 173 I = 2, 6, 2
173 MCNEY(I, 7) = MCNEY(I, 7) + MCNEY( 1, I )
DO 174 I = 2, 6, 2
174 MCNEY(2, 7) = MCNEY(2, 7) + MCNEY( 2, I )
DO 169 I = 1, 2
169 MCNEY(3, 7) = MCNEY(3, 7) + MCNEY(I, 7)
DO 165 J = 1, 6
165 MCNEY(3, J) = MCNEY(3, J) + MCNEY(I, J)
WRITE( 6, 5358) 'HEAD
WRITE( 6, 5356) 'HEAD
WRITE( 6, 6060)

6060 FFORMAT(//, $1X,'ACCIDENTS AND COSTS',//, $4X,'($ DOLLARS')$/,$3H I *
$100(I=1),HI/*,2(3H I,14X,1HI,22X,1HI,22X,1HI,16X,1HI,/
I,3H I,14X,1HI,5X,'FATALITIES',7X,1HI,6X,'INJURIES',8X,1HI,3X,'PRO
2PERTY DAMAGE',4X,1HI,5X,'TACTALS',5X,1HI,/,2(3H I,14X,1HI,22X,1HI,
322X,1HI,22X,1HI,16X,1HI,/,3H I,14X,1HI,16X,1HI,/
100(I=1),HI/*,2(3H I,14X,1HI,22X,1HI,22
6X,1HI,22X,1HI,16X,1HI,/,3H I,100(I=1),HI/*,3H I,14X,1HI,
73(22X,1HI,16X,1HI)
WRITE( 6, 6061) ( LX(I), I = 1, 3), ( MCNEY( 1, J), J = 1, 7)

6061 FFORMAT(3H I,14X,1HI,3(22X,1HI),16X,1HI,/,3H I, 3A4,2X,1HI,3( *
$8X, 1X,'$S,X,1HI),3X,'$S,F10.0,2X,1HI,/,3H I,14X,1HI,3( 122X,1HI),16X,1HI)
WRITE( 6, 6061) ( LX(I), I = 10, 12), ( MCNEY(2, J), J = 1, 7)
WRITE( 6, 6062) ( LX(I), I = 13, 15), ( MCNEY(3, J), J = 1, 7)

6062 FFORMAT(3H I,14X,1HI,3(22X,1HI),16X,1HI,/,3H I,100(I=1),1HI,/
73(22X,1HI,16X,1HI)
*3H 1,14X,1H,3(22X,1H),16X,1H,4/3H 1,3A,4,2X,1H,3(F8,4, 1X,
1*$,F0,3X,1H),3X,*$,F10,0,2X,1H,4/2(3H 1,14X,1H,22X,1H,22X
2,1H,22X,1H,16X,1H,4/3H 1,100(1H=),1H,4/1*)
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
RETURN
END
SUBROUTINE FIRST
DIMENSION REC(234)
COMMON /DATA/ RCOSTS(3,13,6),FRATES(3,13,6),EXCCST(3,10,5),
*TAB6(3,12),TAE8(10,3),TAB7(3),TAB15(3),TAB2(4,4),
1TAB16(10,3),TAB25(12,3),EMFCL(3,12,3),TAE2E(15,3),TAB27(3,3),
2TAB26(3,3),TAE2E(3,2),FUEL(3,10,5)
C
C REAC ALL TABLES FROM TAPE FILE 10
C
C RECORC 1 HAS TABLES 2,4, + 5
READ(10) (REC(L),L=1,234)
L = 1
DO 630 I=1,3
DO 630 J=1,13
DO 631 K=1,6
RCOSTS(I,J,K) = REC(L)
631 L=L+1
630 CONTINUE
C
C RECORC 2 HAS TABLES 12,13, + 14
READ(10) (REC(L),L=1,234)
L = 1
DO 635 I=1,3
DO 635 J=1,13
DO 636 K=1,6
FRATES(I,J,K) = REC(L)
636 L=L+1
635 CONTINUE
C
C RECORC 3 HAS TABLES 9,10,11,6,8,7, + 15
READ(10) (REC(L),L=1,234)
C
L = 1
DO 652 I=1,3
DO 652 J=1,10
DO 651 K=1,5
EXCCST(I,J,K) = REC(L)
651 L=L+1
652 CONTINUE
C
L = 161
DO 653 I=1,3
DO 645 J=1,12
TAB6(I,J) = REC(L)
645 L=L+1
653 CONTINUE
C
L = 167
DO 654 I=1,10
DO 648 J=1,3
TAB6(I,J) = REC(L)
648 L=L+1
654 CONTINUE
L=217
DC 656 I = 1,3
TAB7(I) = REC(L)
TAB15(I) = REC(L+3)
655 L = L + 1
C C C
C RECREC 4 HAS TAELES 17,18,19,2,16, + 29
C READ(10) (REC(L),L=1,224)
C L = 1
DO 656 I =1,3
DO 656 J=1,10
DC 670 K=1,5
FUELCA(I,J,K) = REC(L)
670 L=L+1
656 CONTINUE
C L = 151
DO 657 I =1,4
DO 671 J=1,4
TAB2(I,J) = REC(L)
671 L=L+1
657 CONTINUE
C L = 167
DO 658 I =1,10
DO 672 J=1,3
TAB16(I,J) = REC(L)
672 L=L+1
658 CONTINUE
C L = 157
DO 659 I =1,12
DO 673 J=1,3
TAB29(I,J) = REC(L)
673 L=L+1
659 CONTINUE
C C
C RECREC 5 HAS TAELES 22,23,24,28,27,26, + 25
C READ(10) (REC(L),L=1,234)
C L = 1
DO 660 I=1,3
DO 660 J=1,12
DO 674 K=1,3
EMPOL(I,J,K) = REC(L)
674 L=L+1
660 CONTINUE
C L = 109
DO 661 I =1,15
DO 675 J=1,3
TAB28(I,J) = REC(L)
675 L=L+1
661 CONTINUE
C
L = 144
DO 662 I = 1,3
DO 676 J = 1,3
TAB27(I,J) = REC(L)
TAE26(I,J) = REC(L+5)
676 L = L + 1
662 CONTINUE
C
L = 172
DO 663 I = 1,3
DO 677 J = 1,2
TAB25(I,J) = REC(L)
677 L = L + 1
663 CONTINUE
REWIND 10
RETURN
END
### U.S. 59 (SOUTHWEST FREEWAY - HOUSTON, TEXAS INBOUND DIRECTION) ****

**FREQ3CP ANALYSIS FROM 6:00 AM TO 9:30 AM**

**AFTER CONTROL**

The following data was stored by FREQ3CP:

<table>
<thead>
<tr>
<th>VEH-HRS</th>
<th>PASS-HRS</th>
</tr>
</thead>
<tbody>
<tr>
<td>FRE ways TRAVEL TIME</td>
<td>3435.</td>
</tr>
<tr>
<td>INPUT DELAY</td>
<td>639.</td>
</tr>
<tr>
<td>OUTPUT DELAY</td>
<td>0.</td>
</tr>
<tr>
<td>TOTAL TRAVEL TIME</td>
<td>4074.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>VEH-MI.</th>
<th>PASS-MI.</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL TRAVEL DISTANCE</td>
<td>193078.</td>
</tr>
<tr>
<td>DIVERSION TRAVEL DISTANCE</td>
<td>12284.</td>
</tr>
</tbody>
</table>
APPENDIX C

ECOANA SAMPLE OUTPUT
*** U.S. 59 (SOUTHWEST FREEWAY - HOUSTON, TEXAS INBOUND DIRECTION) ****

FREQ3CF ANALYSIS FROM 6:00 AM TO 9:30 AM BEFORE CONTROL

THE FOLLOWING DATA WAS STORED BY FREQ3CF

<table>
<thead>
<tr>
<th>VEH+HRS</th>
<th>PASS+HRS</th>
</tr>
</thead>
<tbody>
<tr>
<td>FREEWAY TRAVEL TIME 7146.</td>
<td>9504.</td>
</tr>
<tr>
<td>INPUT DELAY 326.</td>
<td>512.</td>
</tr>
<tr>
<td>OUTPUT DELAY 17.</td>
<td>23.</td>
</tr>
<tr>
<td>TOTAL TRAVEL TIME 7549.</td>
<td>10041.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>VEH+MI</th>
<th>PASS+MI</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL TRAVEL DISTANCE 207660.</td>
<td>276188.</td>
</tr>
<tr>
<td>DIVERSION TRAVEL DISTANCE 0.</td>
<td>0.</td>
</tr>
</tbody>
</table>
**VEHICLE TYPES AND PERCENTAGES USED IN THIS CONTROL PERIOD**

<table>
<thead>
<tr>
<th>VEHICLE TYPE</th>
<th>PERCENTAGE</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.915</td>
<td>ALL CEG,PU (2-AXLES, 4-TIRES)</td>
</tr>
<tr>
<td>2</td>
<td>0.670</td>
<td>SL TRUCKS (OTHER THAN AECVE)</td>
</tr>
<tr>
<td>3</td>
<td>0.010</td>
<td>SEMI AND T.T. TRUCKS</td>
</tr>
<tr>
<td>4</td>
<td>0.005</td>
<td>ELSES</td>
</tr>
</tbody>
</table>
### U.S. 59 (SOUTHWEST FREeway - HOUSTON, TEXAS INBOUND DIRECTION) ####

FREGCP ANALYSIS FROM 6:00 AM TO 9:10 AM BEFORE CCEATRCL

**TRAVEL TIME DELAY AND COSTS**

<table>
<thead>
<tr>
<th></th>
<th>DELAY</th>
<th>VEHICLE &amp; DRIVER</th>
<th>PASS. ONLY</th>
<th>TOTAL COST</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>VEH-HRS</td>
<td>PASS-HRS</td>
<td>COST (DOLLARS)</td>
<td>CGST (DOLLARS)</td>
</tr>
<tr>
<td>CN FREeway</td>
<td>7145</td>
<td>2258</td>
<td>$ 45520</td>
<td>$ 14679</td>
</tr>
<tr>
<td>CN Ramp</td>
<td>386</td>
<td>127</td>
<td>2862</td>
<td>13</td>
</tr>
<tr>
<td>OFF Ramp</td>
<td>17</td>
<td>5</td>
<td>175</td>
<td>47</td>
</tr>
<tr>
<td>DIVERSION</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>TOTALS</strong></td>
<td>7548</td>
<td>2450</td>
<td>$ 53081</td>
<td>$ 14939</td>
</tr>
</tbody>
</table>
### Vehicle Operating Costs

<table>
<thead>
<tr>
<th>Vehicle Type 1</th>
<th>Vehicles 2 &amp; 4</th>
<th>Vehicle Type 3</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP Freeway</td>
<td>$ 20546</td>
<td>$ 4046</td>
<td>$ 1021</td>
</tr>
<tr>
<td>CP Ramp</td>
<td>$ 122</td>
<td>$ 22</td>
<td>$ 3</td>
</tr>
<tr>
<td>CP Ramp</td>
<td>$ 5</td>
<td>$ 1</td>
<td>$ 0</td>
</tr>
<tr>
<td>Diversions - Uniform Speed</td>
<td>$ 0</td>
<td>$ 0</td>
<td>$ 0</td>
</tr>
<tr>
<td>Diversions - Speed Changes</td>
<td>$ 0</td>
<td>$ 0</td>
<td>$ 0</td>
</tr>
<tr>
<td>Diversions - Idling</td>
<td>$ 0</td>
<td>$ 0</td>
<td>$ 0</td>
</tr>
</tbody>
</table>

**Totals**

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>*** Totals ***</td>
<td>$ 21665</td>
<td>$ 4069</td>
<td>$ 1024</td>
</tr>
</tbody>
</table>
### U.S. 59 (Southwest Freeway) - Houstons, Texas (Inbound Direction)

**FRECP Analysis From 6:00 AM To 9:30 AM**

**Before Control**

#### Fuel Consumption

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Vehicular 2 &amp; 4</th>
<th>Vehicle Type 3</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA Freeway</td>
<td>11118 GALS</td>
<td>2674 GALS</td>
<td>604 GALS</td>
</tr>
<tr>
<td>CA Ramp</td>
<td>130 GALS</td>
<td>18 GALS</td>
<td>1 GALS</td>
</tr>
<tr>
<td>CFF Ramp</td>
<td>5 GALS</td>
<td>0 GALS</td>
<td>0 GALS</td>
</tr>
<tr>
<td>Diversion - Uniform Speed</td>
<td>0 GALS</td>
<td>0 GALS</td>
<td>0 GALS</td>
</tr>
<tr>
<td>Diversion - Speed Changes</td>
<td>0 GALS</td>
<td>0 GALS</td>
<td>0 GALS</td>
</tr>
<tr>
<td>Diversion - ICLINE</td>
<td>0 GALS</td>
<td>0 GALS</td>
<td>0 GALS</td>
</tr>
</tbody>
</table>

*** Totals ***

|                 | 11253 GALS | 2652 GALS | 665 GALS | **14550 GALS** |

---
### Pollution Emissions

(Kilograms)

<table>
<thead>
<tr>
<th></th>
<th>Vehicle Type 1</th>
<th>Vehicle Types 2 &amp; 4</th>
<th>Vehicle Type 3</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>CN Freeway</td>
<td>241 870 68 24</td>
<td>225 193 28 5</td>
<td>854 876 1116 92 34</td>
<td></td>
</tr>
<tr>
<td>CN Ramp</td>
<td>312 17 2 0 0</td>
<td>167 0 0 0 0</td>
<td>419 23 2 0 0</td>
<td></td>
</tr>
<tr>
<td>CFF Ramp</td>
<td>14 0 0 0 0</td>
<td>4 0 0 0 0</td>
<td>18 0 0 0 0</td>
<td></td>
</tr>
<tr>
<td>Diversion</td>
<td>0 0 0 0 0</td>
<td>0 0 0 0 0</td>
<td>0 0 0 0 0</td>
<td></td>
</tr>
<tr>
<td>Totals</td>
<td>654 872 68 24</td>
<td>225 193 28 5</td>
<td>897 899 1118 92 34</td>
<td></td>
</tr>
</tbody>
</table>

- **CC** = Carbon Monoxide
- **HC** = Hydrocarbons
- **NO** = Nitrogen Oxides
- **FR** = Particulates
- **SO** = Sulfur Oxides

**FRECJF Analysis From 6:00 AM To 9:20 AM**

Before Control
# U.S. 59 (SOUTHWEST FREEWAY = HOUSTON, TEXAS INBOUND DIRECTION) 

**FREQ55P ANALYSIS FROM 6:00 AM TO 9:30 AM BEFORE CONSTRUCTION**

## ACCIDENTS AND COSTS

<table>
<thead>
<tr>
<th></th>
<th>FATALITIES</th>
<th>INJURIES</th>
<th>PROPERTY DAMAGE</th>
<th>TOTALS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NUMBER $ COST</td>
<td>NUMBER $ COST</td>
<td>NUMBER $ COST</td>
<td>$ COSTS</td>
</tr>
<tr>
<td>CAN FREEWAY</td>
<td>0.0051 $ 2255</td>
<td>0.1672 $ 4035</td>
<td>0.2677 $ 242</td>
<td>$ 6537</td>
</tr>
<tr>
<td>DIVERSION</td>
<td>0.0 $ 0</td>
<td>0.0 $ 0</td>
<td>0.0 $ 0</td>
<td>$ 0</td>
</tr>
<tr>
<td>TOTALS</td>
<td>0.0051 $ 2255</td>
<td>0.1672 $ 4035</td>
<td>0.2677 $ 242</td>
<td>$ 6537</td>
</tr>
</tbody>
</table>
APPENDIX D

ECOANA PROGRAM FLOWCHART
VTYPE(1-4) - Fractional parts of 4 vehicle types.

By Vehicle Types

- TABA(1-4) - Uniform approach speed
- TABB(1-4) - Number stops per veh-mi
- TABC(1-4) - Average vehicle-hrs per stop
- TABD(1-4) - Number speed changes per veh-mi
- TABE(1-4) - Average Speed reduction

HEAD - 1st line of page heading
HEADB - 2nd line of page heading
MROAD - Accident location (TAB 28)
NTYPE - Highway type (TAB 28)
MHIGHT - Highway type (TAB 29)
LSEVER - Accident location (TAB 27)
IDVER - Diversion route (TAB 28)

Subroutine first brings economic tables from storage file to dimensioned ARRAYES.

Vehicle percentages into working file.

All vehicle types 4 are included in economic tables for type 2.

TAPE 3 has data stored by FREQ3CP.

Record 1 has

- LANE(1-40) - Number of lanes per subsection
- DVM(1-40) - Diverted veh-mi travel by Time Slice
- NSEC - Number of subsections
- NTS - Number of Time Slices
- FAC - Persons per vehicle

Begin Time Slice processing.

Record 2 through record NTS has

- SPEED(1-40) - Speed (MPH)
- VC(1-40) - Volume to capacity ratio
- FVM(1-40) - Veh-mi travel on freeway
- IQUE(1-40) - Freeway queue status
- CUM(1-40) - Cumulative measures
NS = Present subsection number

Drop all decimal points of speed.

Maximum speed limit 65. MPH.

No queue = 0, partial queue = 1, total queue = -2

Determine number of lanes in this subsection (TAB 6 has V/C and Level of Service by number of lanes).

Drop all decimal places smaller than hundredth for V/C.

Convert real to integer for limit check.

Object of this DO-LOOP is to place VC in Table 6. JJ is Level of Service. (1 - 5)

Limit is L/S F(5)
J.J should have some value 1-5. If not, force to L/S F(6).

If for some reason the level of service is not found, the level of service will be set at F (or 6).

In L/S F, speed must be .LE. to 35 MPH and not greater than 35 MPH.

L/S F means a total queue in subsection and speed .LE. 35 MPH.

L/S F(6) and speed set at MAX 35 MPH.

L/S A - E.
Speed ranged from 35 MPH and greater.

In Tables 3, 4, 5 (or 12, 13, 14) a check must be made to insure that the L/S chosen (JJ) and speed range (KK) fall into a range of valid rate data.
The correct L/S column (JJ) is reached.

If speed ranged (KK) is .LT. the lowest valid rate (IB) - set ranged value to IB.

Likewise, if KK .GT. upper valid rate (IC), set ranged value to IC.

L/S column (IA) is changed and valid rate data limits changed.

L/S is checked for L/S E(5) to L/S A(1).

End of DO-LOOP.

All 5 L/S columns have been checked and no JJ/KK meeting something wrong - by pass further processing.

Entry due to KK set to 7 and JJ = 6

RATE(vehicle type) = Running Cost Rate
RAT (vehicle type) = Fuel Consumption Rate

3 vehicle types

End of DO LOOP.
RATE(IA) = RCOSTS(IA,KK,JJ)+AI* (RCOSTS(IA,KK+1,JJ)-RCOSTS(IA,KK,JJ))

RAT (IA) = FRATES(IA,KK,JJ)+AI* (FRATES(IA,KK+1,JJ)-FRATES(IA,KK,JJ))

TFVM(IA) = TFVM(IA)+FVM(NS)*RATE(IA)*VTYPE(IA)

TFCON(IA) = TFCON(IA)+FVM(NS)*RAT(IA)*VTYPE(IA)

NO

TFVM(4) = TFVM(4)+FVM(NS)*RATE(2)*VTYPE(4)

TFCON(4) = TFCON(4)+FVM(NS)*RAT(2)*VTYPE(4)

Began Veh-Miles of travel summation

TFVM(vehicle type) = Total Freeway Vehicle Miles
FVM = Freeway Veh-Mi
RATE = ¢/V-M
VTYPE = #Type/Vehicle
TFCON(vehicle type) = Total Freeway Fuel Consumption
RAT = Gals/V-M

TFVM & TFCON for Buses

Rename of speed ranged.

Pollution tables have only maximum 60 MPH
(60+6)=12

Every speed above 60 set to 60

EPOL(vehicle type, emission type) = Grams/Mile
EMPOL(vehicle type, speed ranged, emission type)
Entry for speed \(\lt\) 60 MPH and \(A_I\) non-zero.

EPOL (vehicle type, emission type)

\[ EPOL = EMPOL + AI \times (EMPOL_{\text{ja},kp+1,jb} - EMPOL_{\text{ja},kp,jb}) \]

POLLs (vehicle type, emission) = Grams

\[ \text{POLLS} = \text{POLLS} + \text{EPOL} \times FVM(\text{NS}) \times \text{TRICK}(\text{JA}) \]

TVM = Total Vehicle Miles of Travel

\[ \text{TVM} = \text{TVM} + FVM(\text{NS}) \]

VMBLN(#lanes) = Veh-Mi Travel by # lanes

Necessary because of accident analysis rate given in # lanes.

End of processing for the subsections.

End of processing for the Time Slice.
Entry after all Time Slices have been analyzed.

Put large ECOANA HEADING

Sum up all diverted veh-mi of travel from all Time Slices.

PDVM = Number pass-mi of travel on diversion route

Page HEADINGS information.

All SUMMARY information contained in last Time Slice record in variable (CUM) is printed.

Bring up new page and put heading information.

Begin processing for Travel Time calculations

TVH = Total Vehicle Hours Delay
TPH = Total Passenger Hours Delay
TORVH = Total Vehicle Hours Delay at On-Ramps
TORPH = Total Passenger Hours Delay at On-Ramps
OFFRV = Total Vehicle Hours Delay at Off-Ramps
OFFRP = Total Passenger Hours Delay at Off-Ramps

ITT arrays used to hold printout information.

T = Total Cost of Time-Freeway
TVH = Total Vehicle Hours on Freeway
VTYPE = #/Vehicle
TAB2(vehicle type, 1) = Time Cost - Driver and Vehicle
Filling printout array - Freeway.

\[ ITT(l,1) = TVH \]
\[ ITT(l,2) = TPH-TVH \]
\[ ITT(l,3) = T \]
\[ ITT(l,4) = (TPH-TVH) \times TAB2(1,2) \]
\[ ITT(l,5) = ITT(l,3) + ITT(l,4) \]

\[ T = 0, \quad I = 1 \]

\[ T = T + (TORVH \times VTYPE(I) \times TAB2(I,3)) \]

\[ I = I + 1 \]

\[ I \text{ GT } 4 \]

\[ ITT(2,1) = TORVH \]
\[ ITT(2,2) = TORPH-TORVH \]
\[ ITT(2,3) = T \]
\[ ITT(2,4) = (TORPH-TORVH) \times TAB2(I,4) \]
\[ ITT(2,5) = ITT(2,3) + ITT(2,4) \]

\[ T = 0, \quad I = 1 \]

\[ T = T + (OFFRV \times VTYPE(I) \times TAB2(I,3)) \]

\[ I = I + 1 \]

Filling printout array - On-Ramp

\[ -TAB2(VEH \text{ TYPE}, 4) = \text{ Cost of Pass. Time in Stopped Vehicle} \]

\[ (40D) \]

Filling printout array - Off-Ramp

\[ ITT(3,1) = OFFRV \]
\[ ITT(3,2) = OFFRP-OFFRV \]
\[ ITT(3,3) = T \]
\[ ITT(3,4) = ITT(3,2) \times TAB2(1,4) \]
\[ ITT(3,5) = ITT(3,3) + ITT(3,4) \]

\[ APOC = TPH/TVH \]
\[ DPM = APOC \times DWM \]
\[ A = DWM/TABA(1) \]

\[ T = 0, \quad I = 1 \]

\[ T = T + (A \times VTYPE(I) \times TAB2(I,1)) \]

\[ I = I + 1 \]

\[ I \text{ GT } 4 \]

\[ T = \text{ Total Cost of Delay on Diversion Route} \]
B = Pass Hours of Delay on Diversion Route

Filling printout array - Diversion

Creating vertical sums.

Printing Travel Time Summary Information.
End of Travel Time Costs Analysis.

Beginning of Operating Cost Analysis.
IAX(7,4) used as printout array for Operating Costs
KAX(7,4) used as printout array for Fuel Usage

Combine veh type 4 with veh type 2 veh miles travel.

Beginning of DO-LOOP.

IAX(1, veh type) = Cost ($/veh mi) Freeway
TAB7(veh type) = Cost Idling ($/veh-hr)
IAX(2, veh type) = Cost $ for Stopped - On-Ramp
IAX(3, veh type) = Cost $ for Stopped - Off-Ramp
TABA = Approach Speed Diversion Route
C = Diverted veh mi by type
IAX(4, veh type) = Cost $Uniform Speed - Diversion
(KAX(4, veh type) = Grams Fuel Used - Uniform Speed Diversion
B = Speed (MPH) Due to Change
Tables 9, 10, 11 have speed changes in 10 MPH increments.

If speed change other than 10 MPH find fractional part there of.

Is speed changed to equal to speed in Tables 9, 10, 11.

Is speed changed to .LT. speed in Table

Keep moving speed search to right in Tables 9, 10, 11 until find speed range.

Initial speed and/or speed changed to greater than 50 MPH - error caused by improper Tables TABA-TABE definitions

Speed changed to equals exactly that in Tables 9, 10, 11.

RT = Cost (¢) for this vehicle type - Excess Running
RRT = Fuel used (grams) for this vehicle type - Excess Running
EXCOST(veh type, speeds, speed change) = ¢/cycle
FUELCN(veh type, speeds, speed change) = gals/cycle
Speed changed not on 10 MPH increments

TABD(veh type) = # speed changes/mile
IAX(5,veh type) = Cost ($) due to speed changes - Diversion
(KAX(5,veh type) = Gals fuel used - speed changes - Diversion
(TAX(6,veh type) = Cost ($) due to idling - Diversion
(KAX(6,veh type) = Gals fuel used - idling - Diversion

End of DO-LOOP.
Creating horizontal and vertical sums.

Bring up new page and print heading information.

Write Operating Costs Summaries.

End Operating Cost Analysis.

Begin Fuel Consumption Analysis.

Combine Veh-Type 4 with type 2.

Begin DO-LOOP.

The majority of KAX array created during operating cost analysis.

Create horizontal and vertical summaries.
Bring up new page and write heading information.

Printout Fuel Consumption Summaries.
End of Fuel Consumption Analysis.

Start of Emissions Analysis

LOX(1, veh-type, pollutants) = Kilograms ON FREEWAY
Pollutant = 1 Carbon Monoxides
         = 2 Hydrocarbons
         = 3 Nitrogen

I = Veh-Type
J = Pollutants

Pollutant = 4 Particulates
Pollutant = 5 Sulfur Oxides

A = conversion factor 60 min
    1 hr * 1 kg. 1000 g.

LOX(2, veh-type, pollutant) = Kilograms ON RAMP
TAB26(veh-type, pollutant) = Grams/Minute Idling Rates
LOX(3, veh-type, pollutant) = Kilograms OFF RAMP
Range the approach speed on Diversion Route into 5 MPH increment.

LOX(4, Veh-Type, Pollutant) = Kg. due to Uniform Speed-Diversion Route

Same as above except for Pollutants 4 & 5.

Create vertical and horizontal sums in output array LOX.
Bring up new page and print heading information

Write the Pollution Emissions Summaries
End of Pollution Analysis

Start of Accident Analysis

MROAD = 1 Rural  
= 2 Urban  
= 3 Urban Metered  

TABLE 28

NTYPE = 0 Freeways  
= 7 Expressways  
= 11 Undivided  
= 13 Divided  

TABLE 28

MHIGHT = 1 - 12 for Highway Type TABLE 29

VMBLN = Veh-Miles by # lanes ON Freeway
TAB28(Highway-Type,Location) = Accident rate per million veh-miles.

VMBLN(I) = (VMBLN(I) * TAB28(N+I,M)) / 1000000.
ECOANA (cont.)

YES

FATAL = 0.
TINJUR = 0.
PD = 0.
I = 1

FATAL = FATAL + (VMBLN(I)*TAB29(NODE,1))/100.
TINJUR = TINJUR + (VMBLN(I)*TAB29(NODE,2))/100.
PD = PD + (VMBLN(I)*TAB29(NODE,3))/100.

I = I + 1

NO

DO 3031 = 1,3
DO 3033 = 1,7
303 MONEY(I,J) = 0.

MONEY(1,1) = FATAL
MONEY(1,3) = TINJUR
MONEY(1,5) = PD
IACC = 3

LSEVER .NE. 0

FATAL = FATAL *TAB27(1,IACC)
TINJUR = TINJUR*TAB27(2,IACC)
PD = PD *TAB27(3,IACC)
MONEY(1,2) = FATAL
MONEY(1,4) = TINJUR
MONEY(1,6) = PD

NN = 11
MM = 2

IACC = LSEVER

YES

S136

MA = 7
MB = 3
ACCS = (DDVM*TAB28(NN,MM))/10^6
FATS = ACCS*TAB29(MA,1)/100.
TINJS = ACCS*TAB29(MA,2)/100.
TPD = ACCS*TAB29(MA,3)/100.
MONEY(2,1) = FATS
MONEY(2,3) = TINJS
MONEY(2,5) = TPD

CC

16

MONEY(1,1) = Total # of Deaths
(1,3) = Total # of Injuries
(1,5) = Total # of Property Damage Acc
FREeway

LSEVER = 1 Rural
2 Suburban
3 Urban

TABLE 27

ON

MONEY(2,1) = Total # of deaths on Diversion Routes
(2,3) = Total # of Injuries on Diversion Routes
(2,5) = Total # of property damage on diversion Routes

MA chosen for Urban 2 lane roadway Table 29 for Diversion.
MB chosen for Urban Table 27 for Diversion
FATS = FATS * TAB27(1, MB)
TINJS = TINJS * TAB27(2, MB)
TPD = TPD * TAB27(3, MB)
MONEY(2, 2) = FATS
MONEY(2, 4) = TINJS
MONEY(2, 6) = TPD
I = 2

MONEY(1, 7) = MONEY(1, 7) + MONEY(1, 1)
MONEY(2, 7) = MONEY(2, 7) + MONEY(2, 1)

I = I + 2

NO

I.GT.6

YES

I = 1

MONEY(3, 7) = MONEY(3, 7) + MONEY(I, 7)

J = 1

MONEY(3, J) = MONEY(3, J) + MONEY(I, J)

J = J + 1

NO

J.GT.6

YES

I = I + 1

YES

I.GT.2

NO

WRITE HEADINGS

WRITE ACCIDENT COST SUMS

END

MONEY(2, 2) = Cost Deaths on Diversion
(2, 4) = Cost Injuries on Diversion
(2, 6) = Cost Property Damage on Diversion

Creating Horizontal and Vertical Sums.

Bring up new page and print heading information.

Write the Accident Costs Summaries.

End of Accident Analysis and Program
SUBROUTINE FIRST

Subroutine Entry.

Rewind Tape.

Read Record 1,234 units long into array REC

Start DO-LOOP where RCOSTS(3,13,6) is filled.

TABLE 3
A B C D E F
5 10 15 ... 65

RCOSTS(I,J,K) filled with Tables 3, 4, 5 (Operating Costs)

Read Tape.

Record 2 has tables 12, 13, 14 (fuel consumption)
Subroutine First (Cont.)

1
L = 1
I = 1

J = 1
K = 1

FRATES(I,J,K) = REC(L)

L = L + 1
K = K + 1

NO
K.GT.6
YES
J = J + 1

NO
J.GT.13
YES
I = I + 1

NO
I.GT.3
YES

READ

10

REC(L), L = 1,234

L = 1
I = 1

J = 1
K = 1

EXCOST(I,J,K) = REC(L)

L = L + 1
K = K + 1

NO
K.GT.5
YES
J = J + 1

I = I + 1
YES
J.GT.10
NO

NO
I.GT.3
YES

FRATES(I,J,K) filled with Tables 12, 13, 14 (fuel consumption rates)

Read Tape.

Record 3 has Tables 9, 10, 11, 6, 8, 7, 15.

EXCOST(I,J,K) filled with Tables 9, 10, 11 (Excess Running Costs of Speed Cycle Changes)
Subroutine First (Cont.)

L = 151
I = 1

J = 1

TAB6(I,J) = REC(L)

L = L + 1
J = J + 1

NO

J.GT.12

YES

I = I + 1

TAB7(I) = REC(L)
TAB15(I) = REC(L+3)

L = L + 1
I = I + 1

NO

1.GT.3

YES

READ 10

REC(L), L = 1,234

B

8

L = 218
I = 1

YES

1.GT.3

NO

TAB8(10,3)
(Running costs on city streets, by vehicle-type and uniform speed)

TAB8(3,12)
(Freeway volume to capacity ratios, by lanes and level of service)

Read Tape.

Record 4 has Tables 17, 18, 19, 2, 16, 29.
Subroutine First (Cont.)

FUELCO(3,10,5) (Excess fuel consumption rates for speed cycle changes by vehicle-types)

TAB2(4,4) (Value of time by vehicle-type and driving mode)

TAB16(10,3) (Fuel consumption rates on city streets, by vehicle-type and uniform speed)
Subroutine First (Cont.)

1. \( L = 197 \)
2. \( I = 1 \)
3. \( J = 1 \)
4. \( \text{TAB29}(I,J) = \text{REC}(L) \)
5. \( L = L + 1 \)
6. \( J = J + 1 \)
7. \( \text{READ 10} \)
8. \( \text{REC}(L), L = 1,234 \)
9. \( I = 3 \)
10. \( \text{TABLE 24} \)
11. \( I = 2 \)
12. \( \text{TABLE 23} \)
13. \( I = 1 \)
14. \( \text{TABLE 22} \)
   - \( \text{CO NC NO} \)
   - 5
   - 10
   - 15
   - \( \ldots \)
   - 50
15. \( \text{J=12} \)
16. \( \text{EMPOL}(3,J,K) = \text{REC}(L) \)
17. \( L = L + 1 \)
18. \( K = K + 1 \)
19. \( \text{K.GT.3} \)
20. \( J = J + 1 \)
21. \( I = I + 1 \)
22. \( \text{J.GT.12} \)
23. \( \text{I.GT.3} \)
24. \( 0 \)
25. \( 6 \)

\text{TAB29}(12,3) \) (Percentage distribution by Accident Severity).

Read Tape.

Record 5 has Tables 22, 23, 24, 28, 27, 26, 25

\text{EMPOL}(3,12,3) \) (Pollution emissions of vehicle-types, by pollutant and average speed)
Subroutine First (Cont.)

1. \( L = 109 \)
2. \( I = 1 \)
3. \( J = 1 \)
4. \( \text{TAB28}(I,J) = \text{REC}(L) \)
5. \( L = L + 1 \)
6. \( J = J + 1 \)
7. \( \text{IF } J \geq 3 \text{ THEN } I = I + 1 \)
8. \( \text{IF } I \geq 15 \text{ THEN RETURN} \)
9. \( L = 154 \)
10. \( I = 1 \)
11. \( J = 1 \)
12. \( \text{TAB27}(I,J) = \text{REC}(L) \)
13. \( \text{TAB26}(I,J) = \text{REC}(L + 9) \)
14. \( L = L + 1 \)
15. \( J = J + 1 \)
16. \( \text{IF } J \geq 3 \text{ THEN } I = I + 1 \)
17. \( \text{IF } I \geq 3 \text{ THEN RETURN} \)
18. \( L = 172 \)
19. \( I = 1 \)
20. \( J = 1 \)
21. \( \text{TAB25}(I,J) = \text{REC}(L) \)
22. \( L = L + 1 \)
23. \( J = J + 1 \)
24. \( \text{IF } J \geq 2 \text{ THEN } I = I + 1 \)
25. \( \text{IF } I \geq 3 \text{ THEN RETURN} \)

- \( \text{TAB28}(15,3) \) (Motor vehicle accident rates; by highway-type and location of accident)
- \( \text{TAB27}(3,3) \) (Motor vehicle accident unit costs per reported accident by severity and location)
- \( \text{TAB26}(3,3) \) (Idling pollution rates by vehicle type and type of pollutant)
- \( \text{TAB25}(3,2) \) (Particulates and sulfur oxides pollution rates by vehicle types)
### METRIC CONVERSION FACTORS

#### Approximate Conversions to Metric Measures

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<th>Symbol</th>
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<th>Multiply by</th>
<th>To Find</th>
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#### Approximate Conversions from Metric Measures

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<tr>
<td>ft³</td>
<td>cubic meters</td>
<td>35</td>
<td>cubic feet ft³</td>
</tr>
<tr>
<td>yd³</td>
<td>cubic yards</td>
<td>1.3</td>
<td>cubic yards yd³</td>
</tr>
</tbody>
</table>

#### TEMPERATURE (exact)

<table>
<thead>
<tr>
<th>°F</th>
<th>Fahrenheit temperature</th>
<th>°C</th>
<th>Celsius temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>5/9 (after subtracting 32)</td>
<td></td>
<td>9/5 (then add 32)</td>
<td></td>
</tr>
</tbody>
</table>

°F 9/5 (then add 32)  
32°C  
°F

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SO Catalog No. C13.10:286.