REFERENCES

1. Highway Capacity Manual. HRB, Special Rept. 87, 1965.
2. Compilation of Air Pollution Emission Factors. U.S. Environmental Protection Agency, Rept. AP-42, 2nd Ed., Supplement 5, Dec. 1975.

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Abridgment

Line Source Emissions Modeling

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The objective of this paper is to describe the development of the line source sorting model NETSEN II and its use in conjunction with the automobile exhaust emissions modal analysis model of the U.S. Environmental Protection Agency (EPA) (1). Speed-profile analogies from the Regional Air Pollution Study of the St. Louis air quality control region (AQCR), developed for use in the modal emissions model, are used.

MODAL EMISSIONS MODEL

The automobile exhaust emissions modal analysis model developed by the Calspan Corporation for EPA was designed to calculate the amounts of hydrocarbons (HC), carbon monoxide (CO), and oxides of nitrogen (NO_x) emitted by individual automobiles or groups of automobiles stratified by age and geographic location (1). Emission rates were deduced from surveillance tests performed on a test fleet of 170 automobiles in six American cities at varying altitudes. Emissions were output for any given second-by-second driving sequence within a speed range of 0 and 96.8 km/h (0 and 60 mph). The model developers recognized that the emissions response of an automobile depends on the speed profile experienced by its occupants as they travel from origin to destination. The developers also recognized that different light-duty vehicles have separate emissions responses for the same speed, acceleration, and deceleration profiles. The model does not treat meteorological or transport processes. It specifically details the distribution of emissions along a user-defined highway link and computes the total CO, HC, and NO_x contributions to the atmosphere from the highway source.

The inputs into the EPA modal emissions model include both traffic and emissions data. The traffic inputs are representative second-by-second speed profiles on the defined line sources, the number of automobiles assignable to the particular speed profiles on the defined line sources, their age distribution by model year, and the relative altitude at which they are operated. The emission parameters include emission-rate coefficients that are specific to speed profiles and are either user supplied or produced by default in the computer program itself. Because of cost and time, unless the user has a vehicle fleet and dynamometer testing equipment, the default emission-rate coefficients should be used. The emission-rate coefficients supplied by the model do not include the effects of cold starts, which generate a sizable portion of automobile emissions. No deterioration factors are applied, but they are indirectly incorporated in that the vehicle fleet used in the surveillance program reflected age and maintenance effects.

The modal emissions model estimates actual CO and HC emissions within 13 percent but only predicts NO_x within 80 percent. Because the model was developed for a single vehicle fleet, its ability to reproduce emissions from additional vehicle fleets was also tested. The model replicated performance to within 30 percent. Although this error seems significant, the input data from the model's own original vehicle fleet could not be replicated any better a second time. Both microscale and mesoscale emission-analysis methods have this drawback.

The modal emissions model is capable of operating at a truly microscale level. It allows for highly specific analysis of the emissions effects of traffic congestion. In using the model for this purpose, however, the user must define the established regional highway network—a major undertaking for a region the size of St. Louis. In addition, second-by-second speed-profile data and localized data on the emission response of vehicles must be collected either in the field or by development of a systematic scheme of speed-profile analogies for line sources.

DESCRIPTION OF NETSEN II MODEL

The network sensitivity model NETSEN II is an updated version of NETSEN, which was designed in an EPA study (2). The updated version has additional variables and subroutines and the ability to test for the following roadway characteristics in defining a line source: average daily traffic, five types of special topography, four types of capacity alterations, eight types of sensitive land uses, five types of activity centers, five types of progressive movement, channelization, functional classification, link distance, peak speed differences, truck and bus volumes, and volume/capacity (V/C) ratio.

Definition of a Line Source

The definition of a line source hinges on the capability of analyzing the highway network and its traffic and design attributes at varying levels of detail, and that capability depends on the availability of data and the level of spatial refinement sought by the user for input into pollution models such as the modal emissions model. Thus, if adequate data are available, the user has a range of capabilities, from developing a very refined set of descriptors—termed ultimate line sources—to developing a very unrefined set of descriptors—termed gross line sources. The following basic definition of a line source was used in the development of the NETSEN II program: "A line source is the smallest segment of inventoried roadway depictable with a given specific set of attributes for the roadway" (2).

NETSEN II was designed to allow the user to select those links that have relevant characteristics at a level of refinement determined by the user.

Logic

The model begins by reading control cards that define the attributes for which the model is to test the line sources. Next, a line source from the roadway inventory link file is input into the model. The model then begins a series of sequential tests of the line source for the attributes previously defined in the control card. If the line source passes all the tests, it is output for further computation of its emissions and another line source is read in. If the line source fails an attribute test, testing of that line source ceases and the program goes back and inputs a new line source. When all of the line sources from the roadway inventory link file are tested, the set of line sources that passes the tests is ready for use in the modal emissions model.

Two specific points about NETSEN II are of major importance:

1. The network can be tested at any relevant level of data attributes. These levels can run from very gross descriptions (testing for all freeway links) to a very refined set of descriptors [testing for links that have a freeway classification with, for example, average daily traffic (ADT) of 40 000 to 45 000 vehicles/d and rolling topography].
2. The level of attribute refinement the user chooses to test may vary with the detail of the data available. The level of refinement of the data may also vary according to what the user determines is necessary for the study of emissions. Thus, there is complete flexibility in the behavioral aspects of the network with respect to the estimation of emissions.

SPEED-PROFILE ANALOGIES

A critical element in this research has been the development of a methodology for constructing speed-profile analogies for roadway segments for which no speed-profile data have been collected. Development of such analogies is necessary if the modal emissions model is to compute emissions for the entire AQCR network.

Speed-Profile Data

A basic item of data for this research was a study of speed characteristics for the St. Louis region conducted by the East-West Gateway Coordinating Council under contract to the Federal Highway Administration and EPA. The study provided second-by-second speed data over a variety of roadways on 16 different circuitous routes in the St. Louis region. Each roadway segment was run a total of 12 times. Speed-profile data existed for approximately 70 to 80 percent of the total kilometers of freeway in the St. Louis AQCR, but there were adequate speed-profile data for only about 50 percent of the arterial roadways.

Development of Methodology

Two basic approaches to analogy development were explored. The first was to attempt to construct second-by-second speed profiles for roadway segments for which data had not been collected by locating a segment of roadway that has traffic-flow parameter values similar to those of the segment in question. The traffic-flow parameters most indicative of emissions behavior are hourly volume, V/C ratio, average speed, and acceleration noise (defined as the standard deviation of velocity about the mean). Because a speed profile has an associated average speed and acceleration noise, it would be possible to physically construct a second-by-second speed profile of the appropriate length for the roadway segment without speed-profile data. But there are two basic problems with this approach. First, the data on which the analogy is based are not uniformly available and, if they were available, would probably not be applicable to peak-hour, worst case conditions. Second, the analogy between the segment with speed-profile data and the segment without speed-profile data is made on the basis of parameters such as peak-hour average speed and V/C ratio, but a single speed profile is only a single sample from some supposedly stable distribution of possible profiles on a segment. There does not appear to be any direct means of aggregating numerous speed-profile samples over the same segment. When this problem is combined with the problem of specifying what constitutes a peak-hour average speed or V/C ratio, the technique loses much of its desirability.

The second technique explored, and the one ultimately used for arriving at analogies, begins by cross classifying every line source segment in the entire network by three relevant and available indicators of traffic-flow quality: ADT, V/C ratio, and functional class of roadway. These three parameters imply much of the operational nature of a particular roadway segment. For purposes of this research, four appropriate ADT ranges were selected for each of three functional classes. In addition, four ranges of V/C ratio were selected that yielded 48 discrete roadway classifications; coupling these classifications with the use of peak and off-peak descriptors increased the number of possible classes of roadway operation to 96. For each of the 48 possible roadway classifications, a segment was sought for which plausible speed-profile data existed. In actuality, only 29 of the 48 classes currently exist in the St. Louis AQCR network. Two speed profiles were selected for each of these 29 base segments—one that represented off-peak operating conditions and one that represented peak-hour operating conditions.

Peak and off-peak speed profiles for each segment were run through the modal emissions model with a reasonable vehicle mix to arrive at unadjusted emission rates for each of the two profiles and for each of the 29 roadway classes. These rates were then adjusted for an ambient temperature of 29°C (85°F) and 10 percent cold operation by using EPA adjustment factors (3). In the emissions computation software, a set of line sources that pass the parameter tests of NETSEN II are checked to see which of the possible roadway classes they are contained in, and the appropriate emission rate is applied for the hour of interest.

This second methodology allows the use of appropriate traffic-engineering and emissions inputs to the emissions computation process but makes full use of available data. Based on the number of desired categories for each of the parameters, the classification scheme can be as refined as the user desires and the data will allow.

EMISSIONS SOFTWARE SYSTEM AND EXAMPLE OUTPUT

The software system designed to compute emissions for line sources consists of three basic programs. The first is the network sorting model, NETSEN II, the inputs to which consist of appropriate user control cards for selection of line sources and the network roadway inventory. The output of NETSEN II is a set of line sources that meet specified characteristics. These line sources are then passed to the ECOMP program, which computes the line source emissions by using these outputted line sources as the first input.

The second input to the ECOMP program is the emission rates computed by the modal emissions model. The modal emissions program uses the emission coefficients supplied by the model and the peak and off-peak profiles from each of the 29 roadway segments identified as representative of each of the analogy classes. The results of the modal emissions program are adjusted for 20 percent cold operation and an ambient temperature of 25°C (75°F) and are used as input in the ECOMP program for light-duty vehicles. The ECOMP program uses different modal emission rates for peak and off-peak operations.

The third set of inputs to the ECOMP program is the emission factors for trucks, which are computed from EPA publication AP-42 (3). For light-duty trucks, heavy-duty gasoline-powered vehicles, and heavy-duty diesel-powered vehicles, separate emission factors were determined for calendar year 1975 (3) by using an average speed of 48 km/h (30 mph), an ambient temperature of 25°C, and, for light-duty trucks, 10 percent cold operation. These emission rates were applied to hourly volumes for these three classes of trucks based on an assumed distribution among all vehicles of 5 percent light-duty, 4 percent heavy-duty diesel-powered, and 1 percent heavy-duty gasoline-powered trucks.

The fourth input to the ECOMP program is a control card to determine the total percentage of all trucks, the hours of the day for which emissions data are desired, and whether or not emissions are to be added to the grid totals or stored separately as hourly totals. Emissions of SO_2 and particulates were computed by ECOMP based on emission rates for each of the four types of vehicles for the appropriate hourly volumes under consideration. These SO_2 and particulate rates were taken from EPA publication AP-42 (3).

The outputs from the ECOMP program consist of three possible types. First, the program outputs on the printer an hourly summary for each line source that consists of geographic information, roadway volumes, functional roadway class, and emissions totals for the five types of pollutant. The second type of output is similar to the first except that it is stored on tape for later use. The third type of output is the totaling of all line source emissions for each grid. The last two outputs are optional and may be specified by the user.

In a freeway example that used NETSEN II, the line sources located by the program were freeways with ADTs in the range of 60 000 to 80 000 and V/C ratios in the range of 0.60 to 0.90. Fifty-seven line sources representing 49.2 km (30.5 miles) of roadway and 3.5 million vehicle·km (2.2 million vehicle miles) of travel fit this description. The ECOMP program computed total emissions for this set of line sources for the hours of 4:00 to 6:00 p.m., which resulted in 271.8 kg of HC, 4397.1 kg of CO, 367.9 kg of NO_x, 14.8 kg of SO_2, and 36 kg of particulates.

Another example consisted of all line sources that were principal arterials with ADTs in the range of 10 000 to 20 000 and with V/C ratios in the range of 0.30 to 0.60. These specifications resulted in 114 line sources representing 81.9 km (50.8 miles) of roadway and 1.04 million vehicle·km (0.6 million vehicle miles) of travel. The emissions for this set of line sources were computed for the 8:00 to 9:00 a.m. period and resulted in 97 kg of HC, 1334.1 kg of CO, 247.3 kg of NO_x, 2.6 kg of SO_2, and 6.4 kg of particulates.

CONCLUSIONS AND RECOMMENDATIONS

The data analysis and modeling efforts of the project yielded several tangible outputs:

1. The updated and refined version of the NETSEN model, NETSEN II, which is capable of defining line sources at any level of data refinement and inputting such line sources to a variety of emissions models, in this particular case of integrating with the modal emissions model by using the speed profile as the key linking variable;
2. Development of a truly microscale emissions estimation model, which allows emissions to be analyzed as a function of highly localized traffic operating conditions and roadway descriptions, through integration of NETSEN II and the modal emissions model;
3. The ability to develop accurate analogies of speed-profile and emission characteristics for links that do not possess speed-profile field data (these analogies are built by appropriate analysis of cross-classified links possessing speed-profile data, over a range of ADT, V/C ratio, and functional class); and thus
4. An exhaustive and accurate statement of emissions obtained from line sources in the St. Louis AQCR [encompassing sources, descriptions, attributes, and total emissions for CO, HC, NO_x, SO_2, and particulates from 2209 km (1370 miles) of roadway].

The following areas require further research:

1. Very refined measurement of second-by-second speed profiles for an exhaustive set of geometric design-traffic operations combinations, such as one-way streets, progressive signalization systems, links crossing intersections with channelized or signalized turn lanes (i.e., development of a "case book" of speed-profile typology, possibly for cities of varying size and urban characteristics, much as the Highway Capacity Manual classifies conditions for design and capacity analysis); and
2. The potential capability for studying speed-profile and emission characteristics by using speed and delay-related traffic-flow theories such as those for acceleration noise, freeway shock-wave phenomena, and queuing.

REFERENCES

1. Automobile Exhaust Emission Modal Analysis Model. U.S. Environmental Protection Agency, 1974.
2. Methodology for the Determination of Emission Line Sources. U.S. Environmental Protection Agency, Feb. 28, 1975, p. 40.
3. Compilation of Air Pollutant Emission Factors. U.S. Environmental Protection Agency, AP-42, Supplement 5, Dec. 1975.

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