United States
Environmental Protection
Agency

Office of Mobile Source Air Pollution Control
Emission Control Technology Division
2565 Plymouth Road
Ann Arbor, Michigan 48105

EPA 460/3-84-004
March 1984

Air

EPA

Mobile Source Exposure Estimation

EPA 460/3-84-004

Mobile Source Exposure Estimation

by

Melvin N. Ingalls

Southwest Research Institute
6220 Culebra Road
San Antonio, Texas 78284

Contract No. 68-03-3073

EPA Project Officer: Robert J. Garbe

Prepared for

ENVIRONMENTAL PROTECTION AGENCY
Office of Mobile Source Air Pollution Control
Emission Control Technology Division
2565 Plymouth Road
Ann Arbor, Michigan 48105

March 1984

This report is issued by the Environmental Protection Agency to report technical data of interest to a limited number of readers. Copies are available free of charge to Federal employees, current contractors and grantees, and nonprofit organizations - in limited quantities - from the Library Services Office, Environmental Protection Agency, 2565 Plymouth Road, Ann Arbor, Michigan 48105.

This report was furnished to the Environmental Protection Agency by Southwest Research Institute, 6220 Culebra Road, San Antonio, Texas, in fulfillment of Work Assignment 6 of Contract No. 68-03-3073. The contents of this report are reproduced herein as received from Southwest Research Institute. The opinions, findings, and conclusions expressed are those of the author and not necessarily those of the Environmental Protection Agency. Mention of compnay product names is not to be considered as a endorsement by the Environmental Protection Agency.

FOREWORD

This project was conducted for the U.S. Environmental Protection Agency by the Department of Emissions Research of Southwest Research Institute. The project was begun in June 1982 and completed in May 1983. The project was conducted under Work Assignment 6 of Contract 68-03-3073, and was identified within Southwest Research Institute as Project 05-6619-006.

Mr. Robert J. Garbe of the Emission Control Technology Division, Office of Mobile Source Air Pollution Control, Environmental Protection Agency, Ann Arbor, Michigan, served as EPA Project Officer. Mr. Charles T. Hare, Manager, Advanced Technology, Department of Emissions Research, Southwest Research Institute, served as the Project Manager. The project was under the supervision of Melvin N. Ingalls, Senior Research Engineer, who served as Project Leader and principal investigator. The assistance of Mr. Thomas McCurdy and Mr. George Duggan of the EPA, Office of Air Quality Planning and Standards, and Mr. Roy Paul of PEDCo, Inc., in running the NAAQS Exposure Model (NEM) is gratefully acknowledged.

SUMMARY

This project was conducted to provide the nationwide annual person hours of exposure to non-reactive mobile source pollutants. The first activity of the project was to determine the suitability of the National Ambient Air Quality Standards (NAAQS) Exposure Model (NEM), as used in a study of alternative standards for CO to provide the exposure estimate. It was determined that, by itself, the NEM CO study did not provide a sufficiently accurate estimate of mobile source exposure for the following reasons:

- The CO monitor data used were rolled back to meet the ambient standard being studied.
- There was only one mobile source microenvironment included in the NEM.
- Additional nonautomotive CO sources, such as smoking and gas stoves were included in the NEM microenvironments.

The NEM for CO, with modified inputs, could be used in conjunction with a mobile source microenvironment exposure model to produce the desired exposure estimates. The NEM can be thought of as a "people specific" model, since it follows groups of people through their daily activities. The mobile source microenvironment exposure model developed for this project is a "place specific" model in that it calculates exposure for a given place and time, and is not concerned with where the people in the microenvironment are before or after their stay in the microenvironment. Exposure in four separate microenvironments was examined: parking garages, street canyons, on-expressways, and roadway tunnels.

For these microenvironments, measured CO concentrations were used as the indicator of mobile source pollutant concentrations. CO concentrations were obtained from the published literature for parking garages, on expressways, and tunnels. Street canyon CO concentrations were determined by averaging 23 CO monitors from the EPA SAROAD data base which were identified as being in street canyons. The nationwide population in these microenvironments for each hour of the day was obtained from published literature.

Using the CO concentrations and the hourly population for each microenvironment, the nationwide annual person hour exposure to CO was calculated using the mobile source microenvironment model for parking garages, street canyons and tunnels. The on-expressway exposure was calculated as part of the NEM rerun. The exposure estimates obtained were in the form of person hours of exposure as a function of CO concentrations. To convert these exposure distributions to exposures that could be used for any mobile source pollutant,

the CO concentrations were divided by an emission factor appropriate to the microenvironment. This produced the exposure distribution that would be experienced from a 1.0 gram per minute emission factor. To obtain exposure for any pollutant, the 1.0 gram per minute exposure distribution is multiplied by the emission factor for that pollutant.

To obtain the exposure everywhere else but in the three microenvironments, the NEM for CO was rerun with the following changes from the published NEM CO study:

- Air Quality monitor data were used as measured, not "rolled back."

- No indoor sources, such as smoking or gas stoves, were used.

- Additional concentration intervals below 7 ppm CO were added to the printout.

The exposure distributions produced by the rerun of NEM were converted to exposure distributions for a 1.0 gram per minute emission factor in the same manner as the microenvironment exposure distributions, using the nationwide urban CO emission factor for 1978, which was the median year of the NEM air quality data base.

The microenvironment and NEM exposure distributions have not been combined at this time. This is because the microenvironment and NEM exposure distributions for 1.0 gram per minute must each be multiplied by a different emission factor to obtain the nationwide exposure estimate for a given pollutant. Once each distribution has been multiplied by the appropriate emission factor, the distributions can be added together to obtain the nationwide exposure estimate for that pollutant.

TABLE OF CONTENTS

	Page
FOREWORD	iii
SUMMARY	v
LIST OF FIGURES	ix
LIST OF TABLES	xi
I. INTRODUCTION	1
II. INVESTIGATION OF METHODOLOGY	3
III. MICROENVIRONMENT POLLUTANT CONCENTRATIONS FROM MOBILE SOURCES	7
IV. NUMBER OF PERSONS IN MICROENVIRONMENTS	29
V. EXPOSURE IN MOBILE SOURCE MICROENVIRONMENTS	59
VI. MOBILE SOURCE NEM EXPOSURE ESTIMATE	73
VII. NATIONWIDE EXPOSURE TO MOBILE SOURCE POLLUTANTS	85
VIII. CONCLUSIONS AND RECOMMENDATIONS	89
REFERENCES	91
APPENDICES	
A. DEVELOPMENT OF LOGNORMAL POLLUTANT DISTRIBUTIONS FOR PARKING GARAGES AND ROADWAY TUNNELS	
B. FORTRAN LISTING OF SAROAD FILE EDITING PROGRAM FOR STREET CANYON MONITORS	
C. FORTRAN LISTING OF MICROENVIRONMENT EXPOSURE MODEL FOR PARKING GARAGES	
D. FORTRAN LISTING OF MICROENVIRONMENT EXPOSURE MODEL FOR STREET CANYONS	
E. FORTRAN LISTING OF MICROENVIRONMENT EXPOSURE MODEL FOR TUNNELS	
F. UNIVAC 1100 RUNSTREAMS FOR NEM RERUNS	

LIST OF FIGURES

Figure		Page
1	Parking garage CO concentration distribution, 25 percent active cars, average wind speed	11
2	Wind speed distribution, average of seven U.S. cities	13
3	Frequency Distribution of CO concentrations outside three cars on Los Angeles Freeways	22
4	CO concentration as a function of Hourly Percent ADT for the Sumner Tunnel (1961)	24
5	CO concentration as a function of Hourly Percent ADT for an average Roadway Tunnel	26
6	Hourly average cars in motion for weekdays in Parking Garages	32
7	Hourly average cars in motion for Saturdays in Parking Garages	33
8	Hourly average cars in motion for Sundays in Parking Garages	34
9	Number of person trips to CBD per person in urban areas	36
10	Hourly traffic distribution in the CBD for an average weekday	39
11	Hourly traffic distribution in the CBD for Saturday	42
12	Hourly traffic distribution in the CBD for Sunday	43
13	Pedestrians for individual days of the week as a percent of total weekly pedestrians	44
14	Hourly pedestrian distribution in the CBD for weekdays	46
15	Hourly pedestrian distribution in the CBD for Saturdays	47
16	Expressway traffic by day of the week	48
17	Hourly expressway traffic for weekdays	52
18	Hourly expressway traffic for Sundays	53
19	Hourly distribution of people in the NEM "transport vehicle" environment in four cities for Saturdays	54

LIST OF FIGURES (Cont'd)

Figure		Page
20	Hourly tunnel traffic for weekdays	56
21	Hourly tunnel traffic for weekends	57
22	Nationwide cumulative exposure distribution in parking garages	65
23	Nationwide cumulative person hour exposure distribution in street canyons	68
24	Nationwide cumulative person hour exposure distribution in roadway tunnels	72

LIST OF TABLES

Table		Page
1	CO Levels Found in Parking Garages	9
2	Probability Distribution Parameters for Parking Garage Pollutant Distributions	14
3	Discrete Pollutant Distributions for Parking Garages	15
4	SAROAD CO Monitors Used in Street Canyon Analysis	16
5	Descriptive Statistics for Street Canyon CO Readings	18
6	Distribution of Hourly Average CO Levels in Street Canyons	19
7	Pollutant Concentration Intervals for Street Canyons	20
8	Measured CO on Expressways	21
9	CO Levels Found in Roadway Tunnels	23
10	Pollutant Concentration Intervals for Roadway Tunnels	27
11	Distributions of Hourly Average CO Levels in Roadway Tunnels	28
12	Parking Garage Construction in the U.S., 1967-1982	30
13	Estimated CBD Daily Traffic as a Percent of Weekly Traffic	37
14	Daily Person Trips and Vehicles in Street Canyons	38
15	Distribution of People Assigned to the "Transport Vehicle" Mode in the NEM CO Report	50
16	Total Person Hours of Exposure, on-Expressway Situation	50
17	Traffic Distribution by Day of the Week for Several Situations	55
18	Values of Variables Used in Determination of Parking Garage Person Hour Exposure Estimate	63
19	Person Hour Exposure Distribution for Parking Garages	64
20	Values of Variables Used in Determination of Street Canyon Person Hour Exposure	66

LIST OF TABLES (Cont'd)

Table		Page
21	Person Hour Exposure Distribution for Street Canyons	67
22	Values of Variables Used in Determination of Roadway Tunnel Person Hour Exposure	69
23	Person Hour Exposure Distribution in Roadway Tunnels	71
24	NEM Input Modifications Required	74
25	Person Hours of Exposure to Mobile Source CO for Chicago	75
26	Person Hours of Exposure to Mobile Source CO for Los Angeles	76
27	Person Hours of Exposure to Mobile Source CO for Philadelphia	77
28	Person Hours of Exposure to Mobile Source CO for St. Louis	78
29	1980 Person Hours of Exposure to CO in Four Cities	80
30	Values of Variables Used to Extrapolate NEM Exposure in Four Cities to Nationwide Exposure	81
31	1980 Nationwide Urban Mobile Source CO Exposure from NEM	82
32	1980 NEM Nationwide Urban Exposure for Mobile Source Pollutants	83
33	Total Person Hours of Exposure in Parking Garage, Street Canyon and Tunnel Microenvironments	83
34	1980 Rural Exposure to Mobile Source Pollutants	86
35	1980 Total Nationwide (Urban and Rural) Exposure to Mobile Source Pollutants Exclusive of Three Micro-environments	86

I. INTRODUCTION

Internal combustion engines used in motor vehicles produce exhaust gases that contain a multitude of chemical compounds. Four of these pollutants are regulated by standards (hydrocarbons, CO, NO_x and particulate matter). In devising means to control these four regulated pollutants, undesirable chemical compounds may inadvertently be produced. Malfunction of the engine and emission control systems can also change the concentrations of the various chemical species in the exhaust. Additionally, alternative fuels proposed for use in motor vehicles can produce greatly different compounds and concentrations of compounds than are currently produced by gasoline and diesel fuels. The EPA has instituted a program to determine if any of these unregulated mobile source emissions cause or contribute to a risk to public health, welfare or safety.

Previous Work

The work reported on here is the latest in a series of projects on the subject of unregulated emissions conducted for the EPA by Southwest Research Institute. Previous projects have developed methodologies for measurement of unregulated pollutants in vehicle exhaust,(1,2,3)* determined the magnitude of these unregulated emissions in a variety of vehicles,(1,4-8) evaluated the effects of engine and emission control system malfunctions,(9-12) and measured unregulated emissions using a variety of alternative fuels.(13-17) Thus, the exhaust emission rates, in terms of mass per distance or mass per time, of many unregulated pollutants are known.

To determine effects on health and welfare, emission rates of these unregulated pollutants must be transformed into the ambient pollutant concentrations to which people are exposed. Another of the previous projects at SwRI examined localized situations in which the dispersal of mobile source pollutants is hindered, causing higher than usual concentrations.(18) Several situations involving small areas, called microscale areas, were identified. Mathematical dispersion models of these situations were selected and validated to allow the prediction of ambient concentrations in these microscale areas, based on knowledge of vehicle exhaust emission rates. These models allowed the identification of areas of high mobile source pollution and permitted the evaluation of the health and welfare effects of short term, high level exposure to these unregulated emissions.(19)

It was not possible from that study to ascertain long term effects due to chronic exposure, such as cancer risk, for unregulated pollutants. This present project was conducted to provide annual exposure information

*Superscript numbers in parentheses refer to references at end of this report.

resulting from mobile source pollutants which can then be used to evaluate health effects from long term exposure. The exposure is expressed in terms of person hours. Person hours of exposure are simply the number of people in a situation multiplied by exposure time in that situation in hours. Thus, 1000 person hours of exposure can be one person exposed for 1000 hours, 1000 people exposed for one hour, or any other values of persons and hours whose product is 1000.

Objective

The objective of this project was to develop the methodology to obtain the nationwide, annual person hours of exposure to any mobile source pollutant. Then, using that methodology, the annual exposure in person hours can be determined as a function of ambient concentration for any mobile source pollutant.

Approach

To determine the annual exposure in person hours to any mobile source pollutant, the number of persons exposed to the pollutant in various places must be known as a function of time. The ambient concentration in these places must also be known as a function of time. The exposure in person hours can then be ascertained, expressed either as the number of person hours in various concentration intervals or as an average concentration for the entire population examined.

The ambient concentrations of most unregulated pollutants are not available from direct measurements. The concentrations of these pollutants must be inferred from measurement of some other pollutant. For this project CO was used as a surrogate, since urban CO is entirely mobile source related. If the CO concentration in an urban area is known, then the concentration of other mobile source pollutants can be estimated by multiplying the CO concentration by the ratio of the new pollutant emission rate to the CO emission rate:

$$\text{Pollutant Concentration} = \text{CO concentration} \left(\frac{\text{Pollutant emission rate}}{\text{CO emission rate}} \right)$$

This approach assumes that the desired pollutant and CO have equivalent dispersion and reaction characteristics in the ambient air.

At the start of the projeect, there was no method available to combine the concentrations from mobile sources, including the important microenvironments, with the person in the various environments. The project approach was to first determine if methods existed that could be used either directly or with modification. If methods did exist, it was planned to become familiar with their use, then use them to determine exposure. If no satisfactory method existed, a methodology would be developed. After collecting the necessary data, the methodology would be applied to yield the desired relationship between person hours of exposure and pollutant concentration.

II. INVESTIGATION OF METHODOLOGY

Determining person hours of exposure requires that the pollutant concentrations for the areas of mobile source exposure be known, and that the number of people in these areas be known. There are two basic approaches to determining person hours of exposure. One approach is to follow people through their various activities during the day, determining the amount of time spent in various locations. In this report, this approach is referred to as "people specific." The second approach is to look at the places where people encounter mobile source pollutants, then determine the population in those places for each hour of the day. This approach is referred to as "place specific." If only total person hours of exposure is desired, and not an individual person's exposure pattern, then the place specific approach appears to be the easiest and most accurate.

While all locations in urban environments are exposed to some concentration of pollutants from mobile sources, the highest concentrations occur in small, confined areas where people and vehicles are in close proximity. These areas are referred to as microscale areas or microenvironments, and include such areas as personal garages, parking garages, street caynons, expressways, and tunnels. Thus, any method must be able to include these microenvironments.

At the start of the project, it was learned that the EPA Office of Air Quality Planning and Standards (OAQPS) had developed an exposure model to evaluate the exposure profile for various levels of pollutant ambient standards. A study had just been completed for CO using this model.(33) If it were possible to use the OAQPS model CO results, the project would be spared the expense and time of developing a new model for mobile source exposure. The OAQPS-developed model had been given the acronym "NEM", from "NAAQS Exposure Model."

Evaluation of the NEM CO Report

The NEM basically traces the movement of people in an individual city, determining the location of similar groups of people for each hour of the day, each day for a year. It is a "people specific" model. A pollutant concentration in each location is estimated for each hour of the year. As used in the CO study, it determined the hourly exposure of 56 different groups of people moving through six different neighborhood types. In any neighborhood, the groups can be in one of six microenvironments.

The groups of people, called "Activity-Occupation" (A-O) groups, had been determined from studies of people's activities. The number of people assigned to each group for a given city was determined from census information. The A-O groups have titles such as: sales workers, laborers, housewives, and children under five.

The six different neighborhood types provide the basis for the air quality level. For each city, one CO monitor was chosen to represent each neighborhood type. Thus, for each hour of the year, there is a different CO concentration associated with each neighborhood type.

The actual exposure level takes into account the fact that people can be exposed to more or less CO than the monitor level because of their immediate surroundings--their microenvironment. Six microenvironments are used: indoors (home), indoors (work), transport vehicle, roadside, outdoors, and kitchen. For each microenvironment there is a single multiplication factor and an additive factor applied to the hourly CO monitor values.

The NEM produces a person-hour exposure distribution in various pollutant concentration intervals for a single city. Currently, NEM CO results are available for four cities. These four city results are then extrapolated to the entire country.

The NEM study was reviewed in detail for its applicability to mobile source exposure estimation. It was concluded that the CO study, as published, was not satisfactory for use in determining exposure estimates from mobile sources for the following reasons:

1. Since the purpose of the NEM analysis was to study the effect of ambient CO standards, the representative CO monitor data was "rolled back," (i.e., reduced) so that all areas meet the three different CO standards being investigated. Thus, the exposure distributions obtained did not represent an actual distribution which could be used with a calendar year CO mobile source emission factor, but rather a distribution that would exist <u>if</u> certain ambient CO standards were met.

2. The microenvironments considered were only:

    - indoors (home)
    - indoors (work)
    - in a vehicle
    - roadside
    - outdoors
    - kitchen

   A number of microscale environments with the possibility of high ambient concentrations from mobile sources that were identified under EPA Contract 68-03-2884, Task Specification 1, were not included in the NEM study.

3. The microenvironments used in the NEM CO study included CO sources other than vehicles, such as smoking and gas stoves. To properly use the CO data to indicate mobile source emissions there must be no other known CO sources.

4. The use of multipliers on the CO monitor data to obtain microenvironment CO levels is not sufficient in mirco-environments that contain large numbers of mobile sources. In these cases, there is probably no relationship between the neighborhood monitor CO level and the CO level in the microenvironment. The work done at SwRI under Contract 68-03-2884 indicates that the number of vehicles and the microenvironment ventilation rate are the controlling factors for the CO level in the microenvironment. These factors have little effect on outdoor CO monitors, nor are they constant from one microenvironment to anohter in the same neighborhood.

None of the preceding is intended as criticism of the NEM CO study. The remarks are only intended to indicate that the NEM study was not, by itself, a satisfactory method to meet the objective of the present project.

While the NEM model does not adequately cover the microenvironments of concern in mobile source exposure, it could be satisfactory for the mesoscale exposure (e.g., in a suburban housing development), if the monitor CO values were used "as is," (not rolled back) and the microenvironment additive factors (which were used to account for sources such as smoking, etc.) were set to zero.

Final Methodology

Since the NEM could provide an exposure estimate of mesoscale exposure, which accounts for most of the yearly person hours of exposure, it was decided that the NEM computer program should be rerun with the following changes to the input instructions:

- CO monitor data would be used "as is"
- No additive sources, such as smoking, would be used in the NEM microenvironments

To determine the person hours of exposure to those mobile source microenvironments not accounted for by the NEM, a new model was developed. Four microenvironments were investigated: parking garages, street canyons, expressways and roadway tunnels. The NEM appears to satisfactorily cover the microenvironments where people are exposed to lower levels of mobile source pollutants, such as non-street caynon, non-expressway streets, in the NEM "outdoor" and "beside roadway" microenvironments. Thus, non-street canyon, non-expressway streets are not examined separately, since to do so would not make an appreciable change in the NEM-generated exposure distribution.

The mobile source microenvironment model is a "place specific" model. To obtain annual person hours of exposure in each of the important mobile source microenvironments, the model uses the population in a microenvironment for each hour of the day. Several discrete pollutant concentration frequency distributions were developed for each microenvironment. For each hour of the day, the frequency of occurrence of each concentration interval is multiplied by the microenvironment population for that hour to obtain person hour exposure distribution for that hour. The total exposure is obtained by multiplying the single hour distribution by the number of days in a year, them summing the distribution from each hour of the day.

To obtain the range of CO concentrations for the various microenvironments considered in this project, information from literature searches done under Contract 68-03-2884, and the EPA SAROAD air quality monitor data base, was used. The number of persons nationwide in each microenvironment for each hour of the day was determined from information in the literature. The NEM results representing only mobile source emissions can be combined with person-hour exposure distributions from the four microenvironments (parking garages, street canyons, expressways, and tunnels) to obtain a single nationwide person-hour exposure distribution to mobile source pollutants.

III. MICROENVIRONMENT POLLUTANT CONCENTRATIONS FROM MOBILE SOURCES

In order to estimate the exposure of persons to mobile source pollutants, information is needed on the ambient concentrations of these pollutants in each microenvironment. Since it is not possible to know the pollutant concentration in every occurrence of the microenvironment for all hours of the year, some method of estimating the distribution of pollutant concentration values is required.

From an examination of a number of individual examples of each microenvironment, an estimate of the average concentration and range of concentrations within that microenvironment can be obtained. If an assumption is made about the shape of the distribution, then a mathematical description of the distribution can be obtained.

Pollutant concentrations within a microenvironment change with the hour of the day. The change is, in general, dependent on number of vehicles and ventilation rate. Thus, several concentration distributions for each microenvironment may be necessary, either as a function of time of day, number of vehicles, or ventilation rate.

Use of Carbon Monoxide Concentrations

Nationwide, mobile sources produce approximately 76 percent of the total carbon monoxide emitted into the atmosphere.[20] For the microenvironments considered in this study, mobile sources are the only significant source of CO. Thus, CO measurements in these microenvironments can be used to determine the level of any mobile source pollutant.

Pollutant concentrations are proportional to the exhaust emission rate ("emission factor"). For example, the concentration of a pollutant emitted from vehicles at the rate of 4 g/min will be twice as high as the concentration of pollutant emitted at 2 g/min in the same situation. Thus, CO concentration measurements can be used to determine the concentration of any unregulated mobile source emission by multiplying the CO concentration by the ratio of the unregulated emission factor to the CO emission factor. In this project, the CO concentration is divided by the CO emission factor in g/min, producing a concentration equivalent to a 1.0 g/min emission factor. To obtain the pollutant concentration for any unregulated emission, the concentration at 1.0 g/min is multiplied by the appropriate unregulated emission factor expressed in grams per minute.

The CO emission factors were obtained from the EPA publication "Compilation of Air Pollutant Emission Factors: Highway Mobile Sources," EPA 460/3-81-005,[21] or directly from the MOBILE 2 computer program which was used to generate the emission factors in the published compilation.

Different emission factors were used for the different microenvironments since average vehicle speed varies with the situation. Also, the calendar year, or years, when measured CO levels were available varied with each microenvironment.

Use of Frequency Distributions of Pollutant Concentrations

Any investigation of actual pollutant concentrations in any environment reveals a rather wide range of pollutant levels. Thus, persons in these environments at different times are exposed not just to one pollutant concentration, but to a range of concentrations. The concentration level depends mainly on the number of vehicles present and the amount of ventilation (natural or artificial). The concentrations vary not only with time at a single location, but also from location to location at a given time. By accounting for the occurrence of pollutant concentration ranges for all locations of a microenvironment for a year, a single pollutant concentration frequency distribution can be developed which takes into account the concentration variation with time and location.

In most of the microenvionments investigated in this study, insufficient CO measurements were available to define the concentration frequency distribution for the measured data. In those cases where measured data were not available, some assumption has to be made about the mathematical form of the distribution. The lognormal distribution has been used for about 15 years to describe the distribution of ambient pollutant measurements both with time and location.[22] The lognormal distribution gets its name from the fact that the logarithms of the independent variable are normally distributed. Over the years, a lively debate has been conducted in the literature on whether the lognormal distribution was the best representation of the concentration distribution. While other distributions, such as the Weibull distribution, have been suggested, the lognormal appears to be the most widely used. For this study, the lognormal distribution has the additional virtue of being definable from available concentration values. Therefore, the lognormal distribution was chosen as the mathematical form to use when there were insufficient data to define the distribution from measured values.

The expression for the two-parameter lognormal distrubution is:[26]

$$dF(x) = \frac{1}{x\sigma\sqrt{2\pi}} \exp\left[-\frac{1}{2\sigma^2}(\ln x - \mu)^2\right] dx$$

where:

x = pollutant concentration
μ = mean
σ^2= variance

The distribution can be completely defined if μ and σ^2, are known. Appendix A presents the various relationships between μ and σ and the mean, median and mode which were used in this project to define the lognormal distributions for each microenvironment from measured concentration values.

Parking Garage Pollutant Concentrations

The first microenvironment for which ambient air concentrations of pollutants were developed was the parking garage. While CO concentrations in parking garages have been a concern for years, few quantitative data are available. What is available, is often only as a maximum CO or average CO concentration. These values are not sufficient for this project. A distribution of concentrations is needed, since using an average concentration would eliminate any high-level exposures. However, there was not sufficient information in the literature to determine this distribution. Table 1 is a list of measured parking garage CO concentrations found in the literature. Additionally, the modeling study done under Contract 68-03-2884 calculated a CO concentration of 37 ppm in a "typical" (mode average) garage and 374 ppm for a "severe case" parking garage. These CO values all indicate that pollutant concentrations are not normally distributed, but rather are skewed, with a long "tail" at the higher concentrations.

TABLE 1. CO LEVELS FOUND IN PARKING GARAGES

CO Levels	Reference No.	Study Location	Study Date
20 ppm to over 100 ppm (off scale 100). Several peaks appear as though they would exceed 150 ppm	27	Detroit	1961
0-200 ppm Car Park A (Sat.) 0-20 ppm Car Park A (Tues.) 0-200 ppm Car Park B1 0-30 ppm Car Park B2 33 ppm @ 200 car/hr Car Park B4 Max. 110-130 ppm Car Park C1 50 ppm Car Park C2 105 ppm Car Park D1 Max. 400-450 ppm Car Park D2 (mech. vent.)	28	England	1976
30-87 ppm eight hr avg	29	Philadelphia	1977
peaks often above 200 ppm max 365 ppm	30	Los Angeles	1975

Since adequate data to define the distribution do not exist, it was decided to choose a distribution equation, then use the CO values for the typical and severe parking garage from Contract 68-03-2884 to define the distribution. The concentration distribution is then in a mathematical form which could easily be modified if measured data become available in the future. As explained earlier, the lognormal distribution was chosen to represent the pollutant concentration distributions where there were insufficient data to define the distribution experimentally. As shown in Appendix A, a lognormal distribution can be completely defined if the median and mode of the distribution are known. For this project, the typical garage CO value developed under Contract 68-03-2884 [18] was used as the mode. The median was adjusted so that the frequency of occurrence in the "severe" concentration range was approximately equal to one garage. Assuming 10,000 parking garages in the country, this is equivalent to a frequency of occurrence of 0.01 percent.

While ultimately distributions in $\mu g/m^3$ based on an emission factor of 1 g/min are required, a distribution in ppm CO, using the calculated typical and severe levels was first computed for a better visualization of the distribution and for comparison to the data in Table 1. The mode was taken as 37 ppm [18] and the median adjusted until the frequency of occurrence in the 300 to 400 ppm interval was approximately 0.01 percent. This resulted in a median value of 48. This distribution is shown in Figure 1. Note that the largest number of occurrences are in the range of the CO values shown in Table 1.

This study requires ambient concentrations in $\mu g/m^3$ based on a 1.0 g/min emission rate. The typical concentrations obtained from the modeling work done under Contract 68-03-2884 were actually calculated using a one gram per minute emission factor. The typical garage has an ambient air level of 3900 $\mu g/m^3$ for 1.0 g/min pollutant emission rate; the severe garage, a level of 46,100 $\mu g/m^3$. [18] For both these situations, the active cars represented 25 percent of parking capacity. For this distribution, the mode was 3900 $\mu g/m^3$ and the median 5500 $\mu g/m^3$, giving a μ of 8.6125 and a σ of 0.58632 (see Appendix A).

The model used for parking garage ambient concentrations in Contract 68-03-2884 indicates that after a short period, for instance 10 minutes, the concentrations are essentially proportional to the number of cars divided by the effective ventilation rate. Thus, concentrations will vary with number of active cars. The active cars vary from 0 to 21.3 percent of parking capacity (see Section IV). To keep the number of concentration distributions reasonable, it was decided to develop three distributions, one each for 3, 9 and 19 percent active cars. These distributions were developed by scaling the 25 percent mode and median by the ratio of active cars to 25 percent active cars, since concentration varies linearly with number of cars.

As mentioned above, pollutant concentration varies not only with number of active cars, but also with effective ventilation rate. The $\mu g/m^3$

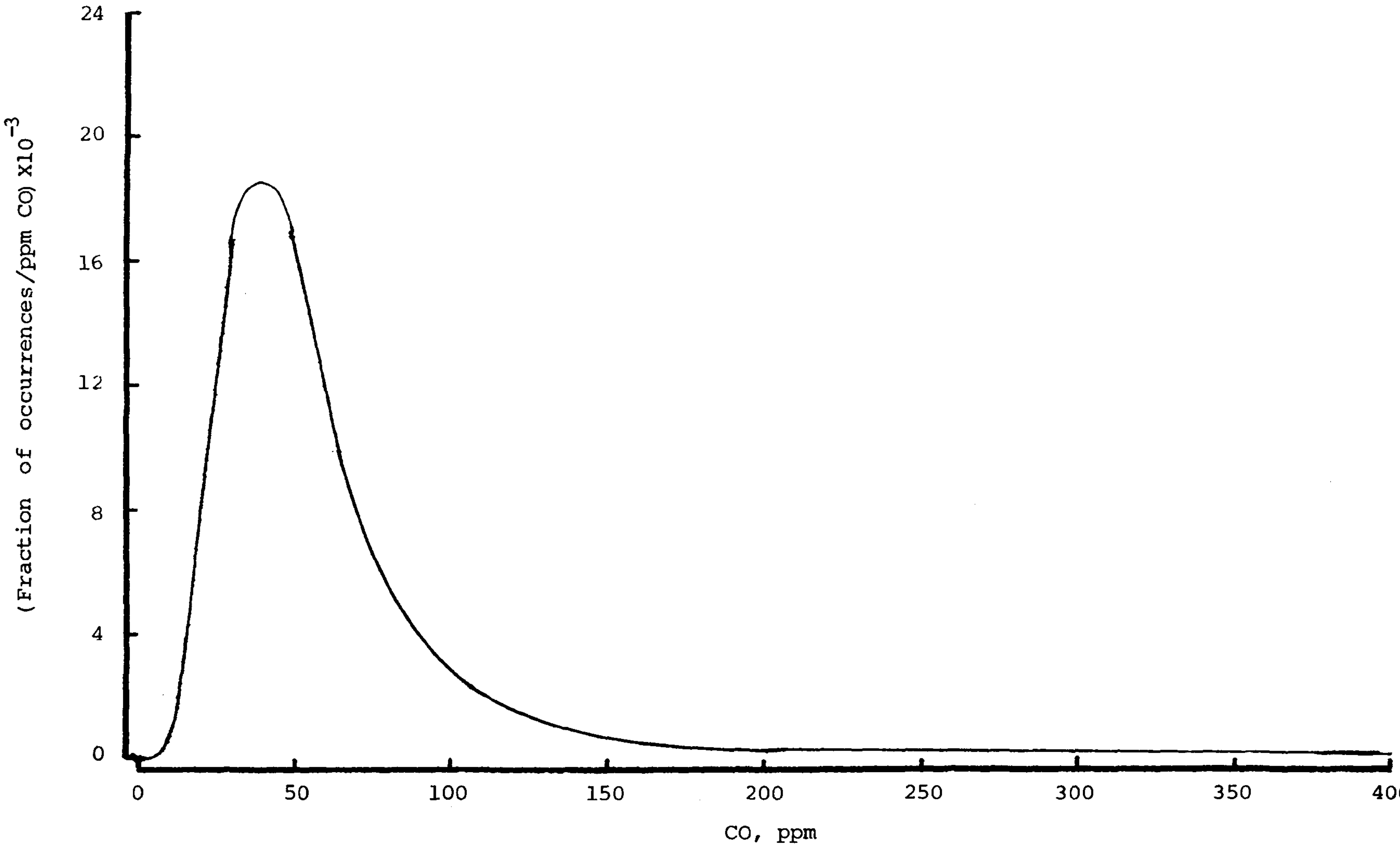

Figure 1. Parking garage CO concentration distribution, 25 percent active cars, average wind speed

pollutant levels for the typical garage were calculated assuming a naturally ventilated garage with an "avergae" value for wind speed. Ninety percent of garages in the country are naturally ventilated,[18] with ventilation rate depending on wind speed. Since the person hour exposure for this study is to be for an entire year, the ventilation rate can be expected to vary during the year as wind speed varies. It has been shown in a number of studies that wind speed at a given measuring station varies lognormally.[31]

To obtain an estimate of how wind speed varies through the country, the annual wind speed distributions for seven cities were averaged. The wind speed distributions for each city were obtained from the NOAA publication "Airport Climatological Summary."[32] The average of the seven distributions is shown in Figure 2. Note that approximately 65 percent of the time the average wind speed is between 4 and 10 knots, 25.5 percent of the time it is between 11 and 27 knots, and 9.5 percent of the time it is 3 knots or less.

The pollutant distributions above were calculated using approximately a seven knot wind speed for the typical (mode) garage. To account for the concentration variation with wind speed, two other wind speeds, 1.5 knots and 14 knots, were chosen to represent ventilation rates lower and higher than the mode. Pollutant concentration distributions were calculated using three wind speeds by multiplying the mean and mode of each of the three distributions calculated at 7 knots by the ratio: 7.0/new wind speed, since pollutant concentration is inversely proportional to ventilation rate.

These calculations resulted in nine pollutant distributions; three distributions depending on ventilation rate of each of three levels of active cars. The mode, median, μ and σ of each of the distributions are shown in Table 2.

The continuous pollutant distributions generated must be converted into discrete distributions to obtain the person hour exposure for parking garages. A computer program was written to evaluate the expression for the lognormal distribution, producing frequences of occurrence for each pollutant interval. Table 3 shows the relative frequencies for each pollutant interval in all nine of the pollutant frequency distributions. The pollutant intervals were arbitrarily chosen. The values shown in Table 3 are one of the inputs used to calculate the person hours of exposure in parking garages as explained in Section V of this report.

Street Canyon Pollutant Concentrations

The street canyon exposure calculated in this project is for people outside on the sidewalk or in vehicles in the street canyon. It does not include people in buildings adjacent to the street canyon. Unlike parking garages, where there have been few measurements of vehicle pollutant levels, CO samples have been taken in downtown street canyons by fixed monitors for

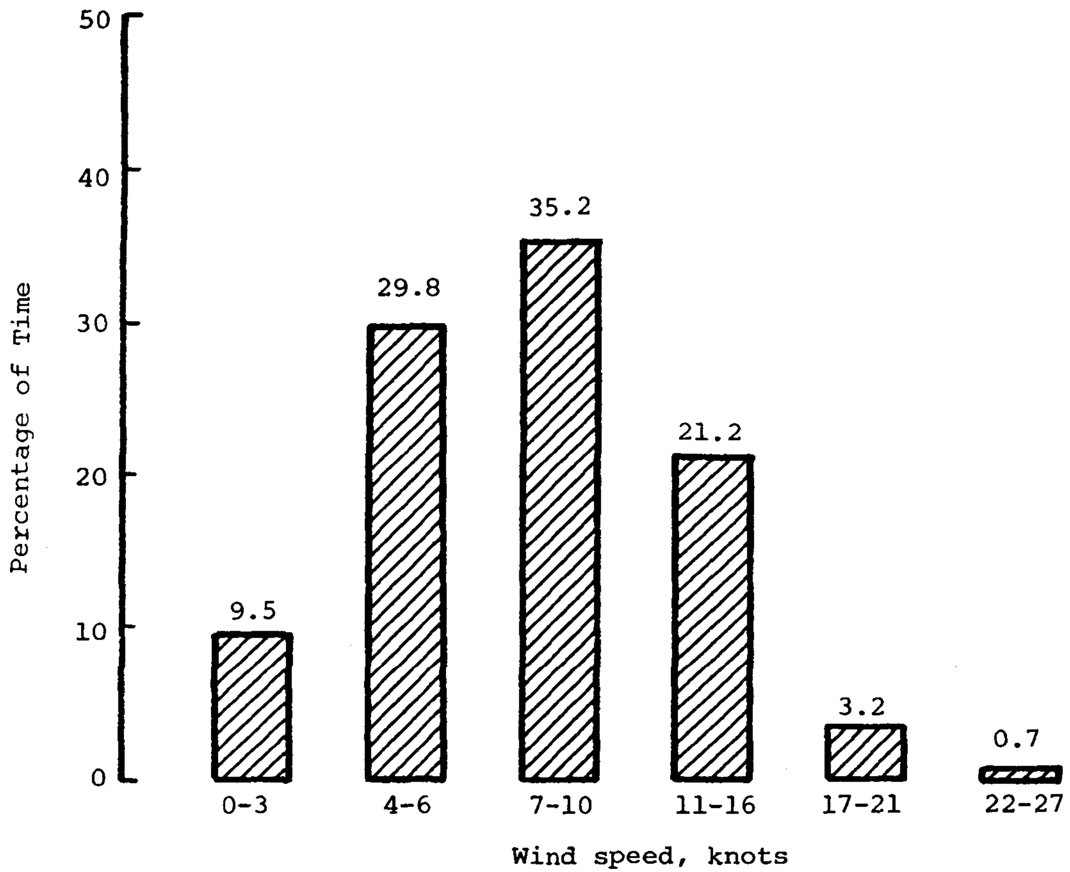

Figure 2. Wind speed distribution, average of seven U.S. cities

TABLE 2. PROBABILITY DISTRIBUTION PARAMETERS FOR PARKING GARAGE POLLUTANT DISTRIBUTIONS

Percent Active Cars	Wind Speed, Knots	Probability Distribution Parameters, $\mu g/m^3$ Mode	Median	μ	σ
19	1.5	14000	19500	9.8782	0.5756
	7	3000	4200	8.3428	0.5801
	14	1500	2100	7.6496	0.5801
9	1.5	6500	9300	9.1378	0.5985
	7	1400	2000	7.6009	0.5972
	14	700	1000	6.9078	0.5972
3	1.5	2200	3000	8.0064	0.5569
	7	470	660	6.4922	0.5827
	14	235	330	5.7991	0.5827

a number of years. The National Air Data Branch of the EPA was contacted regarding the information that could be retrieved from the data bank of monitor readings using the SAROAD (Storage and Retrieval of Aerometrics Data) system. From the information received, it appeared that there was the potential for obtaining a great deal of information regarding CO levels in street canyons. However, the data that were easily available were not sufficient for the needs of the project. Since the raw data for CO is stored by hour of the day, it is possible to get summaries of specific monitors by hour of the day for each month of a year. These data could be used to obtain frequency distributions for weekday, Saturday and Sundays.

To use the stored monitor data, it was necessary to know which monitors are in street canyons close to street level. There are currently over 4000 active sites, which makes it a time-consuming task to locate CBD sites manually. Discussions with personnel in EPA's Office of Air Quality Planning and Standards led to the EPA group that is charged with inspection of all monitors that are part of the National Air Monitoring (NAM) network. This group was able to furnish a list of central city monitors which are known to be in street canyons. The list is contained in Table 4.

TABLE 3. DISCRETE POLLUTANT DISTRIBUTIONS FOR PARKING GARAGES

Pollutant Concentration Interval, $\mu g/m^3$	Fraction of Time in Interval								
Pct. Active cars:	19	19	19	9	9	9	3	3	3
Wind Speed, kts:	1.5	7	14	1.5	7	14	1.5	7	14
0-360	0.0000	0.0000	0.0034	0.0000	0.0054	0.0435	0.0003	0.1481	0.5656
360-463	0.0000	0.0001	0.0035	0.0000	0.0052	0.0540	0.0004	0.1196	0.1569
463-618	0.0000	0.0004	0.0131	0.0000	0.0176	0.1096	0.0020	0.1805	0.1389
618-773	0.0000	0.0013	0.0248	0.0000	0.0308	0.1211	0.0053	0.1497	0.0684
773-1030	0.0000	0.0062	0.0661	0.0001	0.0760	0.1845	0.0203	0.1698	0.0475
1030-1288	0.0000	0.0132	0.0885	0.0004	0.0958	0.1433	0.0368	0.0967	0.0159
1288-1546	0.0000	0.0215	0.0981	0.0009	0.1016	0.1024	0.0520	0.0535	0.0058
1546-1804	0.0000	0.0299	0.0971	0.0017	0.0975	0.0708	0.0630	0.0298	0.0023
1804-2061	0.0000	0.0370	0.0898	0.0028	0.0881	0.0490	0.0690	0.0172	0.0010
2061-2319	0.0001	0.0428	0.0840	0.0043	0.0775	0.0337	0.0713	0.0100	0.0004
2319-2577	0.0001	0.0466	0.0698	0.0058	0.0663	0.0232	0.0701	0.0059	0.0002
2577-3000	0.0004	0.0804	0.0929	0.0133	0.0873	0.0242	0.1069	0.0053	0.0001
3000-4000	0.0026	0.1844	0.1370	0.0401	0.1267	0.0269	0.1969	0.0046	0.0001
4000-5000	0.0062	0.1513	0.0665	0.0703	0.0610	0.0074	0.1235	0.0009	0.0000
5000-6000	0.0113	0.1125	0.0325	0.0818	0.0298	0.0024	0.0731	0.0002	0.0000
6000-8000	0.0403	0.1371	0.0255	0.1678	0.0236	0.0014	0.0691	0.0001	0.0000
8000-10000	0.0615	0.0666	0.0072	0.1472	0.0068	0.0002	0.0243	0.0000	0.0000
10000-15000	0.2008	0.0567	0.0037	0.2410	0.0036	0.0001	0.0149	0.0000	0.0000
15000-20000	0.1929	0.0111	0.0003	0.1132	0.0003	0.0000	0.0017	0.0000	0.0000
20000-25000	0.1494	0.0029	0.0000	0.0538	0.0001	0.0000	0.0003	0.0000	0.0000
25000-30000	0.1060	0.0008	0.0000	0.0252	0.0000	0.0000	0.0001	0.0000	0.0000
30000-40000	0.1226	0.0004	0.0000	0.0206	0.0000	0.0000	0.0000	0.0000	0.0000
40000-50000	0.0579	0.0001	0.0000	0.0056	0.0000	0.0000	0.0000	0.0000	0.0000

TABLE 4. SAROAD CO MONITORS USED IN STREET CANYON ANALYSIS

SAROAD No.	Hourly Readings Available[a]	State	City
10 1960 085H01	7848	FL	Jacksonville
10 2700 018G01	8144	FL	Miami
10 4360 056G01	7782	FL	Tampa
11 0200 043F01	6309	GA	Atlanta
14 1220 040F01	7616	IL	Chicago
15 2040 034F01	7912	IN	Indianapolis
18 2380 026G01	7782	KY	Louisville
19 2020 017F01	5814	LA	New Orleans
21 0120 034H02	7768	MD	Baltimore
22 0240 022F01	6512	MA	Boston
22 2160 007F01	1084	MA	Springfield
23 1180 021G01	8030	MI	Detroit
33 4680 058F01	8090	NY	New York
33 4680 062F01	8023	NY	New York
34 0700 029G01	8002	NC	Charlotte
36 1220 021G01	7945	OH	Cincinnati
39 7140 045H01	8336	PA	Philadelphia
39 7260 005G01	6716	PA	Pittsburgh
41 0300 009F01	7948	RI	Providence
44 2540 021G01	8659	TN	Nashville
45 1310 053H01	7899	TX	Dallas
45 4570 046F01	2320	TX	San Antonio
49 1840 077F01	8529	WA	Seattle
09 0020 022I12	N.A.[b]	DC	Washington
26 4280 079H01	N.A.	MO	St. Louis

[a] 8760 hours in one year
[b] Data from these monitors requested, but not available

The purpose in obtaining these data was to provide as large a measured CO base as possible from which to generate a street canyon pollutant frequency distribution. Data from all the cities were merged in one set of CO readings regardless of city size or other variables. The time and effort allotted to this project were not sufficient to weight the individual monitor values by city size, street size, or traffic density, or to compare individual monitor distributions. The data, as received, were formatted to have 12 hours of data from one station on each line. This means that one day's data from one station required two lines. If all 12 hours of data were missing, the whole line was skipped. Thus, some days would have two lines of data and some would have only one line. The statistical computer program used to analyze the information (Statistical Package for the Social Sciences, SPSS) could not handle this type of variable format. The data from the monitoring stations were also not all in the same units. Some data were in ppm and some in milligrams per cubic meter. The readings themselves consisted of four integers, with the decimal point location for the data indicated elsewhere on the line. Additionally, it was desired to separate out weekdays, Saturdays and Sundays. This required checking the date of each line and assigning the CO readings to the correct category. With approximately 14,000 lines of data, the editing process obviously had to be computerized. A FORTRAN computer program was written to provide the necessary editing. Appendix B contains a listing of the editing program.

Once edited, the data were processed using the SPSS program to obtain frequency distributions, the mean, median, and range of the CO data in ppm for each hour of the day for weekdays, Saturdays and Sundays. The minimum, maximum, mean and median for each hour are presented in Table 5.

Next, the CO distributions for each hour of the day were investigated. CO distributions were generated using the SPSS computer program for each hour of the day. The ppm CO concentrations were divided into 19 intervals. To reduce the number of distributions to a more manageable level, the individual hourly distributions were examined and similar distributions combined. This resulted in six distributions for each day type. These CO distributions are shown in Table 6. These values are presented in terms of ppm CO, because it is a familiar unit. For use in the project, the ambient concentrations should be in $\mu g/m^3$ for an emission factor of 1.0 g/min.

From the published "Mobile 2" data, Table G-9 of Reference 21, a 1981 CO emission factor of 50.51 g/mile was obtained, using a 75°F day. At 19.6 miles/hr, this emission factor is equivalent to 16.50 g/min. Using this emission factor, the CO ppm intervals were converted to "$\mu g/m^3$ of pollutant" intervals by multiplying the ppm CO values by the appropriate conversion factor (1157/16.50 = 70.12). The new intervals are shown in Table 7. The distributions using the $\mu g/m^3$ intervals were used to determine the person hour exposure in street canyons, as explained in Section V.

On-Expressway Pollutant Concentrations

The approach to this project was to use the NEM CO study results wherever possible. Since the NEM contains a "transport vehicle" microenvironment, it was decided to use this microenvironment for the on-expressway situation, if at all possible. The NEM computer program attempts to estimate the CO concentrations in cars by multiplying a CO monitor reading by a constant. As part of the NEM CO study, a literature review was conducted to determine what this multiplier should be. The investigation indicated that the "transport vehicle" microenvironment multiplier should be between 1.3 and 4.7. A value of 2.1 was chosen as the best estimate.[33]

TABLE 5. DESCRIPTIVE STATISTICS FOR STREET CANYON CO READINGS

Hour Ending	Weekdays Concentration, ppm			Saturdays Concentration, ppm			Sundays Concentration, ppm		
	Range	Mean	Median	Range	Mean	Median	Range	Mean	Median
1 am	0-12	1.63	1.09	0-11	2.26	1.95	0-19.4	2.26	1.72
2	0-12.5	1.37	0.99	0-13	2.10	1.49	0-16.0	2.03	1.48
3	0-12.0	1.16	0.83	0-12	1.85	1.18	0.15.3	1.78	1.13
4	0-12.5	0.99	0.75	0-9	1.42	1.00	0-14.3	1.39	0.99
5	0-15.0	0.98	0.79	0-9.5	1.20	0.96	0-13.6	1.14	0.88
6	0-11.3	1.38	1.02	0-7.3	1.21	0.98	0-12.4	1.04	0.84
7	0-17.1	2.57	2.04	0-8.8	1.49	1.06	0.11.6	1.12	0.96
8	0-24.5	3.97	3.47	0-8.5	1.78	1.49	0-10.0	1.22	0.99
9	0-28.5	4.41	3.81	0-10.2	1.99	1.70	0-10.4	1.21	1.00
10	0-17.6	3.96	3.36	0-19.0	2.12	1.87	0-12.2	1.30	1.02
11	0-18.0	3.92	3.37	0-9.5	2.28	1.99	0-10.2	1.36	1.04
Noon	0-18.5	3.97	3.45	0-11.0	2.40	2.01	0.9.0	1.46	1.04
1 pm	0-22.3	4.06	3.49	0-17.0	2.45	2.01	0.10.2	1.57	1.16
2	0-19.9	3.94	3.41	0-17.0	2.53	2.02	0-9.2	1.64	1.22
3	0-16.0	3.97	3.51	0-17.5	2.62	2.03	0-11.2	1.80	1.34
4	0-19.2	4.32	3.96	0-13.0	2.62	2.04	0-11.5	1.85	1.39
5	0-20.8	4.89	4.42	0-13.3	2.57	2.02	0-11.0	1.94	1.45
6	0-22.7	4.33	3.65	0-14.0	2.48	1.99	0-11.2	1.99	1.50
7	0-20.5	3.07	2.46	0-14.5	2.30	1.94	0-12.9	1.98	1.53
8	0-18.3	2.57	2.02	0-11.5	2.35	1.97	0-11.1	1.97	1.60
9	0.17.0	2.35	1.98	0-11.6	2.34	1.96	0-13.5	1.94	1.55
10	0-19.6	2.32	1.98	0-17.0	2.45	1.99	0-10.3	1.87	1.48
11	0-16.0	2.28	1.96	0-16.4	2.59	2.04	0-10.4	1.81	1.32
Midnight	9-17.0	2.15	1.73	0-11.5	2.50	2.00	0-10.7	1.65	1.18

TABLE 6. DISTRIBUTION OF HOURLY AVERAGE CO LEVELS IN STREET CANYONS

PPM CO Interval	Percent Frequency for Time Interval Shown					
	Weekdays					
	1-6am	7am	8-9am	10am-3pm	4-6pm	7-Mid.
0.0-0.5	33.58	6.21	1.91	2.23	1.82	9.23
0.6-1.5	40.51	28.58	11.37	12.92	10.05	29.54
1.6-2.5	14.35	25.68	18.62	19.88	16.16	25.37
2.6-3.5	6.31	17.50	18.18	18.00	16.73	15.50
3.6-4.5	2.71	10.00	15.05	14.27	14.21	8.85
4.6-5.5	1.30	5.41	10.49	10.39	11.33	4.77
5.6-6.5	0.60	3.00	8.11	7.57	9.34	2.75
6.6-7.5	0.34	1.39	6.03	5.49	6.75	1.66
7.6-8.5	0.15	0.98	3.26	3.50	4.70	0.95
8.6-9.5	0.07	0.57	2.39	2.36	3.24	0.56
9.6-10.5	0.04	0.35	1.63	1.42	2.16	0.26
10.6-11.5	0.02	0.10	1.04	0.76	1.28	0.18
11.6-12.5	0.02	0.12	0.66	0.51	0.84	0.10
12.6-13.5	--	0.04	0.35	0.32	0.53	0.09
13.6-15.5	<0.01	0.04	0.47	0.29	0.50	0.12
15.6-18.5	--	0.02	0.30	0.09	0.24	0.04
18.6-21.5	--	--	0.07	0.01	0.09	0.02
21.6-24.5	--	--	0.03	<0.01	0.01	--
24.6-29.5	--	--	0.02	--	--	--

	Saturday					
	1-3am	4-6am	7-8am	9-noon	1-6pm	7-mid.
0.0-0.5	19.87	31.37	16.47	8.39	6.13	9.92
0.6-1.5	32.46	40.96	42.22	33.20	29.98	30.70
1.6-2.5	19.46	16.04	23.39	27.34	26.22	23.11
2.6-3.5	11.62	6.18	10.79	15.64	15.69	15.72
3.6-4.5	6.50	3.31	4.57	8.29	9.47	9.55
4.6-5.5	3.72	1.14	1.41	4.24	5.48	4.62
5.6-6.5	2.61	0.57	0.70	1.49	3.25	2.38
6.6-7.5	1.68	0.30	0.30	0.78	1.67	1.57
7.6-8.5	1.01	0.07	0.10	0.38	0.98	1.16
8.6-9.5	0.50	0.07	0.05	0.15	0.56	0.62
9.6-10.5	0.34	--	--	0.03	0.27	0.34
10.6-11.5	0.13	--	--	0.03	0.10	0.19
11.6-12.5	0.07	--	--	0.03	0.08	0.05
12.6-13.5	0.03	--	--	--	0.05	0.02
13.6-15.5	--	--	--	--	0.02	0.02
15.6-18.5	--	--	--	--	0.05	0.05
18.6-21.5	--	--	--	0.03	--	--

TABLE 6 (CONT'D). DISTRIBUTION OF HOURLY AVERAGE CO LEVELS FOR STREET CANYONS

PPM CO Interval	Percent Frequency for Time Interval Shown					
	Sunday					
	1-2am	3-4am	5-10am	11am-2pm	3-11pm	Midnight
0.0-0.5	18.51	27.18	28.73	18.47	14.84	20.64
0.6-1.5	31.90	38.85	48.47	46.72	39.46	40.87
1.6-2.5	20.31	16.18	15.09	19.76	21.86	18.15
2.6-3.5	11.49	8.30	4.89	9.30	11.60	11.20
3.6-4.5	7.64	3.84	1.43	2.99	5.74	4.77
4.6-5.5	3.08	1.97	0.91	1.67	2.96	2.49
5.6-6.5	3.38	1.66	0.17	0.48	1.54	0.73
6.6-7.5	1.44	0.93	0.12	0.25	0.89	0.62
7.6-8.5	1.08	0.41	0.05	0.20	0.43	0.10
8.6-9.5	0.41	0.31	0.03	0.10	0.28	0.21
9.6-10.5	0.15	--	0.03	0.05	0.26	0.10
10.6-11.5	0.21	0.16	0.02	--	0.11	0.10
11.6-12.5	0.21	--	0.05	--	0.01	--
12.6-13.5	--	0.10	--	--	0.02	--
13.6-15.5	0.05	0.10	0.02	--	--	--
15.6-18.5	0.10	--	--	--	--	--
18.6-21.5	0.05	--	--	--	--	--

TABLE 7. POLLUTANT CONCENTRATION INTERVALS FOR STREET CANYONS

PPM CO	$\mu g/m^3$ at 1.0g/min[a]
0-.5	0-35
.6-1.5	36-105
1.6-2.5	106-175
2.6-3.5	176-245
3.6-4.5	246-315
4.6-5.5	316-386
5.6-6.5	387-456
6.6-7.5	457-526
7.6-8.5	527-596
8.6-9.5	597-666
9.6-10.5	667-736
10.6-11.5	737-806
11.6-12.5	807-876
12.6-13.5	877-947
13.6-15.5	948-1087
15.6-18.5	1088-1297
18.6-21.5	1298-1508
21.6-24.5	1509-1718
24.6-29.5	1719-2069

[a]Based on a CO emission factor of 50.51 g/mile for the FTP for 1981. At 19.6 miles per hour this is equivalent to 16.50 g/min. One ppm CO = 1157 $\mu g/m^3$.

Using the 2.1 multiplier and the maximum one hour CO reading occurring in each of the four cities used in the NEM study, the highest CO values used for the NEM transport microenvironment are 52 ppm for Chicago, 66 ppm for Los Angeles, 40 ppm for Philadelphia and 48 ppm for St. Louis. The maximum geometric means for the transport microenvironment from the six monitors used in each city are: 6 ppm, 8 ppm, 5 ppm, and 11 ppm for Chicago, Los Angeles, Philadelphia, and St. Louis, respectively.(33)

The work done at SwRI in developing an on-expressway model, under Contract 68-03-2884, indicates that using a multiplier on a CO value from a fixed monitor is not the best way to determine CO levels on expressways. Nevertheless, the CO distribution for the transport microenvironment resulting from the NEM calculations is probably as good as any alternate distribution that could be developed with reasonable effort. To check the reasonableness of the NEM distributions, they were compared to the results of the only studies of on-expressway CO measurements found in the literature. (34-48) A summary of the CO ranges found in these studies is presented in Table 8. Concentration distributions from Reference 38, for three cars, are shown in Figure 3.

TABLE 8. MEASURED CO ON EXPRESSWAYS

	CO PPM					
Cumulative	1966[a]		est. 1979[b]		1982 Los Angeles[c]	
Frequency %	Chicago	St. Louis	Chicago	St. Louis	Car 2	Cars 1 & 3
25	24	28	12	14	12	10
50	30	38	15	19	20	12
75	46	44	22	21	21	15
90	50	51	24	25	22	20
95	--	56	--	27	30	25

[a] From Reference 34
[b] Reference 34 values multiplied by ratio of 1979 to 1966 CO emission factors (30.57/62.06)
[c] From Reference 38

Notes: Reference 35 gives values of 15-20 ppm CO with only one reading (at 45 ppm) higher than 25 ppm in 1974.
Reference 36 gives values of 15-45 ppm CO in 1977

Comparing the maximum NEM transport microenvironment CO concentrations with the 95 percent levels in Table 8, the NEM maximums do not appear unreasonable, considering that maximum values correspond to the 99.99 percentile of a distribution. The geometric mean values from the NEM study appear to be reasonable, considering that the distributions shown in Figure 3 are one minute averages, while the NEM values are one hour averages. Since there are so few measured on-expressway CO data, and the NEM CO values do not appear to be grossly out of line, the NEM concentration

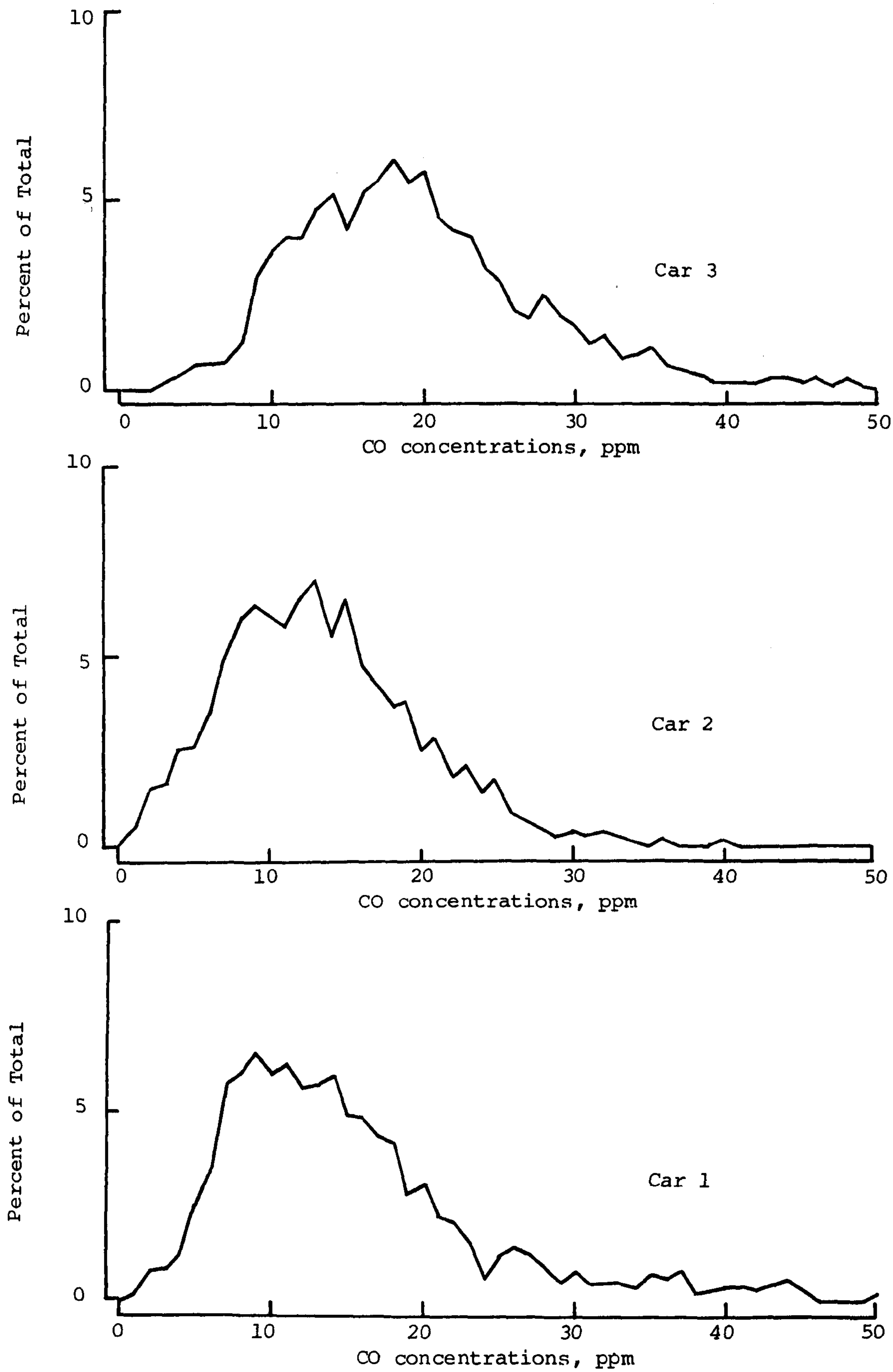

Figure 3. Frequency Distribution of CO concentrations outside three cars on Los Angeles Freeways

will be used for the on-expressway microenvironment. The NEM program uses actual hourly CO measurements (or estimated, if actual value missing) from the SAROAD data base, so no frequency distribution information is produced by the NEM. While frequency distributions could conceivably be developed from the hourly measurements, the time and effort allotted to this study did not permit the development of such distributions.

Roadway Tunnel Pollutant Concentrations

The literature on air pollution in tunnels had been extensively investigated under Contract 68-03-2884. While CO is monitored in almost all mechanically ventilated tunnels, there are few published CO data. A list of the information found is presented in Table 9. The most complete study found was in Reference 39, which had CO levels for the Sumner Tunnel in Boston. From the information presented on the Sumner Tunnel in Reference 39, plots of both average and maximum CO levels as functions of percent of average daily traffic (ADT) per hour for weekdays were developed. These plots are shown in Figure 4.

TABLE 9. CO LEVELS FOUND IN ROADWAY TUNNELS

CO Concentrations	Reference No.	Study Location	Study Date
110 ppm (7:30-8:00 A.M., No. Tube) 190 ppm (7:30-8:00 A.M., So. Tube)	39	Squirrel Hill Tunnel Pittsburgh, PA	1969
140 ppm (5:00-5:45 P.M., West Tube)	39	Liberty Tunnel Pittsburgh, PA	1969
75 ppm (avg over 3 days) rarely exceeded 180 ppm	39	Baltimore Harbor Tunnel Baltimore, MD	~1971
12-144 ppm mean 30-238 ppm peak	39	Sumner Tunnel Boston, MA	1961
40-200 ppm (North tube) 10-60 ppm (Center tube)	39	Lincoln Tunnel New York, NY	est. 1970
10-100 ppm avg (West Tube) 250 max	39	Fort Pitt Tunnel Pittsburgh, PA	1971
40-250 ppm	39	Armstrong Tunnel Pittsburgh, PA	~1971
42-122 ppm (Brooklyn bound tube)	40	Brooklyn Battery Tunnel New York, NY	~1971

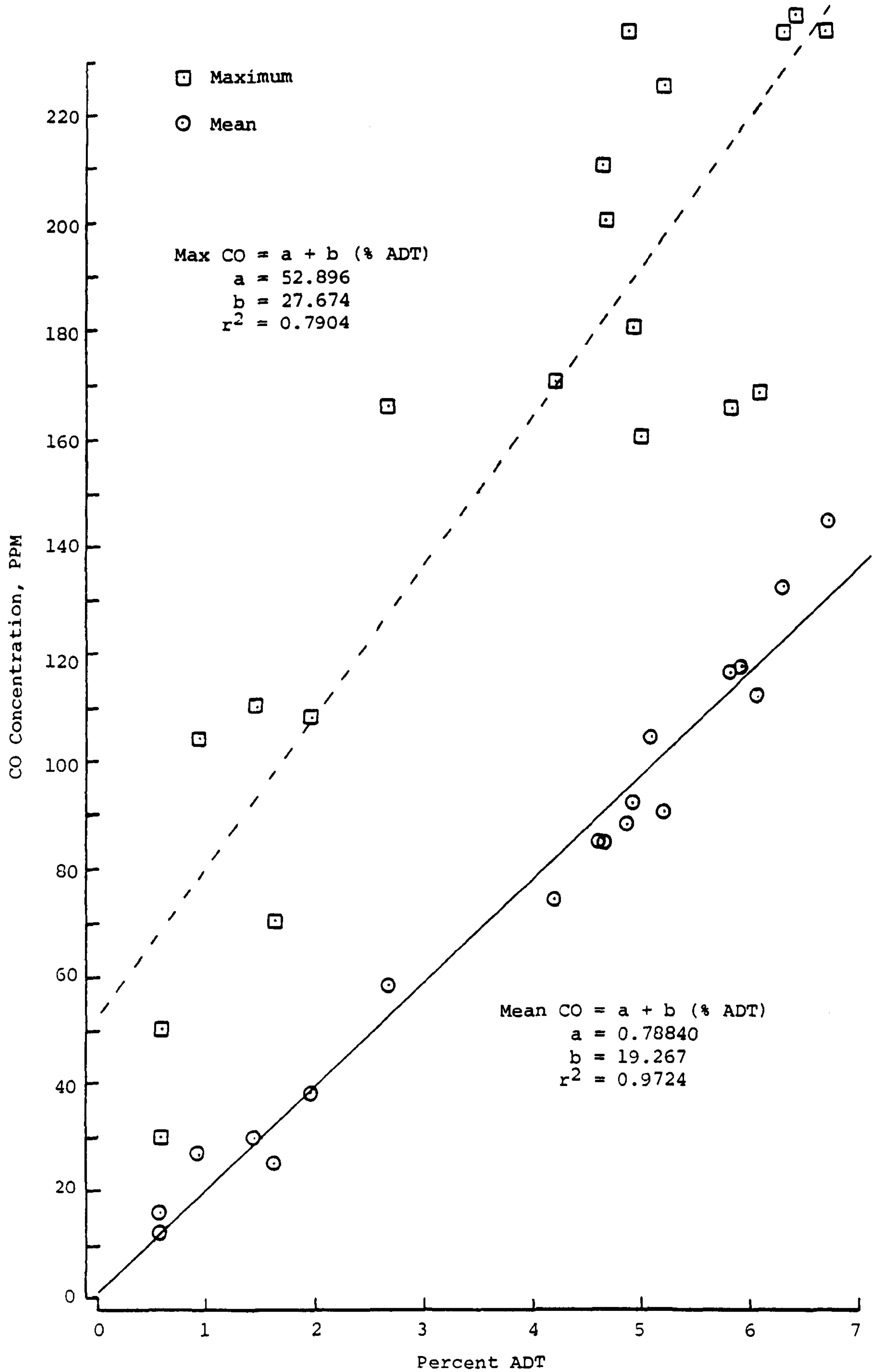

Figure 4. CO concentration as a function of hourly percent ADT for the Sumner Tunnel (1961)

All tunnels have ventilation systems designed for some maximum CO rate at the maximum expected traffic levels. This means that for all tunnels, the CO relationship with percent of average daily traffic (ADT) should be similar. The maximum design CO level has generally been in the 200 to 250 ppm CO range. Maximum hourly traffic is rarely over eight percent of ADT. Thus, the Sumner Tunnel data can be used as the basis for development of pollutant concentration distributions for roadway tunnels.

A linear regression was performed on the average CO concentrations and the percent ADT values shown in Figure 4. The results of that analysis are shown on the figure, together with the results of the regression analysis of the maximum values. As might be expected, the maximum CO values did not produce as good a linear fit as the mean CO values. The mean CO level is obviously a function of the percent ADT.

For this study, a pollutant distribution representing the concentrations over all tunnels, for all days of the year, is required. Since the concentrations are a function of percent ADT, seven different distributions were developed, one for each of seven different levels of percent ADT. If the pollutant concentration is assumed to be lognormally distributed for a given percent ADT as a result of tunnel-to-tunnel variability, fleet composition, weather and traffic flow variability, then, with the mean concentration taken as the distribution mean and the maximum concentration as an indication of the range, the distributions could be defined from the data on hand. However, from a summary of tunnel ventilation in Reference 18, the Sumner Tunnel appears to have a worse than average ventilation rate in terms of cubic meters per meter of lane, while having higher than average ADT. Thus, the Sumner Tunnel is likely to have higher CO levels than an average tunnel.

The Sumner Tunnel ventilation rate is approximately 25 percent less than the average rate. This can be taken into account by reducing the mean CO value shown in Figure 4 by 25 percent at a given percent ADT. The maximum values will not be changed since they are values that are found in tunnels and must be included in the distribution. The ADT in the Sumner Tunnel is approximately 1.6 times higher than the mean ADT for all tunnels. (18,39) To account for this, the percent ADT can be increased 1.6 times for a given CO concentration. Again the maximum values are not adjusted. When these two adjustments are made, the relationships between hourly percent ADT and CO concentrations for an average tunnel are as shown in Figure 5.

Assuming that the CO concentration in tunnels has a lognormal distribution, the CO distribution can be determined from the mean and maximum CO values at any percent ADT. See Appendix A for the method used to obtain these distributions. CO distributions were determined for roadway tunnels at one percent ADT intervals starting with 0.5 percent ADT and ending at 6.5 percent ADT. The equations obtained from the calculations in Appendix A are continuous ppm CO distributions. This project requires discrete distributions in terms of $\mu g/m^3$ for a 1.0 g/min emission factor. However, it is also desirable to have the discrete distributions in terms of ppm CO for comparison with measured data.

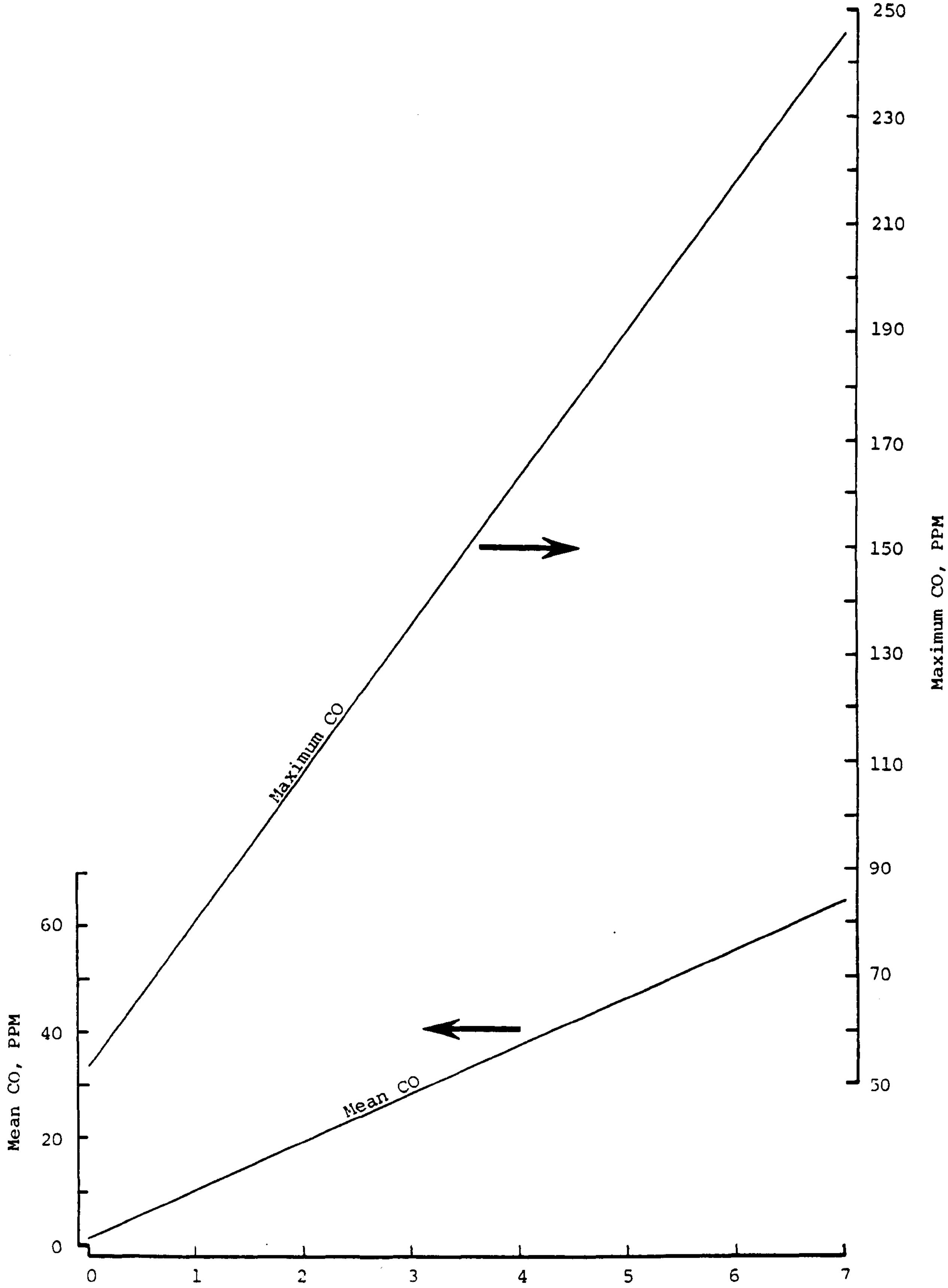

Figure 5. CO concentration as a function of Hourly Percent ADT for an average Roadway Tunnel

To convert from ppm CO to μg/m^3 at 1.0 g/min, the emission factor for vehicles in tunnels is required. The Sumner Tunnel data were taken in 1961. Therefore, a 1961 CO emission factor should be used to convert the data in Figure 5 to a 1.0 g/min emission factor. A national average fleet emission factor for 1961 is not available from published EPA emission factors. To obtain the 1961 emission factor, Ms. Lois Platte at the EPA Mobile Source Laboratory in Ann Arbor, MI was contacted. At her direction, the EPA emission factor computer program, MOBILE 2, was run to generate a 1961 national fleet CO emission at 35 mph. The resulting emission factor was 62.06 g/mile, which converts to 36.2 g/min at 35 mph. The conversion factor for ppm CO at 36.2 g/min to μg/m^3 at 1.0 g/min is: 31.96 = 1157/36.2. The concentration intervals are shown in Table 10. The discrete pollutant distributions in terms of ppm CO are shown in Table 11 for various levels of hourly percent ADT. These distributions, with the μg/m^3 interval values replacing the ppm CO values, were used to determine the person hour exposure in tunnels, as explained in Section V.

TABLE 10. POLLUTANT CONCENTRATION INTERVALS FOR ROADWAY TUNNELS

PPM CO	μg/m^3 at 1.0 g/min[a]
0	0
6.26	200
12.52	400
18.77	600
21.90	700
25.03	800
28.16	900
31.29	1000
37.55	1200
43.80	1400
50.06	1600
56.32	1800
62.58	2000
68.83	2200
75.09	2400
81.35	2600
93.86	3000
125.15	4000
187.73	6000
250.30	8000

[a]Based on a 1961 CO emission factor of 62.06 g/mile at 35 mph. This is equivlaent to 36.20 g/min. One ppm CO = 1157 μg/m^3 CO.

TABLE 11. DISTRIBUTIONS OF HOURLY AVERAGE CO LEVELS IN ROADWAY TUNNELS

PPM CO Interval	Frequency for Percent ADT Shown 0.5	1.5	2.5	3.5	4.5	5.5	6.5
				Weekdays			
0-6.26	0.777	0.288	0.067	0.013	0.006	0.001	0.000
2.26-12.52	0.129	0.317	0.230	0.109	0.045	0.018	0.007
12.52-18.77	0.044	0.169	0.218	0.175	0.105	0.057	0.030
18.77-21.90	0.011	0.052	0.086	0.088	0.068	0.045	0.027
21.90-25.03	0.008	0.038	0.071	0.081	0.071	0.052	0.035
25.03-28.16	0.006	0.029	0.058	0.073	0.071	0.057	0.042
28.16-31.29	0.004	0.022	0.047	0.065	0.068	0.059	0.047
31.29-37.55	0.006	0.030	0.069	0.105	0.120	0.116	0.100
37.55-43.80	0.004	0.019	0.046	0.077	0.099	0.107	0.102
43.80-50.06	0.003	0.012	0.032	0.056	0.078	0.092	0.095
50.06-56.32	0.002	0.008	0.022	0.041	0.061	0.077	0.085
56.32-62.58	0.001	0.005	0.015	0.030	0.047	0.063	0.074
62.58-68.83	0.001	0.004	0.011	0.022	0.036	0.051	0.062
68.83-75.09	0.001	0.003	0.008	0.016	0.028	0.041	0.052
75.09-81.35	0.001	0.002	0.006	0.012	0.021	0.033	0.043
81.35-93.86	0.001	0.003	0.007	0.016	0.029	0.047	0.065
93.86-125.15	0.001	0.003	0.008	0.019	0.033	0.057	0.085
125.15-187.73	0.001	0.001	0.004	0.009	0.019	0.035	0.056
187.73-250.30	0.000	0.000	0.001	0.001	0.002	0.005	0.009

IV. NUMBER OF PERSONS IN MICROENVIRONMENTS

This study is concerned with the total, nationwide, annual person hours of exposure. As such, it is not necessary to know which particular people are exposed, or how the microenvironment is related to other exposures. It is only necessary to know how many people are in each microenvironment for each hour of the day. To determine the microenvironment hourly population, information on the number of locations, size range, and daily usage of each microenvironment were required. The published literature, as well as special sources, were used to obtain the best possible estimates of these parameters.

Number of persons in Vehicles

To obtain the hourly population for all microenvironments, an estimate of the number of persons in each vehicle is required. There are a variety of estimates given in the literature. Early in this project, it was realized that obtaining an accurate estimate of person hour exposure would require defining the microenvironment populations on Saturday and Sunday, as well as during the work week (called "weekdays" in this report). Thus, any differences in vehicle occupancy between weekdays and weekends should be included in the calculations. The vehicle occupancies used in this study, taken from References 41 and 42, are shown below.

	Weekday	Saturday	Sunday
Cars	1.4[a]	2.3[a]	2.3[a]
Buses	26[b]	23[b]	10.6[b]

[a]From Reference 41
[b]From Reference 42

Population of Parking Garages

From the literature search conducted under Contract 68-03-2884, Task Specification 1, approximately 70 abstracts on parking garages were reviewed for information on usage and pollutant levels. Of these, ten had some useful information. The earlier study of parking garages had obtained information from several different sources on the number of parking garages in the country. The result was an estimate that varied from 5300 to 10,000 parking garages in the country.[18] This spread in the estimated number of garages was too large to provide the estimate of the population in parking garages needed for this project.

For this project, a list of parking garage construction projects since 1967 was obtained from Data Resources, Inc. This company provides construction statistics based on the F. W. Dodge data bank of construction projects. F. W. Dodge is widely recognized as the authoritative source for statistics on all types of construction projects. The parking garage construction projects in the U. S. from 1967 to 1982 are listed in Table 12. The total number of projects from 1967 to 1980 is 8499. There were approximately 1291 public parking garages in existence in 1965.[(18)] In Reference 18, construction data found in the magazine, "Parking," indicated that there were an average of 330 parking garages built per year between 1971 and 1980. Apparently, the construction reported was primarily public parking garages. The F. W. Dodge data is for all construction, and shows approximately 592 garages constructed per year between 1971 and 1980. The difference between the two construction estimates is apparently a number of private garages included in the Dodge statistics. If the same ratio of public to private garages has always existed, then there would be almost twice as many parking garages in 1965 as the 1291 estimated garages. Assuming 2500 garages in 1965, and assuming 600 built in 1966, the number of parking garages in 1980 would be 11,600.

TABLE 12. PARKING GARAGE CONSTRUCTION IN THE U.S., 1967-1982

Year	Number of Projects
1967	682
1968	664
1969	646
1970	587
1971	482
1972	535
1973	642
1974	546
1975	503
1976	493
1977	544
1978	837
1979	717
1980	621
1981	633
1982	596

Source: F.W. Dodge/Data Resources, Inc.

The total number of parking spaces in these 11,600 parking garages was calculated from the information in Reference 18 and from the information supplied by Data Resources, Inc. The garages were divided into two groups, one with 6200 large garages averaging 740 spaces per garage, and the other with 5400 smaller garages averaging 150 spaces per garage. The total number of spaces is then 5,398,000.

Only three references could be found that had information on cars in motion by time of day in a parking garage.[27,30,43] Since there are over 10,000 parking garages in the country, this is an extremely small sample. Nevertheless, this information will be used to represent the nationwide average, since it is all that is available. From the three references, a composite of weekday vehicles in motion as a percent of garage parking capacity was obtained for each hour of the day. Similar information for Saturday was derived from data in Reference 43. The percent of vehicles in motion by hour for Sunday was estimated considering the values for weekdays and Saturday together with the fact that for most garages, Sunday would be a day of greatly reduced activity. The average percent of cars in motion by hour for each of the three types of days is shown in Figures 6, 7, and 8.

Two important points about the fraction of active cars need to be emphasized. The curves presented are on a per hour basis. However, the actual time any one vehicle is in motion is much less than one hour, generally on the order of five minutes. Thus, the vehicles in motion at any instant would equal the hourly fraction divided by twelve. For the maximum fraction of active cars per hour (21.34 percent), this gave 1.78 percent active cars at any instant. This figure agrees well with an Aerospace Corp. study[44] which found an average of 1.5 percent active cars at all times in Los Angeles garages. The percent of cars in motion is important since it will be used to select the proper pollutant concentration distribution in the calculation of person hours of exposure. The second point is that the people in the cars are, in general, not exposed to the garage pollution levels for a full hour. A fifteen minute exposure has been used in this study.

The total nationwide person hours of exposure for any hour of the day was obtained by multiplying the hourly fraction of cars in motion by the total number of garage parking spaces available nationwide, then multiplying by 1.4 persons per car for weekdays or 2.3 persons per car for weekends, then dividing by 4.0. This calculation is carried out internally within the mobile source microenvironment computer program, so there is no need to calculate hourly person hours separately. However, an example may help in visualizing the number of people involved in the parking garage microenvironment. For the weekday hour ending at 11 a.m., the active cars are 0.213 of the total spaces, thus the number of people in the parking garage microenvironment during that hour in 1980 was:

$$0.213 \times (5.398 \times 10^6) \times 1.4 = 1{,}609{,}684 \text{ persons}$$

Then: $1{,}609{,}684/4 = 402{,}421$ person hours of exposure

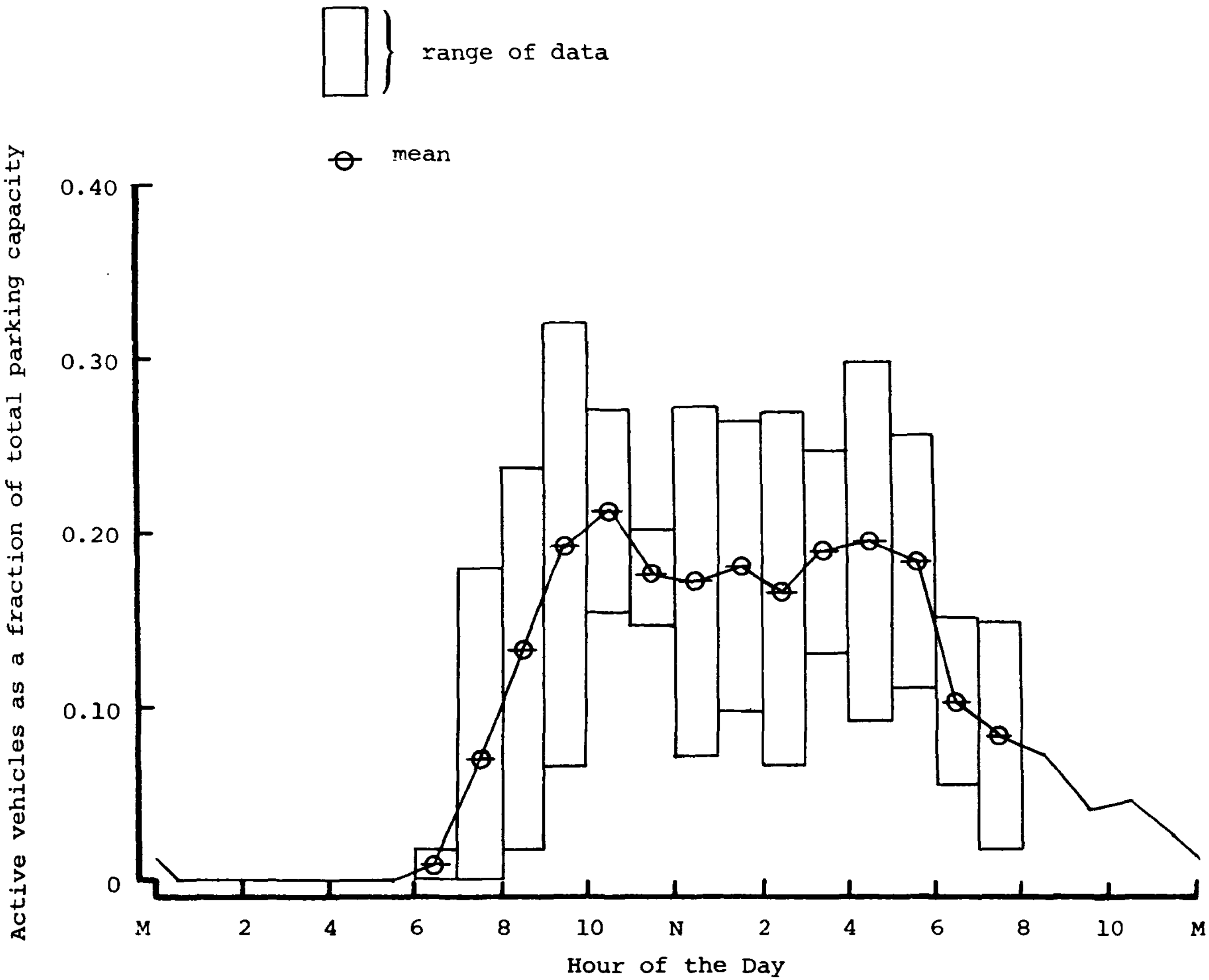

Figure 6. Hourly average cars in motion for weekdays in Parking Garages

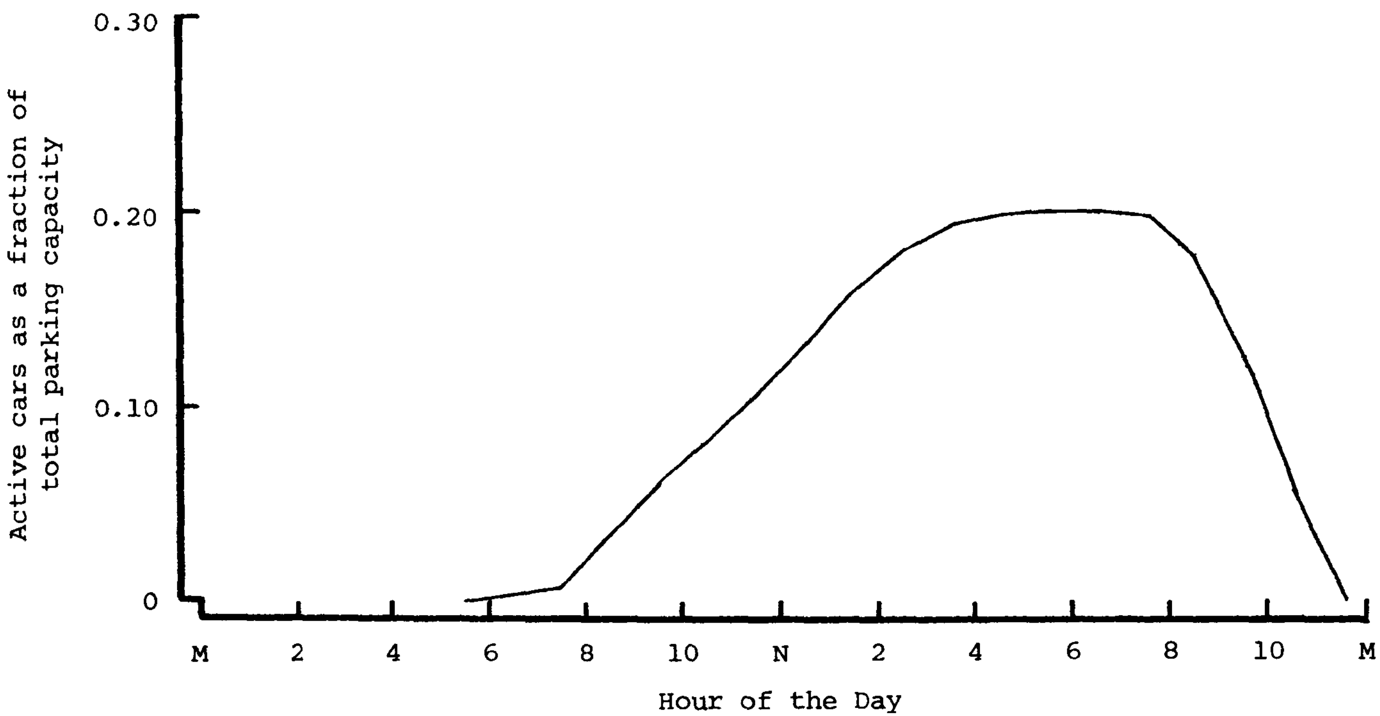

Figure 7. Hourly average cars in motion for Saturdays in Parking Garages

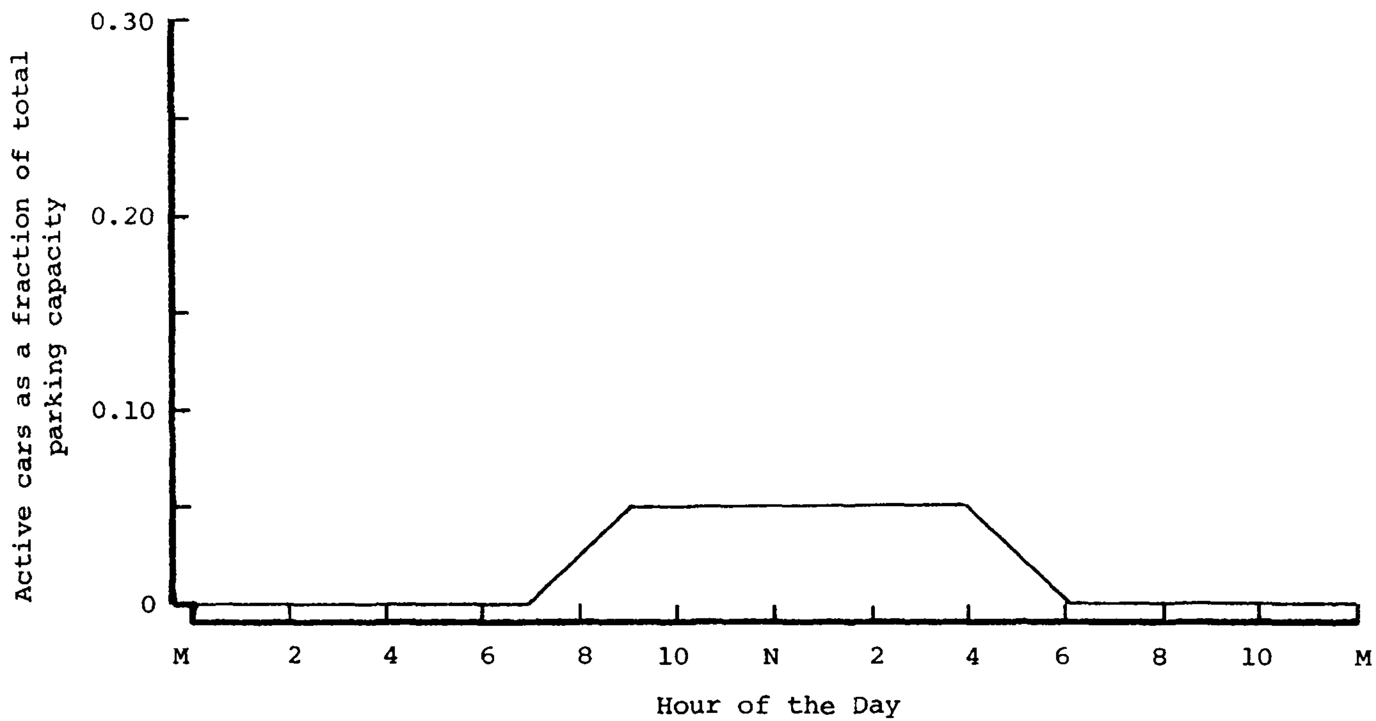

Figure 8. Hourly average cars in motion for Sundays in Parking Garages

Number of People in Street Canyons

Recall that the street canyon exposure in this project is for pedestrians and motorists within the canyon; it does not include persons in buildings adjacent to the street canyon. Therefore, the number of people and exposure times are those outside in the canyon. Because of sparsity of information on street canyon populations on hand, a computerized literature search was run to assist in locating additional information. The search generated a listing of 994 abstracts. An examination of the abstracts revealed only eight references with information useful to the project. In addition, three other references were located by other means. Only four references had information useful in determining the total number of people per day traveling to, from, or within the central business district (CBD) in vehicles.

It was clear from the information obtained that the street canyon population would have to be obtained in two parts: vehicular and pedestrian. After examining the data found in the references, it appeared that the best way to arrive at CBD population in vehicles was to use CBD cordon counts, which were available for the peak traffic hour for a number of cities in Reference 45. Table 10-40, in Reference 45, lists the peak hour person cordon count for the top 20 urbanized areas in the U.S. Based on these counts, there were 2,245,000 people passing the CBD cordon limits during the peak traffic hour in the 20 most populous urban areas.

Peak hour traffic generally averages about eight percent of total daily traffic.[41,46] Using this value, there would be a total of 28,062,500 person trips whose origin and destination are within the CBD. Approximately 2.5 percent of all trips in an urban area are within the CBD and 27.5 percent of all trips (urban and rural) either originate or end in the CBD, with other than a CBD origin or destination.[47] Thus, total trips in the CBD are approximately nine percent higher (2.5/27.5 = 0.09) than measured at the cordon. To account for the intra-CBD trips, which are not measured at the cordon, the cordon counts were multiplied by 1.09, giving 30,616,188 person trips, into, out of, or within the CBD. The total population of these urban areas was given as 64,920,646. Using these figures, an average of 0.472 CBD trips/person per day was obtained.

Two other studies of individual cities (Rochester, NY, and San Antonio, TX) yielded 0.578 and 0.737 CBD trips per person.[48, 49] From Reference 45, the urban population averages 2.43 trips per person per day for all purposes. Reference 47 indicates that 24.5 percent of all urban trips are into, out of, or within the CBD. These two figures give 0.60 trips per person per day for the CBD. The available data on CBD person trips per day is plotted as a function of urban population in Figure 9. Some studies have indicated that there is an increasing number of CBD trips per person as the size of the urban area decreases. In Figure 9, this trend appears very weak. In any case, the 0.60 CBD trips per person appears high. A more reasonable average, obtained from population weighting the data in Figure 9, is 0.473 CBD trips per day per person.

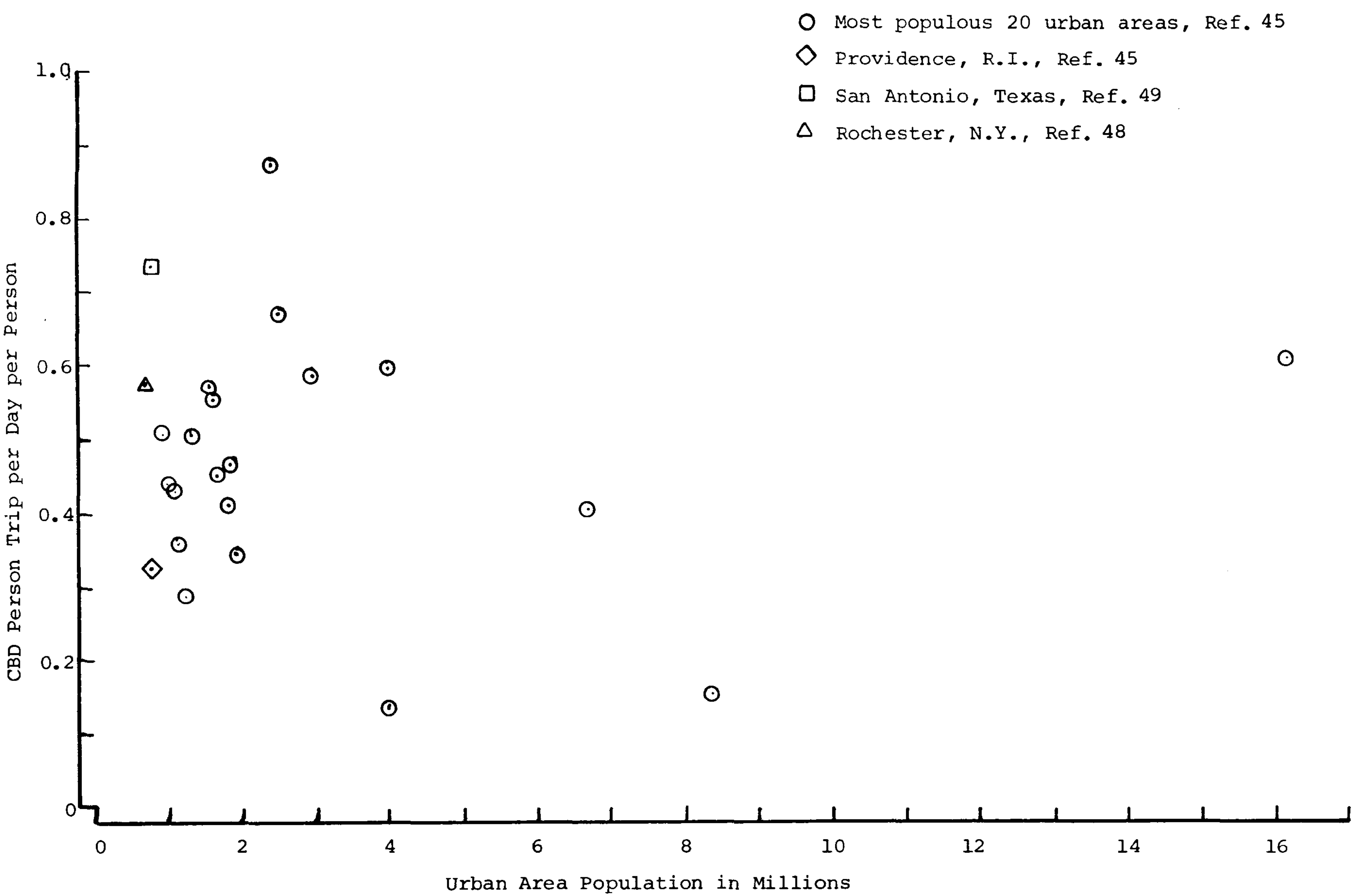

Figure 9. Number of person trips to CBD per person in urban areas

Using the NEM CO study value for 1980 urban population of 132,023,885 and 0.473 CBD trips per person, there are approximately 62,500,000 CBD trips per day in the U.S. In earlier studies, it was assumed that street canyons comprised 60 percent of the CBD streets.(18) If CBD trips are considered equally distributed over the CBD, then there are 37,500,000 (62,500,000x.600) person exposures in vehicles to the street canyon environment each day on weekdays.

For estimates of number of persons exposed on Saturday and Sunday, three weekly traffic distributions from two different references were used. (46,47) The average weekly urban traffic distribution obtained from these references is shown in Table 13.

TABLE 13. ESTIMATED CBD DAILY TRAFFIC AS A PERCENT OF WEEKLY TRAFFIC

	Urban[a]	CBD[a]	Nashville Urban[b]	Average	Used
Sunday	13.2	5.8	10.5	9.9	10
Monday	14.5	15.5	15.2	15.1	15
Tuesday	13.7	15.3	14.7	14.6	15
Wednesday	13.7	15.0	14.7	14.5	15
Thursday	14.0	14.8	14.7	14.5	15
Friday	15.0	15.5	15.9	15.5	15
Saturday	16.2	17.8	14.8	16.3	15

[a] Reference 47
[b] Reference 46

In Table 13, the values in the column headed "Used," are the daily traffic percentages used in this study for street canyons. The weekday values were adjusted to give the same percentage for all weekdays, the Sunday value rounded off to the nearest whole percent, and the Saturday values adjusted so that the total was 100 percent.

The total number of person trips and vehicles in street canyons for each day of the week was calculated starting with the base figure of 37,500,000 persons trips in vehicles on weekdays. Of the person trips to and from the CBD, 47.4 percent are by car and 52.6 percent by transit.(45) Of the transit trips, 74 percent are bus passengers and 26 percent are rail passengers. (58) These facts can be used to determine the total person trips into the CBD as follows:

$$37{,}500{,}000 = 0.474y + 0.74\,(0.526y)$$

Where y = total number of person trips into the CBD

Solving this equation gives 43,441,000 person-trips in the CBD each weekday, with 20,590,000 (0.474 times 43,441,000) person trips by auto and 16,903,000 (0.74 times 0.526 times 43,441,000) person trips by bus. Using these values and the values of 1.4 persons per car and 26 persons per bus on weekdays as shown earlier, the weekday vehicle trips in the CBD can be calculated as shown below:

$$\text{Weekday vehicle trips} = \frac{20{,}590{,}000}{1.4} + \frac{16{,}903{,}000}{26} = 15{,}358{,}000$$

The daily vehicle trips for Saturday and Sunday can be calculated from the weekday vehicle trips and the daily vehicle trip relationships in Table 13. The Saturday and Sunday vehicle trips are 15,358,000 and 10,240,000 respectively. Using these vehicle trip values, the persons per vehicle shown earlier and the weekday ratio between car person trips and bus person trips (20,590,000/16,903,000 = 1.22) the Saturday and Sunday person trips can be calculated using the following equation:

$$\text{person trips} = (1.22 + 1)\ \frac{BV}{\left[1.22\left(\frac{B}{C}\right) + 1\right]}$$

Where: B = persons per bus

C = persons per car

V = vehicle trips

The average persons per vehicle can then be obtained by dividing the person trips by the vehicle trips. The results of these calculations are presented in Table 14.

TABLE 14. DAILY PERSON TRIPS AND VEHICLES IN STREET CANYONS

	Weekdays	Saturday	Sunday
Daily person trips	37,500,000	59,410,000	36,380,000
Daily vehicle trips	15,358,000	15,358,000	10,240,000
Persons per vehicle	2.44	3.87	3.55

The hourly traffic flow as a fraction of daily traffic for weekdays was obtained from Reference 41. A population weighed average for the data from various city sizes was used. The hourly traffic distribution is shown in Figure 10.

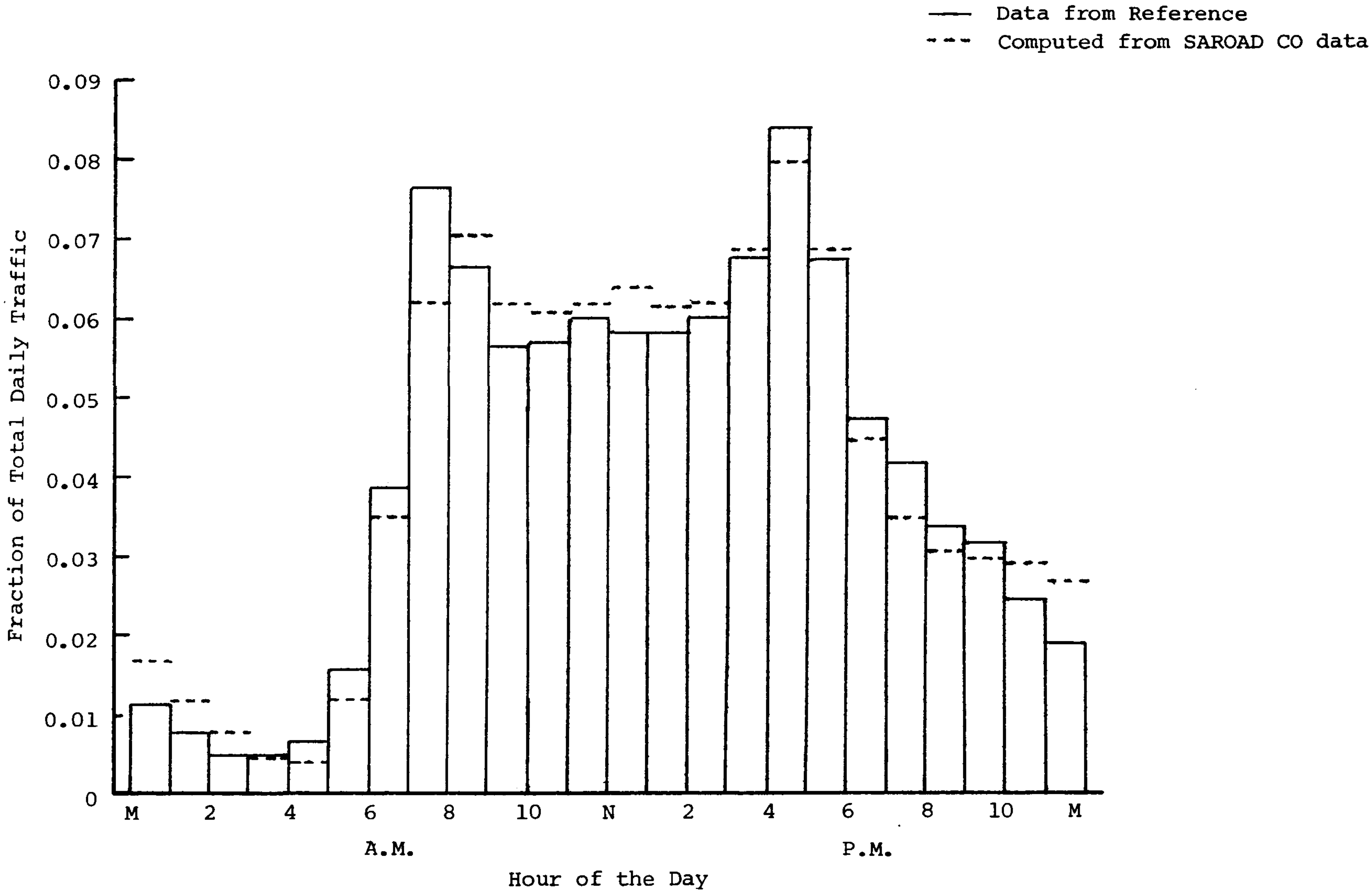

Figure 10. Hourly traffic distribution in the CBD for an average weekday

Saturday and Sunday traffic distributions were not found in the literature for the CBD. However, if the assumption that the CO is almost entirely from mobile sources is correct, then the hourly traffic distribution should be able to be deduced from the measured hourly CO distributions for street canyons given in Section III. To check the assumption that CO level is related to traffic, the weekday traffic distribution presented in Figure 10 was paired with the SAROAD concentration data in Section III by hour of the day. A linear regression was performed using the mean hourly CO level and the hourly percent ADT. The regression analysis produced a coefficient of determination, r^2 , of 0.9598. The equation and its coefficients are:

$$p = a + bx$$

Where: p = hourly percent ADT

x = hourly mean ppm CO

$a = -1.4972$

$b = 1.9276$

To see the physical meaning of this equation, the linear form can be rearranged as follows:

$$P = b\ (x - c)$$

In this form, "c" can be thought of as the background concentration, (assumed constant for the entire day), and "b" as reciprocal of the contribution of one percent ADT to the ambient CO PPM.

Since:

$$P = b\ (x - c\ ) = bx - bc$$

then: $a = -bc$

and: $c = -\frac{a}{b}$

Thus, from the regression analysis, the background concentration is $-(-1.4972/1.9276) = 0.777$ ppm for weekdays, and "b" (the reciprocal of the ADT "emission factor") is 1.9276 percent ADT/PPM.

The percent ADT for each hour of the day for weekdays was calculated using the above equation. These values are also shown in Figure 10 for comparison with traffic count data. As would be expected from the high coefficient of determination, the two values of ADT agree closely, demonstrating that the hourly CO pattern can be used to develop an hourly traffic pattern.

Implicit in the equation is some actual value for the weekday ADT. To apply this equation to Saturday and Sunday, the "b" coefficient must be adjusted for the traffic count difference between weekdays and Saturdays and Sundays. The "b" coefficient was changed by the ratio of weekday vehicles to Saturday and Sunday vehicles. The ratio was 1.0 for Saturday and 1.5 for Sunday. However, when the weekday equation, adjusted for traffic differences, was applied to the Saturday and Sunday CO distribution, the calculated hourly percent ADT values did not total 100 percent.

After some thought, it was realized that the weekend on-the-road fleet had a smaller percentage of commercial vehicles (mostly trucks) than the weekday fleet. Since truck CO emissions can be several times car emissions, this change would reduce the fleet CO emission factor on weekends. With lower mobile source CO emissions and reduced industrial activity, the weekend background will also probably be lower.

If the emission factor and background are assumed to be equal on Saturday and Sunday, but the Sunday traffic is two-thirds of the Saturday traffic, then two equations can be written for the percent ADT as a function of PPM with only two unknowns; the background and the "b" coefficient. When these two equations are solved, the resulting background level is 0.589 PPM. The "b" coefficient for Saturday, which has the same total traffic as weekdays, is 2.650. This is equivalent to a 28 percent reduction in the weekday fleet emission factor. The "b" coefficient for Sunday is 1.5 times the Saturday coefficient (or 3.975) to account for the reduced Sunday traffic. The percent of ADT distributions which result from applying these equations to the hourly PPM readings in Table 5 of Section III, are shown in Figures 11 and 12 for Saturday and Sunday, respectively.

Three references for pedestrian street canyon population were all that could be found in the literature.[50, 51, 52] The total number of pedestrian trips was calculated from Reference 52, which indicated that there were 5.8 weekday pedestrian trips for each weekday vehicle trip into the Chicago CBD. Since no other information could be found, this number was used for all CBD's in the country. At 5.8 pedestrian trips per trip in a vehicle and 37,500,000 person trips in vehicles (Table 14), there are 89,076,000 pedestrian trips in the U. S. each weekday.

From a study of Seattle pedestrians,[51] the daily pedestrians as a percent of total weekly pedestrians were calculated. This distribution by day of the week is shown in Figure 13. The average weekday pedestrian trips are 16.54 percent of the total weekly trips. The total weekly trips are then 538,552,000. Saturday trips are 13.0 percent of the weekly trips, giving 70,012,000 pedestrian trips on Saturday in the U. S. Sunday pedestrian trips are 4.3 percent of the total weekly trips, or 23,158,000 Sunday pedestrian trips.

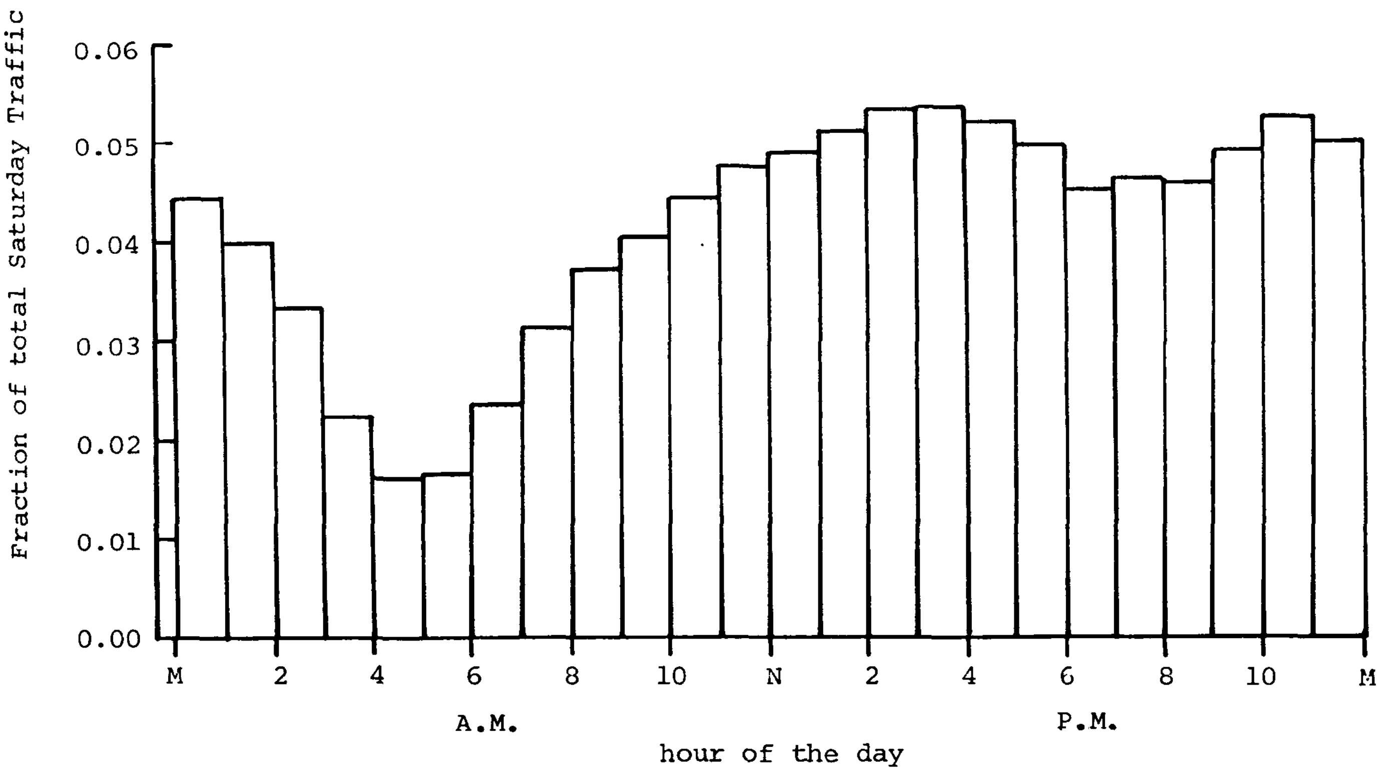

Figure 11. Hourly traffic distribution in the CBD for Saturday

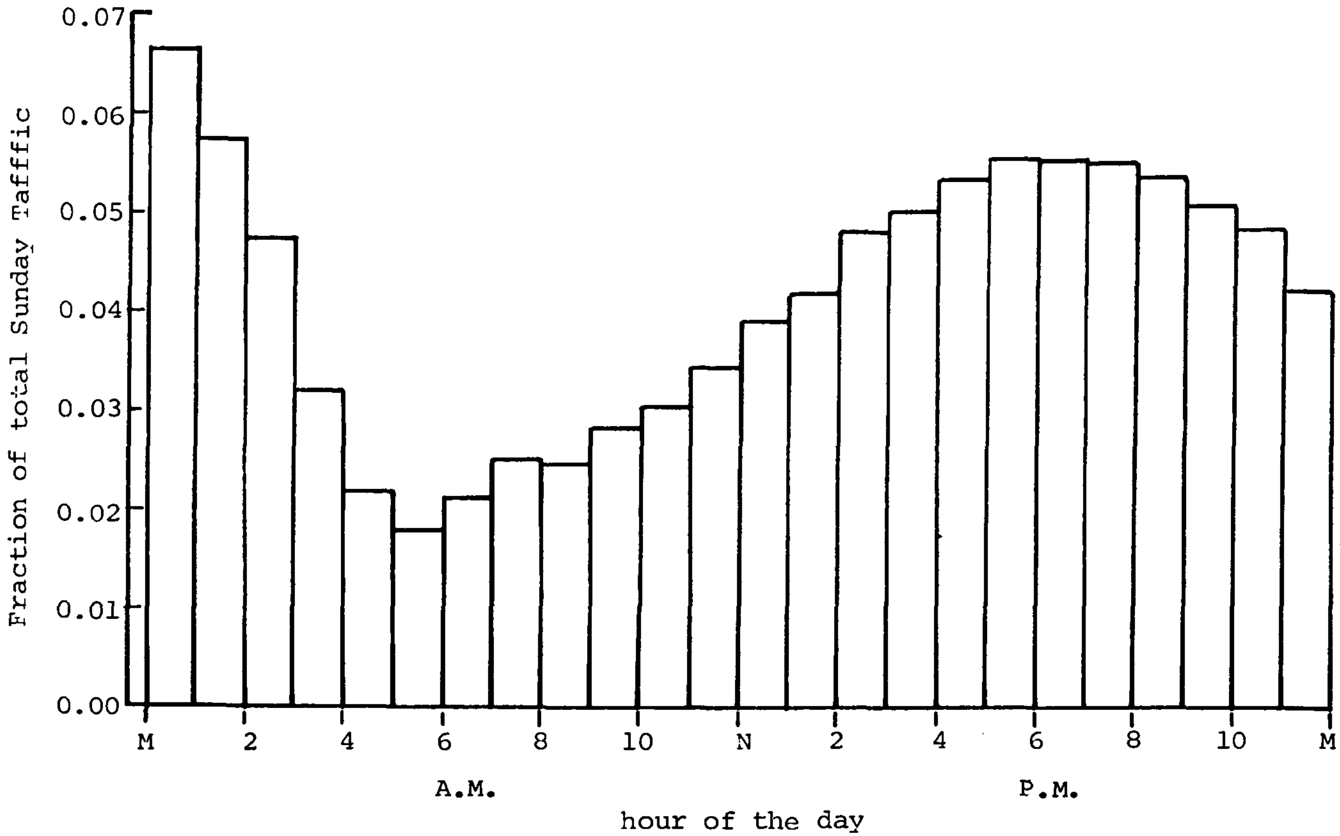

Figure 12. Hourly traffic distribution in the CBD for Sunday

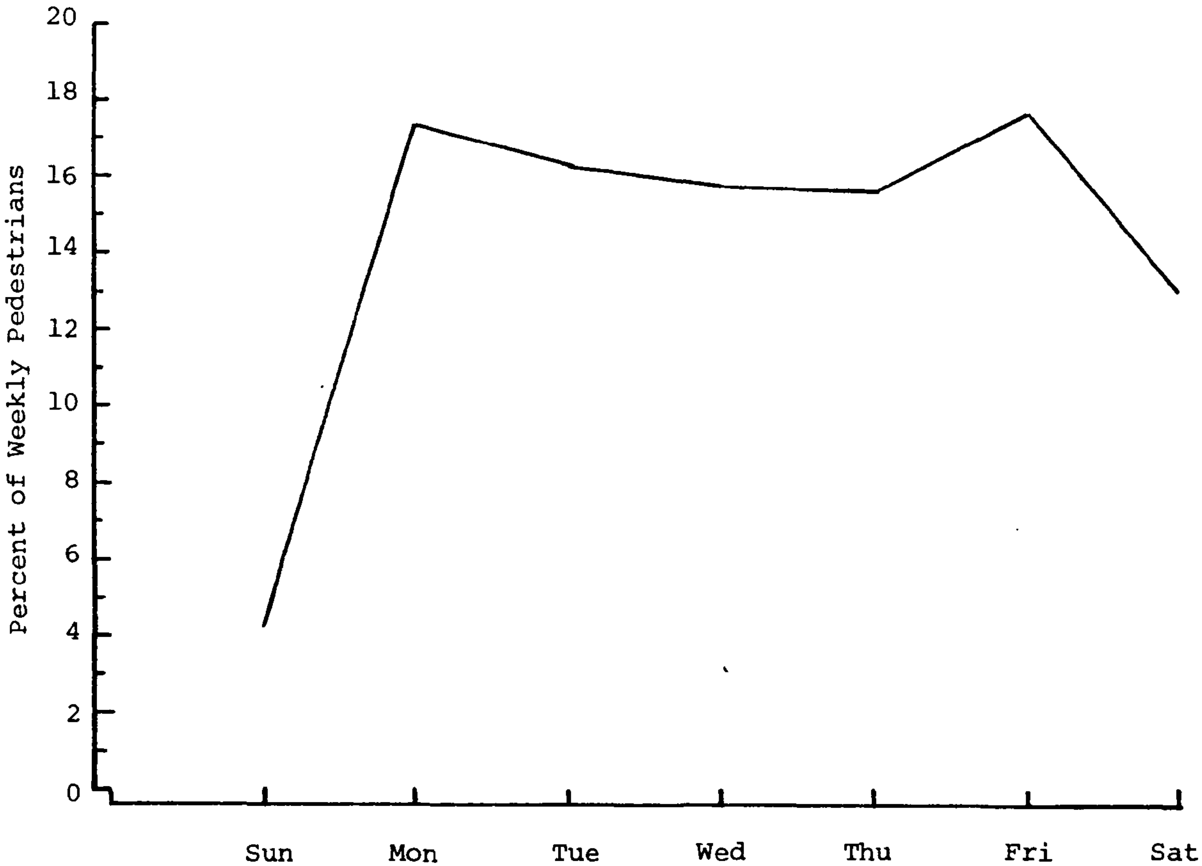

Figure 13. Pedestrians for individual days of the week as a percent of total weekly pedestrians

From the three references, hourly distributions of pedestrians in street canyons for weekdays and Saturdays were developed. These distributions are shown in Figures 14 and 15 as percent of total daily pedestrians. There were no distribution data available for Sundays. Therefore, the Saturday distribution in percentage terms was used for Sunday also. There were no data in the literature as to how long people spend for each pedestrian trip. Therefore, the exposure period was assumed to be 15 minutes.

Number of Persons on Expressways

The total number of people on expressways and their hourly distribution were determined from traffic count information in the literature. Since the NEM has a "transport vehicle," microenvironment, which could be used for the expressway exposure, the number of persons and hourly distribution of people used in the NEM "transport vehicle" microenvironment were also compiled and compared with the values from traffic counts to determine how well the NEM values agreed with the expressway literature.

The total number of persons on expressways can be determined if the total miles of expressway, the average daily expressway traffic, and the average trip length are known, as shown below.

$$\frac{\text{miles of expressway}}{\text{miles of expressway/trip}} \times \text{vehicles} \times \frac{\text{persons}}{\text{vehicles}} = \text{person trips}$$

From the work done at SwRI under Contract 68-03-2884, it was determined that there were 16,910 miles of urban expressway, and that the average daily traffic was 47,664.[18] A thorough search of the literature was conducted to define the expressway trip distance. Almost no data were found. Average urban trip distances (including nonexpressway trips) were found, but were obviously dominated by short nonexpressway trips, since the mean values of trips for all purposes were all between 1 and 4 miles. Three studies were found that could be used in combination to define expressway trip length.[53,54,55] Unfortunately, they all dealt with the Los Angeles area.

From Reference 55, using results from the 1967 "LART" study, the average time on freeways in the L. A. area, for persons using the freeway, can be computed as 13.3 minutes. Reference 53 gives the average speed at peak hour L. A. freeway traffic as 31.46 mph. Using this average speed and 13.3 minutes as the average time, gives an average of 7.0 miles of expressway travel per trip. Los Angeles, however, is infamous for its long commuting trips. In older eastern cities, the average expressway trip has the possibility of being much shorter. Five miles per expressway trip nationwide appears to be a reasonable estimate.

The average daily traffic (ADT) of 47,664 given in Reference 18 is for a seven day week. Using the weekly expressway distribution from Reference 49, as shown in Figure 16, the weekday ADT is 50,714, the Saturday ADT is 45,043, and the Sunday ADT is 35,033.

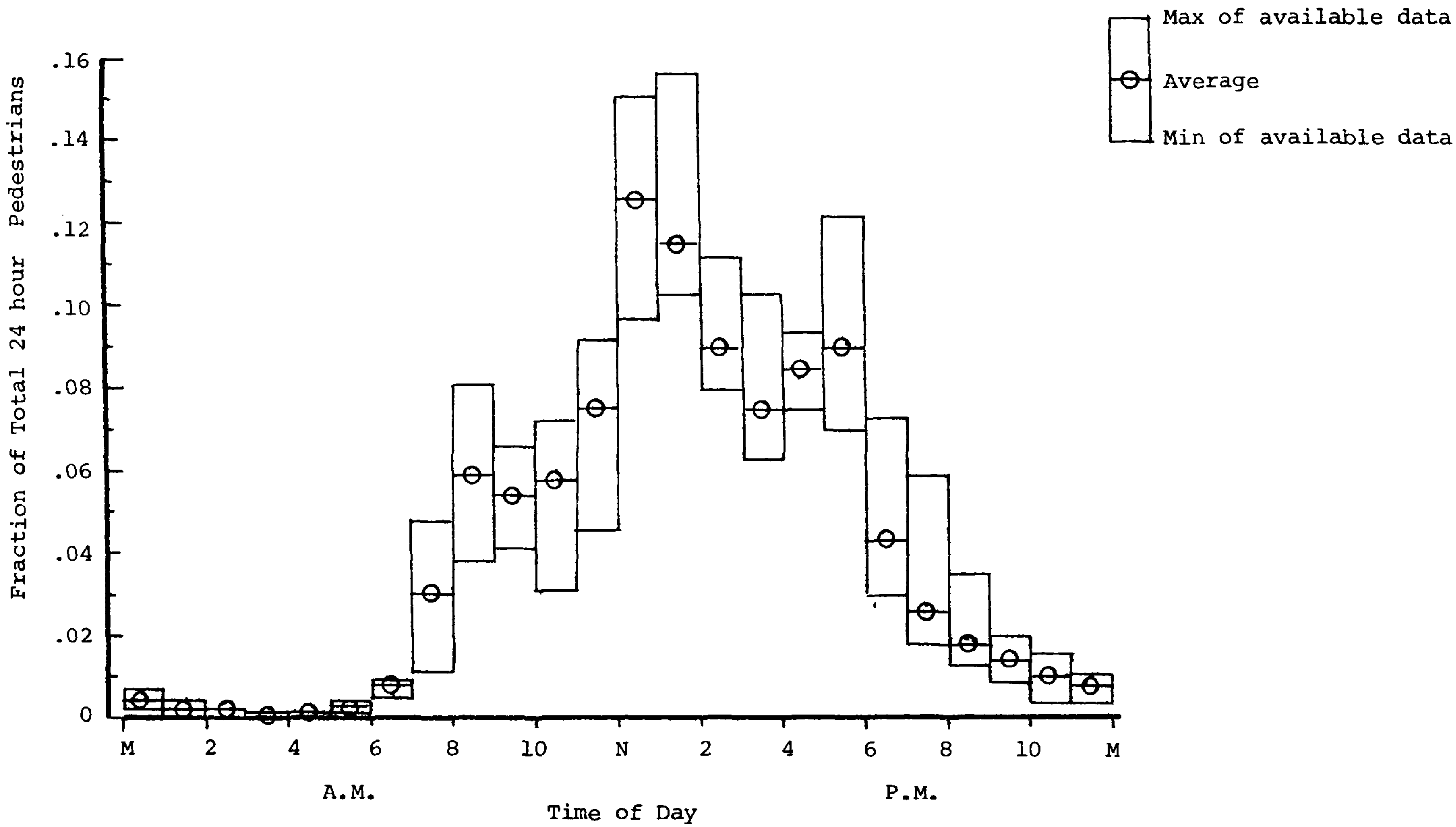

Figure 14. Hourly pedestrian distribution in the CBD for weekdays

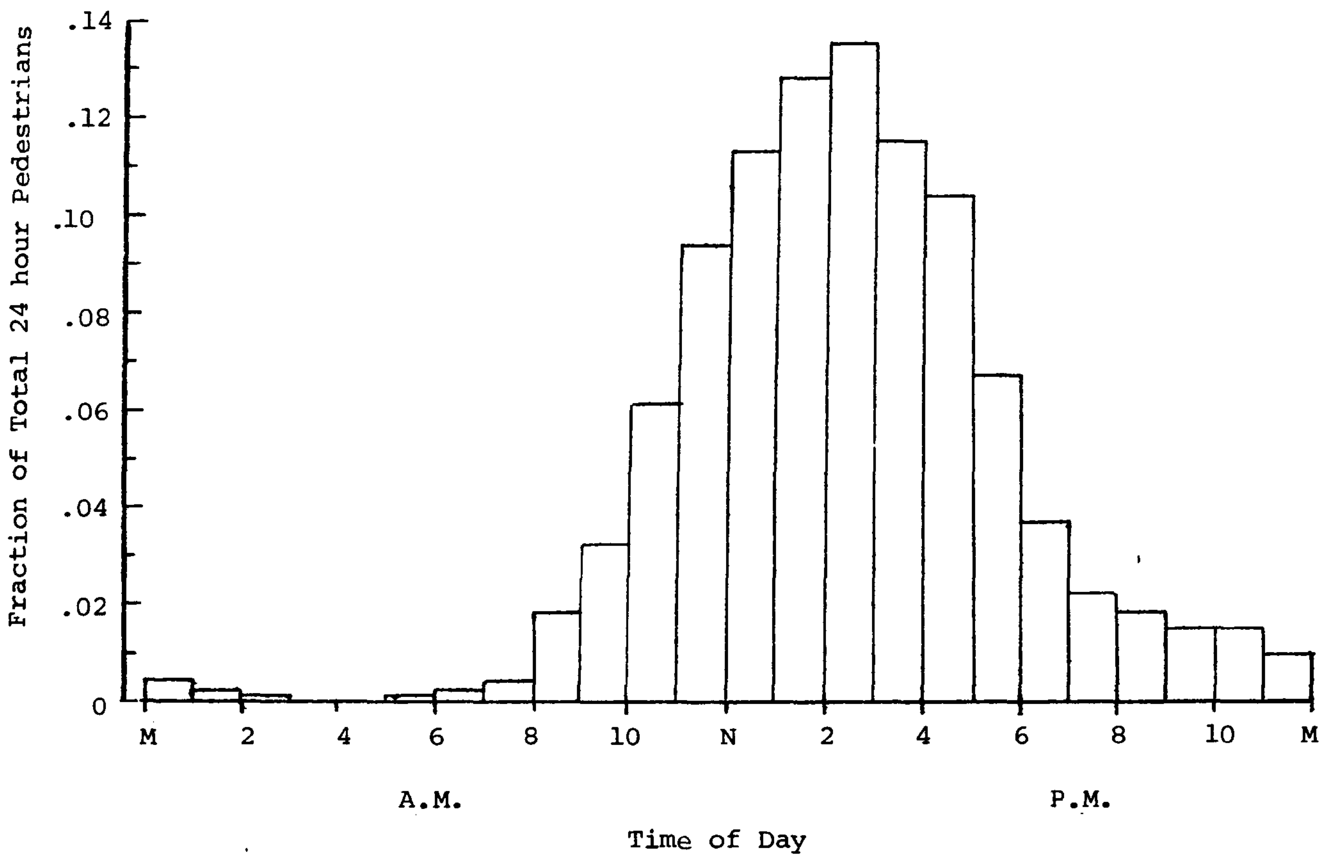

Figure 15. Hourly pedestrian distribution in the CBD for Saturdays

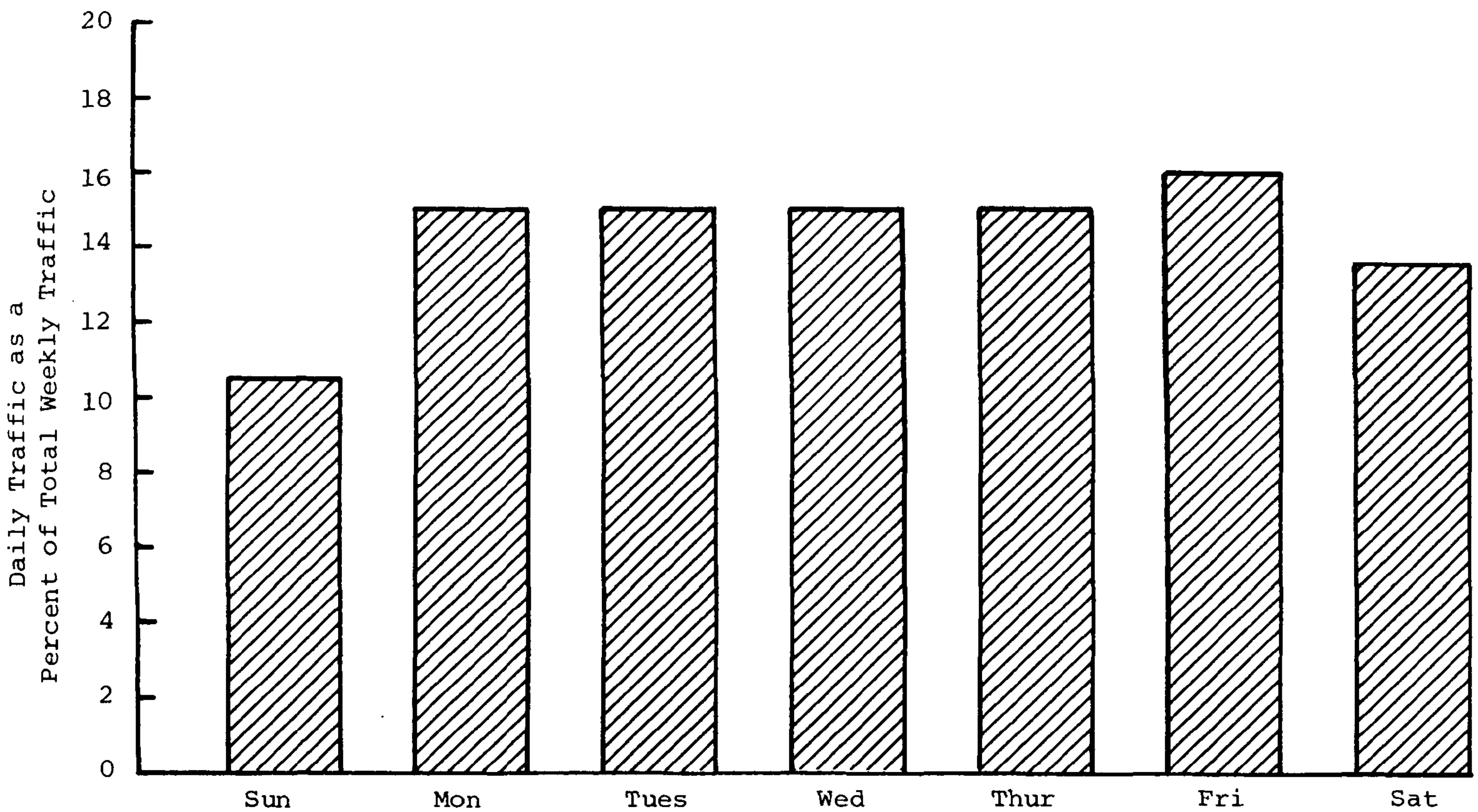

Figure 16. Expressway traffic by day of the week

Computing the total person exposures, using 16,910 miles of urban expressway, average weekday daily traffic of 50,714, average trip length of five miles and 1.4 persons per car, gives 240,120,647 person exposures per weekday. However, as shown above, trip times are on the order of one quarter hour. Using the 240,120,647 weekday person exposures calculated above, at one quarter hour per exposure gives 60,030,162 person hours of weekday expressway exposures. Similar calculations can be made for Saturday and Sunday using the ADT given above, five miles per expressway trip, and 2.3 persons per vehicle. The total person trips and person hours of expressway exposure for the three day types are:

	Person trips	Person hours
Weekdays	240,120,647	60,030,162
Saturday	350,371,480	87,592,870
Sunday	272,507,692	68,126,923

While the NEM has a "transport vehicle" microenvironment as part of the model, the total number of persons exposed to this situation was not readily available from the NEM CO report. It was necessary to tally the people and hours from the activity files of the age-occupation (A-O) groups. The numbers of persons assigned to the NEM "transport vehicle" category for weekdays, Saturday and Sunday were calculated using the A-O assignments in the April 1982 draft of the NEM CO study. The NEM study was actually run for four cities, then scaled up to a nationwide estimate. The "transport vehicle" population from the four cities must then also be scaled. Table 15 shows the NEM "transport vehicle" hourly distribution and four city totals, as well as a scaled nationwide estimate. The scaling factor for the nationwide estimate is the total national urban population given in Chapter 8 of the April 1982 draft NEM CO report, divided by the total non-farm population of the four urban areas studied (132,023,885 ÷ 15,190,177 = 9.30). The NEM CO study uses a one-hour exposure time for all environments. Thus, using the NEM study, a nationwide expressway exposure estimate of 100,075,843 person hours per weekday was calculated. The NEM person hours in the "transport vehicle" microenvironment and the person hours derived from traffic counts are compared in Table 16.

As can be seem from Table 16, the NEM person hours are approximately 65 to 70 percent higher than the person hours calculated in this study. This is not to imply that the NEM "transport vehicle" microenvironment figures are incorrect. The NEM "transport vehicle" category represents all vehicular travel, of which automotive expressway travel is obviously just a subset. It is reasonable, therefore, that the NEM "transport vehicle" category should contain more person hours of exposure.

TABLE 15. DISTRIBUTION OF PEOPLE ASSIGNED TO THE "TRANSPORT VEHICLE" MODE IN THE NEM CO REPORT[a]

Hour of day	Number of People in all Four Cities: Weekday	Saturday	Sunday
Mid - 1 am	--	--	--
1 - 2	--	--	--
2 - 3	30,041	--	--
3 - 4	--	--	--
4 - 5	--	--	--
5 - 6	--	--	--
6 - 7	487,539	--	--
7 - 8	1,538,501	--	--
8 - 9	1,081,739	--	1,165,518
9 - 10	727,154	2,109,330	3,451,698
10 - 11	884,372	2,032,865	2,387,678
11 - noon	217,109	308,943	1,705,864
noon - 1 pm	198,317	614,568	351,393
1 - 2	497,537	2,332,526	579,666
2 - 3	1,436,532	2,383,733	281,118
3 - 4	773,521	358,224	250,811
4 - 5	1,473,064	1,014,843	807,800
5 - 6	1,288,102	619,711	--
6 - 7	122,815	13,411	237,141
7 - 8	--	2,221,929	1,120,290
8 - 9	--	1,227,262	174,942
9 - 10	--	156,333	--
10 - 11	--	159,299	--
11 - mid.	--	--	--
4 City Total	10,756,341	15,552,977	12,510,919
National Estimate[b]	100,075,843	144,703,230	116,400,249

[a] Calculated from data contained in the April 1982 draft of "The NAAQS Exposure Model (NEM) Applied to Carbon Monoxide"
[b] Four city total multiplied by 9.30

TABLE 16. TOTAL PERSON HOURS OF EXPOSURE ON-EXPRESSWAY SITUATION

	Person Hours of Exposure	
	Third Study[a]	NEM CO Study[b]
Weekday	60,030,162	100,075,843
Saturday	87,592,870	144,642,686
Sunday	68,126,923	116,351,547

[a] on-expressway exposure only
[b] "transport vehicle" microenvironment

The hourly distribution of people in the on-expressway microenvironment was also investigated. The hourly weekday expressway traffic distribution was obtained from Reference 41 as a percent of daily traffic. This distribution is shown in Figure 17. There are few weekend expressway traffic distributions in the literature. A Sunday expressway distribution for an urban Chicago expressway was found in the "Highway Capacity Manual," Reference 46. This distribution is shown in Figure 18. No information was found on Saturday expressway traffic distribution.

An examination of the microenvironment assignments in the NEM activity pattern subgroups shows that an effort was made to distribute people in the "transport vehicle" microenvironment throughout the day and on weekends. These assignments were, in general, made on an intuitive basis.[33] The NEM weekday hourly distribution presented in Table 15, was also calculated as a percent of daily traffic. This distribution is also shown in Figure 17. While the two distributions are somewhat similar, in that they peak at the same hours, the peaks are much higher in the NEM distribution. In addition, the NEM distribution has an anomalous peak at 2 to 3 p.m. Similar calculations were done for the Saturday and Sunday NEM person hour distributions.

The Sunday distribution is plotted on Figure 18, together with the distribution from this study. The Saturday distribution is shown on Figure 19. The Sunday distributions do not compare well at all. The NEM distribution has extremely high percentages between 9 and 11 a.m., which are not confirmed by traffic count data. The Saturday NEM distribution also has some very high percentages for the same hours. It is apparent from the weekday and Sunday distributions found in the literature, that hourly traffic does not really reach these levels.

From this analysis, it is clear that for mobile source exposure, the NEM model needs to be rerun, changing the number and distribution of cohorts in the transportation vehicle microenvironment to more accurately reflect the person hour exposure in the on-expressway situation. However, the effort allotted to this project was not sufficient to permit the reprogramming of the NEM A-O activity file to change the number and distribution of people in the "transport vehicle" microenvironment. Nevertheless, the "transport vehicle" microenvironment was used for the on-expressway exposure because it contained reasonable CO concentrations. It should be kept in mind that a more accurate person hour exposure distribution is possible from the NEM with changes in the cohort assignments to the "transport vehicle" microenvironment.

Persons in Urban Roadway Tunnels

From previous studies at SwRI, the total number of urban tunnels[59] is known, as well as the average daily traffic for all days of the week (52,000).[18] If the weekly traffic distribution is known, then the weekday and Saturday and Sunday average tunnel ADT can be calculated. Since tunnels occur on all types of roadways, expressways, arterials, etc., it was decided to average the weekly traffic distribution for several different road types to obtain a weekly distribution for urban tunnels. These distributions and the average are shown in Table 17. It was not possible to weight them by population, traffic, road type, etc., since these values were not available in the references.

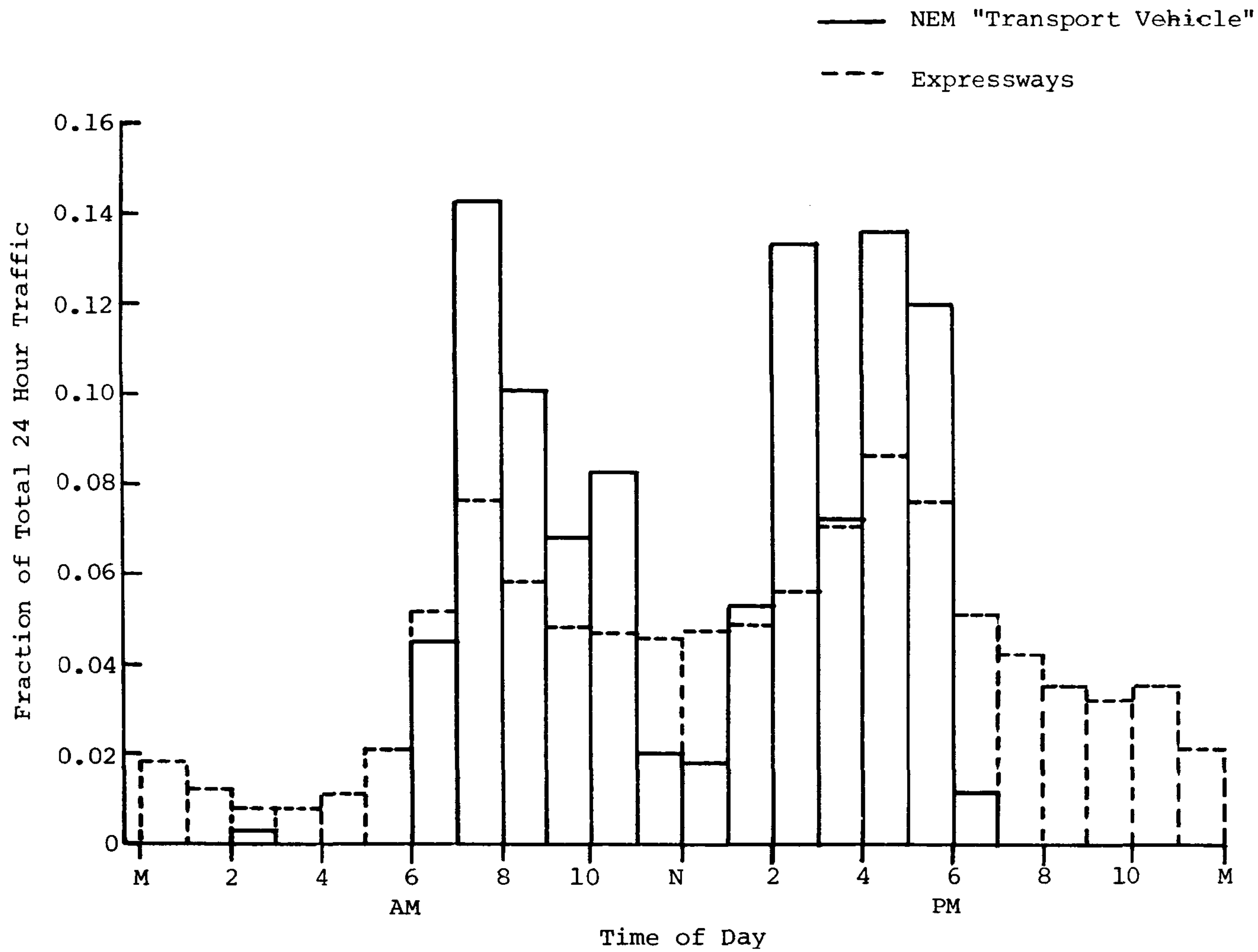

Figure 17. Hourly expressway traffic for weekdays

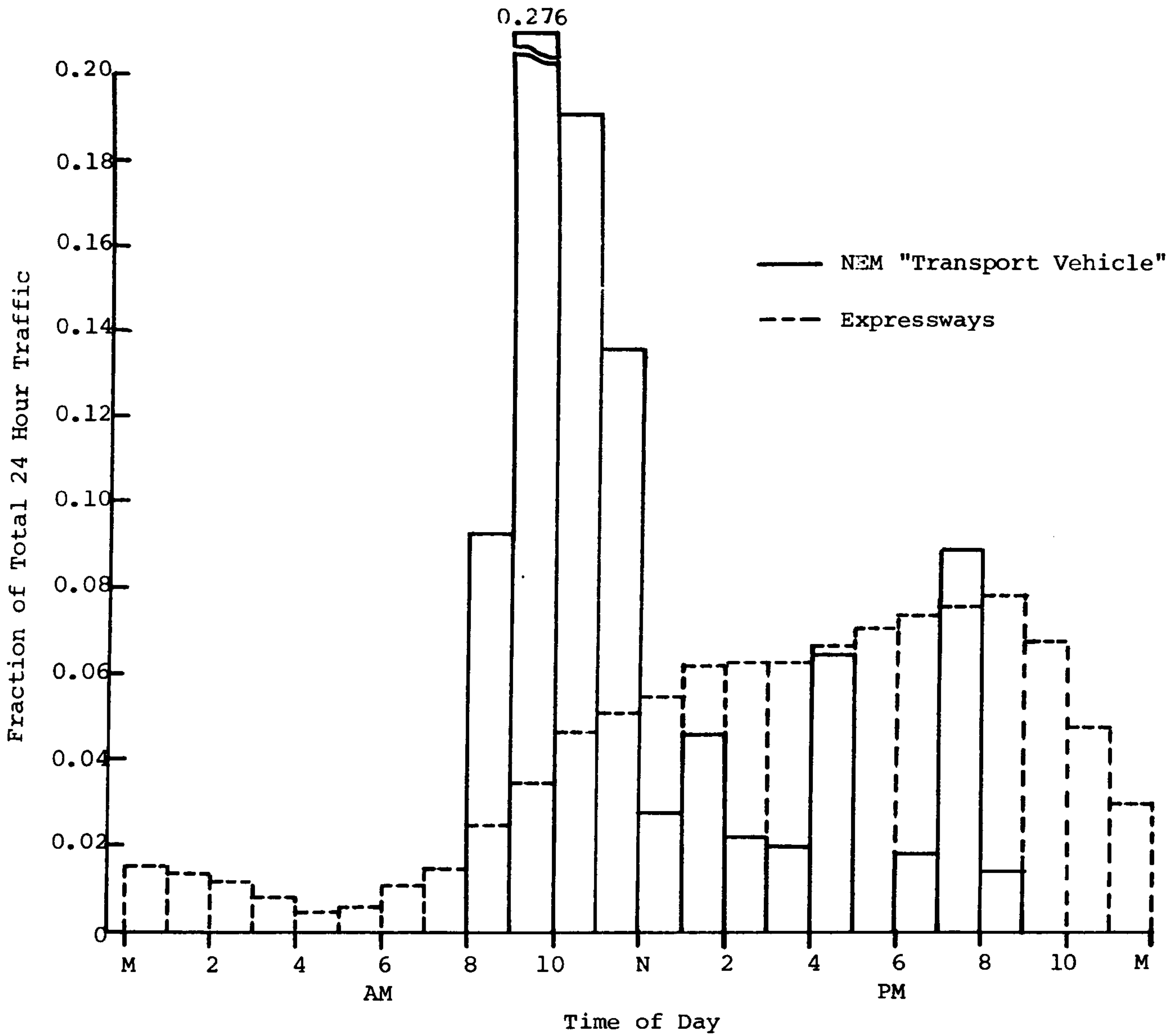

Figure 18. Hourly expressway traffic for Sundays

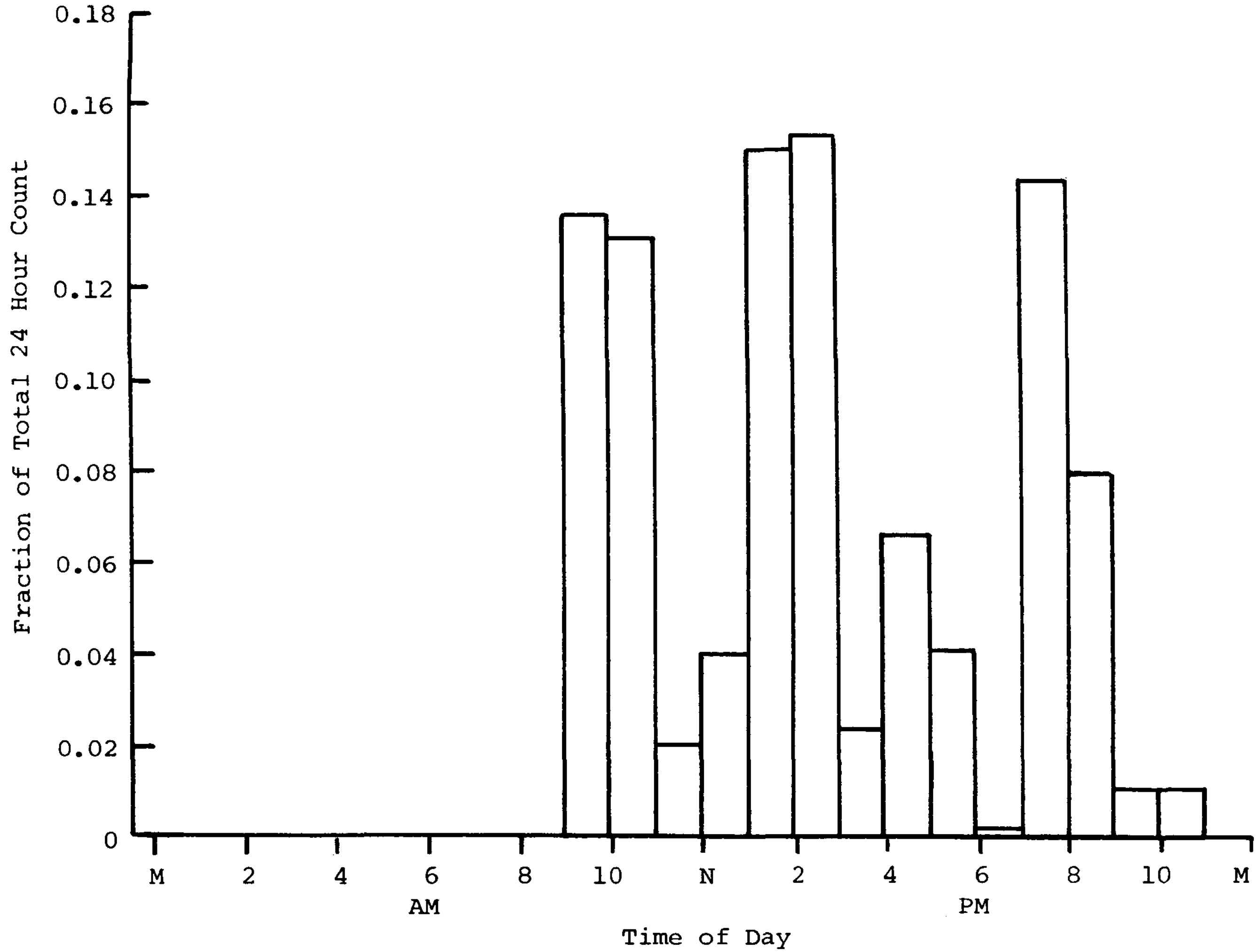

Figure 19. Hourly Distribution of people in the NEM "transport vehicle" environment in four cities for Saturdays

TABLE 17. TRAFFIC DISTRIBUTION BY DAY OF THE WEEK FOR SEVERAL SITUATIONS

	Daily Traffic as a Percent of Weekly Traffic				
	Urban[a]	CBD[a]	Nashville Urban[b]	San Antonio Expressway[c]	Unweighted Average
Sunday	13.5	5.8	10.5	10.5	10.1
Monday	14.5	15.5	15.2	15.0	15.1
Tuesday	13.7	15.3	14.7	15.0	14.7
Wednesday	13.7	15.0	14.7	15.0	14.6
Thursday	14.0	14.8	14.7	15.0	14.6
Friday	15.0	15.5	15.9	16.0	15.6
Saturday	16.2	17.8	14.8	13.5	15.6

[a] Reference 47
[b] Reference 46
[c] Reference 49

From the seven day average ADT of 52,000 and the information in Table 17, the total traffic for all 59 urban commuter tunnels can be calculated. Using 1.4 persons per car on weekdays and 2.3 persons per car on weekends, the person exposures for each day type can also be calculated. The results of these calculations are shown below.

Day Type	Total Vehicles/Day	Person Exposure/Day
Weekday	3,199,924	4,479,894
Saturday	3,350,256	7,705,589
Sunday	2,169,076	4,988,875

The hourly traffic distribution for two tunnels for weekdays and weekends was found in the literature. (39,56) One tunnel was identified as the Sumner tunnel in Boston, the other tunnel simply as an "urban tunnel." The hourly traffic distributions for these two tunnels are shown in Figure 20 for weekdays, and Figure 21 for weekends. For each day type, the distributions from the two tunnels look very similar. The data were taken from different studies conducted during different years, but there is possibility that the tunnel identified in Reference 56 as an "urban tunnel," is, in fact, the Sumner tunnel. It is used nevertheless, since there is so little information in the literature. No data were found on the individual period of exposure. Considering that a large number of the exposures occur during peak traffic periods when traffic is moving at its slowest rate, a five minute period of exposure was chosen for tunnels.

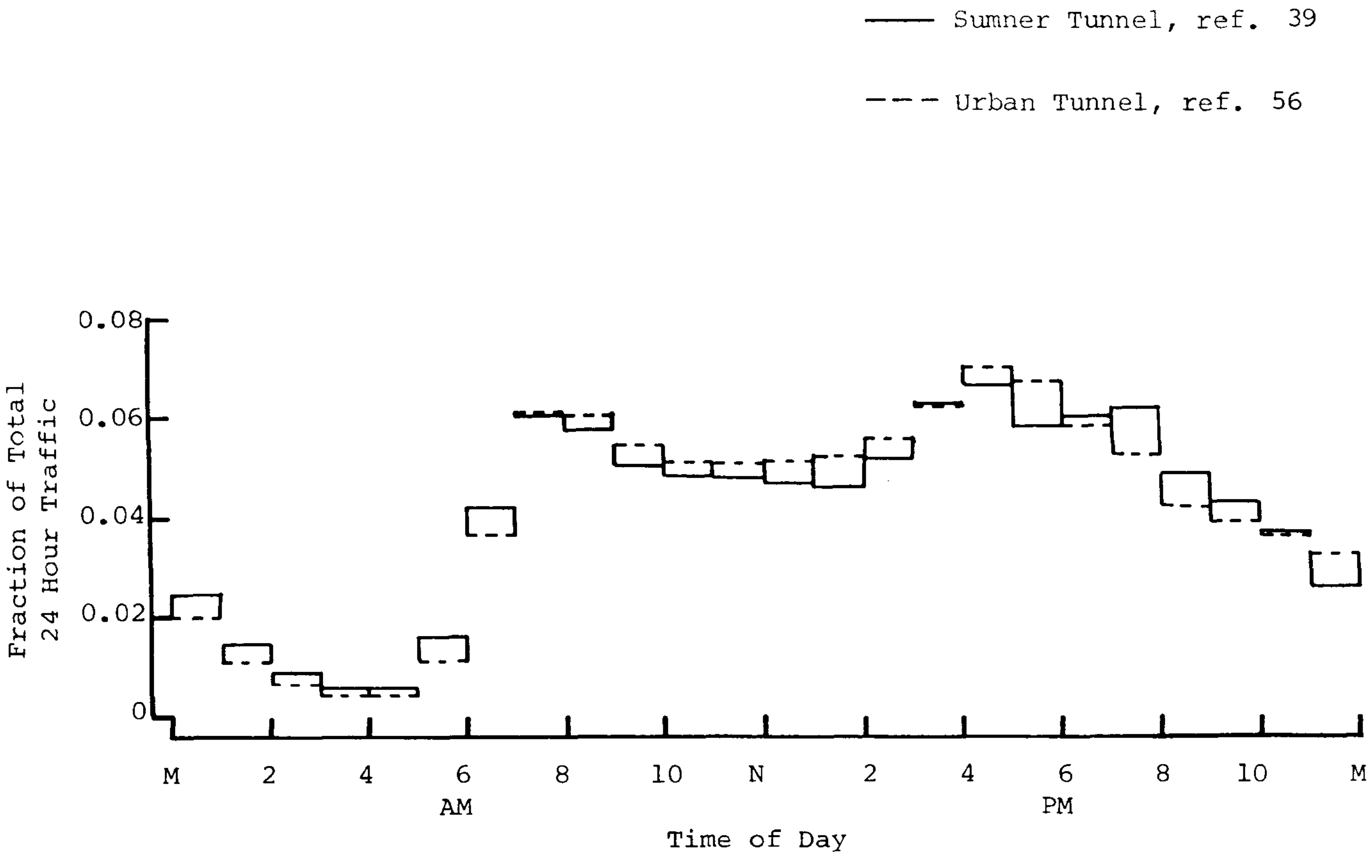

Figure 20. Hourly tunnel traffic for weekdays

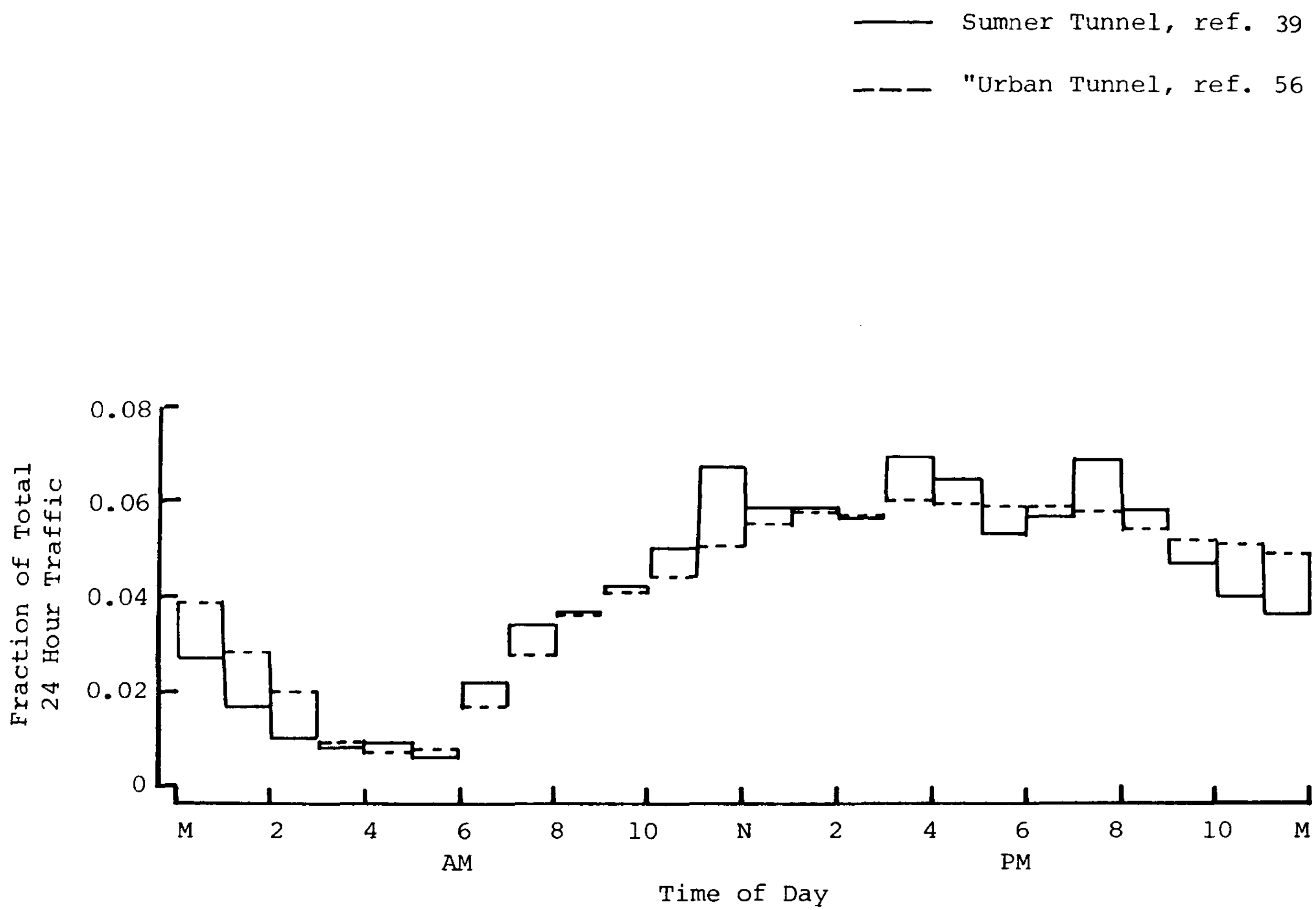

Figure 21. Hourly tunnel traffic for weekends

V. EXPOSURE IN MOBILE SOURCE MICROENVIRONMENTS

There are several microenvironments that contribute to mobile source pollutant exposure. Of these environments, four are considered the most significant in terms of total person hours of exposure. These four are: parking garages, street canyons, on-expressways, and roadway tunnels. The NEM can be used for only one of these four microenvironments: The on-expressway microenvironment. The person hours of exposure from the other three microenvironments must be determined independently of the NEM using a model specifically developed for that purpose.

Microenvironment Exposure Model

To calculate only person hours of exposure in a specific microenvironment, no information about the movement of people from place to place is required. All that is required is the population and concentration distributions, nationwide, for each microenvironment. This approach to calculating person hours of exposure is referred to as "place specific" as contrasted to the NEM which is considered "people specific" since it follows a group of people through the day.

For a place specific model, the number of people in the microenvironment multiplied by the hours per year each pollutant concentration interval occurs gives the person hours of exposure in the microenvironment to that concentration interval. Because pollutant concentration is a direct function of the number of vehicles, the most accurate estimates are obtained by considering hourly populations, with pollutant concentration ranges appropriate to that population. Since hourly populations are different for weekdays, Saturdays and Sundays, three sets of hourly population figures are required. The person hours of exposure are summed for all hours of the day and all day types for the entire year to give the annual person hours of exposure. The mathematical expression for the model is:

$$P_k = \sum_{j=1}^{3} \sum_{i=1}^{24} a_j T_{ij} F_{ijk}$$

Where:

P_k = population exposures to concentration interval "k"

T_{ij} = population during hour "i" in the microenvironment on day type "j"

F_{ijk} = frequency of occurrence of concentrations in interval "k" during hour "i" of day type "j"

a_j = number of type "j" days in a year

After calculating the person hours within a given pollutant interval, the intervals are summed to yield the cumulative frequency distribution. The number of weekdays per year was taken as (52x5) + 1 = 261. From this was subtracted 13 holidays, for a total of 248 weekdays. The holidays were further divided into 10 "Saturday type" holidays and 3 "Sunday type." Thus, there were 52 + 10 = 62 "Saturdays," and 52 + 3 = 55 "Sundays."

The pollutant concentration distributions were generally not available by hour. For each microenvironment, the model was modified to account for the way in which the pollutant concentration distribution was related to the microenvironment population. While it would be possible to develop one computer program to handle all the variations, it was considered to be more cost effective to use a separate computer program for each microenvironment. The computer programs are listed in Appendices C, D and E for parking garages, street canyons and roadway tunnels, respectively.

For each of these three mobile source microenvironments, hourly populations and pollutant concentration distributions were developed and have been presented in previous sections of this report. The remainder of this section covers the results of applying the microscale exposure model to parking garages, street canyons and tunnels.

Exposure in Parking Garages

The actual model algorithm used for the parking garage situation was somewhat different from the general form shown above. This change was necessary since the pollutant concentrations for parking garages given in Section III of this report were not functions of time of day, but rather, functions of the number of active cars and wind speed. Also, the hourly populations, as shown in Section IV of this report, were expressed as the fraction of total parking capacity in motion, not actual people.

The computer program considers each of the day types (weekday, Saturday, and Sunday) separately. For each hour of the day, for each day type, the program obtains the fraction of active cars in the garage per hour, then divides by 12 to obtain the fraction of active cars at any instant. Using this value, a set of concentration distributions corresponding to that fraction of active cars is chosen for that day type and hour. The set of concentration distributions consists of a distribution for each of three wind speed ranges. Starting with the fraction of the total people exposed for each of the selected pollutant concentration intervals at the lowest wind speed, the total number of person hours in each interval was obtained by multiplying the total number of active cars (total spaces times fraction of active cars), the number of people per car, the number of days per year of the particulate day type, and the fraction of time the wind was in that particular speed range.

The person hours in each concentration interval are summed as each successive wind speed, hour of the day, and day type is considered. Expressed mathematically the program processed the equation:

$$P_k = \sum_{j=1}^{3} \sum_{i=1}^{24} \sum_{m=1}^{3} a_j \, (SNC_{ij}/4) \, F_{km} \, W_m$$

where:

P_k = person hours of exposure in concentration interval "k"
S = total number of parking garage parking spaces available nationwide
N = number of persons per car
C_{ij} = hourly fraction of total parking capacity in motion
F = frequency of occurrence of concentration interval k. A function of concentration "k", fraction of active cars at any instant, and wind speed "m".
a_j = number of type "j" days per year
W_m = fraction of time wind is within speed range "m"
i = hours
j = day type
m = wind speed interval

People generally are not exposed to the garage pollutant levels for a full hour. A fifteen minute exposure was used in this study. Thus, for a given hour, the computer program divides the hourly population by four. After the person hours in each concentration interval were calculated, the intervals were summed to give the cumulative frequency distribution.

Since cars in motion at any instant obtained from the garage population curves are always less than two percent of capacity (see Section IV), the high extremes, such as can be found when a garage is emptying at the end of an entertainment event or workday, would not be considered. These situations do occur regularly and should be included in the study. There are data which show that the cars in motion at any instant in these situations can be as high as 25 percent of capacity.[18] These situations normally last about one-half hour, for either filling or emptying.

For work related peaks, it was estimated that 25 percent of the garages experience this type of use at a rate of five times per week. For entertainment events, it was estimated that 25 percent of the garages experience this type of usage at a rate of one per week. To account for the first of the situations, the 5:00 P.M. calculation was split into two parts. For 75 percent of the population, the concentration frequencies were from the distributions for 3 percent active cars. For 25 percent of the population, the concentration frequencies were from the distribution for 19 percent active cars (see Table 3). The second situation was accounted for by modifying the 10:00 P.M. Saturday calculation in a like manner.

Table 18 contains a list of the variables that were used in the parking garage exposure model. Where it was necessary to estimate a value, the estimates were made from impressions and inferences gleaned from the information on parking garages collected under EPA Contract 68-03-2884, Task Specification 1.[18]

The nationwide annual person hours of exposure in parking garages above selected pollutant concentration values calculated from the model are listed in Table 19 and presented in graphic form in Figure 22. The figure indicates that the concentration intervals are sufficiently close to allow linear interpolation to obtain person hours at concentrations other than those given in Table 19.

This information can be used to determine the person hours of exposure to various levels of any mobile source pollutant. If the complete relationship is desired, then the concentrations at a given person hours of exposure should be multiplied by the parking garage emission factor for the particular pollutant. If all that is desired is the person hours of exposure above some concentration of the pollutant, then the actual pollutant concentration, in $\mu g/m^3$ is divided by the emission factor to obtain a concentration at 1.0 g/min emission factor. The person hours of exposure above this level are then obtained by linear interpolation of Table 19.

As an example, suppose the person hours of exposure in parking garages to CO above the one hour NAAQS of 35 ppm are desired. The 35 ppm is converted to $\mu g/m^3$ by multiplying by 1157, then divided by the 1980 parking garage CO emission factor of 5 g/min. This gives 8099 $\mu g/m^3$ at 1.0 g/min emission factor. Interpolating between 8000 and 10,000 $\mu g/m^3$ in Table 19 gives 26.821×10^6 annual person hours of exposure above 35 ppm CO in parking garages.

Exposure in Street Canyons

The previous report sections presented the concentration distributions, total persons in vehicles, total pedestrians, and hourly distributions of vehicles and pedestrians in street canyons for weekdays, Saturdays and Sundays. The values of these parameters are summarized in Table 20. These values were used in the computer model to obtain a nationwide person hour exposure distribution for street canyons. The computer program used was similar to the program used to calculate the parking garage exposure distribution. For the street canyon case, the time of an individual exposure was also taken as 15 minutes. The concentration distribution used was a function of time of day and day type. The computer program processes the expression:

$$P_k = \sum_{j=1}^{3} \sum_{i=1}^{24} [(V_j C_{vij} + P_j C_{pij})/4] \, K_{kij} \, a_j$$

TABLE 18. VALUES OF VARIABLES USED IN DETERMINATION OF PARKING GARAGE PERSON HOUR EXPOSURE ESTIMATE

Variable	Value
1. Total Spaces	5.398×10^6 = (6200x740) + (5400x150)
2. Persons per car	1.4 on weekdays, 2.3 on weekends
3. Active time per vehicle	5 minutes
4. Exposure time per person	15 minutes
5. Percent time in wind speed range	9.5%, 0 to 3 kts 65.0%, 4 to 10 kts 25.5%, >10 kts
6. Number of weekdays	248
7. Number of holidays	13
8. Number of Saturdays	62 (52 + 10 holidays)
9. Number of Sundays	55 (52 + 3 holidays)
10. Percent of garages experiencing peak active cars	25%
11. Number of hours of peak activity	310/year (248 + 62)
12. Fraction of active cars per hour (exclusive of peak activity)	varies with type of day and hour of day. Minimum = 0, maximum = .2134
13. Distribution of exposure with concentration	lognormal distribution with separate distribution for ranges of active cars and wind speed. Concentrations vary from 0 to 50,000 $\mu g/m^3$

TABLE 19. PERSON HOUR EXPOSURE DISTRIBUTION FOR PARKING GARAGES

Concentration Exceeded, $\mu g/m^3$	Person Hours (in millions)
0	1520.380
360	1182.417
463	1016.489
618	802.033
773	639.181
1030	461.891
1288	358.797
1546	296.807
1804	254.810
2061	224.255
2319	199.532
2577	178.714
3000	150.486
4000	100.445
5000	68.766
6000	48.830
8000	27.293
10000	17.753
15000	8.667
20000	5.375
25000	3.379
30000	2.131
40000	0.683

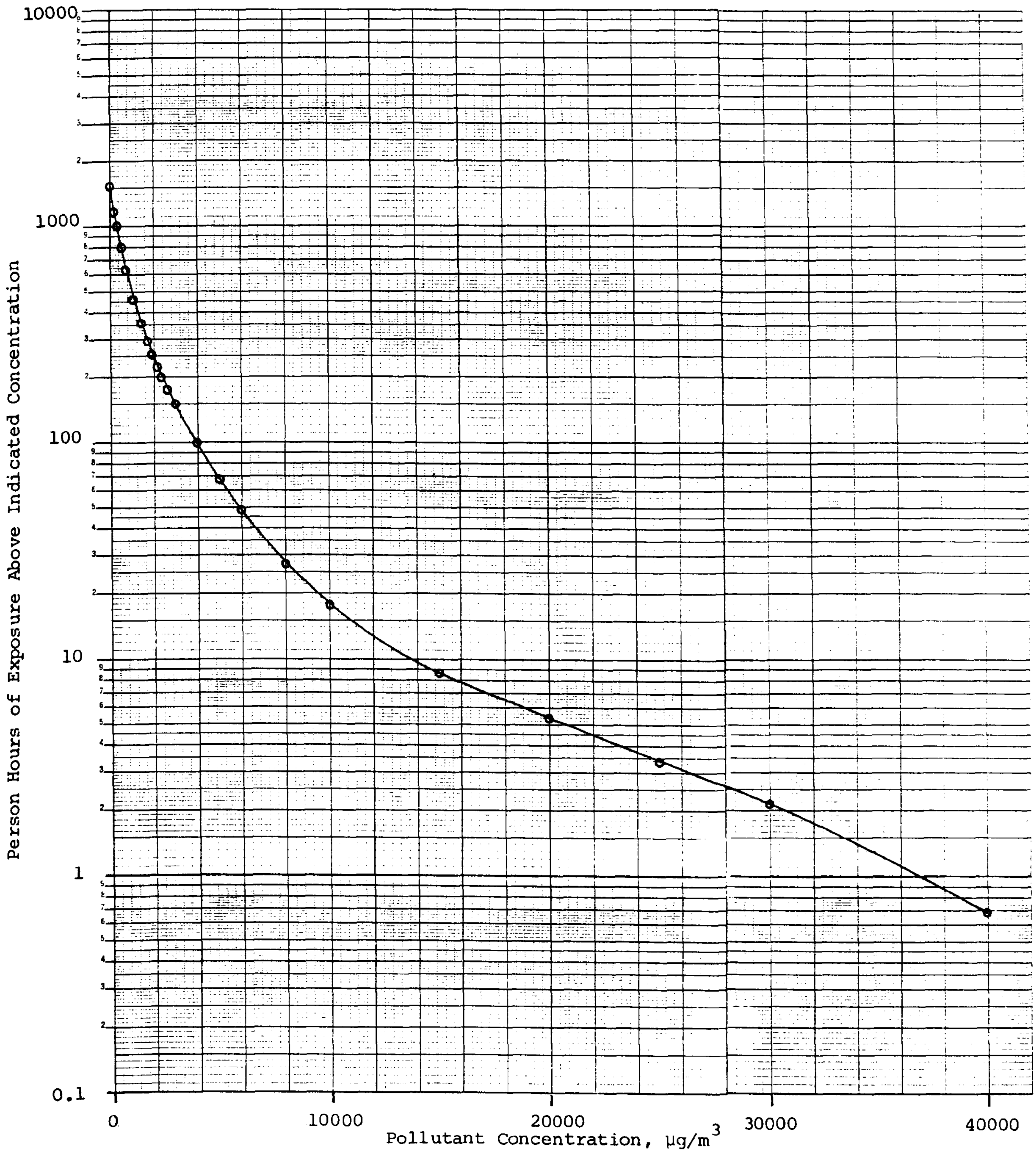

Figure 22. Nationwide Cumulative Exposure Distribution in Parking Garages

TABLE 20. VALUES OF VARIABLES USED IN DETERMINATION OF STREET CANYON PERSON HOUR EXPOSURE

Variable	Value
Total nationwide persons in vehicles in street canyons per day	37,500,000 on weekdays 59,410,000 on Saturdays 36,380,000 on Sundays
Total pedestrians in street canyons	89,076,000 on weekdays 70,012,600 on Saturdays 23,158,000 on Sundays
Exposure time per person	15 minutes
Number of weekdays	248
Number of Holidays	13
Number of Saturdays	62 (52 plus 10 holidays)
Number of Sundays	55 (52 plus 3 holidays)
Fraction of street canyons average daily traffic	Varies by hour of the day and day type from 0.5 to 8.5 percent ADT
Fraction of total daily pedestrians in street canyons	Varies by hour of the day and day type from 0 to 13 percent of total daily pedestrians
Distribution of pollutant concentrations	Determined from street canyon CO monitors in SAROAD data base. Concentrations vary by hour of the day and day type from 0 to approximately 2100 $\mu g/m^3$.

Where:

- P_k = person hours of exposure in concentration interval "k" per year
- V = total number of persons in vehicles in street canyons per day for each day type
- P = total number of pedestrians in streets canyons per day for each day type
- C_v = hourly fraction of total people in vehicles in street canyons
- C_p = hourly fraction of pedestrians in street canyons
- K_{kij} = fraction of time pollutant in concentration interval k. A function of concentration interval, time of day and day type
- a_j = number of type "j" days per year
- j = day type: weekday, Saturday and Sunday
- i = hour of the day

After calculating the person hours in a given pollutant interval, the intervals were summed to give the cumulative frequency distribution, as shown in Table 21. Figure 23 is a plot of this distribution. The figure indicates that the concentration intervals are sufficiently close to allow linear interpolation to obtain person hours at concentrations other than those given in Table 21.

TABLE 21. PERSON HOUR EXPOSURE DISTRIBUTION FOR STREET CANYONS

Concentration Exceeded $\mu g/m^3$ [a]	Millions of Person Hours
0	9907.003
35	9324.053
105	7332.058
175	5295.949
245	3691.592
315	2520.097
386	1709.217
456	1124.188
526	713.121
596	451.391
666	275.330
736	165.660
806	103.723
876	63.166
947	38.209
1087	14.141
1297	3.332
1508	0.577
1718	0.164

[a] for 1.0 g/min emission factor

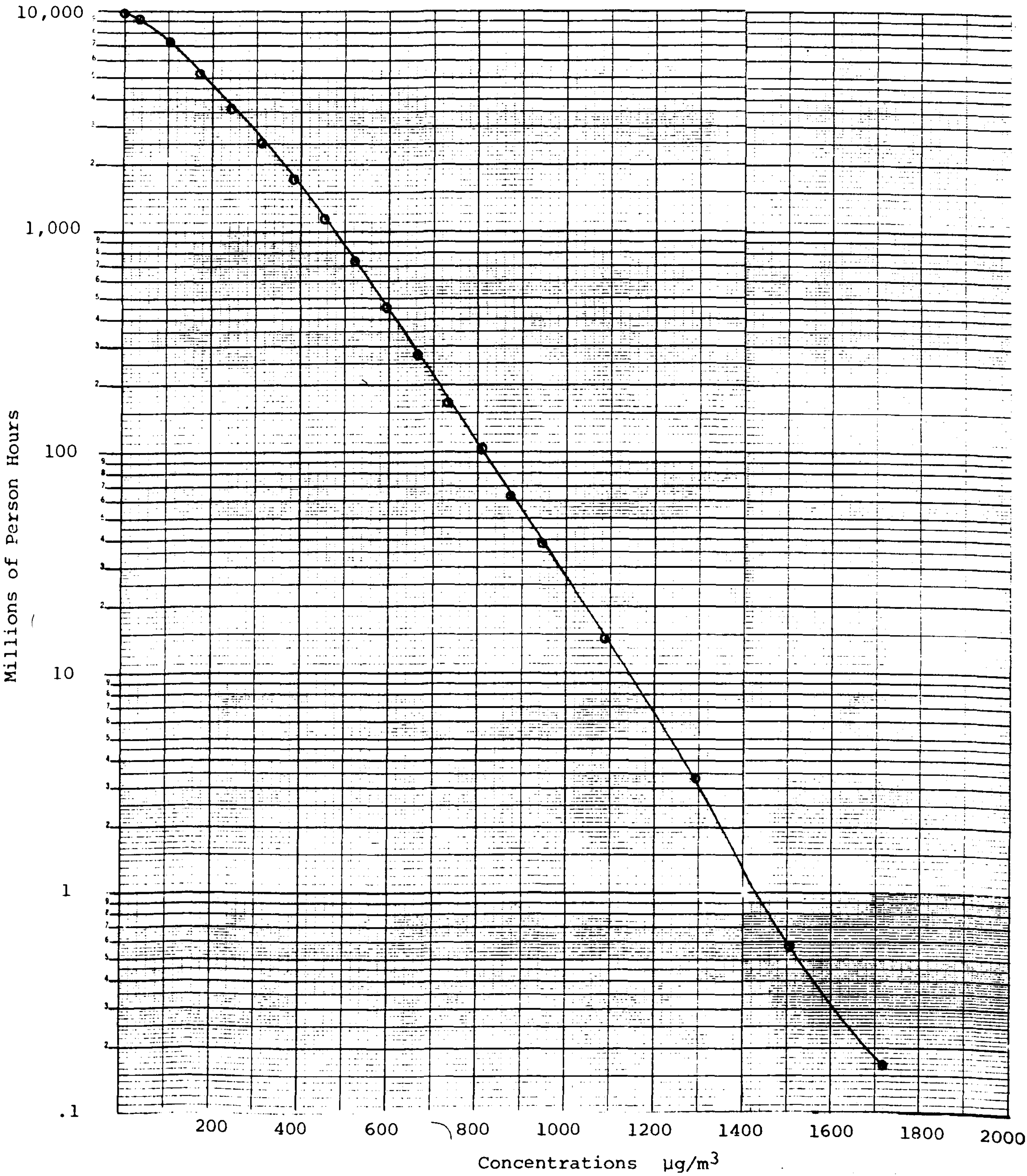

Figure 23. Nationwide cumulative person hour exposure distribution in street canyons

The table can be used to determine the street canyon exposure for any pollutant in the same manner as for parking garages. For example, to obtain the person hours of CO exposure in street canyons above the CO one hour NAAQS of 35 ppm, first convert the 35 ppm to $\mu g/m^3$ by multiplying by 1157. The 40495 $\mu g/m^3$ obtained is divided by the 1980 street canyon CO emission factor of 17.9 g/min, to give 2263 $\mu g/m^3$ at 1.0 g/min emission factor. This is above the highest concentration shown in Table 21. Therefore all that can be ascertained is that, in street canyons, less than 0.164 million person hours of exposure occur annually at CO levels above 35 ppm.

Exposure in Roadway Tunnels

The roadway tunnel person hour exposure distribution can be calculated using the total tunnel traffic and hourly traffic distribution from Section IV, together with the pollutant concentration distributions from Section III. A summary of the exposure model input values is given in Table 22. The person hour distribution for roadway tunnels was calculated

TABLE 22. VALUES OF VARIABLES USED IN DETERMINATION OF ROADWAY TUNNEL PERSON HOUR EXPOSURE

Variable	
Total nationwide person exposures in roadway tunnels	Weekdays - 4,479,894 Saturdays - 7,705,589 Sundays - 4,988,875
Exposure time per person	5 minutes
Number of weekdays	248
Number of Saturdays	62 (52 plus 10 holidays)
Number of Sundays	55 (52 plus 3 holidays)
Fraction of tunnel average daily traffic	Varies by hour of the day and day type from 0.5 to 6.9 percent ADT
Distribution of pollutant concentrations	Lognormal distributions, with six separate distributions, one for each of six different values of ADT. Concentrations vary from 0 to approximately 8000 $\mu g/m^3$.

in the same manner as the street canyon distribution, except that the exposure time was taken as 5 minutes and the pollutant concentration was a function of ADT rather than time of day. The computer algorithm for roadway tunnels is:

$$P_k = \sum_{j=1}^{3} \sum_{i=1}^{24} [(V_j C_{vij})/12]\, F_{kij}\, a_j$$

where:

P_k = person hours of exposure in concentration interval "k" per year
V = total number of persons in vehicles in tunnels per day for each day type
C_v = hourly fraction of total people in vehicles in tunnels
F_{kij} = fraction of time pollutant in concentration interval k. A function of concentration interval, and C_v
a_j = number of type "j" days per year
j = day type: weekday, Saturday or Sunday
i = hour of the day

After calculating the person hours in a given pollutant interval, the intervals were summed to give the cumulative frequency distribution. The cumulative frequency distribution for person hours of exposure in roadway tunnels is given in Table 23. A plot of the distribution is shown in Figure 24. The figure indicates that the concentration intervals are sufficiently close to allow linear interpolation to obtain person hours at concentrations other than those given in Table 23.

The table can be used to determine the tunnel exposure for any pollutant in the same manner as for parking garages and street canyons. For example, to obtain the person hours of CO exposure in tunnels above the one hour CO NAAQS of 35 ppm, convert 35 ppm to $\mu g/m^3$ by multiplying by 1157 to give 40495 $\mu g/m^3$. The 1980 tunnel CO emission factor is 26.92 g/mile[21] at 35 mph or 15.7 g/min.[21] The 40495 $\mu g/m^3$ concentration is divided by 15.7 to give 2579 $\mu g/m^3$ at one gram/min emission factor. Interpolating between 2400 and 2600 $\mu g/m^3$ in Table 23, gives 22.583×10^6 person hours of exposure in tunnels above 35 ppm CO.

TABLE 23. PERSON HOUR EXPOSURE DISTRIBUTION IN ROADWAY TUNNELS

Concentration Exceeded $\mu g/m^3$ (a)	Millions of Person Hours
0	148.859
200	144.970
400	138.681
600	128.618
700	122.167
800	115.082
900	107.536
1000	99.815
1200	84.812
1400	70.884
1600	58.722
1800	48.353
2000	39.686
2200	32.598
2400	26.794
2600	22.089
3000	15.171
4000	6.418
6000	0.847

(a) for 1.0 g/min emission factor

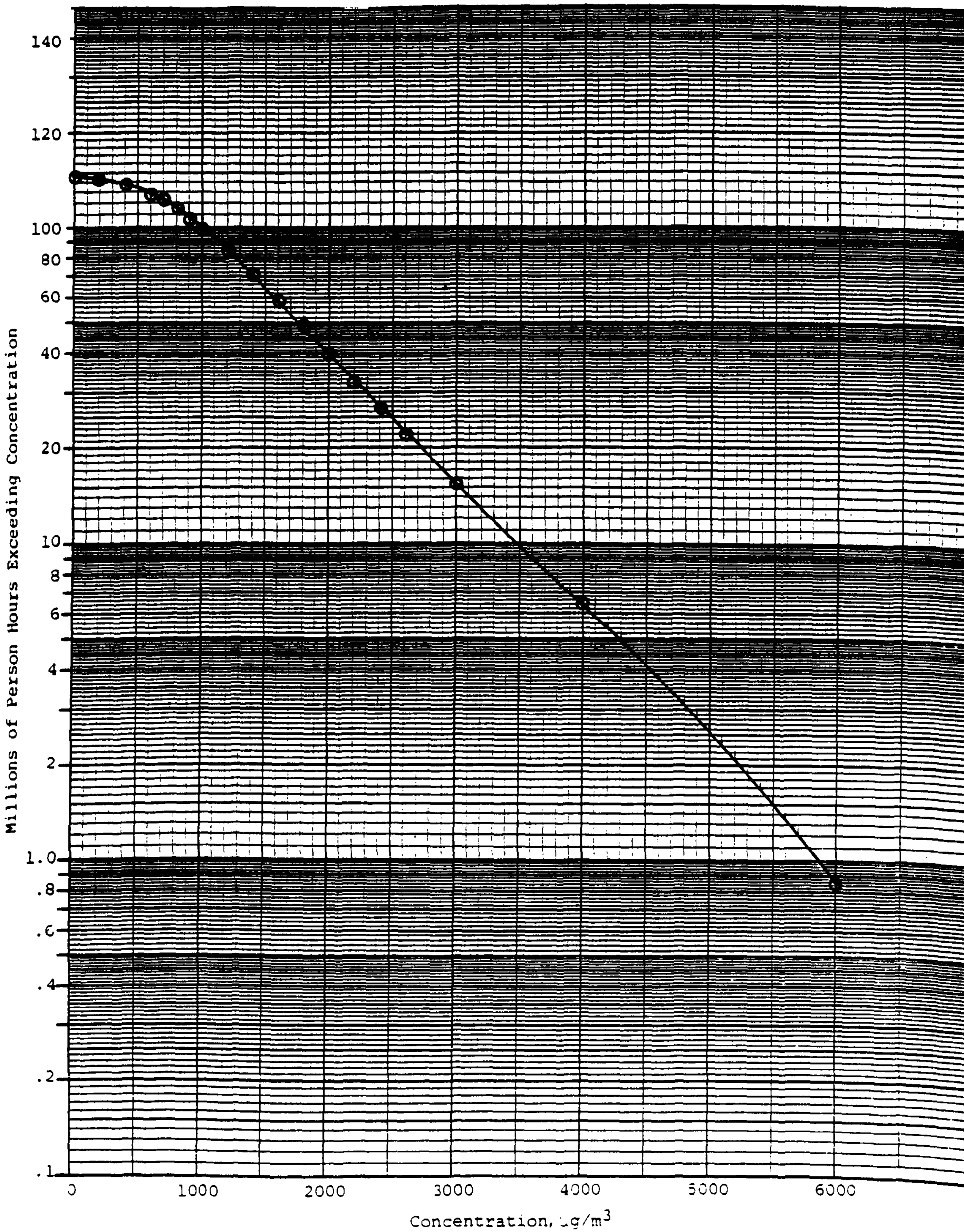

Figure 24. Nationwide cumulative person hour exposure distribution in roadway tunnels

VI. MOBILE SOURCE NEM EXPOSURE ESTIMATE

The methodology for this project was to use the NEM computer model to provide the bulk of the exposure estimate, then add to that estimate exposure from several mobile source microenvironments not included in the NEM.

As explained in Section II, it was found that the input used in the NEM CO study was not structured to provide a satisfactory estimate of mobile source pollutant exposure. It could be used, however, if rerun with modified inputs. As the project progressed, it was also determined that a better estimate of mobile source exposure could be obtained if, for the NEM "transport vehicle" microenvironments, the number of people and their hourly distribution could be modified. Thus, the NEM computer program was rerun to provide a more useful estimation of mobile source pollutant exposure.

New NEM Input

Several of the input parameters used in the NEM CO study required changes in the input values. The modifications required are listed in Table 24. After investigating the NEM input files and the structure of the NEM program, it was found that changes to the activity patterns would require more effort than was available for this project. Therefore, the new NEM run did not include changes to the activity patterns(Item 3 in Table 24).

The NEM computer program is stored on the UNIVAC computer at the EPA's National Computer Center (NCC) in Research Triangle Park, N.C. The EPA Office of Air Quality Planning and Standards (OAQPS) has used the NEM program extensively for a variety of pollutants over the past several years. It was learned from personnel in the OAQPS that most of the files required to modify the air quality data and microenvironment factors, while not used in the published NEM CO study, did exist. A search of the input files stored on the computer at the NCC located the necessary files.

New Exposure Distribution for the Four Cities

Using the modified input files, the NEM model was rerun for CO for the four cities used in the NEM CO report. For record purposes, the UNIVAC computer runstreams for these computer runs are included in Appendix F. The cumulative exposure distributions are shown in Tables 25 to 28 for Chicago, Los Angeles, Philadelphia and St. Louis, respectively.

It is emphasized that the published CO study was done for the purposes of regulatory analysis. The exposure distributions listed in the draft versions of that report represent exposures that <u>would</u> occur if certain CO standards were met. The exposure distributions shown in Tables 25 to 28

TABLE 24. NEM INPUT MODIFICATIONS REQUIRED

Input Area	Modification required
1. Air Quality Data (CO monitors)	EPA study used a variety of rollback factors. Rollback factors must be set equal to 1.0 so that CO data is used "as is."
2. Microenvironment Factors	The EPA study used multiplicative factors for all, and additive factors for some, microenvironments. All additive factors must be set to zero.
3. Activity Patterns	EPA CO study has nationwide estimates for only a portion of the U.S. population. This study requires using all people (all ages and both sexes). The hour by hour assignment of people to environments will require extensive modification. These modifications are necessary to correctly calculate the expressway microenvironment and account for people in microenvironments not considered by the NEM.
4. Concentration Levels	This input defines the CO intervals in the distribution. It must be modified to give more intervals in the lower ppm range.

TABLE 25. PERSON HOURS OF EXPOSURE TO MOBILE SOURCE CO FOR CHICAGO

Total Population, One Hour Averaging Time

Concentration Exceeded (ppm)	Low Exercise	Medium Exercise	High Exercise	Any Exercise
60.0				
50.0	2,250			2,250
40.0	164,000			164,000
35.0	359,000			359,000
30.0	1,470,000	4,610		1,480,000
25.0	3,090,000	25,300		3,110,000
20.0	10,200,000	125,000		10,300,000
15.0	32,900,000	444,000		33,400,000
12.0	72,200,000	1,600,000	57,900	73,800,000
9.0	181,000,000	5,560,000	344,000	187,000,000
7.0	385,000,000	16,000,000	1,360,000	403,000,000
6.0	566,000,000	29,700,000	2,570,000	598,000,000
5.0	915,000,000	60,800,000	5,930,000	982,000,000
4.0	1,410,000,000	118,000,000	12,900,000	1,540,000,000
3.0	2,460,000,000	260,000,000	33,100,000	2,760,000,000
2.0	5,470,000,000	586,000,000	83,700,000	6,140,000,000
1.5	8,850,000,000	867,000,000	130,000,000	9,850,000,000
1.0	13,100,000,000	1,180,000,000	176,000,000	14,500,000,000
0.5	17,500,000,000	1,470,000,000	222,000,000	19,200,000,000
0.0	18,900,000,000	1,560,000,000	234,000,000	20,700,000,000
Max. Concentration	51.1	32.2	14.6	51.1
Encounters at Max.	2,260	4,620	15,000	2,260

TABLE 26. PERSON HOURS OF EXPOSURE TO MOBILE SOURCE CO FOR LOS ANGELES

Total Population, One Hour Averaging Time

Concentration Exceeded (ppm)	Low Exercise	Medium Exercise	High Exercise	Any Exercise
60.0				
50.0	297,000			297,000
40.0	881,000			881,000
35.0	4,900,000			4,900,000
30.0	10,300,000			10,300,000
25.0	33,500,000	188,000		33,700,000
20.0	79,100,000	1,530,000	145,000	80,800,000
15.0	187,000,000	9,010,000	568,000	197,000,000
12.0	509,000,000	29,100,000	2,540,000	540,000,000
9.0	1,240,000,000	104,000,000	13,100,000	1,350,000,000
7.0	2,940,000,000	243,000,000	32,500,000	3,210,000,000
6.0	4,860,000,000	357,000,000	57,300,000	5,270,000,000
5.0	7,780,000,000	629,000,000	109,000,000	8,520,000,000
4.0	12,200,000,000	1,000,000,000	180,000,000	13,400,000,000
3.0	19,700,000,000	1,750,000,000	330,000,000	21,800,000,000
2.0	39,400,000,000	3,290,000,000	597,000,000	43,300,000,000
1.5	51,200,000,000	4,310,000,000	866,000,000	56,400,000,000
1.0	54,300,000,000	4,550,000,000	875,000,000	59,700,000,000
0.5	60,100,000,000	5,020,000,000	1,010,000,000	66,200,000,000
0.0	61,500,000,000	5,100,000,000	1,030,000,000	67,600,000,000
Max. Concentration	58.8	28.8	22.8	58.8
Encounters at Max.	66,400	107,000	43,400	66,400

TABLE 27. PERSON HOURS OF EXPOSURE TO MOBILE SOURCE CO FOR PHILADELPHIA

Total Population, One Hour Averaging Time

Concentration Exceeded (ppm)	Low Exercise	Medium Exercise	High Exercise	Any Exercise
60.0	35,600			35,600
50.0	43,300			43,300
40.0	88,800	10,500		99,300
35.0	283,000	10,500		294,000
30.0	438,000	10,500		449,000
25.0	2,310,000	64,700		2,380,000
20.0	5,180,000	70,200		5,250,000
15.0	10,100,000	281,000		10,400,000
12.0	30,000,000	1,110,000	215,000	31,300,000
9.0	73,900,000	5,040,000	854,000	79,800,000
7.0	169,000,000	11,400,000	1,750,000	182,000,000
6.0	317,000,000	17,400,000	2,180,000	336,000,000
5.0	480,000,000	34,800,000	4,570,000	520,000,000
4.0	980,000,000	75,000,000	10,200,000	1,060,000,000
3.0	1,660,000,000	160,000,000	23,100,000	1,850,000,000
2.0	4,890,000,000	445,000,000	67,700,000	5,410,000,000
1.5	7,380,000,000	715,000,000	134,000,000	8,230,000,000
1.0	9,470,000,000	917,000,000	144,000,000	10,500,000,000
0.5	16,400,000,000	1,480,000,000	285,000,000	18,200,000,000
0.0	23,300,000,000	1,990,000,000	380,000,000	25,700,000,000
Max. Concentration	71.4	42.0	14.3	71.4
Encounters at Max.	35,600	10,500	58,600	35,600

TABLE 28. PERSON HOURS OF EXPOSURE TO MOBILE SOURCE CO FOR ST. LOUIS

Total Population, One Hour Averaging Time

Concentration Exceeded (ppm)	Low Exercise	Medium Exercise	High Exercise	Any Exercise
60.0				
50.0	79,200			79,200
40.0	135,000			135,000
35.0	181,000			181,000
30.0	326,000	6,520		332,000
25.0	631,000	6,520		638,000
20.0	3,280,000	121,000		3,400,000
15.0	8,340,000	405,000	17,800	8,760,000
12.0	19,400,000	987,000	120,000	20,500,000
9.0	61,000,000	3,550,000	591,000	65,200,000
7.0	131,000,000	7,970,000	1,110,000	141,000,000
6.0	221,000,000	13,700,000	1,840,000	236,000,000
5.0	389,000,000	26,200,000	3,150,000	418,000,000
4.0	715,000,000	58,300,000	7,880,000	782,000,000
3.0	1,570,000,000	144,000,000	25,700,000	1,740,000,000
2.0	3,750,000,000	334,000,000	61,500,000	4,140,000,000
1.5	5,380,000,000	481,000,000	90,700,000	5,950,000,000
1.0	7,390,000,000	646,000,000	123,000,000	8,160,000,000
0.5	9,000,000,000	771,000,000	145,000,000	9,910,000,000
0.0	9,700,000,000	826,000,000	158,000,000	10,700,000,000
Max. Concentration	55.9	31.4	19.8	55.9
Encounters at Max.	29,500	6,520	3,260	29,500

are estimates of exposures that did occur in the calendar year of the air quality data used. Thus, it is not possible to directly compare the exposures shown in Tables 25 to 28 with those in the draft versions of the NEM CO report.

Nationwide Exposure Estimate

The nationwide CO exposure distribution was calculated from the distribution for the four cities following the procedure used in the April and December 1982 draft NEM CO reports.[33,57] Before estimating the nationwide exposure, it was necessary to obtain the distribution for each city for 1980. The calendar year for the air quality data used for each city varied by city. The years were: 1979 for Chicago, 1977 for Los Angeles and 1978 for Philadelphia and St. Louis.

To adjust the distribution from each city, the CO levels were multiplied by the ratio of the 1980 FTP CO emission factor to the city base year FTP CO emission factor.

$$\text{1980 ppm} = \text{city base year ppm} \; \frac{\text{1980 FTP CO g/mile}}{\text{city base year FTP CO g/mile}}$$

These calculations produced different CO intervals for each city. Linear interpolation between the new CO values was used to produce person hour distributions with the original CO intervals for each city. These person hour distributions for all four cities are shown in Table 29.

To extrapolate the four cities to a nationwide exposure estimate, the NEM CO study divided the 105 urban areas in the country with a population of 200,000 or more (1970 census) into four categories. Each category corresponded to one of the four cities investigated in the NEM CO study. The relative CO distribution obtained for the study city was assumed to represent all urban areas in that category. The urban areas were assigned to one of the four cities based on such considerations as proximity to the base area, average wind speed, observed peak CO concentration, climate, and general character of the area.[57] The nationwide CO exposure estimate for 1980 was calculated using the following relationships.

$$E(c) = \frac{\text{Total Population 1980}}{\text{Total Population 1970}} \times \frac{\text{Total Urban Population in 1970}}{\text{Total Population >200,000 in 1970}} \times \sum_{i=1}^{4} e_i(c)\, f_i$$

where:

$E(c)$ total nationwide CO exposure distribution

$e_i(c)$ = CO exposure distribution for city "i"

$f_i = \dfrac{\text{Total population in city "i" type areas}}{\text{Population of city "i"}}$

TABLE 29. 1980 PERSON HOURS OF EXPOSURE TO CO IN FOUR CITIES

Concentration Exceeded ppm	Person Hours (Millions)			
	Chicago	Los Angeles	Philadelphia	St. Louis
60.0	0.000	0.000	0.036	0.000
50.0	0.000	0.000	0.038	0.000
40.0	0.118	0.389	0.068	0.104
35.0	0.262	0.742	0.103	0.136
30.0	1.000	3.840	0.319	0.205
25.0	2.530	10.000	1.030	0.424
20.0	8.270	41.100	3.640	1.850
15.0	28.500	124.000	8.240	6.510
12.0	62.400	251.000	19.600	13.900
9.0	163.000	837.000	59.300	46.300
7.0	350.000	1,830.000	132.000	104.000
6.0	515.000	2,960.000	207.000	156.000
5.0	846.000	5,720.000	391.000	290.000
4.0	1,368.000	9.284,000	759.000	579.000
3.0	2,501.000	16,500.000	1,520.000	1,340.000
2.0	5,662.000	34,200.000	4,400.000	3,460.000
1.5	9.064.000	48,100.000	7,050.000	5,190.000
1.0	13,843.000	53,300.000	9,870.000	7,550.000
0.5	18,868.000	64,800.000	17,100.000	9,670.000
0	20,700.000	67,600.000	25,700.000	10,700.000

The value used for each of the variables is shown in Table 30. When all the various factors are multiplied together, for each of the values of CO in Table 29, the equation becomes:

$$\begin{aligned} \text{National Person Hours} = & \left[21.051 \text{ (Chicago person hours)}\right] \\ & + \left[4.368 \text{ (Los Angeles person hours)}\right] \\ & + \left[9.963 \text{ (Philadelphia person hours)}\right] \\ & + \left[18.211 \text{ (St. Louis person hours)}\right] \end{aligned}$$

The nationwide Urban CO exposure distribution resulting from these calculations is presented in Table 31. Again, since the NEM CO study was conducted to study the effects of various levels of ambient CO standards, there is no table in the published NEM CO study comparable to Table 31.

TABLE 30. VALUES OF VARIABLES USED TO EXTRAPOLATE NEM EXPOSURE IN FOUR CITIES TO NATIONWIDE EXPOSURE

Variable	Value[a]
Total urban population >200,000 (1970)	103,137,849
Total urban population in 1970	118,447,000
Total population 1970	203,212,000
Total population 1980	226,505,000
Total population of Chicago (1970)	2,364,970
Total population of Chicago-like urban areas >200,000 (1970)	38,894,365
Total population of Los Angeles (1970)	7,719,108
Total population of Los Angeles-like urban areas >200,000 (1970)	26,339,249
Total population of Philadelphia (1970)	2,935,244
Total population of Philadelphia-like urban areas >200,000 (1970)	20,553,523
Total population of St. Louis (1970)	1,219,561
Total population of St. Louis-like urban areas >200,000 (1970)	17,350,712

[a] From References 33 and 57

TABLE 31. 1980 NATIONWIDE URBAN MOBILE SOURCE CO EXPOSURE FROM NEM

One Hour Average Concentration Exceeded (CO PPM)	Person Hours (Millions)
60.0	0.323
50.0	0.341
40.0	6.687
35.0	12.160
30.0	44.420
25.0	113.900
20.0	419.900
15.0	1,334.000
12.0	2,839.000
9.0	8,462.000
7.0	18,440.000
6.0	28,470.000
5.0	51,580.000
4.0	86,700.000
3.0	162,700.000
2.0	371,000.000
1.5	558,600.000
1.0	772,000.000
0.5	1,010,000.000
0.0	1,156,000.000

NEM Exposure Estimate for Mobile Sources

For the evaluation of unregulated pollutants, the person hour exposure distribution is needed in terms of $\mu g/m^3$ at a 1.0 g/min emission factor rather than in ppm CO. To convert Table 31 to the required distribution, the CO values are converted to $\mu g/m^3$ by multiplying by 1157, then adjusted to one gram/min by dividing by the 1980 FTP CO emission factor of 17.9 g/min (54.65 g/mile at 19.6 mph).[18] The nationwide person hour exposure distribution in $\mu g/m^3$ for a 1.0 g/min emission factor is presented in Table 32.

To properly combine the NEM results with the results from the parking garage, street canyons, and roadway tunnel, the total person hours represented by these three microenvironments must be subtracted from the NEM distribution.

Table 33 lists the person hours of exposure for each of the three microenvironments together with the total annual person hours of exposure for all three situations. Ideally, these person hours would be subtracted, in

TABLE 32. 1980 NEM NATIONWIDE URBAN EXPOSURE FOR MOBILE SOURCE POLLUTANTS

Mobile Source Pollutant Concentrations, $\mu g/m^3$ [a]	Person Hours from NEM (Millions)	NEM Person Hours Minus Microenvironment Person Hours (Millions)
0	1,156,000.000	1,144,424.000
32	1,010,000.000	999,886.000
65	772,000.000	764,269.000
97	558,600.000	553,006.000
129	371,000.000	367,285.000
194	162,700.000	161,071.000
259	86,700.000	85,832.000
323	51,580.000	51,063.000
387	28,470.000	28,184.000
452	18,440.000	18,255.000
582	8,462.000	8,377.300
776	2,839.000	2,810.600
970	1,334.000	1,320.600
1293	419.900	415.700
1616	113.900	112.760
1939	44.420	43.975
2262	12.160	12.038
2585	6.681	6.614
3232	0.341	0.338
3878	0.323	0.320

[a] For a 1.0 g/min emission factor

TABLE 33. TOTAL PERSON HOURS OF EXPOSURE IN PARKING GARAGE, STREET CANYON AND TUNNEL MICROENVIRONMENTS

Microenvironment	Yearly person hours of exposure (millions)
Parking Garage	1,520.380
Street Canyons	9,970.003
Tunnels	148.859
Total	11,576.240

the form of numbers of people, from the NEM A-O groups in the central city that would logically be in these microenvironments. The A-O groups would include: students over 18, professional and administrative, sales workers, and clerical workers. One method would be to have the NEM exposure concentrations set at zero for the number of persons involved in the three microenvironments. The total person hours could then be subtracted from 0 ppm in the NEM person hour distribution in Table 32. To do this the NEM "kitchen" microenvironment multiplicative factor would be set equal to zero, then, each hour, the number of people equal to those exposed to the three microenvironments would be assigned to the kitchen microenvironment. Since the ambient pollutant level would then be multiplied by zero, these people would be put in the interval containing zero ppm for that hour. Any persons presently assigned to the kitchen microenvironments would be reassigned to the "indoor-home" microenvironment, which has the same multiplicative factor as the kitchen has currently.

Unfortunately, the time and effort allotted to this study did not permit this adjustment to the A-O group population and activity patterns. A less exact, but more expeditious method of subtracting the required person hours from the NEM is to proportionally remove them from each of the NEM concentration intervals. If 20 percent of the total NEM person hours are in the interval between 65 and 97 $\mu g/m^3$, then 20 percent of the person hours to be subtracted would be taken from this interval. Using the total person hours in the three microenvironments as 11,576,240, the NEM exposure distribution was adjusted to give the exposure without the microenvironments. This adjusted exposure is also shown in Table 32.

VII. NATIONWIDE EXPOSURE TO MOBILE SOURCE POLLUTANTS

To obtain the total urban person hour exposure to mobile source pollutants, the microscale exposure distribution from Section V (Tables 19, 21 and 23) must be combined with NEM exposure distribution from Section VI (Table 32). It should again be emphasized that the exposure estimates for mobile sources in this report are based on CO. The use of these CO based exposures as surrogates for other mobile source pollutants must be approached with reasoned caution. While CO is probably the best surrogate to use on a national basis for a mobile source surrogate, especially for the NEM model, other mobile source pollutants may not have the same emission rates under the same vehicle operating conditions or chemical reactivity as CO (e.g., the spatial and temporal distributions may be different). Adjustments or corrections to these exposure estimates may be appropriate if the mobile source pollutant under study has characteristics which differ markedly from CO. However, in most intended uses of this methodology, a rough assessment of exposures to a mobile source pollutant which has not been adequately monitored in the ambient air is desired, and these estimates may be entirely adequate. Both the microscale exposures and the NEM exposure are for urban situations. The total nationwide exposure should contain rural exposure as well. Therefore, an estimate of rural mobile source exposure is required before a total nationwide exposure estimate can be made.

Rural Exposure

The urban exposure represented by the NEM and microscale models accounts for the exposure of approximately 132 million of the 226.5 million people in the country (1980 census).[33] The remaining 94.5 million people live in rural areas. In general, persons living in rural areas do not experience high concentrations of mobile source pollutants. To estimate the magnitude of rural exposure, CO was again used as the indication of mobile source emissions. Background levels of CO range from 0.03 to 0.22 ppm.[20] However, air masses that have recently traversed urban areas show levels as high as 1.0 ppm in rural areas.[20]

A detailed examination of rural exposure to mobile source pollutants was not part of the scope of this study. However, from the data presented above, it is estimated that all rural exposure to CO is below 2 ppm. Using the 1980 mobile source FTP emission factor for CO of 17.9 g/min, this 2 ppm CO converts to a mobile source exposure upper limit of 129 $\mu g/m^3$ at 1.0 g/min emission factor. For purposes of this study, it was assumed that 50 percent of the person hour exposure was between 0 and 32 $\mu g/m^3$, 30 percent between 32 and 65 $\mu g/m^3$, 15 percent between 65 and 97 $\mu g/m^3$, and 5 percent between 97 and 129 $\mu g/m^3$. For the 94.5 million people in rural areas, the person hour exposure distribution is then as shown in Table 34.

TABLE 34. 1980 RURAL EXPOSURE TO MOBILE SOURCE POLLUTANTS FOR ONE GRAM PER MINUTE EMISSION FACTOR

Concentration Exceeded μg/m³	Person Hours (Millions)
0	827,820.000
32	413,910.000
65	165,564.000
97	41,391.000
129	0.000

Total National Exposure

Since the rural exposure estimate and the NEM urban exposure estimate should always use the same mobile source emission factor, the two distributions can be combined as shown in Table 35. This table gives the

TABLE 35. 1980 TOTAL NATIONWIDE (URBAN AND RURAL) EXPOSURE TO MOBILE SOURCE POLLUTANTS EXCLUSIVE OF THREE MICROENVIRONMENTS FOR ONE GRAM PER MINUTE EMISSION FACTOR

Concentration Exceeded μg/m3(a)	Person Hours (Millions)
0	1,972,244.000
32	1,413,796.000
65	929,833.000
97	594,397.000
129	367,285.000
194	161,071.000
259	85,832.000
323	51,063.000
387	28,184.000
452	18,255.000
582	8,377.300
776	2,810.600
970	1,320.600
1293	415.700
1616	112.760
1939	43.975
2262	12.038
2585	6.614
3232	0.338
3878	0.320

nationwide (urban and rural) mobile source exposure distribution exclusive of the three mobile source microenvironments, for a one gram per minute emission factor. While it is possible to combine this distribution with the microenvironment distributions to produce a single exposure distribution for a 1.0 g/min emission factor, such a distribution would have little use. This is because the pollutant emission factors for each individual environment are different. Therefore, each individual exposure distribution must be multiplied by a different emission factor to obtain the exposure in that environment for a given pollutant.

Two different uses are examined for the exposure distributions developed from this project. The first use is to determine the person hours of exposure above a specified concentration of a specific pollutant. The second use is to develop new sets of exposure distribution tables for a specific pollutant. Ideally, a computer program should be written for both of these problems. However, the time and effort available for this project did not permit the development of the necessary computer program. The paragraphs that follow explain how to manually calculate the solutions to these problems.

Person Hours of Exposure above a Specific Concentration

The total nationwide annual person hours of exposure above a specified mobile source pollutant concentration can be calculated using Tables 19, 21, 23, and 35. The steps are as follows:

1. Divide the specified pollutant concentration, expressed in $\mu g/m^3$, by the 1980 FTP emission factor converted to grams/min for the pollutant being studied. This gives the concentration at a 1.0 g/min emission factor.

2. Enter Table 35, the urban and rural exposure, with the new concentration from Step 1. Read the person hours of exposure exceeding the concentration from the table; linearly interpolating between concentration values, if required.

3. For each of the three microenvironments, divide the specified pollutant concentration by the 1980 emission factor. The emission factor will probably be different for each different microenvironment.

4. Enter the appropriate Table for each of the microenvironments with the new pollutant concentration for each one of the microenvironments. Table 19 is used for parking garages, Table 21 for street canyons, and Table 23 for tunnels. From each of the tables obtain a value for person hours of exposure above the concentration. Interpolate, if necessary.

5. Add the four values of person hours of exposure together to obtain the nationwide number of person hours exposure to the pollutant above the specified concentration.

Tables of Exposure for a Specific Pollutant

Exposure tables showing person hours of exposure above given concentrations of a pollutant can be constructed for any mobile source pollutant for which emission factors are known, using Tables 19, 21, 23 and 35. In fact, for a given pollutant, a single exposure table can be constructed combining the urban plus rural exposure and the microenvironment exposures. The procedure is as follows:

1. For Tables 19, 21, 23, and 35, multiply each concentration reading in each table by the emission factor appropriate to the environment for which the individual table was constructed. This will produce four tables with four different sets of concentration values in terms of $\mu g/m^3$.

2. If units other than $\mu g/m^3$ are desired (for instance, ppm) multiply each concentration in the tables by the appropriate conversion factor at this time.

3. Choose a convenient set of concentration intervals that can be used for all tables. For each table, interpolate to find the person hours of exposure at the chosen concentration values. This will produce four tables with the same concentration values.

4. For each concentration value, add the person hours of exposure for each table to obtain a single table showing the nationwide person hours of exposure for the given pollutant.

VIII. CONCLUSIONS AND RECOMMENDATIONS

The goal of this project was to obtain nationwide annual person hours of exposure to any mobile source pollutant. This goal was accomplished within the appropriate limitations and caveats mentioned previously, including the caution which should be used when assessing pollutants with emissions distributions markedly different from CO. This goal was accomplished. Tables 19, 21, 23, and 35 should be used for this purpose, following the steps shown in Section VII. Additionally, as the result of the work done for this project, several important facts concerning the estimation of exposure to mobile source pollutants were revealed, prompting the conclusions and recommendations below.

Conclusions

Conclusions from this study are:

1. The results of NAAQS Exposure Model (NEM) study of CO exposure do not provide a sufficient estimation of mobile source pollutant exposure.

2. The NEM, with inputs modified from the published CO study inputs, and a mobile source microenvironment exposure model used together were able to provide a reasonable estimate of exposure to any mobile source pollutant.

3. The place specific approach used in the mobile source microscale exposure model developed for this project is an efficient and accurate method for exposure determination when only person hours of exposure is desired.

4. In mobile source microscale situations, CO concentrations are an excellent indicator of the number of vehicles present.

5. Neighborhood monitor concentrations will not adequately predict mobile source pollutant concentrations within microenvironments with a large number of mobile sources.

Recommendations

During the course of this study, a number of data deficiencies, methodology improvements, and needed additional work were identified. From these, a number of recommendations for future action have been developed.

1. To make the results of this study easier to use, a computer program should be written to provide a single, nationwide exposure distribution for any pollutant.

2. To improve the exposure estimates for the on-expressway situation, the number of people in the NEM A-O groups needs to be adjusted, as do the activity patterns of the groups.

3. On a longer range basis, the NEM computer program should be rewritten for nationwide mobile source exposure estimates. It should be structured to utilize a nationwide data base of CO monitor data for the mesoenvironments, as well as national populations. The time frame would be reduced to one quarter hour. Activity patterns would be adjusted to account for the various mobile source microenvironments. The exposure within the microenvironments themselves could possibly be part of the program.

4. Additional mobile source microenvironments need to be included in the exposure estimate. The two most significant areas needed are the personal garage and area sources, such as parking lots and trucking terminals.

5. The best estimate of on-expressway exposure would be obtained by removing this microenvironment from the NEM. It should be possible to identify some of the SAROAD data base monitors as beside expressway monitors. These monitors could be used to better estimate expressway exposure. The on-expressway situation could then be treated as any other microenvironment.

6. Additional measured CO data should be collected for parking garages and tunnels.

7. Additional data are needed on the range and average time of individual exposure periods for each of the microenvironments.

REFERENCES

1. Springer, K. J., and Ingalls, M.N., "Measurement of Sulfate and Sulfur Dioxide in Automobile Exhaust." Prepared for the Environmental Protection Agency under Contract No. 68-03-2118, EPA 460/3-76-015. August 1976.

2. Dietzmann, H. E., Smith, L. R., Parness, M. A., and Fanick, E. R., "Analytical Procedures for Characterizing Unregulated Pollutant Emissions from Motor Vehicles." Interim Report under Contract No. 68-02-2497 to the Environmental Protection Agency, Publication No. EPA 600/2-79-017, February 1979.

3. Smith L. R., Parness, M. A., Fanick, E. R., and Dietzmann, H. E., "Analytical Procedures for Characterizing Unregulated Emissions from Vehicles Using Middle-Distillate Fuels." Interim Report to the Environmental Protection Agency under Contract No. 68-02-2497, Report No. EPA 600/2-80-068, April 1980.

4. Springer, K. J., "Investigation of Diesel-Powered Vehicle Emissions VII." Final Report to the Environmental Protection Agency under Contract 68-03-2116, EPA 460/3-76-034, February 1977.

5. Springer, K. J., "Characterization of Sulfates, Odor, Smoke, POM, and Particulates from Light and Heavy Duty Engines - Part IX." Final Report to the Environmental Protection Agency under Contract No. 68-03-2417, EPA 460/3-79-007, June 1979.

6. Hare, C. T., "Characterization of Gaseous and Particulate Emissions from Light-Duty Diesels Operated on Various Fuels." Final Report to the Environmental Protection Agency under Contract 68-03-2440, EPA 460/3-79-008, July 1979.

7. Smith, L. R., "Characterization of Exhaust Emissions from High Mileage Catalyst-Equipped Automobiles." Final Report to Environmental Protection Agency under Contract 68-03-2884, Task Specifications 7 and 10, EPA 460/3-81-024, September 1981.

8. Smith, L. R., "Unregulated Emissions for Vehicles Operated under Low Speed Conditions." Final Report to the Environmental Protection Agency under Contract 68-03-3073, Work Assignment 4, EPA 460/3-83-006, May 1983.

9. Urban, C. M., "Regulated and Unregulated Exhaust Emission from Malfunctioning Non-Catalyst and Oxidation Catalyst Gasoline Automobiles." Final Report to the Environmental Protection Agency under Contract No. 68-03-2499. Report No. EPA 460/3-80-003, January 1980.

10. Urban, C. M., "Regulated and Unregulated Exhaust Emissions from Malfunctioning Three-way Catalyst Gaseoline Automobiles." Final Report to the Environmental Protection Agency under Contract 68-03-2588, Report No. EPA 460/3-80-004, January 1980.

11. Urban, C. M., "Regulated and Unregulated Exhaust Emissions from A Malfunctioning Three-Way Catalyst Gasoline Automobile." Final Report to the Environmental Protection Agency under Contract 68-03-2692. Report No. EPA 460/3-80-005, January 1980.

12. Urban, C. M., "Unregulated Exhaust Emissions from Non-Catalyst Baseline Cars Under Malfunction Conditions." Final Report to Environmental Protection Agency under Contract 68-03-2884, Task Specifications 4 and 5. Report No. EPA 460/3-81-020, May 1981.

13. Hare, C. T., "Characterization of Gaseous and Particulate Emissions from Light-Duty Diesels Operated on Various Fuels." Final Report to the Environmental Protection Agency under Contract 68-03-2440, EPA 460/3-79-008, July 1979.

14. Ullman, T. L., and Hare, C. T., "Emission Characterization of an Alcohol/Diesel-Pilot Fueled Compression-Ignition Engine and Its Heavy-Duty Diesel Counterpart." Final Report to Environmental Protection Agency under Contract 68-03-2884, Task Specification 6. Report No. EPA 460/3-81-023, August 1981.

15. Bykowski, B. B., "Characterization of Diesel Emissions from Operation of a Light-Duty Diesel Vehicle on Alternate Source Diesel Fuels." Final Report to the Environmental Protection Agency under Contract 68-03-2884, Task Specification 3, Report No. EPA 460/3-82-002, November 1981.

16. Ullman, T. L., and Hare, C. T., "Emission Characterization of a Spark-Ignited, Heavy-Duty, Direct-Injected Methanol Engine." Final Report to the Enviornmental Protection Agency under Contract 68-03-3073, Work Assignment 2, Report No. EPA 460/3-83-003, November 1982.

17. Smith, L. R., Urban. C. R., and Baines, T. M., "Characterization of Exhuast Emissions from Methanol- and Gasoline-Fueled Automobiles." Final Report to Environmental Protection Agency under Contracts 68-03-2884 and 68-03-3073, Task Specifications 11 and 12, and Work Assignments 1 and 3, Report EPA 460/3-82-004, August 1982.

18. Ingalls, M. N., "Estimating Mobile Source Pollutants in Microscale Exposure Situation." Final Report to Environmental Protection Agency under Contract 68-03-2884, Task Specification 1. Report No. EPA 460/3-81-021, July 1981.

REFERENCES (Cont'd).

19. Harvey, C. A., et al "A Study of the Potential Impact of Some Unregulated Motor Vehicle Emissions." SAE Paper 830937 to be presented at the 1983 SAE Passenger Car Meeting, Dearborn, Michigan, June 1983.

20. "Carbon Monoxide", National Research Council, Committee on Medical and Biologic Effect of Environmental Pollutants, National Academy of Sciences, Washington, D.C., 1977.

21. "Compilation of Air Pollutant Emission Factors: Highway Mobile Sources" EPA 460/3-81-005, dated March 1981, U.S., EPA, Office of Mobile Source Air Pollution Control, Emission Control Technology Division, Ann Arbor, Michigan.

22. Larsen, R. I., "A New Mathematical Model of Air Pollutant Concentration Averaging Time and Frequency." Journal of the Air Pollution Control Association, Vol. 19, No. 1, January 1969.

23. Larsen, R. I., "A Mathematical Model for Relating Air Quality Measurements to Air Quality Standards," AP-89, Environmental Protection Agency, Research Triangle Park, N.C., November 1971.

24. Mage, D. T., and Ott, W. E., "Refinements of the Lognormal Probability Model for Analysis of Aerometric Data," APCA Journal Vol. 28, No. 8, August 1978.

25. Johnson, T., "A Comparison of the Two-Parameter Weibull and Lognormal Distributions Fitted to Ambient Ozone Data." Proc. of Specialty Conference on Quality Assurance in Air Pollution Measurement, Air Pollution Control Association, 1979.

26. Aitchison, J., and Brown, J.A.C., The Lognormal Distribution, Cambridge University Press, New Youk, 1957.

27. Hama, G. M., et al, "Air Flow Requirement for Underground Parking Garages," American Industrial Hygiene Journal, December 1961, pp 462-470.

28. Barker, I. W., and Fox, M. F., "Vehicular Pollution in Car Parks," Royal Society of Health Hournal, Vol. 96.

29. Glazer, N., "The Regulation and Control of Carbon Monoxide in Enclosed Parking Garages." APCA Paper 78-4.6, presented at the 71st Annual Meeting of APCA, June 1978.

30. Ayres & Hayakawa, Consulting Engineers, "Project Program Plan and Statement of Probable Costs. Music Center and Mall Garages. Phase I and III." Submitted to County and Los Angeles for Capitol Projects No. 7085.09, 7065.21 amd 7065.22, May 1975.

31. Mage, D. T., "Frequency Distributions of Hourly Wind Speed Measurements," Atmospheric Environment, Vol. 14, pp 367-374, 1980.

32. "Airport Climatological Summary." Climatography of United States No. 90, for various airports. National Climatic Center, National Oceanic and Atmospheric Administration, Asheville, N.C.

33. Johnson, T., and Paul, R. A., "The NAAQS Exposure Model (NEM) Applied to Carbon Monoxide." Draft Final Report by PEDCo Environmental, Inc. for EPA, Contract 68-02-3390, Work Assignments 13 and 16, April 12, 1982.

34. Brice, R. M., and Roesler, J. F., "The Exposure to Carbon Monoxide of Occupants of Vehicles Moving in Heavy Traffic." JAPCA Vol. 16, No. 11, November 1966.

35. Peterson, G. A., and Sabersky, "Measurement of Pollutants Inside an Automobile", JAPCA, Vol. 25, No. 10, October 1975.

36. Chaney, L. W., "Carbon Monoxide Automobile Emissions Measured from the Interior of a Traveling Automobile." Science, Vol. 199, 17 March 1978.

37. Colwill, D. M., and Hickman, A. J., "Exposure of Drivers to Carbon Monoxide," JAPCA, Vol. 30, No. 12, December 1980.

38. Peterson, W. B., and Allen, R., "Carbon Monoxide Exposures to Los Angeles Area Commuters," JAPCA, Vol. 32, No. 8, August 1982.

39. Rodgers, S. J., et al, "Tunnel Ventilation and Air Pollution Treatment," Prepared for FHWA, Office of Research by Mine Safety Appliance Research Crop. Report FHWA-RD-72-15, NTIS No. PB210-360, June 30, 1970.

40. "Study of Air Pollution Aspects of Various Roadway Configurations," Final Report to the New York City Department of Air Resources under Contract 209624 by the General Electric Company, 3198 Chestnut Street, Philadepphia, PA., dated September 1, 1971.

41. Sosslau, A. B., and Hassom, A. B., "Quick-Repsonse Urban Travel Estimation Techniques and Transferrable Parameters," National Cooperative Highway Research Program Report 187. Transportation Research Board, National Research Council, Washington, D.C., 1978.

42. "Short-Range Urban Transit Study, San Antonio, Texas," prepared for the San Antonio Transit System and City of San Antonio by Wilbur Smith and Associates, Houston, Texas, 1972.

43. Thayer, S. D., "Vehicle Behavior In and Around Complex Sources and Related Complex Sources Characteristics, Vol IV--Parking Facilities," Final Report prepared by Geomet, Inc., Rockville, MD, under Contract No. 68-02-1094 Task Orders to the U.S. Environmental Protection Agency, Research Triangle Park, N.C., Publication No. EPA-460/3-74-003d, October 1973.

44. Forrest, L. "Assessment of Environmental Impacts of Light Duty Vehicle Dieselization," Aerospace Report No. ATR-79(7740)-1. Draft Final Report by Aerospace Corporation under Contract DOT-TSC-1530, March 1979.

45. Homburger, W. S., editor, Transportation and Traffic Engineering Handbook, second edition, Prentice Hall, Inc. Englewood Cliffs, N.J.

46. "Highway Capacity Manual," Highway Research Board Special Report 87. Highway Research Board, National Research Council, Washington, D.C. 1965.

47. Matson, T. M., Smith, W. S., and Hurd, F. W., Traffic Engineering, McGraw-Hill Book Company, Inc., New York, N.Y., 1955.

48. Curtin, J. F., "Traffic-Transit-Parking in Downtown Rochester: How to 1975." Contained in Highway Research Board Bulletin 293, Highway Research Board, National Research Council, 1961.

49. "San Antonio-Bexar County Urban Transportation Study Report 6A and 6B - Origin-Destination Survey 1969," Texas Highway Department, Austin, Texas.

50. Pushkarev, B. and Zupan, J. "Pedestrian Travel Demand," Highway Research Record No. 355, Highway Research Board, National Academy of Sciences, Washington, D.C., 1971.

51. Cameron, R. M., "Mechanical Measurements of Pedestrian Volumes." Transportation Research Record No. 498. Transportation Research Board, National Academy of Sciences, Washington, D.C., 1974.

52. Rutherford, G. S., and Schofer, J. L., "Analysis of Some Characteristics of Pedestrian Travel," Transportation Research Record No. 605. Transportation Research Board, National Academy of Sciences, Washington, D.C., 1976.

53. Teague, D. M., "Los Angeles Traffic Pattern Survey" SAE Paper 171 published in "Vehicle Emissions, Part I", SAE Progress in Technology Series, Vol. 6, Society of Automotive Engineers, Inc. pp 17-38, 1964.

54. Kruse, R. E., and Huls, L. A., "Development of the Federal Urban Driving Schedule," SAE Paper 730553 presented at Detroit, MI, Society of Automotive Engineer, Warrensdale, PA, May 1973.

55. Papette, B. and Horowitz, J. "Stochastic Model of Worst Case Exposures to Sulfuric Acid from Catalyst-Equipped Vehicles." U.S. Enviornmental Protection Agency in-house (unpublished) report, November 1975.

56. Schlaug, R. N., and Carlin, T. J., "Aerodynamics and Air Quality Management of Highway Tunnels." Final Report for Contract DOT-FH-11-8538 to Science Applications, Inc. Report FHWA-RD-78-185, January 1980.

57. Johnson, T., and Paul, R. A., "The NAAQS Model (NEM) Applied to Carbon Monoxide." Draft Final Report by PEDCo Environmental, Inc. for EPA Contract 68-02-3390, Work Assignments 13 and 16, December 1982.

58. Meyer, J.R., Kain, J.F., and Wohl, M., The Urban Transportation Problem. Harvard University Press, Cambridge, MA., 1965.

APPENDIX A

Development of Lognormal Pollutant Distributions for Parking Garages and Roadway Tunnels

The Lognormal Distribution

The lognormal distribution has historically been used to describe ambient air concentration distributions. For areas where the pollutant concentration distribution is not completely defined by measured values, but values such as the mean, median, mode or range are known, the properties of the lognormal distribution can be used to define the complete pollutant distribution.

The lognormal distribution is defined as:(1)

$$df(x) = \left(\frac{1}{X\sigma\sqrt{2\pi}}\right) \exp\left[-\frac{1}{2\sigma^2}\left(\ln X - \mu\right)^2\right] dx$$

Obviously, if σ and μ are known, the distribution can be defined for any value of X.

Additionally for a lognormal distribution:(1)

$$\text{Mean, } \bar{X} = e\ (\mu + 1/2\ \sigma^2)$$

$$\text{Median} = e^{\mu}$$
$$\text{Mode} = e^{\mu-\sigma}$$

The coefficient of variation n, defined as the standard deviation divided by the mean is:

$$n = \frac{S}{\bar{X}} = \sqrt{e^{\sigma^2} - 1}$$

For the parking garage, the concentration distributions were developed by using a CO concentration value known to be typical of parking garages as the distribution mode, then adjusting the median so that the frequency of occurence in the 300 to 400 ppm CO range was 0.01 percent. If the median and mode are known, then μ and σ are solved for as follows:

$$\ln(\text{median}) = \ln(e^{\mu})$$

$$\mu = \ln(\text{median})$$

$$\ln(\text{mode}) = \ln(e^{\mu-\sigma^2})$$

$$\mu - \sigma^2 = \ln(\text{mode})$$

$$\sigma = \sqrt{\ln(\text{mode}) - \mu}$$

With μ and σ defined, the entire lognormal distirbution can be defined.

For roadway tunnels a slightly different approach was used. The measured data on concentrations in roadway tunnels produced a mean value and a maximum value of CO concentration as a function of average daily traffic (ADT).

Using the proper CO emission factor, these CO levels were converted to pollutant concentrations for a 1.0 g/minute emission factor (see text). The CO concentrations and pollutant concentrations at 1.0 g/minute for several ADT values are shown in the table below.

			Pollutant Concentration, $\mu g/m^3$ at 1.0 g/min[a]	
ADT	Mean	Max.	Mean	Max.
0.5	5.2	66.7	166.2	2131.8
1.5	14.3	94.4	457.0	3017.2
2.5	23.4	122.1	747.9	3902.5
3.5	32.5	149.8	1038.7	4787.8
4.5	41.6	177.4	1329.6	5669.9
5.5	50.7	205.1	1620.4	6555.3
6.5	59.9	232.8	1914.5	7440.6

[a] based on a CO emission factor of 62.06 g/mile at 35 mph

Assuming that the pollutant concentration is lognormally distributed, the problem is to define the distribution for each value of ADT, given only the mean and maximum concentrations. Note that if the minimum concentration is assumed to be 0 then the range (maximum - minimum) is also known. The expression for the mean of a lognormal distribution is shown above. It can also be shown that the standard deviation, S, can be approximated by the following relationship, assuming that the range available is the result of a large number of observations[2]

$$S = \frac{\text{range}}{6.5}$$

Thus the standard deviation for the tunnel distribution can be estimated from the range. If the standard deviation and mean are known the coefficient of variation is known and σ can be obtained as follows:

$$n = \left(\frac{\frac{\text{range}}{6.5}}{\overline{X}} \right) = \sqrt{e^{\sigma^2} - 1}$$

$$n^2 = e^{\sigma^2} - 1$$

$$e^{\sigma^2} = n^2 + 1$$

$$\sigma^2 = \ln (n^2 + 1)$$

$$\sigma = \sqrt{\ln (n^2 + 1)}$$

Once σ is known, μ can be obtained from the equation for the mean:

$$\bar{X} = e^{(\mu + 1/2\ \sigma^2)}$$

$$\mu + 1/2\ \sigma^2 = \ln \bar{X}$$

$$\mu = \ln \bar{X} - 1/2\ \sigma^2$$

With both μ and σ known the distribution is fully defined. The table below shows the μ and σ for the tunnel pollutant concentration distributions at seven different values of ADT.

ADT	range (max-min)	std. dev. $S = \frac{\text{range}}{6.5}$	mean $= \bar{X}$	$\eta = \frac{S}{\bar{X}}$	σ	μ
0.5	2131.8	327.97	166.2	1.97	1.26	4.32
1.5	2017.2	464.18	457.0	1.02	0.84	5.77
2.5	3902.5	600.38	747.0	0.80	0.71	6.37
3.5	4787.8	736.58	1038.7	0.71	0.64	6.74
4.5	5660.0	872.29	1329.6	0.66	0.60	7.01
5.5	6555.3	1008.51	1620.4	0.62	0.57	7.23
6.5	7440.6	1144.71	1914.5	0.60	0.55	7.40

References:

1. Aitchison, J. and Brown, J.A.C., The Lognormal Distribution, Cambridge University Press, New York, 1957.

2. Sokal, R. and Rohof, T.J., Biometry, W. H. Freeman and Co., 1981,

APPENDIX B

Fortran Listing of SAROAD File Editing Program for Street Canyon Monitors (written for CDC Cyber 173)

```
      GO TO 75
  190 PRINT 2040, ISTA(K),IMON(K),IDAY(K)
  200 GO TO 75
  220 PRINT 2050, ISTA(1),IMON(1),IDAY(1),IMON(2),IDAY(2),ISTA(2)
      CALL DUMREC( DUM,IDUML,IDUM4,K)
      K=1
      WRITE(2,3000)  NAR1(K),ISTA(K),NAR2(K),NAR3(K),IMON(K),IDAY(K),
     1           IDUML,IDUM4,ITYPE(K),IUNT(K),IDEC(K),(DUM(M),M=1,12)
       NAR1(1)=NAR1(2)
      NAR2(1)=NAR2(2)
      NAR3(1)=NAR3(2)
      NAR4(1)=NAR4(2)
      IMON(1)=IMON(2)
      IDAY(1)=IDAY(2)
      ITYPE(1)=ITYPE(2)
      ISTA(1)=ISTA(2)
      IUNT(1)=IUNT(2)
      IDEC(1)=IDEC(2)
      ILINE(1)=ILINE(2)
      DO 225 M=1,12
  225 RDG(M,1)=RDG(M,2)
      I=IMON(K)
      J=IDAY(K)
      GO TO 70
 1000 FORMAT(I3,I7,A3,I3,I2,I2,I1,I6,I2,I2,I1,12F4.0)
 2000 FORMAT(1X,"FOR STATION ",I7," SOMETHING IS WRONG AT ",I2,"/",I2,
     1         "LINE 2")
 2010 FORMAT(1X,"FOR STATION ",I7," DATA IS MISSING FOR MONTH ",I2,
     1         ". NEXT MONTH WITH DATA IS MONTH ",I2)
 2020 FORMAT(1X,"FOR STATION ",I7," DATA IS MISSING FOR MONTH ",I2,
     1         " DAY ",I2,".  NEXT DAY WITH DATA IS DAY " I2)
 2030 FORMAT(1X,"FOR STATION ",I7," THERE IS NO FIRST LINE OF DATA FOR "
     1         ,I2,"/",I2)
 2040 FORMAT(1X,"FOR STATION ",I7," SOMETHING IS WRONG AT ",I2,"/",I2,
     1         "LINE 1")
 2050 FORMAT(1X,"FOR STATION ",I7," THERE IS NO SECOND LINE OF DATA FOR"
     1         1X,I2,"/"I2,".  NEXT DATA IS ",I2,"/",I2," STATION ",I7)
 3000 FORMAT(I3,I7,A3,I3,I2,I2,I1,I6,I2,I2,I1,12F4.1)
  999 STOP
      END
      SUBROUTINE DAYWEK(IMON,IDAY,ITYPE)
      COMMON/SATDA /ISAT(52)/SUNDA /ISUN(52)
      IDATE =(IMON   *100) + IDAY
      ITYPE    = 1
      DO 100 L = 1,52
      IF(IDATE.EQ.ISAT(L)) ITYPE    = 2
      IF(IDATE.EQ.ISUN(L)) ITYPE    = 3
  100 CONTINUE
      RETURN
      END
      SUBROUTINE DUMREC( DUM,IDUML,IDUM4,K)
      DIMENSION  DUM(12)
      DO 200 I= 1,12
       DUM(I) = 99.9
  200 CONTINUE
      IF(K.EQ.1) IDUML = 0
```

```
      PROGRAM EDTEPA(INPUT,OUTPUT,EDDAT,TAPE2=EDDAT,TAPE60=INPUT)
      DIMENSION  IMON(2),IDAY(2),ILINE(2),ITYPE(2), RDG(12,2),IUNT(2)
      DIMENSION  NAR1(2),NAR2(2),NAR3(2),NAR4(2),ISTA(2),DUM(12),IDEC(2)
      ISTA(2) =   1960085
      I=1
      J=1
      K=1
   50 READ 1000,NAR1(K),ISTA(K),NAR2(K),NAR3(K),IMON(K),IDAY(K),
     1ILINE(K), NAR4(K),ITYPE(K),IUNT(K),IDEC(K),(RDG(M,K),M=1,12)
      IF(EOF(60))999,55
   55 CONTINUE
      IF(IDEC(K).NE.1) GO TO 57
      DO 56 L=1,12
   56 RDG(L,K)= RDG(L,K)/10.
   57 IF(IUNT(K).NE.05) GO TO 59
      DO 58 L=1,12
   58 RDG(L,K)= RDG(L,K)/1.15
   59 IF(ISTA(2).EQ.ISTA(1)) GO TO 60
       IF(K.EQ.2) GO TO 220
      I=1
      J=1
      K=1
   60 CONTINUE
      IF(K.NE.1) GO TO 100
      IF(IMON(1).NE.I) GO TO 150
   65 IF(IDAY(1).NE.J) GO TO 170
   70 IF(ILINE(1).NE.0)GO TO 180
      CALL DAYWEK(IMON(K),IDAY(K),ITYPE(K))
   75 WRITE(2,3000) NAR1(K),ISTA(K),NAR2(K),NAR3(K),IMON(K),IDAY(K),
     1      ILINE(K),NAR4(K),ITYPE(K),IUNT(K),IDEC(K),(RDG(M,K),M=1,12)
      IF(ILINE(K).EQ.0)K=2
      GO TO 50
  100 IF(IMON(2).NE.IMON(1).OR.IDAY(2).NE.IDAY(1)) GO TO 220
      IF(ILINE(2).EQ.1) GO TO 110
      PRINT 2000 , ISTA(K),IMON(K),IDAY(K)
  110 CALL DAYWEK(IMON(K),IDAY(K),ITYPE(K))
      WRITE(2,3000) NAR1(K),ISTA(K),NAR2(K),NAR3(K),IMON(K),IDAY(K),
     1      ILINE(K),NAR4(K),ITYPE(K),IUNT(K),IDEC(K),(RDG(M,K),M=1,12)
      J= J+1
      IF(J.LT.32) GO TO 120
      I=I+1
      J=1
  120 K=1
      GO TO 50
  150 PRINT 2010, ISTA(K), I, IMON(K)
      I=IMON(K)
      J=1
      GO TO 65
  170 PRINT 2020, ISTA(K),I,J,IDAY(K)
      J=IDAY(K)
      GO TO 70
C**** IF THERE IS NO FIRST LINE OF DATA
  180 PRINT 2030, ISTA(K),IMON(K),IDAY(K)
      IF(ILINE(K).NE.1) GO TO 190
      CALL DUMREC( DUM,IDUML,IDUM4,K)
      CALL DAYWEK(IMON(K),IDAY(K),ITYPE(K))
      WRITE(2,3000)  NAR1(K),ISTA(K),NAR2(K),NAR3(K),IMON(K),IDAY(K),
     1        IDUML,IDUM4,ITYPE(K),IUNT(K),IDEC(K),(DUM(M),M=1,12)
      J=J+1
```

```
      IF(K.EQ.1) IDUM4 = 042101
      IF(K.EQ.2) IDUML = 1
      IF(K.EQ.2) IDUM4 = 242101
      RETURN
      END
      BLOCK DATA  SATDATE
      COMMON/SATDA/ISAT(52)
      DATA (ISAT(I),I=1,52)/
     1         0103,0110,0117,0124,0131,0207,0214,
     2         0221,0228,0307,0314,0321,0328,0404,
     3         0411,0418,0425,0502,0509,0516,0523,
     4         0530,0606,0613,0620,0627,0704,0711,
     5         0718,0725,0801,0808,0815,0822,0829,
     6         0905,0912,0919,0926,1003,1010,1017,
     7         1024,1031,1107,1114,1121,1128,1205,
     8         1212,1219,1226/
      END
      BLOCK DATA SUNDATE
      COMMON/SUNDA/ISUN(52)
      DATA (ISUN(I),I=1,52)/
     1         0104,0111,0118,0125,0201,0208,0215,
     2         0222,0301,0308,0315,0322,0329,0405,
     3         0412,0419,0426,0503,0510,0517,0524,
     4         0531,0607,0614,0621,0628,0705,0712,
     5         0719,0726,0802,0809,0816,0823,0830,
     6         0906,0913,0920,0927,1004,1011,1018,
     7         1025,1101,1108,1115,1122,1129,1206,
     8         1213,1220,1227/
      END
```

APPENDIX C

Fortran Listing of Microenvironment Exposure
Model for Parking Garages
(written for CDC Cyber 173)

```
      PROGRAM PHDIST(INPUT,OUTPUT)
       REAL NPC
      COMMON/POP/  P(24,5) /CONC / FRAC(23,9)
      DIMENSION  R(2),FTT(3),SUM(23),ICON1(23),ICON2(23),ITITLE(8),X(23)
      DATA ICON1 /0,361,464,619,774,1031,1289,1547,1805,2062,2320,2578,
     1            3001,4001,5001,6001,8001,10001,15001,20001,25001,
     2            30001,40001/
      DATA ICON2 /360,463,618,773,1030,1288,1546,1804,2061,2319,2577,
     1            3000,4000,5000,6000,8000,10000,15000,20000,25000,
     2            30000,40000,50000/
C**** READ INPUT VALUES
      READ 1000, ITITLE
      READ * , TOTCAR
C****
      DO 50 I=1,23
      SUM(I)=0.0
   50 CONTINUE
      DO 900 JDAY = 1,5
      GO TO ( 100,120,140,145,150) JDAY
C***  JDAY=1 IS WEEKDAYS
  100 H=248
      NPC=1.4
      GO TO 160
C***  JDAY=2 IS SAT. + SOME HOLIDAYS
  120 H=62
      NPC=2.3
      GO TO 160
C*    JDAY=3 IS SUN. + 3 HOLIDAYS
  140 H=55
      NPC=2.3
      GO TO 160
C**** JDAYS= 4 IS FOR WORKER RELATED PEAK HOUR
  145 H= 248.
      NPC=1.4
      TOTCAR=.25*TOTCAR
      GO TO 160
C**** JDAYS= 5 IS FOR ENTERTAINMENT RELATED PEAK
  150 H= 62
      NPC=2.3
  160 CONTINUE
      DO 800 IHR= 1,24
      PTC=1.0
      IF(JDAY.EQ.1.AND.IHR.EQ.17) PTC=0.75
      IF(JDAY.EQ.3.AND.IHR.EQ.22) PTC=0.75
      IF(JDAY.GT.3.AND.IHR.GT.1) GO TO 800
  170 IF(JDAY.LE.3) GO TO 180
      N=7
      GO TO 240
  180 IF((P(IHR,JDAY)/12.).GT.6) GO TO 200
      N=1
      GO TO 240
  200 IF((P(IHR,JDAY)/12.).GT.14) GO TO 220
      N=4
      GO TO 240
  220 N=7
  240 CONTINUE
      M=N+2
```

```
      DO 700 LWS = N,M
      IF(LWS.EQ.N)   WF=0.095
      IF(LWS.EQ.N+1) WF=0.65
      IF(LWS.EQ.N+2) WF=0.255
      DO 600 KCON = 1,23
      SUM(KCON) = SUM(KCON) + (FRAC(KCON,LWS) *PTC* TOTCAR*(P(IHR,JDAY)
     1          /4.)    *NPC * H * WF)
  600 CONTINUE
  700 CONTINUE
  800 CONTINUE
  900 CONTINUE
      PRINT 2000 , ITITLE
      DO  940  I= 1,23
  940 PRINT 2010 ,ICON1(I),ICON2(I),SUM(I)
      X(23)=SUM(23)/1E6
      DO 960 I=2,23
      J=I-1
      X(24-I)=X(24-J)+(SUM(24-I)/1E6)
  960 CONTINUE
      PRINT 2020,ITITLE
        PRINT 2040,ICON1(1),X(1)
      DO 980 I=2,23
  980 PRINT 2040,ICON2(I-1),X(I)
 2020 FORMAT(1H1,//,26X,8A10,////,17X,*CONCENTRATION EXCEEDED*,
     1       5X,*PERSON HOURS*,/)
 2040 FORMAT(20X,6X,I5,5X,10X,F9.3)
 1000 FORMAT (8A10)
 2000 FORMAT (1H1,//,26X,8A10,////,17X,*CONCENTRATION INTERVAL*,
     1            5X,*PERSON HOURS*,/)
 2010 FORMAT (20X,I5,*  TO  *,I5,10X,F11.0)
  999 STOP
      END
```

```
              BLOCK DATA CONCEN
              COMMON/CONC/PGFRAC(23,9)
C***          ORDER OF DATA IS  3 PCT,FOR 1.5,7,14 KTS WIND,THEN 9 + 19 PCT.
              DATA((PGFRAC(I,J),J=1,9),I=1,11)/
             A .000,  .148,  .566,  .000,  .005,  .044,  .000,  .000,  .003,
             B .000,  .120,  .157,  .000,  .005,  .054,  .000,  .000,  .004,
             C .002,  .180,  .138,  .000,  .018,  .110,  .000,  .000,  .013,
             D .005,  .150,  .068,  .000,  .031,  .121,  .000,  .001,  .025,
             E .020,  .170,  .047,  .000,  .076,  .185,  .000,  .006,  .066,
             F .037,  .097,  .016,  .000,  .096,  .143,  .000,  .013,  .089,
             G .052,  .053,  .005,  .001,  .102,  .102,  .000,  .022,  .098,
             H .063,  .030,  .002,  .002,  .097,  .071,  .000,  .030,  .097,
             I .069,  .017,  .000,  .003,  .088,  .049,  .000,  .037,  .090,
             J .071,  .010,  .000,  .004,  .077,  .034,  .000,  .043,  .084,
             K .070,  .006,  .000,  .006,  .066,  .023,  .000,  .047,  .070/
              DATA((PGFRAC(I,J),J=1,9),I=12,23)/
             L .107,  .005,  .000,  .013,  .087,  .024,  .000,  .080,  .093,
             M .197,  .005,  .000,  .040,  .127,  .027,  .003,  .184,  .137,
             N .123,  .001,  .000,  .070,  .061,  .007,  .006,  .151,  .067,
             O .073,  .000,  .000,  .081,  .030,  .002,  .011,  .112,  .033,
             P .069,  .000,  .000,  .168,  .024,  .001,  .040,  .137,  .026,
             Q .024,  .000,  .000,  .147,  .007,  .000,  .061,  .067,  .007,
             R .015,  .000,  .000,  .241,  .003,  .000,  .201,  .057,  .004,
             S .001,  .000,  .000,  .113,  .000,  .000,  .193,  .011,  .000,
             T .000,  .000,  .000,  .054,  .000,  .000,  .149,  .003,  .000,
             U .000,  .000,  .000,  .025,  .000,  .000,  .106,  .000,  .000,
             V .000,  .000,  .000,  .021,  .000,  .000,  .123,  .000,  .000,
             W .000,  .000,  .000,  .006,  .000,  .000,  .058,  .000,  .000/
              END
```

```
             BLO K DATA POPPG
             COMMON/POP/PGP(24,5)
       C***  DATA ORDER IS  WEEKDAY, SAT., SUN
             DATA ((PGP(I,J),J=1,5),I=1,12)/
            A          .0000, .0000, .0000, 0.750, 0.750,          M TO 1
            B          .0000, .0000, .0000, 0.000, 0.000,          1 TO 2
            C          .0000, .0000, .0000,  .000,  .000,          2 TO 3
            D          .0000, .0000, .0000,  .000,  .000,          3 TO 4
            E          .0000, .0000, .0000,  .000,  .000,          4 TO 5
            F          .0000, .0000, .0000,  .000,  .000,          5 TO 6
            G          .0099, .0040, .0000,  .000,  .000,          6 TO 7
            H          .0693, .0060, .0125,  .000,  .000,          7 TO 8
            I          .1284, .0340, .0375,  .000,  .000,          8 TO 9
            J          .1943, .0600, .0500,  .000,  .000,          9 TO 10
            K          .2134, .0820, .0500,  .000,  .000,         10 TO 11
            L          .1750, .1060, .0500,  .000,  .000/         11 TO 12
             DATA ((PGP(I,J),J=1,5),I=12,24)/
            M          .1729, .1340, .0500,  .000,  .000,         12 TO 13
            N          .1819, .1610, .0500,  .000,  .000,         13 TO 14
            O          .1678, .1800, .0500,  .000,  .000,         14 TO 15
            P          .1902, .1930, .0500,  .000,  .000,         15 TO 16
            Q          .1960, .1980, .0375,  .000,  .000,         16 TO 17
            R          .1836, .2000, .0125,  .000,  .000,         17 TO 18
            S          .1033, .2000, .0000,  .000,  .000,         18 TO 19
            T          .0829, .1980, .0000,  .000,  .000,         19 TO 20
            U          .0723, .1750, .0000,  .000,  .000,         20 TO 21
            V          .0409, .1200, .0000,  .000,  .000,         21 TO 22
            W          .0449, .0540, .0000,  .000,  .000,         22 TO 23
            X          .0251, .0000, .0000,  .000,  .000/         23 TO 24
             END
```

APPENDIX D

Fortran Listing of Microenvironment Exposure Model for Street Canyons (written for CDC Cyber 173)

```
      PROGRAM SCDIST(INPUT,OUTPUT)
      COMMON/SPOP/  P(24,6) /SCONC / FRAC(19,6,3)
      DIMENSION  TOTP(3),TOTPD(3),SUM(19),ICON1(19),ICON2(19),ITITLE(8),
     1           X(19)
      DATA ICON1 /0,36,106,176,246,316,387,457,527,597,667,737,807,877,
     1            948,1088,1298,1509,1719/
      DATA ICON2 /35,105,175,245,315,386,456,526,596,666,736,806,876,
     1       947,   1087,1297,1508,1718,2069/
C**** READ INPUT VALUES
      READ 1000, ITITLE
      READ * ,(TOTP(I),I=1,3),(TOTPD(I),I=1,3)
C****
      DO 50 I=1,19
      SUM(I)=0.0
   50 CONTINUE
      DO 900 JDAY = 1,3
      GO TO ( 100,120,140) JDAY
C***  JDAY=1 IS WEEKDAYS
  100 H=248
      GO TO 160
C***  JDAY=2 IS SAT. + SOME HOLIDAYS
  120 H=62
      GO TO 160
C*    JDAY=3 IS SUN. + 3 HOLIDAYS
  140 H=55
      GO TO 160
  160 CONTINUE
      DO 800 IHR= 1,24
       GO TO (200,220,240) JDAY
  200 IF(IHR.LE.6) L=1
      IF(IHR.EQ.7) L=2
      IF(IHR.GE.8.AND.IHR.LE.9) L=3
      IF(IHR.GE.10.AND.IHR.LE.15) L=4
      IF(IHR.GE.16.AND.IHR.LE.18) L=5
      IF(IHR.GE.19) L=6
      GO TO 280
  220 IF(IHR.LE.3) L=1
      IF(IHR.GE.4.AND.IHR.LE.6) L=2
      IF(IHR.GE.7.AND.IHR.LE.8) L=3
      IF(IHR.GE.9.AND.IHR.LE.12) L=4
      IF(IHR.GE.13.AND.IHR.LE.18) L=5
      IF(IHR.GE.19) L=6
      GO TO 280
  240 IF(IHR.LE.2) L=1
      IF(IHR.GE.3.AND.IHR.LE.4) L=2
      IF(IHR.GE.5.AND.IHR.LE.10) L=3
      IF(IHR.GE.11.AND.IHR.LE.14) L=4
      IF(IHR.GE.15.AND.IHR.LE.23) L=5
      IF(IHR.GE.24) L=6
  280 CONTINUE
      DO 600 KCON = 1,19
      SUM(KCON) = SUM(KCON) + (FRAC(KCON,L,JDAY) *(((TOTP(JDAY)*P(IHR,
     1   JDAY))    +(TOTPD(JDAY)*P(IHR,JDAY+3)))/4) * H)
  600 CONTINUE
  800 CONTINUE
  900 CONTINUE
```

```
      PRINT 2000 , ITITLE
      PRINT 2005, (TOTP(I),I=1,3), (TOTPD(I),I=1,3)
      PRINT 2007
      DO  940  I= 1,19
  940 PRINT 2010 ,ICON1(I),ICON2(I),SUM(I)
      X(19)=SUM(19)/1E6
      DO 960 I=2,19
      J=I-1
      X(20-I)=X(20-J)+(SUM(20-I)/1E6)
  960 CONTINUE
      PRINT 2000,ITITLE
      PRINT 2005, (TOTP(I),I=1,3), (TOTPD(I),I=1,3)
      PRINT 2020
        PRINT 2040,ICON1(1),X(1)
      DO 980 I=2,19
  980 PRINT 2040,ICON2(I-1),X(I)
 2020 FORMAT(17X,*CONCENTRATION EXCEEDED*,
     1        5X,*PERSON HOURS*,/)
 2040 FORMAT(20X,6X,I5,5X,10X,F9.3)
 1000 FORMAT (8A10)
 2000 FORMAT (1H1,//,26X,8A10,////)
 2005 FORMAT(10X,6F12.0,///)
 2007 FORMAT(17X,*CONCENTRATION INTERVAL*,5X,*PERSON HOURS*,/)
 2010 FORMAT (20X,I5,*  TO  *,I5,10X,F11.0)
  999 STOP
      END
      BLOCK DATA SCCONC
      COMMON/SCONC/SCFRAC(19,6,3)
C***  ORDER OF DATA IS  WEEKDAYS BY HOUR GROUP THEN SAT. AND SUN.
      DATA((SCFRAC(I,J,1),J=1,6),I=1,19)/
     A          .3358,  .0621,  .0191,  .0223,  .0182,  .0923,              WKD
     B          .4051,  .2858,  .1137,  .1292,  .1005,  .2954,              WKD
     C          .1435,  .2568,  .1862,  .1988,  .1616,  .2537,              WKD
     D          .0631,  .1750,  .1818,  .1800,  .1673,  .1550,              WKD
     E          .0271,  .1000,  .1505,  .1427,  .1421,  .0885,              WKD
     F          .0130,  .0541,  .1049,  .1039,  .1133,  .0477,              WKD
     G          .0060,  .0300,  .0811,  .0757,  .0934,  .0275,              WKD
     H          .0034,  .0139,  .0603,  .0549,  .0675,  .0166,              WKD
     I          .0015,  .0098,  .0326,  .0350,  .0470,  .0095,              WKD
     J          .0007,  .0057,  .0239,  .0236,  .0324,  .0056,              WKD
     K          .0004,  .0035,  .0163,  .0142,  .0216,  .0026,              WKD
     L          .0002,  .0010,  .0104,  .0076,  .0128,  .0018,              WKD
     M          .0002,  .0012,  .0066,  .0051,  .0084,  .0010,              WKD
     N          .0000,  .0004,  .0035,  .0032,  .0053,  .0009,              WKD
     O          .0000,  .0004,  .0045,  .0029,  .0050,  .0012,              WKD
     P          .0000,  .0002,  .0030,  .0009,  .0024,  .0004,              WKD
     Q          .0000,  .0000,  .0007,  .0001,  .0009,  .0002,              WKD
     R          .0000,  .0000,  .0003,  .0000,  .0001,  .0000,              WKD
     S          .0000,  .0000,  .0002,  .0000,  .0000,  .0000/              WKD
      DATA((SCFRAC(I,J,2),J=1,6),I=1 ,19)/
     A          .1987,  .3137,  .1647,  .0839,  .0613,  .0992,              SAT
     B          .3246,  .4096,  .4222,  .3320,  .2998,  .3070,              SAT
     C          .1946,  .1604,  .2339,  .2734,  .2622,  .2311,              SAT
     D          .1162,  .0618,  .1079,  .1564,  .1569,  .1572,              SAT
     E          .0650,  .0331,  .0457,  .0829,  .0947,  .0955,              SAT
     F          .0372,  .0114,  .0141,  .0424,  .0548,  .0462,              SAT
```

```
     G          .0261,  .0057,  .0070,  .0149,  .0325,  .0238,                SAT
     H          .0168,  .0030,  .0030,  .0078,  .0167,  .0157,                SAT
     I          .0101,  .0007,  .0010,  .0038,  .0098,  .0116,                SAT
     J          .0050,  .0007,  .0005,  .0015,  .0056,  .0062,                SAT
     K          .0034,  .0000,  .0000,  .0003,  .0027,  .0034,                SAT
     L          .0013,  .0000,  .0000,  .0003,  .0010,  .0019,                SAT
     M          .0007,  .0000,  .0000,  .0003,  .0008,  .0005,                SAT
     N          .0003,  .0000,  .0000,  .0000,  .0005,  .0002,                SAT
     O          .0000,  .0000,  .0000,  .0000,  .0002,  .0002,                SAT
     P          .0000,  .0000,  .0000,  .0000,  .0005,  .0005,                SAT
     Q          .0000,  .0000,  .0000,  .0003,  .0000,  .0000,                SAT
     R          .0000,  .0000,  .0000,  .0000,  .0000,  .0000,                SAT
     S          .0000,  .0000,  .0000,  .0000,  .0000,  .0000/                SAT
      DATA((SCFRAC(I,J,3),J=1,6),I=1,19)/
     A          .1851,  .2718,  .2873,  .1847,  .1484,  .2064,                SUN
     B          .3190,  .3885,  .4847,  .4672,  .3946,  .4087,                SUN
     C          .2031,  .1618,  .1509,  .1976,  .2186,  .1815,                SUN
     D          .1149,  .0830,  .0489,  .0930,  .1160,  .1120,                SUN
     E          .0764,  .0384,  .0143,  .0299,  .0574,  .0477,                SUN
     F          .0308,  .0197,  .0091,  .0167,  .0296,  .0249,                SUN
     G          .0338,  .0166,  .0017,  .0048,  .0154,  .0073,                SUN
     H          .0144,  .0093,  .0012,  .0025,  .0089,  .0062,                SUN
     I          .0108,  .0041,  .0005,  .0020,  .0043,  .0010,                SUN
     J          .0041,  .0031,  .0003,  .0010,  .0028,  .0021,                SUN
     K          .0015,  .0000,  .0003,  .0005,  .0026,  .0010,                SUN
     L          .0021,  .0016,  .0002,  .0000,  .0011,  .0010,                SUN
     M          .0021,  .0000,  .0005,  .0000,  .0001,  .0000,                SUN
     N          .0000,  .0010,  .0000,  .0000,  .0002,  .0000,                SUN
     O          .0005,  .0010,  .0002,  .0000,  .0000,  .0000,                SUN
     P          .0010,  .0000,  .0000,  .0000,  .0000,  .0000,                SUN
     Q          .0005,  .0000,  .0000,  .0000,  .0000,  .0000,                SUN
     R          .0000,  .0000,  .0000,  .0000,  .0000,  .0000,                SUN
     S          .0000,  .0000,  .0000,  .0000,  .0000,  .0000/                SUN
      END
      BLOCK DATA POPSC
      COMMON/SPOP/PSC(24,6)
C***  DATA ORDER IS  WEEKDAY, SAT., SUN
      DATA ((PSC(I,J),J=1,6),I=1,12)/
     A          .0117 , .0444 , .0663 , .004 , .0046 , .0046 ,          M TO  1
     B          .0079 , .0399 , .0572 , .002 , .0023 , .0023 ,          1 TO  2
     C          .0050 , .0334 , .0472 , .001 , .0012 , .0012 ,          2 TO  3
     D          .0050 , .0222 , .0319 , .001 , .0000 , .0000 ,          3 TO  4
     E          .0067 , .0161 , .0219 , .001 , .0000 , .0000 ,          4 TO  5
     F          .0158 , .0165 , .0179 , .003 , .0012 , .0012 ,          5 TO  6
     G          .0388 , .0238 , .0211 , .008 , .0023 , .0023 ,          6 TO  7
     H          .0765 , .0315 , .0249 , .030 , .0046 , .0046 ,          7 TO  8
     I          .0650 , .0370 , .0247 , .059 , .0185 , .0185 ,          8 TO  9
     J          .0565 , .0407 , .0281 , .054 , .0323 , .0323 ,          9 TO 10
     K          .0571 , .0447 , .0305 , .058 , .0611 , .0611 ,         10 TO 11
     L          .0598 , .0479 , .0345 , .075 , .0934 , .0934 /         11 TO 12
      DATA ((PSC(I,J),J=1,6),I=12,24)/
     M          .0580 , .0492 , .0390 , .126 , .1130 , .1130 ,         12 TO 13
     N          .0580 , .0513 , .0419 , .115 , .1280 , .1280 ,         13 TO 14
     O          .0601 , .0538 , .0481 , .090 , .1349 , .1349 ,         14 TO 15
     P          .0674 , .0538 , .0501 , .075 , .1153 , .1153 ,         15 TO 16
     Q          .0840 , .0524 , .0536 , .085 , .1038 , .1038 ,         16 TO 17
```

```
R          .0675 , .0500 , .0555 , .090 , .0669 , .0669 ,          17 TO 18
S          .0472 , .0455 , .0554 , .044 , .0369 , .0369 ,          18 TO 19
T          .0417 , .0466 , .0550 , .026 , .0219 , .0219 ,          19 TO 20
U          .0338 , .0463 , .0538 , .018 , .0185 , .0185 ,          20 TO 21
V          .0317 , .0494 , .0509 , .014 , .0150 , .0150 ,          21 TO 22
W          .0246 , .0530 , .0484 , .010 , .0150 , .0150 ,          22 TO 23
X          .0190 , .0506 , .0422 , .008 , .0092 , .0092 /          23 TO 24
 END
```

APPENDIX E

Fortran Listing of Microenvironment Exposure Model
for Tunnels
(written for CDC Cyber 173)

```
      PROGRAM TUDIST(INPUT,OUTPUT)
      COMMON/TPOP/  P(24,3) /TCONC / FRAC(19,7)
      DIMENSION  TOTP(3),AP(24,3),SUM(19),ICON1(19),ICON2(19),ITITLE(8),
     1           X(19)
      DATA ICON1 /0,201,401,601,701,801,901,1001,1201,1401,
     1            1601,1801,2001,2201,2401,2601,3001,4001,6001/
      DATA ICON2 /200,300,600,700,800,900,1000,1200,1400,1600,1800,
     1       2000,2200,2400,2600,3000,4000,6000,8000/
C**** READ INPUT VALUES
      READ 1000, ITITLE
      READ * ,(TOTP(I),I=1,3)
C****
      DO 50 I=1,19
      SUM(I)=0.0
   50 CONTINUE
      DO 900 JDAY = 1,3
      GO TO ( 100,120,140) JDAY
C***  JDAY=1 IS WEEKDAYS
  100 H=248
      GO TO 160
C***  JDAY=2 IS SAT. + SOME HOLIDAYS
  120 H=62
      GO TO 160
C*    JDAY=3 IS SUN. + 3 HOLIDAYS
  140 H=55
      GO TO 160
  160 CONTINUE
      DO 800 IHR= 1,24
      IF(JDAY.EQ.1) AP(IHR,1) = P(IHR,1)
      IF(JDAY.EQ.2) AP(IHR,2) = P(IHR,2)*(TOTP(2)/TOTP(1))
      IF(JDAY.EQ.3) AP(IHR,3) = P(IHR,3)*(TOTP(3)/TOTP(1))
      IF(AP(IHR,JDAY).LE.0.01) L=1
      IF(AP(IHR,JDAY).GT.0.01.AND.AP(IHR,JDAY).LE.0.02) L=2
      IF(AP(IHR,JDAY).GT.0.02.AND.AP(IHR,JDAY).LE.0.03) L=3
      IF(AP(IHR,JDAY).GT.0.03.AND.AP(IHR,JDAY).LE.0.04) L=4
      IF(AP(IHR,JDAY).GT.0.04.AND.AP(IHR,JDAY).LE.0.05) L=5
      IF(AP(IHR,JDAY).GT.0.05.AND.AP(IHR,JDAY).LE.0.06) L=6
      IF(AP(IHR,JDAY).GT.0.06) L=7
  280 CONTINUE
      DO 600 KCON = 1,19
      SUM(KCON) = SUM(KCON) + (FRAC(KCON,L) *(((TOTP(JDAY)*P(IHR,
     1        JDAY)))/12) * H)
  600 CONTINUE
  800 CONTINUE
  900 CONTINUE
      PRINT 2000 , ITITLE
      DO  940  I= 1,19
  940 PRINT 2010 ,ICON1(I),ICON2(I),SUM(I)
      X(19)=SUM(19)/1E6
      DO 960 I=2,19
      J=I-1
      X(20-I)=X(20-J)+(SUM(20-I)/1E6)
  960 CONTINUE
      PRINT 2020,ITITLE
        PRINT 2040,ICON1(1),X(1)
      DO 980 I=2,19
```

```
  980 PRINT 2040,ICON2(I-1),X(I)
 2020 FORMAT(1H1,//,26X,8A10,////,17X,*CONCENTRATION EXCEEDED*,
     1        5X,*PERSON HOURS*,/)
 2040 FORMAT(20X,6X,I5,5X,10X,F9.3)
 1000 FORMAT (8A10)
 2000 FORMAT (1H1,//,26X,8A10,////,17X,*CONCENTRATION INTERVAL*,
     1                5X,*PERSON HOURS*,/)
 2010 FORMAT (20X,I5,*  TO  *,I5,10X,F11.0)
  999 STOP
      END
      BLOCK DATA TUCONC
      COMMON/TCONC/TUFRAC(19,7)
C***  ORDER OF DATA IS  WEEKDAYS BY ADT FROM 0.5 PCT TO 6.5 PCT
      DATA((TUFRAC(I,J),J=1,7),I=1,19)/
     A  .777  ,  .288  ,  .067  ,  .013  ,  .006  ,  .001  ,  .000  ,       WKD
     B  .129  ,  .317  ,  .230  ,  .109  ,  .045  ,  .018  ,  .007  ,       WKD
     C  .044  ,  .169  ,  .218  ,  .175  ,  .105  ,  .057  ,  .030  ,       WKD
     D  .011  ,  .052  ,  .086  ,  .088  ,  .068  ,  .045  ,  .027  ,       WKD
     E  .008  ,  .038  ,  .071  ,  .081  ,  .071  ,  .052  ,  .035  ,       WKD
     F  .006  ,  .029  ,  .058  ,  .073  ,  .071  ,  .057  ,  .042  ,       WKD
     G  .004  ,  .022  ,  .047  ,  .065  ,  .068  ,  .059  ,  .047  ,       WKD
     H  .006  ,  .030  ,  .069  ,  .105  ,  .120  ,  .116  ,  .100  ,       WKD
     I  .004  ,  .019  ,  .046  ,  .077  ,  .099  ,  .107  ,  .102  ,       WKD
     J  .003  ,  .012  ,  .032  ,  .056  ,  .078  ,  .092  ,  .095  ,       WKD
     K  .002  ,  .008  ,  .022  ,  .041  ,  .061  ,  .077  ,  .085  ,       WKD
     L  .001  ,  .005  ,  .015  ,  .030  ,  .047  ,  .063  ,  .074  ,       WKD
     M  .001  ,  .004  ,  .011  ,  .022  ,  .036  ,  .051  ,  .062  ,       WKD
     N  .001  ,  .003  ,  .008  ,  .016  ,  .028  ,  .041  ,  .052  ,       WKD
     O  .001  ,  .002  ,  .006  ,  .012  ,  .021  ,  .033  ,  .043  ,       WKD
     P  .001  ,  .003  ,  .007  ,  .016  ,  .029  ,  .047  ,  .065  ,       WKD
     Q  .001  ,  .003  ,  .008  ,  .019  ,  .033  ,  .057  ,  .085  ,       WKD
     R  .001  ,  .001  ,  .004  ,  .009  ,  .019  ,  .035  ,  .056  ,       WKD
     S  .000  ,  .000  ,  .001  ,  .001  ,  .002  ,  .005  ,  .009  /       WKD
      END
      BLOCK DATA POPTU
      COMMON/TPOP/PTU(24,3)
C***  DATA ORDER IS  WEEKDAY, SAT., SUN
      DATA ((PTU(I,J),J=1,3),I=1,12)/
     A  .0200 ,    .0330 ,    .0330 ,                              M TO  1
     B  .0128 ,    .0226 ,    .0226 ,                              1 TO  2
     C  .0080 ,    .0153 ,    .0153 ,                              2 TO  3
     D  .0051 ,    .0090 ,    .0090 ,                              3 TO  4
     E  .0054 ,    .0086 ,    .0086 ,                              4 TO  5
     F  .0140 ,    .0073 ,    .0073 ,                              5 TO  6
     G  .0397 ,    .0195 ,    .0195 ,                              6 TO  7
     H  .0611 ,    .0309 ,    .0309 ,                              7 TO  8
     I  .0596 ,    .0362 ,    .0362 ,                              8 TO  9
     J  .0528 ,    .0413 ,    .0413 ,                              9 TO 10
     K  .0505 ,    .0474 ,    .0474 ,                             10 TO 11
     L  .0501 ,    .0593 ,    .0593 /                             11 TO 12
      DATA ((PTU(I,J),J=1,3),I=12,24)/
     M  .0494 ,    .0573 ,    .0573 ,                             12 TO 13
     N  .0498 ,    .0579 ,    .0579 ,                             13 TO 14
     O  .0546 ,    .0566 ,    .0566 ,                             14 TO 15
     P  .0630 ,    .0647 ,    .0647 ,                             15 TO 16
     Q  .0688 ,    .0620 ,    .0620 ,                             16 TO 17
```

R	.0634 ,	.0560 ,	.0560 ,	17 TO 18
S	.0599 ,	.0583 ,	.0583 ,	18 TO 19
T	.0576 ,	.0635 ,	.0635 ,	19 TO 20
U	.0461 ,	.0562 ,	.0562 ,	20 TO 21
V	.0417 ,	.0497 ,	.0497 ,	21 TO 22
W	.0375 ,	.0456 ,	.0456 ,	22 TO 23
X	.0299 ,	.0424 ,	.0424 /	23 TO 24

END

APPENDIX F

UNIVAC 1100 Runstreams for NEM Reruns

Runstream to Produce the NEM Air Quality Input File for Chicaco

```
@RUN,R/R AIRDAT/80,[redacted],EXES/MMSAP,120,9999
@DELETE,C EXES*PRTAQ.
@DELETE,C EXES*AQCHIC.
@COND
@CAT,P PRTAQ.,F33///140
@US*ER.BK1,A PRTAQ.
@ASG,CP EXES*AQCHIC.
@ASG,T AQFILE.
@ASG,A SASD*CO-TRACK.
@COPY,A SASD*EXP-ABS.TRACK-11
@SETC,O
@XQT SASD*EXP-ABS.TRACK-11
 7 1,31 11                           SASD*CO-TRACK.CHICAGO
@COPY AQFILE.,EXES*AQCHIC.
@SETC,X
@US*ER.BK2,N
```

Runstream to Produce the NEM Air Quality Input File for Los Angeles

```
@RUN,R/R AQDAT2/80,[redacted],EXES/MMSAP,120,9999
@DELETE,C EXES*PRTAQLA.
@DELETE,C EXES*AQLA.
@COND
@CAT,P PRTAQLA.,F33///140
@US*ER.BK1,A PRTAQLA.
@ASG,CP EXES*AQLA.
@ASG,T AQFILE.
@ASG,A SASD*CO-TRACK.
@COPY,A SASD*EXP-ABS.TRACK-11
@SETC,O
@XQT SASD*EXP-ABS.TRACK-11
 7 1,75 11                           SASD*CO-TRACK.LOS-ANGELES
@COPY AQFILE.,EXES*AQLA.
@SETC,X
@US*ER.BK2,N
```

Runstream to Produce the NEM Air Quality Input File for Philadelphia

```
@RUN,R/R AQDAT3/80,[redacted],EXES/MMSAP,120,9999
@DELETE,C EXES*PRTAQPHIL.
@DELETE,C EXES*AQPHIL.
@COND
@CAT,P PRTAQPHIL.,F33///140
@US*ER.BK1,A PRTAQPHIL.
@ASG,CP EXES*AQPHIL.
@ASG,T AQFILE.
@ASG,A SASD*CO-TRACK.
@COPY,A SASD*EXP-ABS.TRACK-11
@SETC,0
@XQT SASD*EXP-ABS.TRACK-11
 7 0.96 11                          SASD*CO-TRACK.PHILADELPHIA
@COPY AQFILE.,EXES*AQPHIL.
@SETC,X
@US*ER.BK2,N
EOF:16
0:>
```

Runstream to Produce the NEM Air Quality Input File for St. Louis

```
@RUN,R/R AQDAT4/80,[redacted],EXES/MMSAP,120,9999
@DELETE,C EXES*PRTAQSTLU.
@DELETE,C EXES*AQSTLU.
@COND
@CAT,P PRTAQSTLU.,F33///140
@US*ER.BK1,A PRTAQSTLU.
@ASG,CP EXES*AQSTLU.
@ASG,T AQFILE.
@ASG,A SASD*CO-TRACK.
@COPY,A SASD*EXP-ABS.TRACK-11
@SETC,0
@XQT SASD*EXP-ABS.TRACK-11
 7 2.27 11                          SASD*CO-TRACK.ST-LOUIS
@COPY AQFILE.,EXES*AQSTLU.
@SETC,X
@US*ER.BK2,N
EOF:16
0:>
```

NEM Runstream for Chicago

```
@RUN,R/R NEMRN2/80,[redacted],EXES/MMSAP,30,50
@DELETE,C EXES*PRTNEM1.
@COND
@CAT,P PRTNEM1.,F33///150
@US*ER.BK1,A PRTNEM1.
@ASG,T SUMFILE.
@ASG,A EXES*AQCHIC.
@USE AQFILE.,EXES*AQCHIC.
@COPY,A SASD*EXP-ABS.NEM
@XQT NEM
1
@ADD SASD*TRACK-DATA.YEAR-START/MONDAY
CHICAGO         8               CHIC,ALL PERS, B.E.MICRO(NO SOURCES)AS IS AQ
@ADD SASD*CO-TRACK.BE/BASE
@ADD EXES*MOBILE-DATA.CONCS/20
@ADD SASD*CO-TRACK.CONCS-COHB/14
@ADD SASD*CO-TRACK.CONSTANTS/M
@ADD SASD*TRACK-DATA.CHICAGO/NT-6
@EOF
@US*ER.BK2,N
```

NEM Runstream for Los Angeles

```
@RUN,R/R NEMRN3/80,[redacted],EXES/MMSAP,30,50
@DELETE,C EXES*PRTNEMLA.
@COND
@CAT,P PRTNEMLA.,F33///150
@US*ER.BK1,A PRTNEMLA.
@ASG,T SUMFILE.
@ASG,A EXES*AQLA.
@USE AQFILE.,EXES*AQLA.
@COPY,A SASD*EXP-ABS.NEM
@XQT NEM
1
@ADD SASD*TRACK-DATA.YEAR-START/SATURDAY
LOS-ANGELES     8               ALL PERSONS, B.E. MICRO(NO SOURCES),AS IS AQ
@ADD SASD*CO-TRACK.BE/BASE
@ADD EXES*MOBILE-DATA.CONCS/20
@ADD SASD*CO-TRACK.CONCS-COHB/14
@ADD SASD*CO-TRACK.CONSTANTS/M
@ADD SASD*TRACK-DATA.LOS-ANGELES/NT-6
@EOF
@US*ER.BK2,N
```

NEM Runstream for Philadelphia

```
@RUN,R/R NEMRN4/80,[redacted],EXES/MMSAP,30,50
@DELETE,C EXES*PRTNEMPHIL.
@COND
@CAT,P PRTNEMPHIL.,F33///150
@US*ER.BK1,A PRTNEMPHIL.
@ASG,T SUMFILE.
@ASG,A EXES*AQPHIL.
@USE AQFILE.,EXES*AQPHIL.
@COPY,A SASD*EXP-ABS.NEM
@XQT NEM
1
@ADD SASD*TRACK-DATA.YEAR-START/SUNDAY
PHILADELPHIA     8               PHIL.,ALL PERS.,BE MICRO(NO SOURCES),AS IS AQ
@ADD SASD*CO-TRACK.BE/BASE
@ADD EXES*MOBILE-DATA.CONCS/20
@ADD SASD*CO-TRACK.CONCS-COHB/14
@ADD SASD*CO-TRACK.CONSTANTS/M
@ADD SASD*TRACK-DATA.PHILADELPHIA/NT-6
@EOF
@US*ER.BK2,N
```

NEM Runstream for St. Louis

```
@RUN,R/R NEMRN5/75,[redacted],EXES/MMSAP,25,50
@DELETE,C EXES*PRTNEMSTLU.
@COND
@CAT,P PRTNEMSTLU.,F33///150
@US*ER.BK1,A PRTNEMSTLU.
@ASG,T SUMFILE.
@ASG,A EXES*AQSTLU.
@USE AQFILE.,EXES*AQSTLU.
@COPY,A SASD*EXP-ABS.NEM
@XQT NEM
1
@ADD SASD*TRACK-DATA.YEAR-START/SUNDAY
ST-LOUIS         8               ST. LOU.,ALL PERS.,BE MICRO(NO SOURCES),AS IS AQ
@ADD SASD*CO-TRACK.BE/BASE
@ADD EXES*MOBILE-DATA.CONCS/20
@ADD SASD*CO-TRACK.CONCS-COHB/14
@ADD SASD*CO-TRACK.CONSTANTS/M
@ADD SASD*TRACK-DATA.ST-LOUIS/NT-6
@EOF
@US*ER.BK2,N
```

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA 460/3-84-004	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Mobile Source Exposure Estimation		5. REPORT DATE March 1984 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Melvin N. Ingalls		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Southwest Research Institute 6220 Culebra San Antonio, Texas 78284		10. PROGRAM ELEMENT NO. 11. CONTRACT/GRANT NO. 68-03-3073
12. SPONSORING AGENCY NAME AND ADDRESS Environmental Protection Agency 2565 Plymouth Road Ann Arbor, Michigan 48105		13. TYPE OF REPORT AND PERIOD COVERED Final (June 1982 - May 1983) 14. SPONSORING AGENCY CODE
15. SUPPLEMENTARY NOTES		

16. ABSTRACT

This project was conducted to provide a national exposure, in terms of person hours, to non-reactive mobile source pollutants. The basis for the estimate was the EPA "NAAQS Exposure Model" (NEM) as applied to carbon monoxide, supplemented by four mobile source microenvironments: parking garages, street canyons, on-expressways, and roadway tunnels. From previous studies, both published and unpublished, CO concentration distributions and national population estimates, by hour of the day, for each of these mobile source microenvironments were developed. That information was combined to determine national exposure in the microenvironments. By using the mobile source CO emission factor, exposure to mobile source pollutants based on a pollutant emission rate of one gram per minute was determined for each of the microenvironments and the environments covered by the NEM. The methodology for using this information to determine exposure to any mobile source pollutant, regulated or unregulated was explained.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution Exhaust Emissions Motor Vehicles	Exposure Estimates Parking Garages Tunnels Street Canyons Expressways	
18. DISTRIBUTION STATEMENT Unlimited	19. SECURITY CLASS *(This Report)* Unclassified 20. SECURITY CLASS *(This page)* Unclassified	21. NO. OF PAGES 131 22. PRICE

EPA Form 2220-1 (9-73)

INSTRUCTIONS

1. **REPORT NUMBER**
   Insert the EPA report number as it appears on the cover of the publication.

2. **LEAVE BLANK**

3. **RECIPIENTS ACCESSION NUMBER**
   Reserved for use by each report recipient.

4. **TITLE AND SUBTITLE**
   Title should indicate clearly and briefly the subject coverage of the report, and be displayed prominently. Set subtitle, if used, in smaller type or otherwise subordinate it to main title. When a report is prepared in more than one volume, repeat the primary title, add volume number and include subtitle for the specific title.

5. **REPORT DATE**
   Each report shall carry a date indicating at least month and year. Indicate the basis on which it was selected *(e.g., date of issue, date of approvcl, date of preparation, etc.)*.

6. **PERFORMING ORGANIZATION CODE**
   Leave blank.

7. **AUTHOR(S)**
   Give name(s) in conventional order *(John R. Doe, J. Robert Doe, etc.)*. List author's affiliation if it differs from the performing organization.

8. **PERFORMING ORGANIZATION REPORT NUMBER**
   Insert if performing organization wishes to assign this number.

9. **PERFORMING ORGANIZATION NAME AND ADDRESS**
   Give name, street, city, state, and ZIP code. List no more than two levels of an organizational hirearchy.

10. **PROGRAM ELEMENT NUMBER**
    Use the program element number under which the report was prepared. Subordinate numbers may be included in parentheses.

11. **CONTRACT/GRANT NUMBER**
    Insert contract or grant number under which report was prepared.

12. **SPONSORING AGENCY NAME AND ADDRESS**
    Include ZIP code.

13. **TYPE OF REPORT AND PERIOD COVERED**
    Indicate interim final, etc., and if applicable, dates covered.

14. **SPONSORING AGENCY CODE**
    Leave blank.

15. **SUPPLEMENTARY NOTES**
    Enter information not included elsewhere but useful, such as: Prepared in cooperation with, Translation of, Presented at conference of, To be published in, Supersedes, Supplements, etc.

16. **ABSTRACT**
    Include a brief *(200 words or less)* factual summary of the most significant information contained in the report. If the report contains a significant bibliography or literature survey, mention it here.

17. **KEY WORDS AND DOCUMENT ANALYSIS**
    (a) DESCRIPTORS - Select from the Thesaurus of Engineering and Scientific Terms the proper authorized terms that identify the major concept of the research and are sufficiently specific and precise to be used as index entries for cataloging.

    (b) IDENTIFIERS AND OPEN-ENDED TERMS - Use identifiers for project names, code names, equipment designators, etc. Use open-ended terms written in descriptor form for those subjects for which no descriptor exists.

    (c) COSATI FIELD GROUP - Field and group assignments are to be taken from the 1965 COSATI Subject Category List. Since the majority of documents are multidisciplinary in nature, the Primary Field/Group assignment(s) will be specific discipline, area of human endeavor, or type of physical object. The application(s) will be cross-referenced with secondary Field/Group assignments that will follow the primary posting(s).

18. **DISTRIBUTION STATEMENT**
    Denote releasability to the public or limitation for reasons other than security for example "Release Unlimited." Cite any availability to the public, with address and price.

19. & 20. SECURITY CLASSIFICATION
DO NOT submit classified reports to the National Technical Information service.

21. **NUMBER OF PAGES**
    Insert the total number of pages, including this one and unnumbered pages, but exclude distribution list, if any.

22. **PRICE**
    Insert the price set by the National Technical Information Service or the Government Printing Office, if known.