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AN INTERIM REPORT ON MOTOR VEHICLE EMISSION ESTIMATION

U.S. ENVIRONMENTAL PROTECTION AGENCY

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ON
MOTOR VEHICLE EMISSION ESTIMATION

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ABSTRACT

New gasoline-powered motor vehicle (light-duty and heavy-duty) emission factors, which supersede those in EPA Publication AP-42 (Compilation of Air Pollutant Emission Factors) for carbon monoxide, hydrocarbons, and nitrogen oxides, are presented based on a recent nationwide study of over 1,000 automobiles. These factors account for such variables as the model year, deterioration, and average speed differences. Sample calculations are included to illustrate the method of obtaining emission factors that are most representative of a particular region, vehicle mix (age and type), and average speed.

Methods are given for obtaining estimates of area-wide (region or subregion) emissions attributed to gasoline-powered vehicles. Local traffic survey data, Department of Transportation studies, and other private surveys are used. The emissions contribution from other mobile sources is calculated using the values in Compilation of Air Pollutant Emission Factors. The new emission factors allow a more accurate computation of air quality whether a proportional ("rollback") or a diffusion model is used. They also permit calculation of the differences between alternative transportation systems without determining the absolute values of air quality levels.

These methods have been developed specifically for use by state and local air pollution control agencies preparing transportation control measures and evaluating alternatives.

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INTRODUCTION

State Implementation Plans submitted on or before January 30, 1972, contained plans for meeting national primary ambient air quality standards within 3 years after the date of their approval by the EPA Administrator on May 31, 1972 (40 CFR Part 51). A review of the plans indicated that many states would not meet national ambient air quality standards even with expected emission reductions from emission control devices on late model automobiles (90 percent reduction from 1970 allowable emissions of carbon monoxide and hydrocarbons by 1975, and 90 percent reduction of 1971-model-year average emissions of nitrogen oxides by the 1976 model year). It was recognized that available data were not sufficient to permit states to develop meaningful transportation control schemes or to predict the impact of such schemes on air quality. Consequently, the states were advised to supplement their general transportation control measures, where required, by detailed strategies with a timetable for compliance and to submit these plans on or before February 15, 1973.

The air quality levels resulting from the Federal Motor Vehicle Control Program were approximated by many states that used the normalized pollutant emission rates and reduction ratios presented in Appendix I to 40 CFR 51. Some states prepared transportation-source emission inventories based on factors and methods from the National Air Pollution Control Administration,[1] McGraw and Duprey's Compilation of Emission Factors,[2] and more recently, EPA's Compilation of Air Pollutant Emission Factors.[3] These factors were all nationwide averages and were used with nationwide estimates of vehicle age mix and vehicle miles traveled (VMT). A few large metropolitan areas such as Washington, D.C. and Chicago were able to show substantially lower gasoline-powered motor vehicle emissions because the local vehicle-age mix was biased more toward late-model automobiles (with lower emissions) than was the nationwide age mix. Such late-model vehicle emission factors developed above were extrapolations from early-controlled vehicles, and it was believed their absolute values and variation with speed were subject to error. Thus, a study of nearly 1,000 light-duty vehicles was undertaken covering six major U.S. cities.[4] A somewhat more limited study is underway for heavy-duty vehicles.[5] Data from these projects form the basis of the revised emission factors that will allow a more accurate prediction of the contribution of gasoline-powered vehicles to transportation-related air pollution levels. The emission factors for other mobile sources should be taken from the latest revision of EPA's Compilation of Emission Factors.[3]

Several approaches are presented for calculation of motor vehicle emissions that are based on the availability of mobile source data, i.e., traffic, vehicle age mix, vehicle miles traveled, average speeds, and miles of roadway types. The use of relatively simple proportional models (rollback) does not require the detailed data of a sophisticated air quality diffusion model. Gasoline motor vehicle emission calculation sheets with typical sample calculations of motor vehicle emission factors are included in the appendices of this report for a better understanding of the technique.

1. EMISSION FACTORS FOR GASOLINE-POWERED MOTOR VEHICLES

Emission factors published by the Federal Government in the past have, as a general rule, been "average" values based on nationwide statistics. Compilation of Air Pollutant Emission Factors[3] contains emission factor information by calendar year up to and including 1975. These data were generated by using results of vehicle emission tests on the 1972 Federal Certification Test Procedure (Federal Register, November 10, 1970) and by using nationwide statistics for variables such as vehicle distribution by model year and the fraction of total vehicle miles attributed to heavy-duty vehicles (>6,000 pounds gross vehicle weight). As the motor vehicle population becomes more highly influenced by controlled vehicles, the model year mix becomes increasingly important in emission factor calculation. The general concept of "city specific" emission factors is essential for accurate assessment of gasoline-motor vehicle emission. For this reason, the technique outlined below is recommended in lieu of that used to obtain average nationwide emission factor values.

DEFINITIONS

The following definitions apply to terms that are used in this document:

Light-duty vehicle -- any motor vehicle designated primarily for transportation of property and rated at 6,000 pounds gross vehicle weight (GVW) or less, or designated primarily for transportation of persons and having a capacity of 12 persons or less.

Heavy-duty vehicle -- any motor vehicle designated primarily for transportation of property and rated at more than 6,000 pounds GVW or designated primarily for transportation of persons and having a capacity of more than 12 persons.

1975 Federal Test Procedure -- the Federal motor vehicle emission test as described in the Federal Register, July 2, 1971.

Deterioration factor -- the ratio of the pollutant (p) exhaust factor at x miles to the p exhaust emission factor at 4,000 miles.

Model year mix -- the distribution of vehicles registered by model year expressed as a fraction of the total.

Speed adjustment factor -- the ratio of the p exhaust emission factor at speed x to the p exhaust emission factor as determined by the 1975 Federal Test Procedure (19.6 miles per hour).

Fuel evaporative emissions -- vaporized fuel emitted into the atmosphere from the fuel system of a motor vehicle.

High-altitude emission rates -- substantial changes in emission rates occur in most gasoline-powered vehicles due to increases in altitude. These changes are caused by fuel metering enrichment due to atmospheric pressure variations with altitude. To date, no relationship between mass emissions and altitude has been developed. Tests have been conducted, however, at near sea level and at approximately 5,000 feet above sea level. Since the majority of U.S. urban areas at high altitude are close to 5,000 feet, an arbitrary value at 3,500 feet and above is used to define high-altitude cities.

Calendar year -- a cycle of 365 or 366 days divided into 12 months beginning with January and ending in December.

Model year -- a motor vehicle manufacturer's annual production period. If a manufacturer has no annual production period the term "model year" means "calendar year."

Crankcase emissions -- airborne substance emitted to the atmosphere from any portion of the crankcase ventilation or lubrication systems of a motor vehicle.

Oxides of nitrogen -- the sum of the nitric oxide and nitrogen dioxide contaminants in a gas sample if the nitric oxide is in the form of nitrogen dioxide.

1972 Federal Test Procedure -- the Federal motor vehicle emission test described in the Federal Register, November 10, 1970.

GENERAL EQUATIONS

The calculation of emission factors for carbon monoxide, hydrocarbons, and oxides of nitrogen from light- and heavy-duty vehicle exhaust can be expressed mathematically as:

$$e_{np} = \sum_{i=n-12}^{n+1} c_{ip}\, d_{ipn}\, m_{in}\, s_{ip}$$

where:

e_{np} = emission factor in grams per vehicle mile for calendar year n and pollutant p

c_{ip} = the 1975 Federal Test Procedure emission rate for pollutant p (grams/mile) for the i^{th} model year, at low mileage

d_{ipn} = the controlled vehicle pollutant p emission deterioration factor for the i^{th} model year at calendar year n

m_{in} = the weighted annual travel of the i^{th} model year during calendar year n (the determination of this variable involves the use of the vehicle model year distribution)

s_{ip} = the weighted speed adjustment factor for exhaust emission for pollutant p for i^{th} model year vehicles

In addition to exhaust emission factors, the calculation of hydrocarbon gasoline motor vehicle emissions involves evaporative and crankcase hydrocarbon emission rates. Evaporation and crankcase emissions can be determined using:

$$f_n = \sum_{i=n-12}^{n+1} h_i \, m_{in}$$

where:

f_n = the combined evaporative and crankcase hydrocarbon emission factor for calendar year n

h_i = the combined evaporative and crankcase emission rate for the i^{th} model year

m_{in} = the weighted annual travel of the i^{th} model year during calendar year n

LIGHT-DUTY GASOLINE-POWERED VEHICLE EMISSION FACTORS

Figures 1 through 3 and Tables 1 through 12 contain the necessary input data for the calculation of light-duty, gasoline-powered motor vehicle emission factors.

Test Cycle Emission Rates (c and h)

A recent study of light-duty vehicle exhaust emission rates in six cities resulted in the data presented in Tables 1 through 3.[4] The choice of the six cities was based on the atmospheric areas of the United States.[6] Statistical analysis of the results of these tests in six different cities leads to the conclusion that emission rates should be averaged to cover vehicles in all areas of the United States except those in high-altitude areas (Denver test results) and 1966-1967 models sold only in California. The values presented in Tables 1 through 3 are emission rates for low-mileage (4,000 mile), nondeteriorated vehicles. The evaporative and crankcase hydrocarbon emission values are shown in Tables 11 and 12.

Deterioration Factors (d)

Exhaust deterioration factors for emission-controlled vehicles by model year and pollutant are presented in Tables 4 though 9. Deterioration factors enable the modification of low-mileage emission rates to account for the aging or deterioration of exhaust-emission control devices.

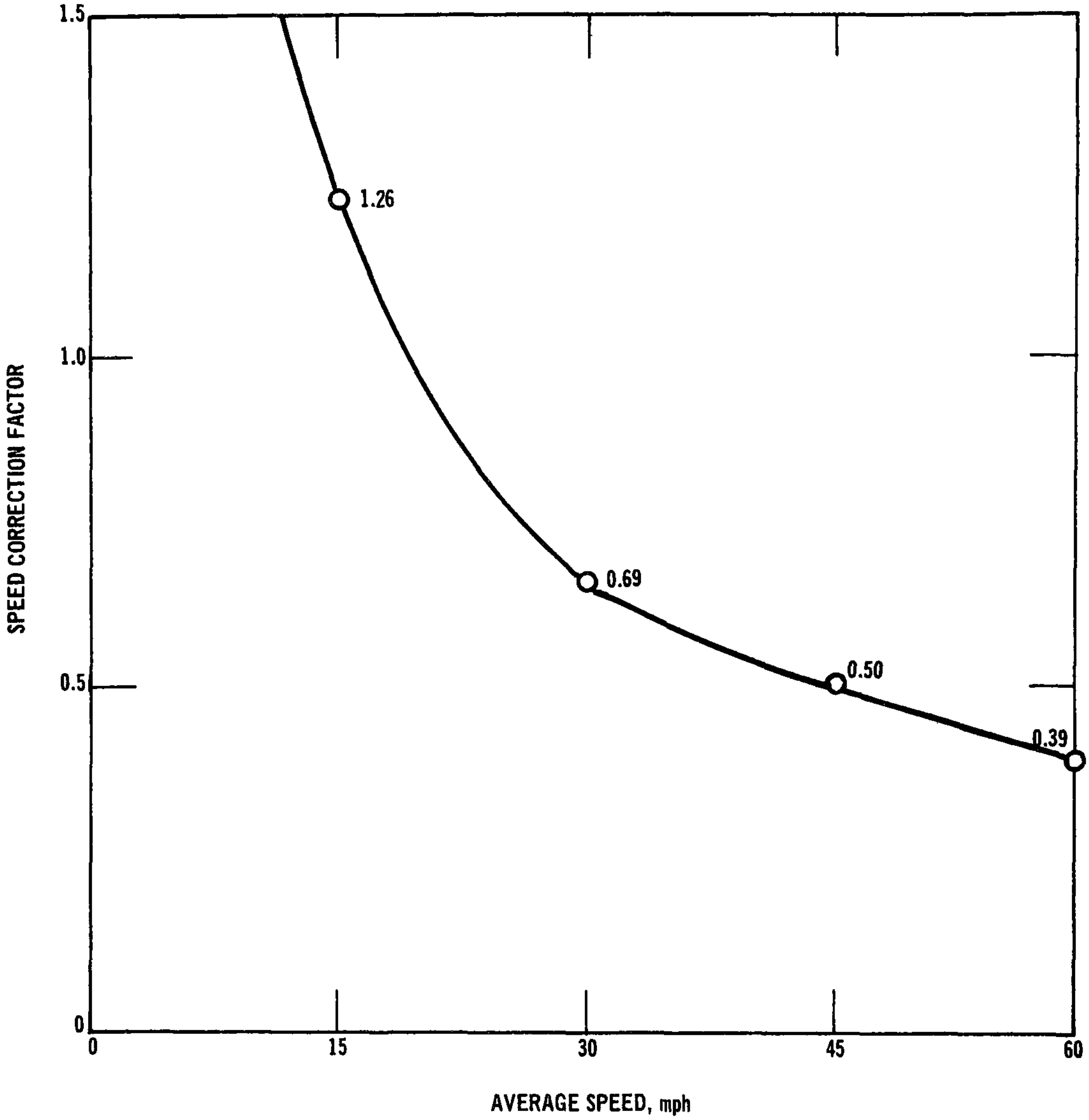


Figure 1. Average speed correction factor for all model years, carbon monoxide.[7]

Weighted Annual Mileage (m)

The determination of m is best illustrated by the example in Table 10. In this example the model year distribution (in this case nationwide) as of December 31 is combined with annual travel by model year. In the calculation of city-specific emission factors, the model year distribution for the area under consideration should be obtained from registration statistics and combined with the annual mileages contained in Table 10, unless localized annual mileage data are available.

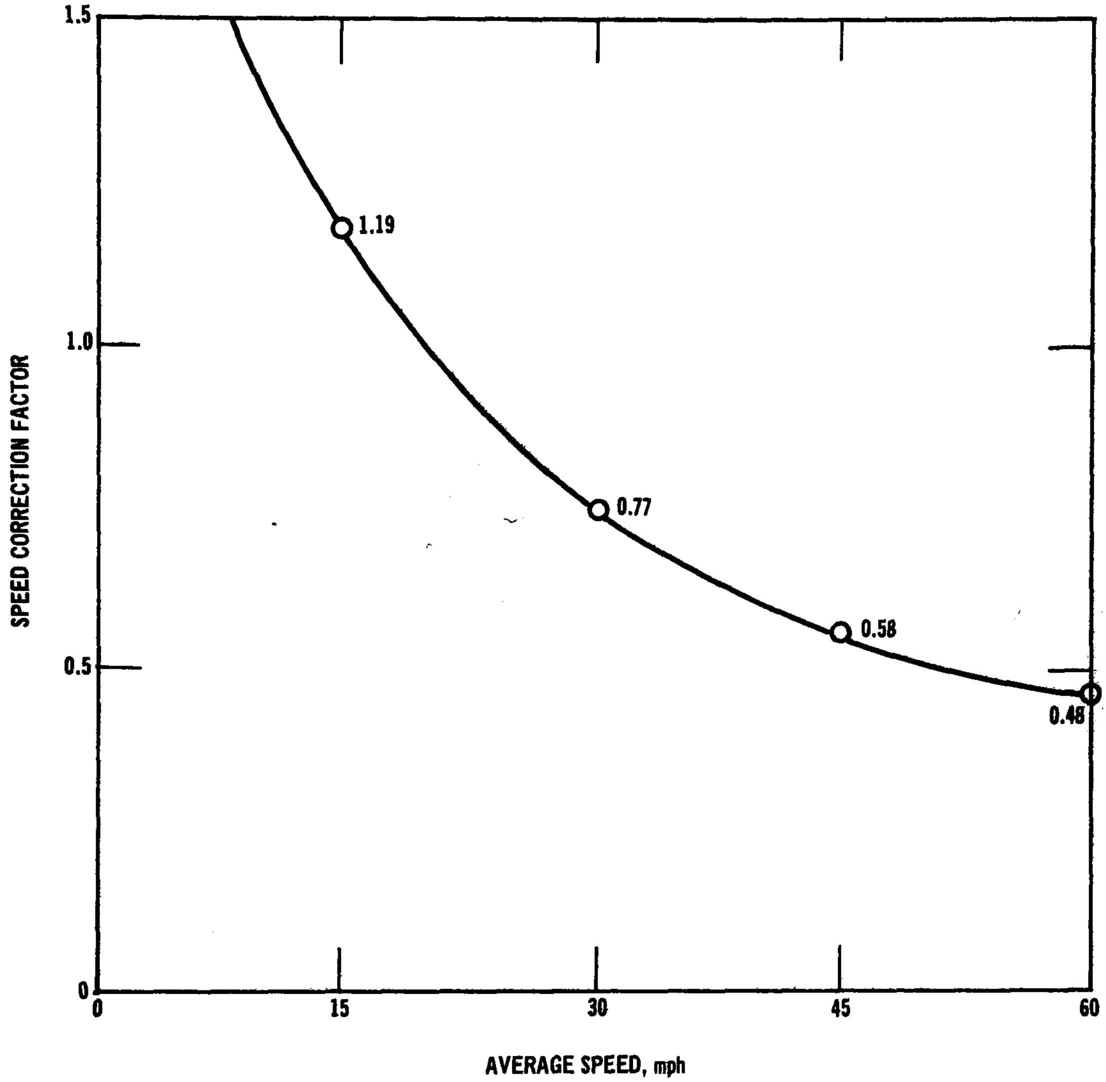


Figure 2. Average speed correction factor for all model years, hydrocarbons.[7]

Weighted Speed Adjustment Factor (s)

The weighted speed adjustment factor enables the calculation of a region-wide emission factor that takes into account variation in average route speed. This variable is calculated using:

$$s_{i_m} = \sum_{j=1}^{n} f_{j_m} v_j$$

where:

s_{i_m} = the weighted speed adjustment factor for exhaust emission of pollutant p for the i^{th} model year during calendar year m

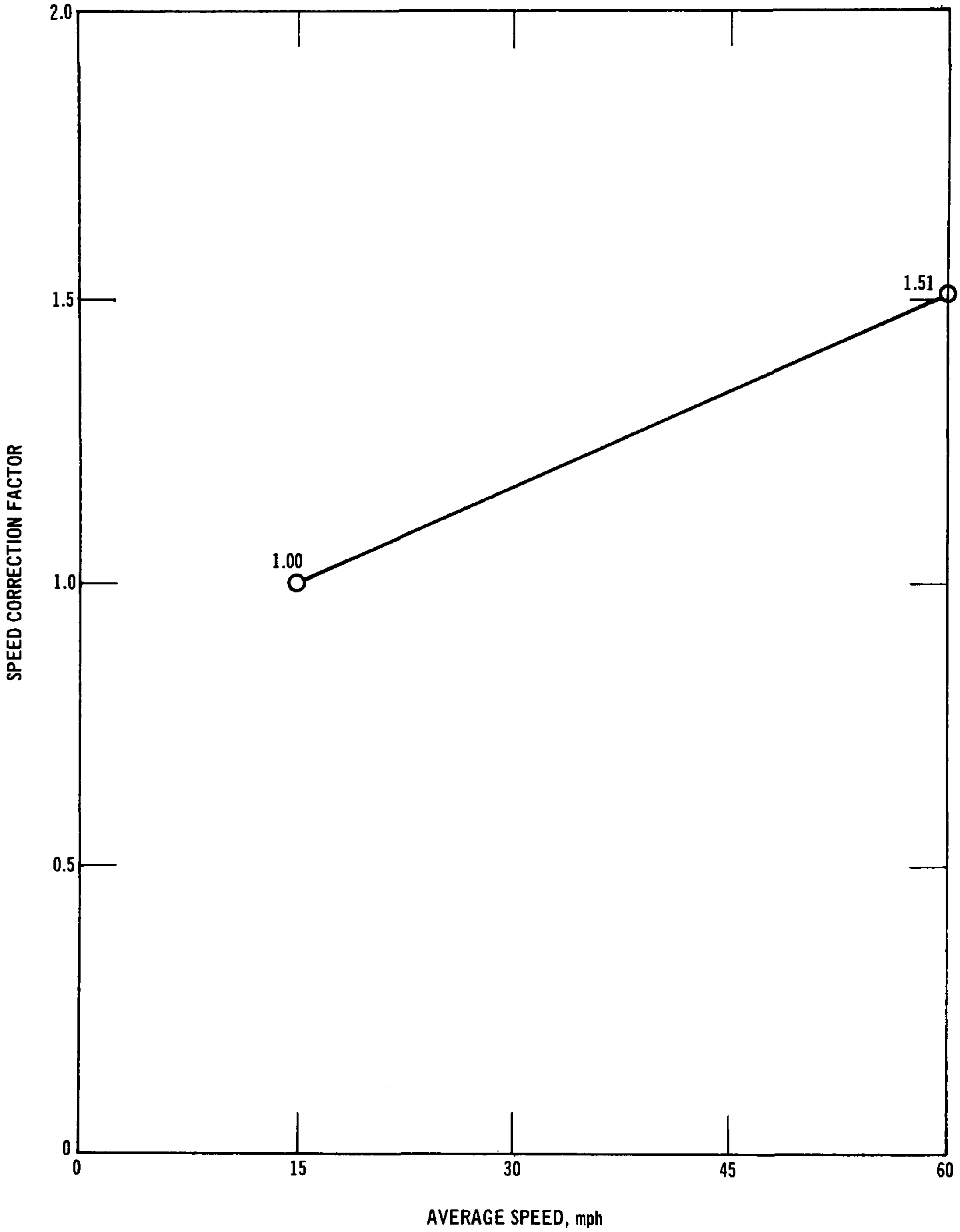


Figure 3. Average speed correction factor for all model years, nitrogen oxides.[4]

Table 1. LIGHT-DUTY VEHICLE EXHAUST EMISSION FACTORS FOR LOW-ALTITUDE CITIES[a]

Model year	Exhaust emission factors at low mileage[b]					
	Carbon monoxide		Exhaust hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Pre-1968	87	54	8.8	5.5	3.6	2.2
1968	46	29	4.5	2.8	4.3	2.7
1969	39	24	4.4	2.7	5.5	3.4
1970	36	22	3.6	2.2	5.1	3.2
1971	34	21	2.9	1.8	4.8	3.0
1972[c]	19	12	2.7	1.7	4.8	3.0
1973-74[c]	19	12	2.7	1.7	2.3	1.4
1975[d]	12.5	7.8	1.3	0.81	2.2	1.4
1976 and later[e]	1.8	1.1	0.23	0.14	0.31	0.19

[a]Excluding California.

[b]References 4, 8-11. It should be noted that pre-1968 results are not at low mileage but are arithmetic means from tests of a random sample of vehicles. There is no reason to present low-mileage emission rates for these vehicles since they are not subject to exhaust control device deterioration.

[c]Estimates based on the relationship of low-mileage emissions to standards for 1971 and earlier controlled vehicles.

[d]Based on EPA low-mileage estimates for the 1975 interim standards.

[e]Based on estimates in Reference 8.

f_{jm} = the fraction of the total annual vehicle miles traveled at speed j during calendar year m

v_j = the vehicular average speed correction factor for average speed j

The carbon monoxide and hydrocarbon speed correction factors are based on tests of uncontrolled vehicles but are assumed to apply to controlled vehicles also. The speed correction factors for nitrogen oxides emissions are based on tests of both controlled and uncontrolled vehicles and are assumed to be a linear relation from the two test points.

HEAVY-DUTY GASOLINE-POWERED VEHICLE EMISSION FACTORS

Calculation of heavy-duty gasoline-vehicle exhaust and evaporative and crankcase emission factors is accomplished using the same equations as those for light-duty vehicles.

Table 2. LIGHT-DUTY VEHICLE EXHAUST EMISSION FACTORS FOR CALIFORNIA

Model year	Exhaust emission factors at low mileage[a]					
	Carbon monoxide		Exhaust hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Pre-1966	87	54	8.8	5.5	3.6	2.2
1966	51	32	6.0	3.7	3.4	2.1
1967	50	31	4.6	2.9	3.4	2.1
1968	46	29	4.5	2.8	4.3	2.7
1969	39	24	4.4	2.7	5.5	3.4
1970	36	22	3.6	2.2	5.1	3.2
1971	34	21	2.9	1.8	3.5	2.2
1972[b]	19	12	2.7	1.7	3.5	2.2
1973-74[b]	19	12	2.7	1.7	2.3	1.4
1975[c]	2.8	1.7	0.33	0.20	1.6	1.0
1976 and later[d]	1.8	1.1	0.23	0.14	0.31	0.19

[a]References 4, 8-11. It should be noted that pre-1968 results are not at low mileage but are arithmetic means from tests of a random sample of vehicles. There is no reason to present low-mileage emission rates for these vehicles since they are not subject to exhaust control device deterioration.

[b]Estimates based on the relationship of low-mileage emissions to standards for 1971 and earlier controlled vehicles.

[c]Based on EPA low-mileage estimates for the 1975 emission standards.

[d]Based on estimates in Reference 8.

Test data for heavy-duty vehicles are limited and the calculation of such emission factors requires the use of variables derived for light-duty vehicles (e.g., s and d).

Test Cycle Emission Rate (c)

Study of heavy-duty vehicle emission rates has been limited to single geographic areas. The emission rates presented in Tables 11 through 15 are divided into nationwide, high altitude, and California. The high altitude and California data are simply modifications of the nationwide data. High altitude values were calculated using the relationship between high and low altitude light-duty vehicle emission rates. California emission rates are simply changes in the nationwide values which reflect the earlier promulgation of emission standards in California.

Deterioration Factors (d)

With the exception of 1975 and later California models, emission standards for heavy-duty vehicles have resulted in relatively small emission reductions on a mass basis. For this reason, the available deterioration factors (for light-duty vehicles)

Table 3. LIGHT-DUTY VEHICLE EXHAUST EMISSION FACTORS FOR HIGH-ALTITUDE CITIES

Model year	Exhaust emission factors at low mileage[a]					
	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Pre-1968	130	81	10	6.2	1.9	1.2
1968	74	46	6.0	3.7	2.2	1.4
1969	48	30	5.4	3.4	2.6	1.6
1970	72	45	6.1	3.8	2.8	1.7
1971	75	47	5.3	3.3	3.1	1.9
1972[b]	42	26	4.9	3.0	3.1	1.9
1973-74[b]	42	26	4.9	3.0	1.4	0.87
1975[c]	20	12	1.8	1.1	1.8	1.1
1976 and later[d]	1.8	1.1	0.23	0.14	0.31	0.19

[a]References 4, 8-11. It should be noted that pre-1968 results are not at low mileage but are arithmetic means from tests of a random sample of vehicles. There is no reason to present low-mileage emission rates for these vehicles since they are not subject to exhaust control device deterioration.

[b]Estimates based on the relationship of low-mileage emissions to standards for 1971 and earlier controlled vehicles.

[c]Based on EPA low-mileage estimates for the 1975 emission standards.

[d]Based on estimates in Reference 8.

Table 4. CARBON MONOXIDE DETERIORATION FACTORS (d) FOR LIGHT-DUTY GASOLINE-POWERED VEHICLES IN ALL AREAS EXCEPT CALIFORNIA[8,9]

Model year	Vehicle age,[a] years								
	1	2	3	4	5	6	7	8	9 and older
1967 and earlier	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1968	1.24	1.35	1.41	1.47	1.53	1.58	1.63	1.67	1.72
1969	1.42	1.53	1.59	1.63	1.68	1.71	1.75	1.79	1.82
1970 through 1974[b]	1.18	1.32	1.38	1.40	1.44	1.47	1.50	1.51	1.56
1975[c]	1.04	1.30	1.36	1.43	1.44	1.49	1.56	1.63	1.69
1976 and later[c]	1.34	1.77	2.14	2.42	2.73	2.99	3.26	3.48	3.77

[a]"0"-year-old vehicles have a deterioration factor of 1.00.

[b]Based on test results for 1970 model year vehicles.

[c]Based on Reference 8 and EPA estimates.

Table 5. EXHAUST HYDROCARBON DETERIORATION FACTORS (d) FOR LIGHT-DUTY GASOLINE-POWERED VEHICLES IN ALL AREAS EXCEPT CALIFORNIA[8,9]

Model year	Vehicle age,[a] years								
	1	2	3	4	5	6	7	8	9 and older
1967 and earlier	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1968	1.12	1.18	1.21	1.23	1.26	1.28	1.30	1.32	1.35
1969	1.10	1.16	1.18	1.21	1.23	1.25	1.28	1.29	1.31
1970 through 1974[b]	1.05	1.10	1.13	1.15	1.17	1.20	1.22	1.24	1.26
1975[c]	1.00	1.13	1.22	1.29	1.37	1.43	1.50	1.56	1.63
1976 and later[c]	1.45	1.95	2.40	2.76	3.14	3.46	3.79	4.07	4.42

[a]"0"-year-old vehicles have a deterioration factor of 1.00.
[b]Based on test results for 1970 model year vehicles.
[c]Based on Reference 8 and EPA estimates.

Table 6. NITROGEN OXIDE DETERIORATION FACTORS (d) FOR LIGHT-DUTY GASOLINE-POWERED VEHICLES IN ALL AREAS EXCEPT CALIFORNIA[8,9]

Model year	Vehicle age,[a] years								
	1	2	3	4	5	6	7	8	9 and older
1972 and earlier	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1973 through 1974[b]	1.11	1.18	1.20	1.21	1.22	1.23	1.24	1.25	1.26
1975	1.00	1.18	1.23	1.23	1.41	1.45	1.45	1.45	1.45
1976 and later[c]	1.34	1.77	2.14	2.42	2.73	2.99	3.26	3.48	3.77

[a]"0"-year-old vehicles have a deterioration factor of 1.00.
[b]Based on test results for 1971 (California) model year vehicles.
[c]Based on Reference 8 and EPA estimates.

should only be used for 1975 and later California heavy-duty vehicles. A deterioration factor of 1.00 should be assumed for all non-California heavy-duty vehicles regardless of model year and for all pre-1975 California heavy-duty vehicles. It is recommended that 1968 CO and HC deterioration factors be applied to 1975 and later California heavy-duty vehicles.

Weighted Annual Mileage (m)

The determination of this variable is illustrated in Table 16. For this example, the nationwide model year distribution of heavy-duty vehicles is used.

Table 7.. CARBON MONOXIDE DETERIORATION FACTORS (d) FOR LIGHT-DUTY GASOLINE-POWERED VEHICLES IN CALIFORNIA[8,9]

Model year	Vehicle age,[a] years								
	1	2	3	4	5	6	7	8	9 and older
1965 and earlier	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1966	1.13	1.21	1.24	1.25	1.28	1.29	1.31	1.32	1.34
1967	1.11	1.18	1.23	1.29	1.35	1.40	1.46	1.50	1.56
1968	1.24	1.35	1.41	1.47	1.53	1.58	1.63	1.67	1.72
1969	1.42	1.53	1.59	1.63	1.68	1.71	1.75	1.79	1.82
1970 through 1974[b]	1.18	1.32	1.38	1.40	1.44	1.47	1.50	1.51	1.56
1975[c]	1.34	1.77	2.14	2.42	2.73	2.99	3.26	3.48	3.77
1976 and later[c]	1.34	1.77	2.14	2.42	2.73	2.99	3.26	3.48	3.77

[a]"0"-year-old vehicles have a deterioration factor of 1.00.

[b]Based on test results for 1970 model year vehicles.

[c]Based on Reference 8.

Table 8. HYDROCARBON DETERIORATION FACTORS (d) FOR LIGHT-DUTY GASOLINE-POWERED VEHICLES IN CALIFORNIA[8,9]

Model year	Vehicle age,[a] years								
	1	2	3	4	5	6	7	8	9 and older
1965 and earlier	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1966	1.14	1.22	1.25	1.27	1.29	1.30	1.32	1.33	1.35
1967	1.07	1.10	1.12	1.14	1.15	1.17	1.18	1.20	1.21
1968	1.12	1.18	1.21	1.23	1.26	1.28	1.30	1.32	1.35
1969	1.10	1.16	1.18	1.21	1.23	1.25	1.28	1.29	1.31
1970 through 1974[b]	1.05	1.10	1.13	1.15	1.17	1.20	1.22	1.24	1.26
1975[c]	1.45	1.95	2.40	2.76	3.14	3.46	3.79	4.07	4.42
1976 and later[c]	1.45	1.95	2.40	2.76	3.14	3.46	3.79	4.07	4.42

[a]"0"-year-old vehicles have a deterioration factor of 1.00.

[b]Based on test results for 1970 model year vehicles.

[c]Based on Reference 8.

Table 9. NITROGEN OXIDES DETERIORATION FACTORS FOR LIGHT-DUTY GASOLINE-POWERED VEHICLES IN CALIFORNIA[8,9]

Model year	Vehicle age,[a] years								
	1	2	3	4	5	6	7	8	9 and older
1970 and earlier	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1971 through 1975[b]	1.11	1.18	1.20	1.21	1.22	1.23	1.24	1.25	1.26
1976 and later[c]	1.34	1.77	2.14	2.42	2.73	2.99	3.26	3.48	3.77

[a] "0"-year-old vehicles have a deterioration factor of 1.00.

[b] Based on test results for 1971 model year vehicles.

[c] Based on Reference 8.

Table 10. SAMPLE CALCULATION OF WEIGHTED ANNUAL TRAVEL BY LIGHT-DUTY VEHICLES (m)[12,13]

Age, years	Nationwide fraction of vehicles in use on Dec. 31 (a)	Average miles driven (b)	a x b	m[a]
0[b]	0.038	3,600[c]	137	0.013
1	0.068	11,900[c]	809	0.075
2	0.117	16,100	1,880	0.174
3	0.111	13,200	1,465	0.135
4	0.098	11,400	1,120	0.103
5	0.106	11,700	1,240	0.115
6	0.105	10,000	1,050	0.097
7	0.087	10,300	896	0.083
8	0.076	8,600	654	0.060
9	0.059	10,900	643	0.059
10	0.036	8,000	288	0.027
11	0.029	6,500	188	0.017
12	0.016	6,500	104	0.010
13 and older	0.054	6,500	351	0.032

[a] $m = \dfrac{a \times b}{\sum a \times b}$

[b] "0" refers to next year's models introduced in the fall.

[c] This number reflects the fact that some vehicles in this age category have been on the road less than 12 months.

Table 11. LIGHT-DUTY AND HEAVY-DUTY VEHICLE CRANKCASE AND EVAPORATIVE HYDROCARBON EMISSIONS FOR ALL AREAS EXCEPT CALIFORNIA[14]

Model year	LDV hydrocarbons		HDV hydrocarbons	
	g/mi	g/km	g/mi	g/km
Pre-1963	7.1	4.4	8.2	5.1
1963 through 1967	3.8	2.4	8.2	5.1
1968 through 1970	3.0	1.9	8.2	5.1
1971	0.5	0.3	3.0	1.9
1972	0.2	0.1	3.0	1.9
1973 and older	0.2	0.1	3.0	1.9

Table 12. LIGHT-DUTY AND HEAVY-DUTY VEHICLE CRANKCASE AND EVAPORATIVE HYDROCARBON EMISSIONS FOR CALIFORNIA[14]

Model year	LDV hydrocarbons		HDV hydrocarbons	
	g/mi	g/km	g/mi	g/km
Pre-1961	7.1	4.4	8.2	5.1
1961 through 1963	3.8	2.4	8.2	5.1
1964 through 1967	3.0	1.9	8.2	5.1
1968 through 1969	3.0	1.9	3.0	1.9
1970 through 1971	0.5	0.3	3.0	1.9
1972	0.2	0.1	3.0	1.9
1973 and older	0.2	0.1	0.2	0.1

Table 13. HEAVY-DUTY GASOLINE-POWERED VEHICLE EXHAUST EMISSION FACTORS FOR ALL AREAS EXCEPT HIGH-ALTITUDE AND CALIFORNIA

	Carbon monoxide		Exhaust hydrocarbons		Nitrogen oxide	
Model year	g/mi	g/km	g/mi	g/km	g/mi	g/km
Pre-1970[a]	140	87	17	11	9.4	5.8
1970 through 1973[b]	130	81	16	9.9	9.2	5.7
1974 and later[c]	130	81	13	7.9	9.2	5.7

[a]Data extracted from References 5 and 14.

[b]Data from Reference 14.

[c]Calculated from information contained in Reference 14. These are low-mileage emission rates.

Table 14. HEAVY-DUTY GASOLINE-POWERED VEHICLE EXHAUST EMISSION FACTORS FOR HIGH-ALTITUDE AREAS[a]

Model year	Carbon monoxide		Exhaust hydrocarbons		Nitrogen oxide	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Pre-1970[b]	210	130	19	12	5.0	3.1
1970 through 1973[c]	190	120	18	11	4.9	3.0
1974 and later[d]	190	120	15	9.3	4.9	3.0

[a]Based on the light-duty vehicle emissions at high altitude compared with light-duty vehicle emissions at low altitude.

[b]Data extracted from References 5 and 14.

[c]Data from Reference 14.

[d]Calculated from information contained in Reference 14. These are low-mileage test results.

Table 15. HEAVY-DUTY GASOLINE-POWERED VEHICLE EXHAUST EMISSION FACTORS FOR CALIFORNIA

Model year	Carbon monoxide		Exhaust hydrocarbons		Nitrogen oxide	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Pre-1970[a]	140	87	17	11	9.4	5.8
1970 through 1971[b]	130	81	16	9.9	9.2	5.7
1972[c]	130	81	13	8.1	9.2	5.7
1973 through 1974[d]	130	81	13	8.1	9.2	5.7
1975[c]	81	50	4.1	2.5	2.8	1.7

[a]Data extracted from References 5 and 14.

[b]Data from Reference 14.

[c]Based on applicable emission standards.

[d]Calculated from information contained in Reference 14. These are low-mileage emission rates.

Weighted Speed Adjustment Factor (s)

Again, data based on actual heavy-duty vehicles are not available. Light-duty vehicle speed correction factors can be used as an approximation for all heavy-duty vehicles, regardless of model year. The calculation of the weighted speed correction factor is accomplished using the same technique as that for light-duty vehicles.

Table 16. SAMPLE CALCULATION OF WEIGHTED ANNUAL TRAVEL BY HEAVY-DUTY VEHICLES (m)[15,16]

Age, years	Nationwide fraction of vehicles in use on Dec. 31 (a)	Annual miles driven (b)	a x b	m[a]
0	0.011	3,500	38	0.003
1	0.090	11,700	1,050	0.095
2	0.105	17,200	1,810	0.164
3	0.085	15,800	1,340	0.121
4	0.080	15,800	1,260	0.114
5	0.083	13,000	1,080	0.097
6	0.075	13,000	975	0.088
7	0.064	11,000	704	0.064
8	0.054	11,000	594	0.054
9	0.045	9,000	405	0.036
10	0.034	9,000	306	0.028
11	0.036	5,500	198	0.018
12	0.031	5,500	170	0.015
13 and older	0.207	5,500	1,138	0.103

[a] $m = \frac{a \times b}{\sum a \times b}$

2. PREDICTION OF GASOLINE-POWERED MOTOR VEHICLE EMISSIONS

Appendix I to 36 FR 22412 describes a method that can be used to approximate regional air quality levels resulting from the Federal motor vehicle control program. A simple equation and normalized emission rates for hydrocarbons, carbon monoxide, and nitrogen oxides are used to calculate expected air quality concentrations for future years. Calculations are based on emissions data for all sources in the base year and the future years, the growth factor for stationary source emissions, and the base line air quality (measured or estimated) in the region. This method cannot be applied to determine the reduction in photochemical oxidant levels resulting from reductions in hydrocarbon emissions. Consequently, Appendix J to 36 FR 22412 is to be used to estimate the percent reduction in hydrocarbon emissions required to achieve the national ambient air quality standard for photochemical oxidants.

The revised emission factors presented earlier do not invalidate Appendix I to 36 FR 22412 when it is used to determine normalized emission rates of hydrocarbons, carbon monoxide, and nitrogen dioxide on a national basis. State Implementation Plans submitted in accordance with 40 CFR part 51 on or before January 30, 1972, generally used this method for estimating whether transportation control measures were required and for estimating the percent reduction in any pollutant concentration required to meet national ambient air quality standards. However, those metropolitan areas in air quality regions requiring such control measures may have air quality and traffic data and technical capability available that warrant a more accurate prediction of air quality levels and evaluation of transportation control measures to effect the desired reduction in national ambient air quality levels.[17]

The basic method for predicting total motor vehicle emissions is to multiply emission factors, modified to represent on-the-road emission rates, by the vehicle miles of travel (VMT). The former National Air Pollution Control Administration used a similar simplified approach for estimating nationwide vehicle emissions.[1] Two types of vehicle operating conditions were assumed, urban and rural. All urban travel was assumed to be at an average speed of 25 miles per hour beginning from a "cold start"; i.e., the vehicle was assumed not to have been driven prior to beginning travel at the urban driving speed. All rural travel was assumed to be at an average speed of 45 miles per hour, beginning from a "hot start." In this case, the vehicle was assumed to have been operated before being driven at the rural speed. The emission factors were then adjusted for these average speeds. A further seasonal adjustment was made. No correction was made for altitude. It should be noted that the emission factors presented in Chapter 1 have been tabulated according to areas where the tests were made, e.g., California, low-altitude (excluding California), and high-altitude (above 3,500 feet). The national miles of travel for passenger cars, trucks, and buses were taken from Highway Statistics.[18] The future projections of national vehicle miles of travel were estimated from the "medium" projections presented in Resources in America's Future.[19] It should be noted that forecasts made prior to the 1970 census assumed a higher growth rate than is now occurring.[20] The total VMT were divided into passenger car and truck miles and further into rural and urban driving, according to the assumed weighting. The national emissions for each pollutant were then obtained by multiplying these vehicle miles traveled by the appropriate emission factor.

Subsequently, a method that modified this approach on a regional basis was developed from appropriate emission factors and the motor vehicle population and driving pattern for the particular region.[21]

Total vehicle travel can be determined from regional transportation studies, local traffic surveys, U.S. Department of Transportation data, and Federal Highway Administration publications.[13,22,23] The statistics available from Highway Statistics[18] include, by state, miles of public roads and streets, average daily traffic loads, number and type of vehicles registered, and estimated motor vehicle (passenger and truck) travel by highway system. Also included are motor fuel consumption and speed trends by roadway type and vehicle type. Highway Statistics[18] assumed that since the total emissions from all gasoline-powered motor vehicles in a region is a function of the vehicle emission factors, the vehicle miles traveled in the region, and the percent travel that is urban or rural, a proportional relationship could be made to obtain regional emissions from the average national emissions. This assumption is valid if the regional vehicle mix of ages, types, makes, and deterioration rates, as well as the percentages of road types, average speeds, and miles of travel, are the same as the national average. The following equations were presented to obtain regional emission estimates:[24]

$$TE = UE + RE$$

$$VE = UF \cdot VMT \cdot a \cdot k$$

$$RE = RF \cdot VMT \cdot 1\text{-}a \cdot k$$

where:

TE	=	Total emission of a pollutant, tons/year
UE	=	Urban emission of a pollutant, tons/year
RE	=	Rural emission of a pollutant, tons/year
UF	=	Urban emission factor, g/mile
RF	=	Rural emission factor, g/mile
VMT	=	Vehicle miles of travel

a = fraction of travel that is urban

k = 1.1023×10^{-6} ton/g (conversion factor)

The emission factors (for both cars and trucks) needed for the calculations were presented for each pollutant (hydrocarbons, carbon monoxide, and oxides of nitrogen) by year and by urban and rural driving. The VMT and the fraction of urban travel were to be obtained from local traffic studies or assumed. (Vehicle miles of travel and projections for future years for most cities are available as a result of the Federal Aid Highway Act of 1962, which required cities with populations over 50,000 to initiate transportation studies in order to qualify for federal aid for road construction.)

This simplified method could be updated by using the latest emission factors presented in Chapter 1 of this report and compiled as shown in Tables B-1, B-2, and B-3 for the vehicle age mix of the region or the age mix of the nation. A sample calculation for a metropolitan area is shown in Appendix A. Adjustment of the emission factor for the speeds of the roadway type, with the miles of the roadway type, vehicle type (light-duty or heavy-duty), and the respective vehicle miles traveled would provide an even more accurate calculation of emissions.

The accuracy of the gasoline-powered motor vehicle emissions prediction is not only dependent on the emission factors, it is also very sensitive to traffic data (vehicle type and age mix, miles of roadway type, average speed) that are best developed by local traffic surveys. Where air quality levels are developed by a proportional or roll-back model, data must be obtained on at least a county-wide basis.[25] The use of a dispersion model requires that the data be developed on a grid basis.[25] The grid size is dependent on the sophistication of the calculation; # grid cells down to 1 mile or 1 kilometer are general. The Chicago area transportation study[26] used traffic zones in the study area that varied from 0.25 square mile in the central business district to 36 square miles in the outlying areas. A study of Washington, D.C.[27] divided the metropolitan area into 48 irregular subareas that were smaller in the central business district than in the suburbs (Figure 4). This unique approach to the evaluation of transportation alternatives provided a method for estimating emissions from transportation data without trip distribution and traffic assignment models. The method makes use of vehicle trip forecasts along with highway network information to estimate future travel, the speeds at which this travel will occur, and the emission levels produced. A simplified flow chart of the method is shown in Figure 5. It should be noted that this method does not directly provide air quality level forecasts, but it can be particularly useful in a gross evaluation of transportation system alternatives.

A typical approach to the calculation of air quality levels from a general transportation model is shown in the flow chart in Figure 6. A further refinement, shown in the flow chart in Figure 7, was done by the Argonne National Laboratory in a study for the City of Chicago.[26] This study also developed the sensitivity of relating emissions to local

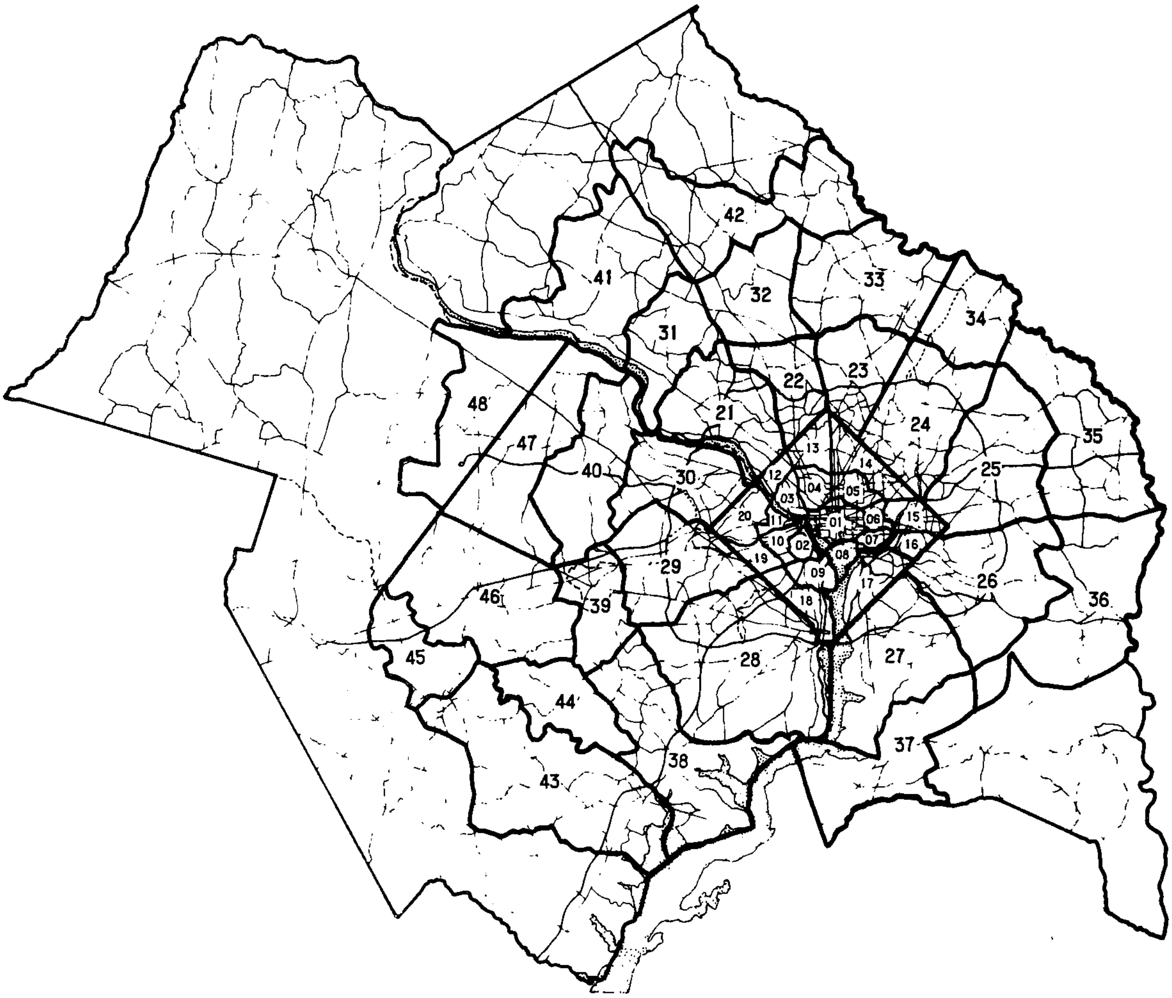


Figure 4. Study areas in metropolitan Washington, D.C. for auto emissions model.[27]

vehicle registration data (age mix) and speed adjustment. The emission estimates for Washington, D.C.,[27] showed a substantial reduction, up to 25 percent, in carbon monoxide estimates when the local vehicle age mix was used in place of the national average. The larger number of late model automobiles with lower emissions that are driven proportionally more than older ones caused the reduction.

EPA's Guide for Compiling a Comprehensive Emission Inventory[28] provides detailed procedures for preparing stationary and mobile source emissions inventories. The section on gasoline-powered motor vehicles is particularly useful. Although this approach requires automatic data processing equipment, it will produce a uniform format that allows ready comparison with other regions and that is compatible with stationary source data now being accumulated. This approach is recommended because of its relationship to EPA's National Environmental Emissions Data System. If the Guide[28] is used, the gasoline-powered vehicle emission factors in Chapter 1 of this report should be used until Compilation of Air Pollutant Emission Factors[3] is revised to include them.

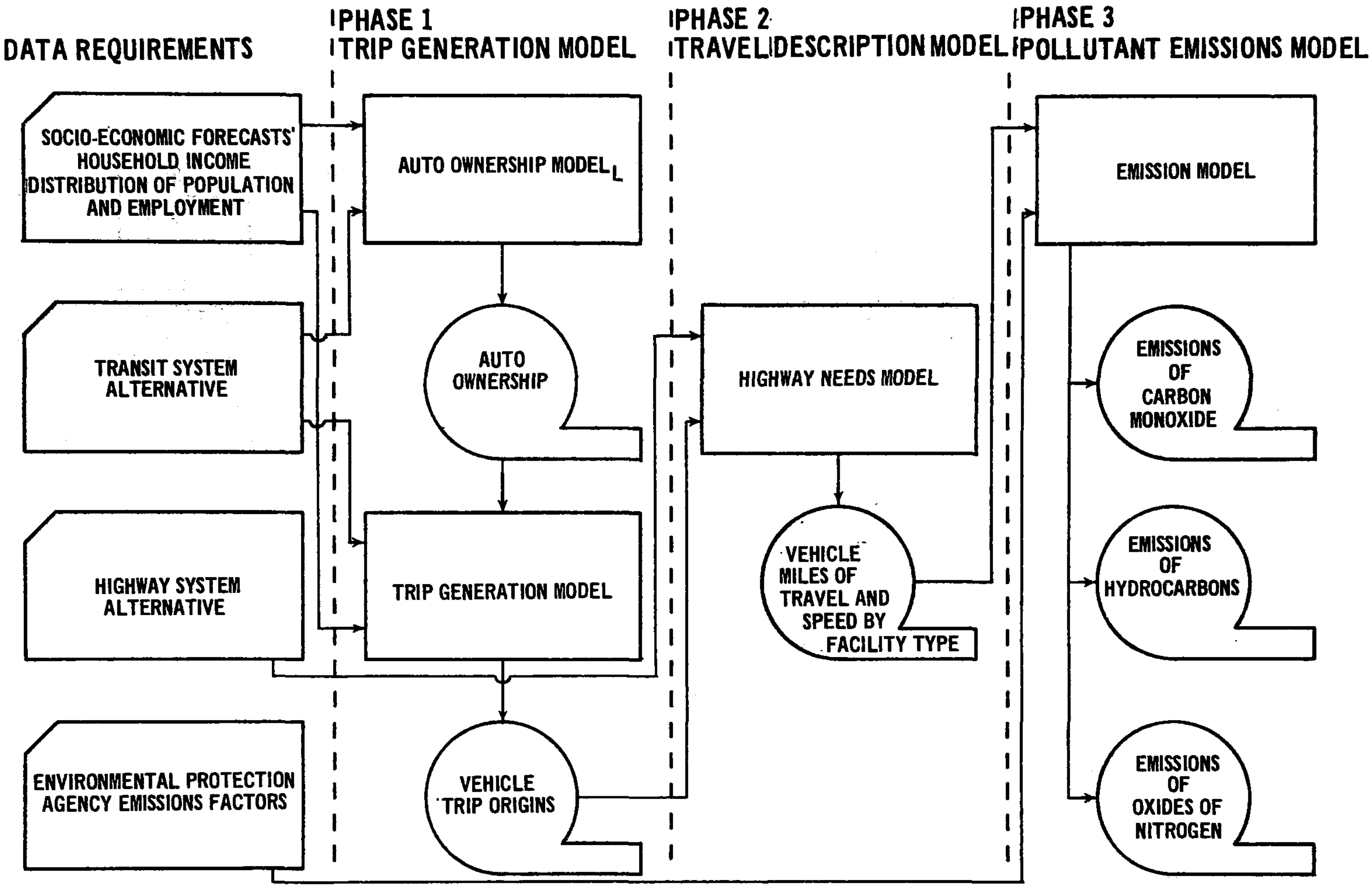


Figure 5. Flow chart of auto emissions model.

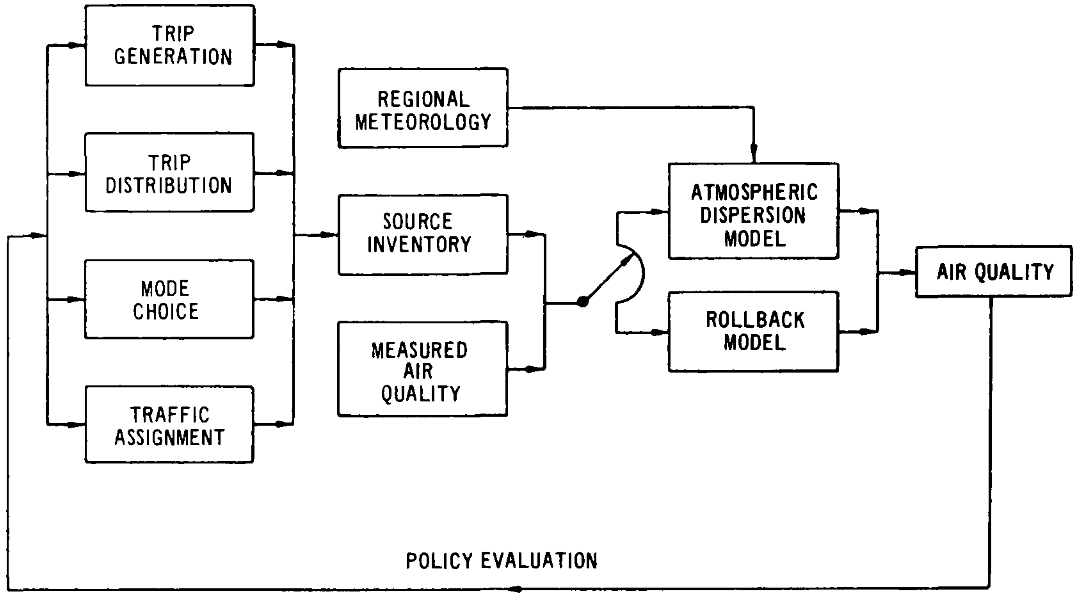


Figure 6. Flow chart of the general transportation-air pollution model.

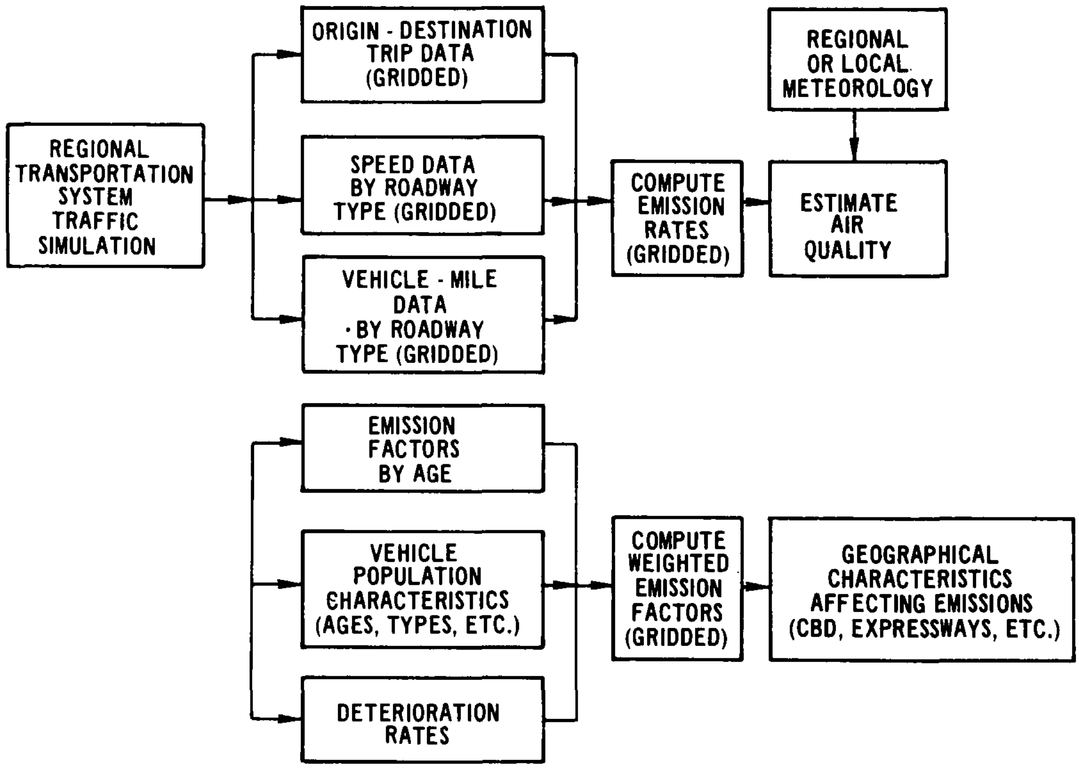


Figure 7. Flow chart of the Argonne transportation-air pollution model.[26]

Where a detailed transportation emissions inventory, air quality data, and the necessary technical expertise are all available, rather sophisticated evaluations of transportation control and highway system alternatives are possible. Such an approach was developed by the Argonne National Laboratory and is summarized in a flow chart (Figure 8).[29] This approach requires the detailed gasoline-powered motor vehicle emission factors developed in Chapter 1 of this report.

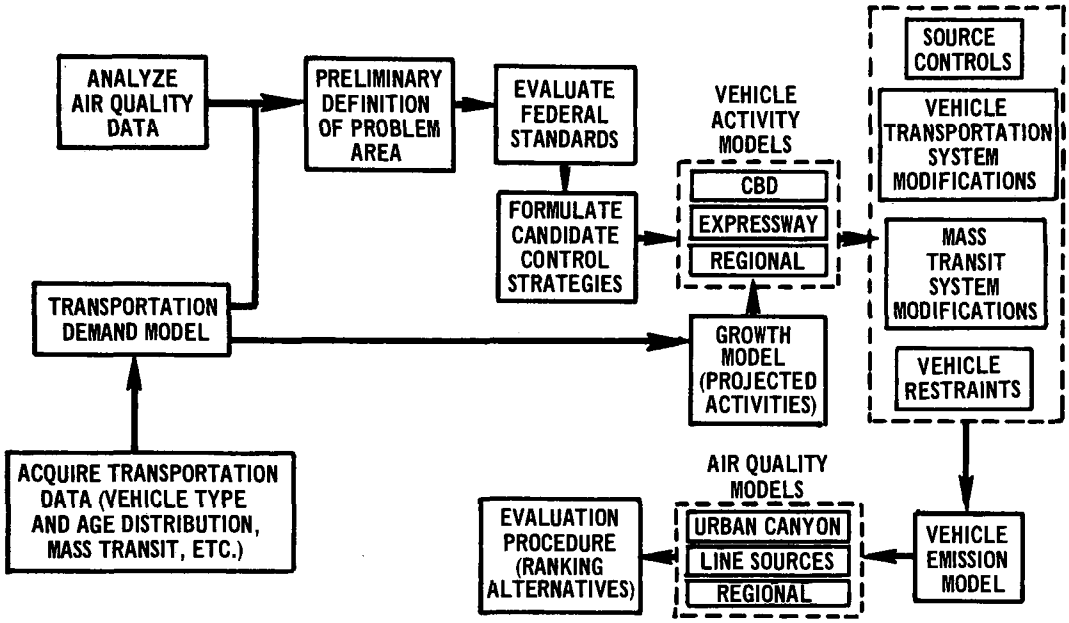


Figure 8. Models for evaluating alternative transportation-related pollution control strategies.[29]

The use of a computerized diffusion model to calculate air quality levels requires that the transportation data be obtained or assumed on a grid network as small as 1 mile or 1 kilometer square. A simplified description of the steps used in the Six Cities Transportation Study[24] is quoted below:

Step 1 - Assignment of VMT and speed to elements of grid network. This required superimposing a rectangular grid network consisting of 1-mile squares or 1-kilometer squares over a base map of the metropolitan area and summation of VMT from each of the individual roadways which may fall within one of the small grids to obtain the total VMT for each element or small grid in the grid network. The speed for each grid of the grid network is obtained by averaging the speeds from each element or roadway within the grid for each time period required, using the VMT along each element of roadway as a weighting factor. In this manner the many vehicular sources moving within an individual grid can be represented by a single stationary source, which produces the same amount of emissions, equal to the size of the individual grid. This equivalent source is called an area source because the emissions from the grid or area source are now considered as evenly distributed or evenly produced over the entire area of the individual grid.

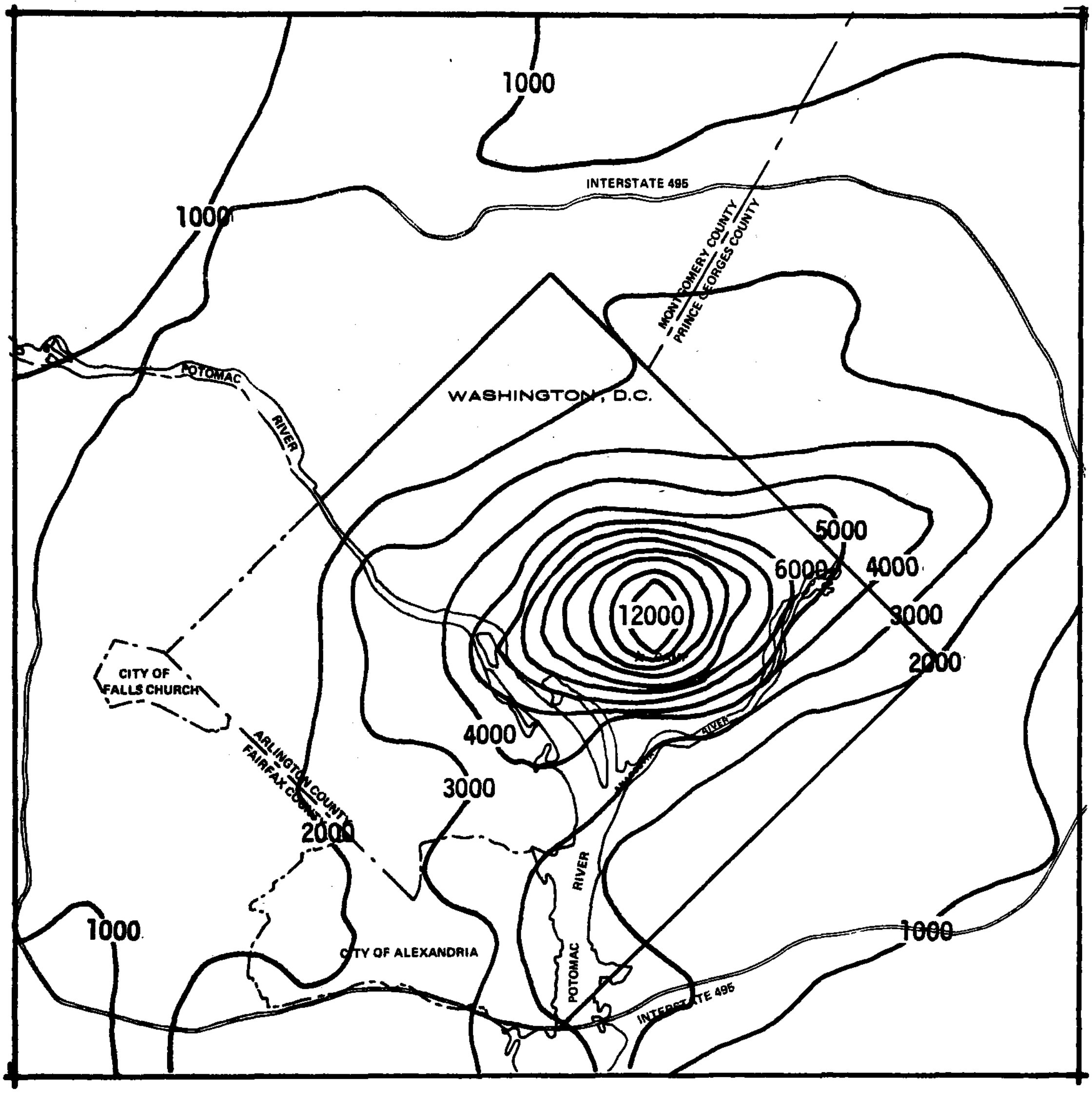
Step 2 - Use of vehicle emission factors (adjusted for vehicle speed and type) to calculate emissions on a per-grid basis.

Step 3 - Conversion of emission rates to pollutant concentration on a per-grid basis by the method of Gifford and Hanna.[17]

Step 4 - Application of transportation control strategies to the data base to obtain predicted concentration patterns for each control strategy for the year 1977.

The resulting concentrations are presented graphically as isopleths over a map of the metropolitan area. One of the isopleths for a particular strategy is shown in Figure 9. A study of this complex makes full use of the revised emission factors, particularly when subregional measures are applied for air pollution control.

In summary, it is emphasized that the gasoline-powered motor vehicle emissions prediction is no better than the poorest of the many factors that comprise the calculation. Further, although highway system alternatives and transportation control alternatives can be evaluated in terms of air quality levels, there is much economy in time and money in initially evaluating total emissions. The most promising transportation control measures being considered can then be selected for detailed study by diffusion modeling.



Isopleth No. D.C.30

City Washington,D.C. Year 1977 Strategy 3	
Pollutant CO Case 4 Time Period 8 Hour Total	
Units $mg/m^3 x 10^3$ Federal Standard 10 mg/m^3	

Figure 9. Sample isopleth from a computerized diffusion model.[30]

APPENDIX A.

SAMPLE CALCULATION

OF

GASOLINE-POWERED MOTOR VEHICLE EMISSION FACTORS

Table A-1. CALCULATION SHEET FOR GASOLINE MOTOR VEHICLE EXHAUST EMISSION FACTORS

Pollutant HYDROCARBONS Vehicle weight class

☐ HDV ☑ LDV

Calendar year 1970 Metropolitan area SAMPLE

Model year	c_i	d_i	m_i[a]	s_i	$c_i d_i m_i s_i$
1971	2.9	1.00	0.013	0.79	0.03
1970	3.6	1.05	0.075	0.79	0.22
1969	4.4	1.16	0.174	0.79	0.70
1968	4.5	1.21	0.135	0.79	0.58
1967	8.8	1.00	0.103	0.79	0.72
1966	8.8	1.00	0.115	0.79	0.80
1965	8.8	1.00	0.097	0.79	0.67
1964	8.8	1.00	0.083	0.79	0.58
1963	8.8	1.00	0.060	0.79	0.42
1962	8.8	1.00	0.059	0.79	0.41
1961	8.8	1.00	0.027	0.79	0.19
1960	8.8	1.00	0.017	0.79	0.12
1959	8.8	1.00	0.010	0.79	0.07
1958	8.8	1.00	0.032	0.79	0.22

$\sum c_i d_i m_i s_i$ = 5.85 g/mi

[a]See Table 14 for sample calculation.

Table A-2. CALCULATION SHEET FOR WEIGHTED SPEED ADJUSTMENT FACTOR FOR EXHAUST EMISSIONS

Pollutant HYDROCARBONS   Metropolitan area SAMPLE

Model year(s) ALL

Average speed (j),[a] miles/hour	f_j[b]	v_j	$f_j v_j$
20	0.40	1.00	0.40
30	0.15	0.77	0.12
40	0.20	0.69	0.14
50	0.15	0.54	0.08
60	0.10	0.48	0.05

$\sum f_j v_j = 0.79$

[a]Speeds used were determined arbitrarily for purposes of this sample calculation.

[b]Determined arbitrarily.

Table A-3. CALCULATION SHEET FOR GASOLINE MOTOR VEHICLE CRANKCASE AND EVAPORATIVE EMISSION FACTORS

Pollutant HYDROCARBONS   Vehicle weight class: ☐ HDV ☑ LDV

Calendar year 1970   Metropolitan area SAMPLE

Model year	h_i	m_i	$h_i m_i$
1971	0.5	0.013	0.01
1970	3.0	0.075	0.22
1969	3.0	0.174	0.52
1968	3.0	0.135	0.40
1967	3.8	0.103	0.39
1966	3.8	0.115	0.44
1965	3.8	0.097	0.37
1964	3.8	0.083	0.32
1963	3.8	0.060	0.23
1962	7.1	0.059	0.42
1961	7.1	0.027	0.19
1960	7.1	0.017	0.12
1959	7.1	0.010	0.07
1958	7.1	0.032	0.23

$\sum h_i m_i = 3.9$ g/mi

APPENDIX B.

GASOLINE-POWERED MOTOR VEHICLE EMISSION CALCULATION SHEETS

Table B-1. CALCULATION SHEET FOR GASOLINE MOTOR VEHICLE EXHAUST EMISSION FACTORS

Pollutant ______________________ Vehicle weight class

☐ HDV ☐ LDV

Calendar year ________________ Metropolitan area ________

Model year	c_i	d_i	m_i[a]	s_i	$c_i d_i m_i s_i$

$\sum c_i d_i m_i s_i =$ g/mi

[a]See Tables 14 and 20 for sample calculations of m_i.

Table B-2. CALCULATION SHEET FOR WEIGHTED SPEED ADJUSTMENT FACTOR FOR EXHAUST EMISSIONS

Pollutant ________________ Metropolitan area ______________

Model year(s) ____________________

Average speed (j)	f_j	v_j	$f_j v_j$

$\sum f_j v_j =$

Table B-3. CALCULATION SHEET FOR GASOLINE MOTOR VEHICLE CRANKCASE AND EVAPORATIVE EMISSION FACTORS

Calendar year ______________ Pollutant HYDROCARBONS

Vehicle weight class: ☐ HDV ☐ LDV

Model year	h_i	m_i	$h_i m_i$

$\sum h_i m_i =$ g/mi

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