Environmental Protection Agency
Region IX
100 California Street
San Francisco, California 94111

October 30, 1973

Technical Support Document for the Metropolitan Los Angeles Intrastate Air Quality Control Region Transportation Control Plan Final Promulgation

Published in
November 12, 1973 Federal Register

I. Introduction:

This document is in support of the EPA promulgated California Transportation Control Plan for the Los Angeles Metropolitan Air Quality Control Region (AQCR), signed on October 30, 1973 by Acting Administrator John Quarles, and published in the November 12, 1973 Federal Register.

The determination of the maximum amount of allowable emissions consistent with the attainment of the National Ambient Air Quality Standards, and the emission reduction strategies needed to reduce emissions to the maximum allowable levels, are outlined and discussed in the following two sections. More detailed information on the control strategies and technical details involved in the plan are found in the appendices.

II. Determination of Allowable Emission to Meet Federal Ambient Air Quality Standards:

The National Ambient Air Quality Standard for photochemical oxidant has been exceeded in this AQCR. The photochemical oxidant control strategy discussed in this report involves the control of high reactive hydrocarbon and other reactive organic gases (RHC). Where possible, the RHC are defined by the most recent EPA guidance on organic gas reactivity. Using the EPA definition of RHC, only the following five hydrocarbons are considered as low or non-reactive: methane, ethane, propane, benzene, and acetylene. The EPA definition of RHC was applied to all mobile exhaust emission sources, and to gasoline vapor emissions from stationary as well as mobile sources.

Due to the lack of a detailed breakdown of the organic gas emissions from stationary sources, the Los Angeles County Air Pollution Control District (APCD) Rule 66 chemical definition of reactivity was used for the remaining stationary sources. Application of the Rule 66 chemical definition of reactivity means that only those organic gases listed under Section 1., 2., 3. of paragraph K. of Rule 66 (e.g., toluene, aromatic compounds with eight or more carbon atoms, olefinic hydrocarbons), are inventoried as RHC and considered for control. It is expected that in the future, a more detailed stationary organic gas emission inventory will be available, which will allow for a completely consistent definition of RHC to be made for both mobile and stationary emission sources of organic gases. An observation that can be made is that the RHC definition inconsistency between the mobile and stationary source emissions in the present RHC inventory results in the stationary source emissions (except stationary gasoline vapor emissions) being artificially low in relation to mobile source emissions.

The nitrogen dioxide (NO_2) ambient air quality standard has been exceeded in the AQCR, with a 1970 maximum yearly arithmetic mean of .094 parts per million (p.p.m.), versus the standard of .05 p.p.m. The control of RHC for meeting the photochemical oxidant standard is the critical factor however, and the implementation of strategies required to meet the oxidant standard will also result in adequate NO_x emission reductions for the attainment of the NO_2 standard.

The carbon monoxide (CO) standard has been exceeded, with a high 8-hour reading of 41 p.p.m. occurring in 1970, versus the standard of 9 p.p.m. The control of RHC for meeting the photochemical oxidant standard is still the critical factor, and the control strategies required to meet the oxidant standard should result in more than adequate CO emission control to meet the CO standard.

The photochemical oxidant 1-hour standard is .08 p.p.m. The critical yearly high 1-hour photochemical oxidant reading of .62 p.p.m., occurred in the AQCR at Riverside in 1970. The stationary RHC emissions in the 1970 base year are estimated to be 255 tons/day, and the mobile RHC emissions are estimated to be 1346 tons/day.

As a result of recommendations received at EPA public hearings and technical meetings, EPA did a statistical analysis of ambient photochemical oxidant data. The statistical analysis entitled "Methodology for Determining the Base Year Oxidant Level," is found in Appendix B. The results of this study validate the use of the observed AQCR yearly high 1-hour 1970 oxidant reading of .62 p.p.m. for control strategy planning purposes.

Mr. Ed Schuck of EPA developed "upper limit" curves for daily 6-9 a.m. average non-methane hydrocarbon concentrations versus the daily maximum 1-hour oxidant reading over a period of time at several locations in this AQCR. This "upper limit" relationship and others, are detailed in the Schuck Papetti paper in Appendix D, entitled "Examinations of the Photochemical Air Pollution Problem in the Southern California Area." From this relationship it is inferred that a 93% reduction in the critical 1970 ambient hydrocarbon concentration would have to occur in order to allow for the attainment of the oxidant air quality standard (i.e., lower the .62 p.p.m. reading to .08 p.p.m.). It is assumed that a 93% reduction in RHC emissions in the AQCR would result in a 93% reduction of ambient hydrocarbon concentrations. The maximum allowable RHC emission rate in 1970 and any future year is then calculated as follows, based on the 1970 base year emission rate, and the Schuck "upper limit" relationship:

$$.07(255 + 1326) = 112 \text{ tons RHC/day}$$

III. Control Strategy Outline:

The EPA rules and regulations that are to affect the majority of the emission reductions outlined in this and the previous section, are identified in section "I. Introduction" of this document.

Summary of Impact of Transportation Control Regulations In the Los Angeles AQCR in 1977

Emission Source and Control Measures	Emissions and Reductions of RHC tons/day
Stationary source emissions 1/ without EPA control strategy	236
Expected reductions	
1. Vapor recovery at gasoline stations	-132
2. Dry cleaning, paint and degreasing solvent controls	-32
Stationary emissions remaining	72
Mobile source emissions without 2/ EPA control strategy	613
Expected reductions	
1. Reductions from only EPA-promulgated VMT* control strategies, assuming a conservative 14% VMT reduction 3/	-61
2. Catalyst retrofit, and mandatory inspection and maintenance	-103
3. Motorcycle limitations	-24
4. VMT reductions and evaporative emission reductions necessary from additional control strategies to be implemented in 1977	-384
Mobile emissions remaining	41
Total emission remaining	113
Total emission allowable	112

*VMT is an abbreviation for "vehicle miles traveled."

1/ Stationary Source Emission Breakdown:

Petroleum Production	6
Petroleum Marketing	132
Organic Solvents	95
Miscellaneous	3
	236

2/ Mobile Source Emission Breakdown:

Petroleum Marketing	20*
Ships & RR	6
Aircraft	25
Motorcycles	45
Heavy Duty Vehicle (HDV) Diesel	24
HDV Gasoline	56
Light Duty Vehicle (LDV) Gasoline	437
	613

*This is the amount of petroleum marketing emissions remaining after gasoline vapor stationary controls are implemented, and therefore can only be reduced by VMT reduction measures.

3/ Using optimistic assumptions and estimates for both EPA and local VMT reduction measures, a total reduction of 43% VMT, or 187 tons/day could occur. A discussion of the basis or rationale for the VMT reductions is found in Appendix C "California VMT Reduction Summary."

Technical reports, control tactic information (including such details as the emission control reduction factors and the population fraction affected by the tactics), and other data and information needed to calculate or understand the emission inventory in the preceding table, are outlined or referenced in the following appendices.

APPENDIX A

Data and References Used In
Emission Inventory Calculations

A. Stationary, Aircraft, Ship and Railroad Emissions

1) Stationary emissions and ship and railroad emissions are based on the California Air Implementation Plan emission inventory. The aircraft emission inventory was calculated by EPA, Washington, D.C. Headquarters staff. The base year emissions are as follows:

Emission Category	1970 RHC Emissions (tons/day)
Petroleum Refining	5.0
Petroleum Marketing	137.0*
Solvent Users	110.8**
Agriculture, Incineration, Combustion	2.4***
Aircraft	38.0*
Ships & Railroads	5.4*

*Considering EPA reactivity factor, see Section F.

**The surface coating segment of the "solvent users" category (49.2 tons RHC/day in 1970) is estimated by EPA in 1977 to be half of that which would be projected from the growth projections in Section D., based on the increased effectiveness and incentives of the present Rule 66.

***Based on an updated Ventura County emission inventory in which agriculture RHC emissions are reduced.

Future or projected emissions, not considering proposed or additional controls, are obtained by applying the appropriate growth factors (see Section D.) to the 1970 base year inventory just discussed. An exception to this is the aircraft inventory, which is estimated by EPA to be reduced to 25 tons/day in 1977.

B. Emission Factors For Vehicles

1) Light and heavy duty vehicle (LDV & HDV) gasoline, HDV diesel, and motorcycle emission factors (including deterioration factors where applicable), were obtained from the following document:

Compilation of Air Pollutant Emission Factors (AP-42) 1973 Edition

Available from:
EPA Office Technical Information & Publications, Office of Air Programs, Research Triangle Park, N. C. 27711

The emission deterioration factors in the EPA AP-42 publication are presented as a function of vehicle age. This analysis, however, relates the deterioration factors to accumulated mileage. The accumulated mileages that are associated with the vehicle ages in AP-42, are as follows:

AP-42 Vehicle Age	Accumulated Mileage
1	17,500
2	33,600
3	46,800
4	58,200
5	69,900
6	79,900
7	90,200
8	98,800
9+	109,700+

The emission factors presented in AP-42, are listed for various model years in terms of grams of pollutant emitted per mile travelled by the vehicle.

C. Vehicle Population, Age Distribution, and Mileage Data

1) Population data obtained from California Air Resources Board:

a) 1970:

Statewide gasoline LDV population	- 10,560,870
Statewide gasoline HDV population	- 277,120
Statewide diesel HDV population	- 84,500
Statewide motorcycle population	- 568,000

Los Angeles AQCR % of statewide population is 49.72%.

b) 1972:

Statewide gasoline LDV population	- 11,331,900
Statewide gasoline HDV population	- 296,300
Statewide diesel HDV population	- 94,800

Los Angeles AQCR % of statewide population is 49.52%.

These populations are used as the most recent base year data from which to project future year populations. Motorcycle population projections are made from the 1970 base year population.

c) 1977:

Los Angeles AQCR % of statewide population is 49.18%. (This factor is used only for projecting the AQCR 1977 motorcycle population, see Section D.2.)

2) Vehicle Age Distributions

a) 1970 (July):

Vehicle Age* (Yr)	LDV** % of Population	Gasoline & Diesel** HDV % of Population
3/8	8.0	6.7
1 1/4	11.1	9.7
2 1/4	9.5	7.8
3 1/4	8.4	6.4
4 1/4	9.2	7.4
5 1/4	9.5	8.0
6 1/4	8.5	7.4
7 1/4	7.4	6.3
8 1/4	6.3	5.2
9 1/4	4.4	3.9
10 1/4	4.1	4.2
11 1/4	2.9	3.7
12 1/4	1.6	2.3
13 1/4	2.0	2.9
14 1/4	1.7	3.1
15 1/4	1.5	2.8
15 1/4+	3.8	12.3

*The 3/8 year old vehicles are 1970 models, the 1/4 year old models are 1969 models, etc.

**Based on State of California Air Resources Board Department of Motor Vehicle data.

b) Post-1972 (July):

Vehicle Age*(Yr)	LDV** % of Population	HDV** % of Population
3/8	7.9	7.2
1 1/4	9.9	8.9
2 1/4	9.5	8.0
3 1/4	9.2	7.5
4 1/4	8.9	7.1
5 1/4	8.5	6.9
6 1/4	8.2	6.8
7 1/4	7.8	6.6
8 1/4	6.7	5.9
9 1/4	5.4	4.9
10/1/4	4.2	4.0
11 1/4	2.9	3.4
12 1/4	2.2	3.0
13 1/4	1.7	2.7
14 1/4	1.5	2.5
15 1/4	1.4	2.4
15 1/4+	4.4	12.5

*The 3/8 year old vehicles are the current year models in the base year or the strategy year, the 1 1/4 year old vehicles are prior year models, etc.

**Based on State of California Air Resources Board and Department of Motor Vehicle data.

3) Vehicle VMT/yr rate, as of July:

Vehicle Age	LDV* VMT/yr	Gasoline HDV** VMT/yr	Diesel HDV** VMT/yr
3/8	20,000***	28,000***	128,000***
1 1/4	16,300****	21,100****	96,000****
2 1/4	13,500	17,950	81,600
3 1/4	10,500	17,950	81,600
4 1/4	9,700	13,960	63,600
5 1/4	8,200	13,960	63,600
6 1/4	7,200	11,000	50,200
7 1/4	6,770	11,000	50,200
8 1/4	6,350	8,420	38,400
9 1/4	5,920	8,420	38,400
10 1/4	5,490	4,270	19,440
11 1/4	5,070	4,270	19,440
12 1/4	4,640	4,270	19,440
13 1/4	4,640	4,270	19,440
14 1/4	4,640	4,270	19,440
15 1/4	4,640	4,270	19,440
15 1/4+	4,640	4,270	19,440

Motorcycle VMT/yr = 4000*****

*Based primarily on California State vehicle age vs. mileage study.

**Based on U.S. Department of Commerce study "U.S. Truck and Inventory Study - 1967."

***The accumulated mileage of a 3/8 yr. old vehicle is determined by multiplying this number by 3/8.

****The accumulated mileage of a 1 1/4 yr. old vehicle is determined by multiplying this number by 1 1/4.

*****Per EPA 1973 edition of "Compilation of Air Pollution Emission Factors" (AP-42).

The accumulated mileage for vehicles older than 1 1/4 years, is determined by adding the accumulated mileage of a 1 1/4 year-old vehicle (see **** above) to the VMT/yr values found in the preceding table, for each vehicle age after 1 1/4, up to and including the vehicle age of interest. This is illustrated by the following example.

Calculate accumulated mileage for 4 1/4 year old LDV:

Mileage = 16,300 x 1 1/4 + 13,500 + 10,500 + 9,700
= 54,100

The accumulated mileage is used for determining vehicle emission deterioration factors (see Section B.).

D. Growth Projections

1) EPA stationary emissions and mobile source population growth projections (except motorcycles) are as follows <u>for the Los Angeles AQCR</u>:

1970-75 growth factor = 1.065
1970-77 growth factor = 1.104
1972-75 growth factor = 1.039
1972-77 growth factor = 1.078

The above factors are California Air Implementation Plan growth projections, based on a California Department of Finance, Population Research Unit Report, "Provisional Projections of California Counties to 2000" dated September 15, 1971.

2) Motorcycle population growth projections <u>for the entire state</u>:

Growth factors are determined using the ratio of estimated statewide motorcycle population projections in the California Department of Motor Vehicle Report No. 31, March 1970. The motorcycle growth rate factors derived from Report No. 31 are as follows:

1970-75 growth factor = 1.46
1970-80 growth factor = 1.91

E. Strategy Assumptions & Reduction Factors

1) State and local programs in effect or committed:

Program	Population Base (Vehicle Model Years or Sources) Affected	Percentage Population Base Afftd. in '70	Percentage Population Base Afftd. by '77	RHC Reduction Factor	CO Reduction Factor	NOx Reduction Factor
NOx retrofit control	1955-65 LDV Exhaust	0%	67%	0.25	0.09	0.23
NOx retrofit control	1966-70 LDV Exhaust	0%	100% approx.	0.12	0.10	0.48
Crankcase (PCV) retrofit control	1955-62 LDV Crankcase	93%	100% approx.	1.00	0.00	0.00
Rule 66 incentives & restrictions	Surface coating	0%	100%	0.50	0.00	0.00

2) Proposed EPA programs:

Program	Population Base (Vehicle Model Years or Sources) Affected	Percentage Population Base Afftd. in '70	Percentage Population Base Afftd. by '77	RHC Reduction Factor	CO Reduction Factor	NOx Reduction Factor
Annual Inspec. Maintenance	All LDV Exhaust	0%	100%	0.15	0.12	0.00
Oxidizing Catalyst Retrofit	1971-74 LDV Exhaust	0%	75%	0.58*	0.50	0.00
Oxidizing Catalyst Retrofit	1966-70 LDV Exhaust	0%	20%	0.58*	0.50	0.00
Dry Cleaning Solvent Control	All RHC Dry Cleaning Sources	0%	100%	0.90	0.00	0.00
New motorcycle emission standards, 1976 & later models	All motor-cycle Emissions**	0%	100%**	0.28	0.28	0.00
Degreasing Solvent Control	All RHC Solvent Sources	0%	100%	0.90	0.00	0.00

*This factor accounts for a hydrocarbon reduction factor of 0.5 and a lowering of the exhaust reactivity factor from 0.77 to 0.64. (See Section F.)

**While only new 1976 and later model years are affected, the entire population is included here because the reduction factors are derived on the basis of the total population.

Program	Population Base (Vehicle Model Years or Sources Affected	Percentage Population Base Afftd. in '70	Percentage Population Base Afftd. by '77	RHC Reduction Factor	CO Reduction Factor	NOx Reduction Factor
Petroleum Marketing Controls	All Petroleum Marketing	0%	100% approx.	0.87	0.00	0.00
Parking surcharge and review, bus & carpool priority treatment, & employees transit incentives*	All gasoline LDV and petrol, marketing emissions	0%	100%	0.14	0.14	0.14
Total gasoline ban	All gasoline vapor and combustion emissions	0%	100%	1.00	1.00	1.00
Total Diesel Fuel Ban	All HDV Diesel	0%	100%	1.00	1.00	1.00

*See Appendix C, "California VMT Reduction Summary," for a discussion of these and other VMT reduction measures.

The June 8, 1973 Federal Register discusses various mobile Source Control programs or tactics, and outlines the reduction factors associated with the tactics.

F. Hydrocarbon Reactivity Factors

Per recent EPA guidelines, the following factors indicate the weight fraction of hydrocarbons that are considered to be reactive (i.e., do not contain unreactive hydrocarbons which are methane, ethane, propane, benzene, acetylene):

Emission Source	Weight Fraction of RHC
Gasoline LDV exhaust	0.77
Gasoline LDV exhaust after catalyst treatment*	0.64
Gasoline HDV exhaust	0.79
Diesel HDV exhaust	0.99
2-stroke motorcycle exhaust	0.96
4-stroke motorcycle exhaust	0.86
Piston & turbine aircraft exhaust	0.90
Gasoline vapor	0.93

*This factor is to be applied to the exhaust of all 1975 and later LDV models, and to those pre-1975 LDV models that are to have retrofit catalyst devices installed.

Crankcase emissions are estimated to consist of equal amounts of uncombusted gasoline vapor and combustion vapor.

A rule 66 chemical definition of reactivity is used for the remaining emission sources.

APPENDIX B

Methodology for Determining the Base Year Oxidant Level

INTRODUCTION

This paper discusses a method for selecting the maximum values used in the calculation of emission reduction requirements.

The methodology described in this paper is neither new nor original. Dr. R. I. Larsen, Meteorology Laboratory, NERC, Research Triangle Park, outlined such a technique in 1967 and has published numerous papers since that time explaining the use of his model in the establishment of standards and in relating air quality measurements to such standards (Reference 1, 2, and 3).

The rationale for selecting this method is outlined and some of the advantages and shortcomings are covered. A comparison of actual measured values with model calculations is provided.

BACKGROUND

The development of a control strategy to achieve a National Ambient Air Quality Standard is frequently based on the premise that the concentration of a man-made pollutant in the ambient air is linearly related to the rate at which the pollutant is emitted in the atmosphere.

This assumption permits the use of a simple proportional (or rollback) model to determine emission reduction requirements. Such a model states that:

$$(100)\ \frac{\text{(current air quality)} - \text{(air quality standard)}}{\text{(current air quality)} - \text{(background)}} = \text{required reduction in percent}$$

Current air quality is defined as the maximum measured concentration.

The development of the transportation control strategies did not rely totally upon the rollback model. A non-linear relationship between oxidant levels and hydrocarbon emissions developed by Schuck (See Appendix B) was also employed. In some areas data was not available for the verification of such a non-linear model and the simple proportional relationship had to be applied.

Regardless of which of these models was used, the selection of an appropriate maximum concentration was a critical factor in determining the emission reduction requirements.

There are several methods that can be used to determine the maximum value needed for these"roll-back" calculations. Among such methods are:

a. Diffusion modeling

b. Selection of a maximum value from a base year

c. Choosing the highest value over a number of years

d. Determining a maximum value by statistical analysis

Diffusion modeling, where validated models can be applied, probably represents the best method for determining both the concentration and the location of high pollutant levels. Unfortunately, a model with the required accuracy is not yet available for determining specific oxidant concentrations.

The selection of a value from a base year, where the year is usually selected as the year of the latest emission inventory, has the advantage of being most closely related to the emission data. It also provides a convenient base for comparing data at different locations. However, high concentrations of oxidant occur under certain, as yet not fully quantified, meteorological conditions and different sets of these conditions may apply to the production of high levels at different locations. Since meteorological parameters do not necessarily follow an annual cycle, the adverse conditions producing high levels may not always occur every year at any given location. The data indicate that maximum levels at a particular monitoring station may vary from year to year by as much as a factor of two. High values within a given region do not always occur at the same site and maximum concentrations selected from all stations within a region may also vary considerably, although not usually by as much as they do at a single location.

Extreme values can occur either because of unusual meteorological conditions or because some abnormal periods would not necessarily be expected to occur every year but perhaps only once in 5 or 10 years. Thus, the selection of such an extreme value could require overly stringent control measures. Conversely, abnormally low values could also be selected if the data record is short.

A statistical analysis of data collected over a period of years tends to smooth out the variations due to the meteorology and to local anomolies. Such an analysis can also provide a prediction with a specified probability of occurrence and the extreme or outlying values can be weighed.

This paper compares the results obtained by applying a particular statistical method to the calculation of maximum oxidant levels with the actual measured maximum concentrations at selected stations from data collected over the past three years.

THE ANALYSIS

Selection of Technique:

The objective of the analysis was to find an oxidant level (concentration) that represented the highest level expected to be achieved with a frequency of one hour per year. The rationale for this objective is the National Ambient Air Quality Standards for oxidant: 160 ug/m3 (0.08 ppm) - maximum 1 hour concentration not to be exceeded more than once per year.

Although there are a number of statistical methods that could be applied, a technique described in the Office of Air Programs publication No. AP-89, "A Mathematical Model for Relating Air Quality Measurements to Air Quality Standards" by R. I. Larsen, November, 1971, seemed to best fit the objective. This model is based on the assumption that the air quality data fit a log-normal distribution. There is some disagreement about whether or not this is an appropriate assumption. For example, Mitchiner & Brewer (5) have suggested the use of a 'double-exponential' distribution. This is a widely known extreme value technique. Their analysis, however, was limited to data collected in three summer months and used only the maximum daily hour data. A report by Mosher, Fisher, and Brunelle (6) indicates peak oxidant concentrations of 0.50 ppm or greater have occurred in Los Angeles County in all months of the year except January and February. The selection of only certain months could, therefore, tend to bias the results. Additionally, extreme value techniques seem most applicable to the selection of an absolute maximum concentration and not necessarily to the concentration expected to occur once per year. However, a comparison of the values calculated by the Mitchiner-Brewer method indicate that they do not differ greatly from Larsen's method, at least at the one station covered in their analysis, even though a different data set was used.

Larsen (7) analyzed all oxidant data for all California stations for the period 1963-1967 and presented the cumulative frequency distributions and a calculated maximum concentration for each station. The tables in that publication were used in conjunction with later available measured data to determine the location (or areas) of the highest concentrations. Stations within those areas were then selected for further analysis. An attempt was made to obtain a three-year period of record for each station. It was felt that the period should be comparable to the latest emission inventory data available (in most cases this was 1970 data) and also should contain a sufficiently long period to help overcome the problem of meteorological variability. A period of 5 to 10 years would have been desirable, but because of the changing patterns of emissions and changing vehicular emission factors, it was felt that a period longer than three years would tend to introduce more emission variability than the meteorological variability that would be factored out. Data for 1972 were not available so the period January, 1969, through December, 1971, was selected. Unfortunately, there were many gaps in the record and data was not available for some of the desired stations.

Fourteen stations were finally selected for analysis and cummulative frequency distributions for the selected stations for the three-year period were then obtained. The data were analyzed according to Larsen (4). A sample of the frequency distribution used is shown in Figure 1.

CALCULATION OF MAXIMUM CONCENTRATIONS

The frequency distribution as given in Figure 1 is plotted on a logarithmic probability graph as indicated in Figure 2. If the data were perfectly log-normally distributed, all points on the graph would be on a straight line. As can be seen in Figure 2, this is not the case. However, the points in the frequency ranges from 10% to .01% do appear to closely approximate a straight line. Since these are the frequencies of most concern when considering very high values, only those points are considered. To find the value that would be expected once a year, Larsen (4) suggested using the .01 and the .10 frequency points and extrapolating the line connecting these points to the desired once per year frequency point. This was done for each location for which frequency distributions were available. The extrapolation can be done either graphically or mathematically. The mathematical method is as follows:

The desired frequency using this log-normal distribution is obtained from

$$f = \frac{r-0.4}{n} \quad (100\%)$$

where: r = the rank of the desired concentration if all the concentrations were ordered from one through the number of possible samples within a selected time period

f = the frequency of occurrence in percent

n = total number of samples

FOR EXAMPLE: To find the frequency corresponding to the highest one-hour average in a year, all of the 8760 one-hour averages in a year would be listed in order from 1 (the highest) to 8760 (the lowest). The rank order, r, then is equal to 1, n, or the total number of samples, is 8760, and

$$f = \frac{1-0.4}{8760} \quad (100\%) \quad = \quad 0.00685\%$$

Next, the extrapolation of the data to this desired frequency, using the two known concentration vs. frequency points, is as follows:

The equation of a straight line passing through two known points x_1y_1 and x_2y_2 is:

$$\frac{y - y_1}{y_2 - y_1} = \frac{x - x_1}{x_2 - x_1}$$

this can be rearranged so that

$$y = y_1 + \frac{y_2 - y_1}{x_2 - x_1}(x-x_1)$$

In this case the x and y without subscripts are the intercepts of the unknown point on this line.

Where we are using the log-normal distribution, the y intercepts are logarithms and the x intercepts are in terms of standard deviations from the median. In a normal distribution each frequency can be located as a distance (standard deviations) from the center of the profile (median).

If the y intercepts are logarithms, then the equation for the straight line becomes:

$$\ln y = \ln y_1 + \frac{\ln \frac{y_2}{y_1}}{(x_2 - x_1)} (x - x_1)$$

The concentration at an unknown point 'x,y' is then equal to the anti-logarithm of

$$\left(\ln y_1 + \frac{\ln \frac{y_2}{y_1}}{(x_2 - x_1)} (x - x_1)\right)$$

or to put it in another form:

$$\text{concentration at } y = \exp\left[\ \ln y_2 + \frac{\ln \frac{y_2}{y_1}}{(x_2 - x_1)} (x - x_1)\ \right]$$

where 'exp' indicates that 'e', the base of natural logarithms, is raised to the power in the brackets. 'e' is approximately equal to 2.71828.

Following Larsen's suggestion (8), the two known points at the .01 and the .10 percentile levels are used to define the straight line we wish to extend. From a statistical table, such as is given in Reference 3 on Page 30, the x intercepts at these percentile points can be determined. In the case of a log-normal profile, the .01 percentile point is 3.72 standard deviations from the median; the .10 percentile point is 3.09 standard deviations; and the unknown point at .00685% is 3.81 standard deviations from the median. The y intercepts are the concentrations at each of these percentile points. These x and y values are then substituted into the above straight line equation and the unknown concentration at the .00685% frequency is determined.

To illustrate the procedure, the data from Figure 1 have been replotted on Figure 3, and the points that are used below have been labeled.

frequency f(%)	concentration y(ppm)	standard deviations x
.00685	to be determined (y)	3.81 (x)
.01	.27 (y_1)	3.72 (x_1)
.10	.23 (y_2)	3.09 (x_2)

Substituting these values into the straight line equation:

$$\text{concentration at } y = \exp\left[\ \ln .27 + \frac{\ln\left(\frac{.23}{.27}\right)}{(3.09-3.72)}\ (3.81-3.72)\ \right]$$

$$= \exp\left[\ -1.30933 + \frac{(-0.16034)}{(-0.63)}\ (0.09)\ \right]$$

$$= \exp\left[\ -1.286424\right]$$

concentration at y = 0.28 ppm

From the example, a concentration of 0.28 ppm would then be the highest concentration expected to be reached (or exceeded) once each year.

These maximum concentrations were calculated for each of the selected stations within each Air Quality Control Region. The results are listed in Table 1.

TABLE I. Hourly average concentrations for selected frequencies of occurence.

LOCATION	Percent of time given concentration equaled or exceeded		
	0.10%	0.01%	0.00685%(Annual Maximum)
South Coast AQCR			
Riverside	0.34	0.56	0.60
Azusa	0.42	0.51	0.52
Pasadena	0.39	0.51	0.53
San Diego AQCR			
San Diego (8th & E)	0.16	0.23	0.24
El Cajon	0.27	0.30	0.30
Sacramento Valley AQCR			
Creekside	0.18	0.24	0.25
Chico	0.14	0.15	0.15
San Joaquin Valley AQCR			
Fresno (So. Cedar)	0.20	0.25	0.26
San Francisco Bay AQCR			
Livermore	0.24	0.32	0.33
San Leandro	0.19	0.27	0.28
Fremont	0.22	0.27	0.28

Data used in this Table were hourly averages for the period of January, 1969, to December, 1971.

It should be noted that these calculated concentrations are not necessarily the highest values to be expected. It is quite possible that this value could be nearly twice as high on an unusually "smoggy" day. Based on this analysis, however, such very "smoggy" days would not normally occur every year.

COMPARISON WITH MEASURED MAXIMA

The calculated maximum values were compared with the actual maximum values that have been reported within each of the Air Quality Control Regions since 1969. These values are shown in Table 2. In all cases the calculated maximum concentration is within .03 ppm of the actual measured maximum, even though an additional year of measured data was considered and the high value for the region may have been reported at a station other than one included in the calculations.

TABLE 2. Comparison of measured and calculated highest hour average oxidant concentrations calculated.

AQCR	Calculated Maximum	Station	Measured Maximum	Station	Year
South Coast	.60	Riverside	.62	Riverside	1970
San Joaquin	.26	Fresno	.24	Modesto	1972
San Diego	.30	El Cajon	.32	Escondido	1972
S.F. Bay Area	.33	Livermore	.36	San Leandro	1971
Sacramento	.25	Creekside	.28	Creekside	1972

The number of occurrences of concentrations in excess of the calculated maximum within each Air Quality Control Region was also tabulated. For comparison, the daily maximum hourly averages from 1969-1972 were used. The calculated maximum was equaled or exceeded three times in the San Francisco Bay Area, once in 1969 and at two separate locations on the same day in 1971. In the South Coast Basin the calculated concentration was exceeded once. In the San Diego Area twice, once each in 1971 and in 1972 in Sacramento once and once in the San Joaquin Air Quality Control Region.

Again, it should be noted that the calculated value represents a level that is expected to be reached or exceeded once per year and that the analysis does not attempt to predict the highest possible concentration. Thus, the occurrence of a concentration greater than the predicted value tends to verify the procedure if no other concentration measured during the year was equal to or greater than the calculated maximum.

EVALUATION OF METHOD

The fact that the calculated values are close to the actual measured concentrations and that the values have been reached or exceeded only once in a given year, would tend to indicate that reliability of Larsen's technique. There are, however, some obvious shortcomings to the analysis presented here. A full three-year period of record was not available from all of the air monitoring stations within each basin, nor from each of the stations listed in Table 1. The shorter the period of record that is available, the less reliable are the calculated values. To improve the reliability, additional data should be analyzed and a larger sample from each Air Quality Control Region should be selected.

Also, it was assumed that the stations selected represented the highest concentrations within the given Air Quality Control Region. This is not necessarily a valid assumption. Although only limited data is available, newly established monitoring sites appear to be recording higher values than some of the listed stations. For example, data from Escondido was used to develop the strategy in the San Diego Air Quality Control Region. The station was established in mid-1972 and the .32 ppm oxidant measured there represents the highest concentration within the San Diego metropolitan area in recent years. Agencies are usually continually expanding their networks to include new areas of high concentrations, and additional analyses should be performed as new data become available.

The calculations were based on the data measured during the years 1969-1971. They reflect only the emissions during that period of time. Assuming no changes in emission patterns or emission controls at the source, these values could be used to predict future air quality. However, none of the areas considered are static with respect to growth, or to the numbers and ages of motor vehicles in operation, or even with respect to the numbers of and outputs from stationary sources. Some care should be exercised in attempting to relate the concentrations to emissions in areas of rapid growth.

The oxidant data do not exactly fit a long-normal distribution and the degree of fit varies at different locations. Thus, use of this method may result in more reliable results in some areas than in others. Also, the calculated maximum is quite sensitive to the selection of the percentile points used in the calculations especially where the log-normal fit is poor. Larsen (4) has suggested the use of the concentrations at the .01 and .1 percent frequencies as being most representative of the distribution of the higher concentrations. In some instances it appears that the point at the .01 percentile fits the overall log-normal distribution least well. The problem is particularly evident when a short period of record is used. In most of the data examined, use of the .1 and the 1 or the 10 percentile points would result in higher maximum levels than when the .01 percentile is included. This would indicate that for some reason, probably meteorological, the maximum possible values are not achieved. In other cases the .01 percentile value seems too high. A study of the individual days could perhaps provide an answer to the reasons why some of the high values seem out of line.

The calculation of the maximum value is quite simple, but it does require the preparation of cumulative frequency distributions. These distributions are best processed by computer because of the large amounts of data required. Once they are available, several other analyses can be performed (see Larsen, 3). Additionally, a comparison of the different yearly and three-year distributions suggests a possible method for trend analysis.

SUMMARY

Air quality data for a number of California air monitoring stations were reviewed and analyzed according to a method suggested by Larsen. The objective of the analysis was to determine a maximum oxidant concentration for certain Air Quality Control Regions that could be related to the available emission data and used to determine the emission reductions needed to achieve the National Ambient Air Quality Standards.

Because of the variability of concentrations from year to year, at least a three-year period of record would appear to be required for analysis. This limits the selection of maximum concentrations to these stations where data have been collected over that long a period and could eliminate areas where higher concentrations are possible.

Although values obtained in this analysis compare favorably with measured conentrations, other statistical approaches may provide equally meaningful solutions and should be compared with this method. The method outlined in this paper, however, is relatively simple and well documented and is applicable to all pollutants. The use of some statistical approach is certainly less arbitrary than the selection of one particular measured concentration.

ACKNOWLEDGEMENTS

The author is indebted to Dr. R. I. Larsen of the Meteorology Laboratory for his assistance and Mr. Don Worley of the Data Systems Division for providing the necessary frequency distributions.

REFERENCES

(1) LARSEN, R. I. (1967) "Determining Reduced Emission Goals Needed to Achieve Air Quality Goals - A Hypothetical Case," YAPCA 17, pp. 823-829

(2) LARSEN, R. I. (1969) "A New Mathematical Model of Air Pollutant Concentration, Averaging Time and Frequency," YAPCA 19, pp. 24-30

(3) LARSEN, R. I. (1971) "A Mathematical Model for Relating Air Quality Measurements to Air Quality Standards," Publication AP-89, U. S. Environmental Protection Agency, Research Triangle Park, NC 27711

(4) LARSEN, R. I. (1973) "An Air Quality Data Analysis System for Interrelating Effects Standards, and Needed Source Reductions," presented at WMO-WHO Technical Conference on Observation and Measurement of Atmosphere Pollution, Helsinki, Finland, July 30 to August 4, 1973

(5) MITCHINER, T. L., and BREWER, J. W., "A Comment on the Method Used by EPA to Calculate Required Reductions in Emissions," University of California at Davis, unpublished

(6) MOSHER, T. C., FISHER, E. L., and BRUNELLE, M. F. (1972) "Ozone Alerts in Los Angeles County," Air Pollution Control District, County of Los Angeles, CA

(7) LARSEN, R. I. (1971) "Air Pollution Concentrations as a Function of Averaging Time and Frequency

(8) LARSEN, R. I. (personal communication, 1973)

Figure 1

CONCENTRATION VS AVERAGING TIME AND FREQUENCY FOR

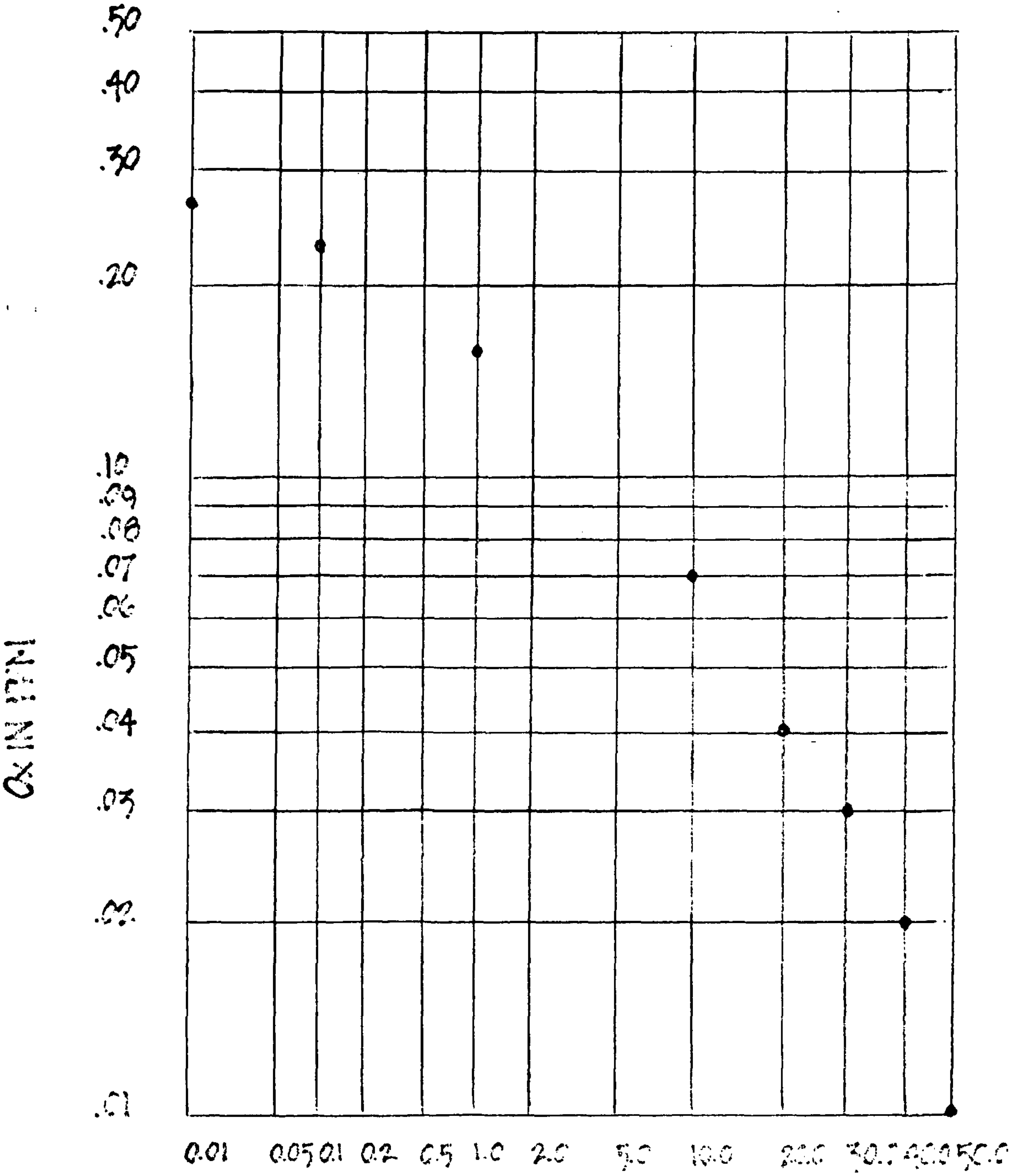
OXIDANT (PPM): LOS ANGELES, S. SAN PEDRO ST. STATION 001

JANUARY 1, 1968 TO DEC. 31, 1971

PERCENT OF TIME CONCENTRATION IS EQUALED OR EXCEEDED

AVERAGING TIME	MEAN	MAX	MIN	PERCENT	0.001	0.01	0.1	1	10	20	30	40	50	60	70	80	90	99	99.9	99.99	99.999	99.999
5 MIN	000.	000.	000.	000.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	000.	000.	000.	000.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	000.	000.	000.	000.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30	000.	000.	000.	000.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1 HOUR	0.03	0.33	0.01	069.	0.33	0.27	0.23	0.16	0.07	0.04	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
3	0.03	0.27	0.01	072.	0.27	0.27	0.21	0.15	0.07	0.04	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
3 6-9 AM	0.01	0.05	0.01	073.	0.05	0.05	0.04	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
8	0.03	0.21	0.01	073.	0.21	0.21	0.18	0.13	0.07	0.04	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
12	0.03	0.12	0.01	073.	0.12	0.12	0.10	0.08	0.05	0.04	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01
1 DAY	0.03	0.10	0.01	074.	0.10	0.10	0.09	0.07	0.05	0.04	0.04	0.03	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01
2	0.03	0.09	0.01	074.	0.09	0.09	0.09	0.07	0.05	0.04	0.04	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01
4	0.03	0.07	0.01	075.	0.07	0.07	0.07	0.06	0.05	0.04	0.03	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01
7	0.03	0.06	0.01	075.	0.06	0.06	0.06	0.06	0.04	0.04	0.03	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01
14	0.03	0.06	0.01	075.	0.06	0.06	0.06	0.06	0.04	0.04	0.03	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01
1 MONTH	0.03	0.05	0.01	075.	0.05	0.05	0.05	0.05	0.04	0.04	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01
2	0.03	0.05	0.01	075.	0.05	0.05	0.05	0.05	0.04	0.04	0.03	0.03	0.03	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01
3	0.03	0.04	0.02	075.	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
6	0.03	0.03	0.02	075.	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
1 YEAR	0.03	0.03	0.02	075.	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
2	0.03	0.03	0.03	050.	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
3	0.03	0.03	0.03	100.	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
6	000.	000.	000.	000.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Figure 1. Cumulative frequency distribution of oxidant concentrations for Los Angeles, Downtown station.



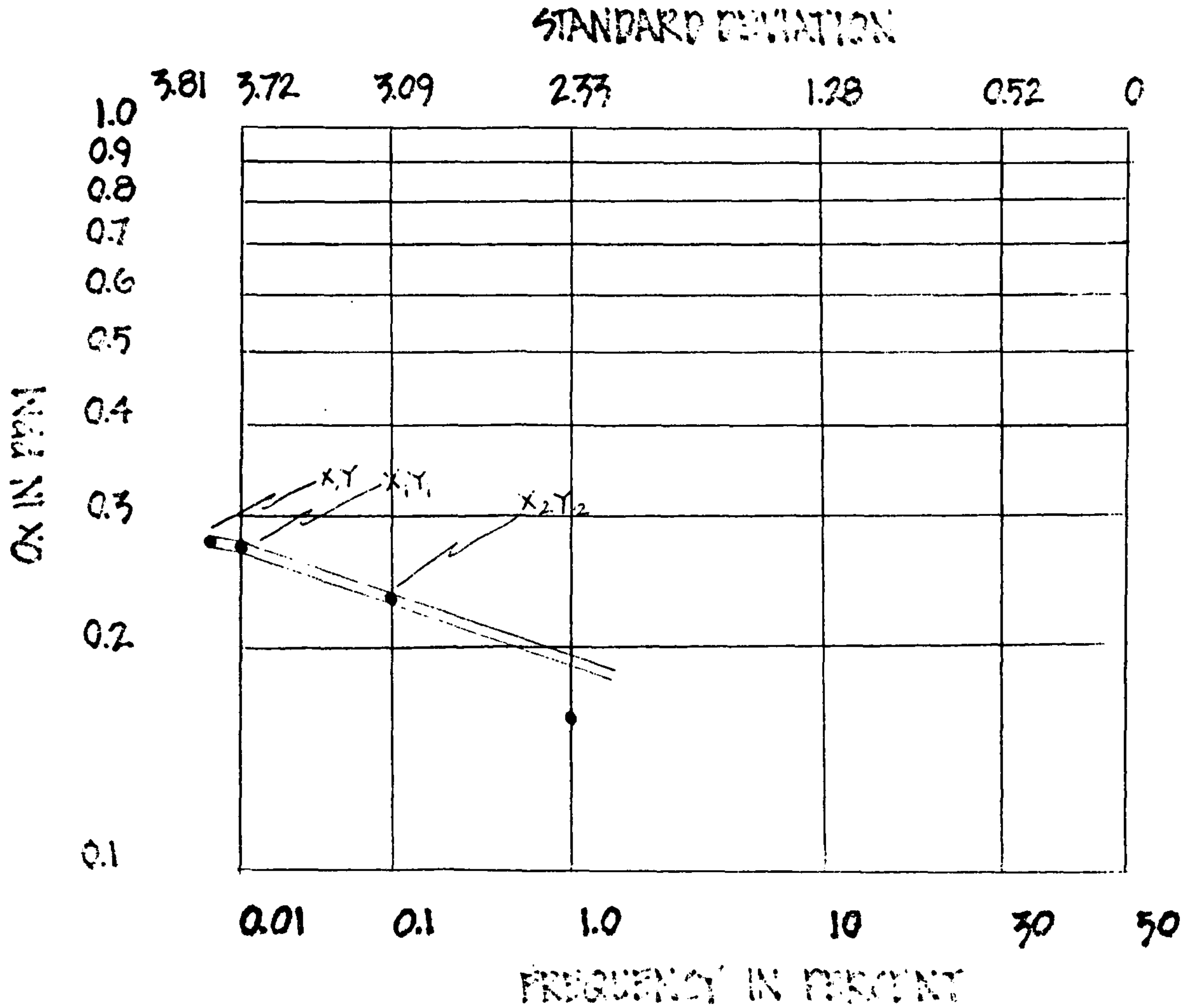
CUMULATIVE FREQUENCY DISTRIBUTION PLOT

DOWNTOWN LOS ANGELES 1969-71

FIGURE 2

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

REGION IX



MAXIMUM OXIDANT CONCENTRATIONS

EXAMPLE CALCULATIONS

FIGURE 3

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION IX

Appendix C

CALIFORNIA VMT REDUCTION SUMMARY:

Presentation of Analytic Basis
for
VMT Reduction Estimates

SUMMARY

Purpose

It is the purpose of this paper to summarize recent studies relating various transportation control measures such as car pooling, bus lanes, gasoline sales limitations, etc., to VMT reductions. In particular, the paper includes those measures proposed for California Transportation Control Plan (TCP).

Concentrating on the measures proposed by EPA and local AQCR task forces, the paper shows the range of VMT reductions that can be expected from the TCP measures individually and combined in a complementary strategy for each AQCR. Determinations of the effective range of VMT reductions achieveable are based on application of various transportation modal split models developed for the purpose of predicting commuter transportation patterns.

Most of the effects of measures promulgated by EPA are predictable within a range of certainty. Results of pilot studies and public reaction attitude surveys have been used as inputs to the data base. Measures that can not be assessed quantitively at this time or that have delayed effects and are unable to effect air quality fast enough for the Clean Air Act standards are not included in EPA promulgation. However, many of these measures have future short and long-term potential. EPA encourages local proposal and implementation of these measures.

Although the socio-economic impact of VMT reduction measures is important, the scope of this analysis is limited to the technical effects. Many of the studies done for EPA have addressed the socio-economic questions.

I. INTRODUCTION

THE ROLE OF VMT MEASURES

In the majority of air quality control regions requiring additional controls, the combined impact of stricter controls on stationary sources and the establishment of an inspection and maintenance system will not provide emission reductions adequate to achieve the air quality standards by 1975. Consequently, EPA has promulgated a variety of measures to reduce vehicle miles traveled in these regions. In several urban areas a shift from present reliance on automobiles occupied by one or two persons to a greater reliance on other forms of transit is essential to the achievement of the air quality standards. Significant reductions in vehicle miles traveled can also be accomplished within a limited time span.

The States have had practically no experience with transportation control measures as a means of dealing with air quality problems and the success of particular VMT reduction measures is difficult to predict. However, recent developments involving bus lanes, mass transit improvements, carpool programs, bikeways, and other innovations indicate that many VMT reduction measures are available and feasible. Furthermore, attitude surveys show that the public in many of our urban areas recognizes the need to place less emphasis on the automobile for urban mobility and is already encouraging the implementation of steps to develop alternative forms of transit.

Some of the regulations being promulgated will have significant effects on the future development of urban transportation in the major cities of this country. A clear implication of these air plans is that future augmentation of mass transit must focus not only on the center city streets but also on urban/suburban routes. It is expected that the regulations will lead not only to substantial reductions in air pollution, noise, congestion, and energy comsumption, but to the development of more mass/rapid transit to serve the growing urban and suburban regions of the nation. The need, desirability, and feasibility of reducing urban auto use are no longer issues. The problem is determining the degree to which VMT reductions can be reasonably implemented within the limited time frames.

The amount of VMT reduction that can be considered "reasonably available" varies greatly according to a city's individual characteristics and the ability of other modes of transportation to absorb the demand that would be created by a significant VMT reduction. A measure cannot be considered "reasonably available" if putting it into effect would cause severe economic and social disruption. Although some reduction in personal travel could certainly be absorbed without disruption, to achieve a significant VMT reduction, the bulk of the travel displaced from single-passenger automobiles must be absorbed by such other modes of transportation as carpools, walking, bicycling, or public transit.

The significant expansion of public transit facilities that can be accomplished by 1975 depends on the upgrading and expansion of bus service. Much can be done in this regard. Scheduling and service can be improved. Individual lanes of freeways and other major roads can be set aside for the exclusive use of buses. Significant numbers of new buses can be purchasds and put into service by 1975; according to the Department of Transportation figures, 2,500 transit buses were sold in this country in 1972, but there is considerable potential for expansion of the transit industry's production by two or three-fold. Foreign sources of supply could provide additional resources.

The Environmental Protection Agency is working with the Department of Transportation to assure increased Federal support for short-term augmentation of mass transit capacity and appropriate modifications of highway facilities to permit increased utilization of mass transit.

In addition to public transit, part of the transportation demand created by VMT reductions can be absorbed by carpools. Private automobiles, which are designed to carry four to six persons, carry an average of 1.1 to 1.4 persons per trip for work trips in major urban areas, and thus represent the largest unused pool of transportation capacity presently available.

The measures mentioned above are primarily concerned with providing an alternative to low-occupancy use of private automobiles. Although measures such as buying more buses and improving bus service, providing for carpool programs, building bicycle paths, and (possibly in the long run) building new rapid transit systems increase the availability and attractiveness of alternative transit forms, VMT reductions will not necessarily be achieved unless disincentive restrictions are placed on the use of automobiles.

The applicability of both measures--incentives such as bus lanes that increase the attractiveness of alternative transit forms and disincentives such as parking limitations that discourage the low-occupancy use of private automobiles--varies according the the conditions in the individual urban area. For example, bus lanes are a more appropriate strategy in Washington, D.C. than certain other areas. Similarly, parking restrictions are more applicable to a major center like Boston than to a small city with few transit alternatives like Fairbanks, Alaska.

After consideration of the already available transit alternatives, the city's local conditions, and the applicability of various incentive and disincentive measures, the

EPA has determined that varying degrees of VMT reduction are feasible in particular areas. The Agency believes a 3 to 10 percent VMT reduction can be achieved in some of the regions by 1975. Since the Clean Air Act specified that all reasonable available measures be instituted before any time extension is granted, the Administrator is taking into consideration all VMT-related measures presently being implemented by a municipality and augmenting those measures with methods that are available, applicable, and adoptable in the individual area by 1975.

Through studies and the public hearing process, the Agency has also determined that it may be unrealistic to expect reductions in auto use greater than 10 to 20 percent by 1977. Generally, reductions beyond 10 to 20 percent would require a special and, in most cases, unreasonable effort unless driving is to be cut without a corresponding increase in mass transit. Achievement of even the levels provided for in these plans will require a strong commitment by local areas to implement strict disincentive programs, improve mass transit, and make carpooling or other programs work.

EPA has promulgated a number of measures designed both to increase the attractiveness of alternative forms of transit and to discourage the low-occupancy use of automobiles. The measures include: regulatory fees for mass transit augmentation, bus/carpool lanes, carpool matching systems, and carpool programs stressing preferential treatment. Local task forces have proposed additional measures, applicable to their particular regions, that will be implemented along with EPA strategies. These measures include: traffic flow improvements, ramp metering, fringe parking for park and ride, dial-a-ride service, bicycle lanes and facilities, reduced transit fares, four day work weeks, and taxation and pricing measures.

State, Local, and Federal Implementation of Control Measures

In order to preserve the intent of the Clean Air Act that pollution problems be dealt with primarily at the local level, the Agency is requiring that State and local governments take action wherever possible and will involve the Federal Government only in the direct implementation of some programs. State and/or locally enforced, Federal promulgated requirements are: retrofit programs; parking supply and surcharge; bus and carpool lanes; inspection and maintenance; and stationary source controls. Federally operated programs will be: motorcycle controls, gasoline limitation, and a bus/carpool incentive regulation directed at major employers.

DESCRIPTION OF EPA PROMULGATED VMT REDUCTION MEASURES

Bus Lanes

Bus priority treatment consists of allocating highway facilities preferentially to buses for the purpose of improving the quality of bus service. Methods of effecting bus priority treatment in the transportation plans include reserved lanes for buses (and/or carpools), preferential access for buses at metered freeway ramps, and certain traffic engineering improvements. The forms of bus lanes set forth in either the plans proposed or approved by the States or promulgated by EPA include normal bus flow lanes, and contra-flow lanes. In California, the Department of Transportation suggested that only certain freeways or major roads be dedicated to the bus lane concept and EPA agreement with this suggestion is reflected in these promulgations. The method of selecting the lanes has been changed from one based on the number of lanes in the road to one looking to the establishment of a coherent network of such lanes along transportation corridors. In some regions, pilot programs will be conducted to discover the best way to implement a full-scale program. In some cases, measures such as the conversion of entire streets to bus and carpool use may prove preferable to limited lanes.

The use of bus (and/or carpool) lanes has been observed to increase mass transit freeway speeds by a factor of two or more. Through the elimination of congestion problems, bus service dependability is increased as late arrivals are significantly reduced. Furthermore, bus ridership will increase, and the fares may eventually be reduced. Because of these factors, the regulations set forth for bus lanes are expected to be a positive inducement to increased bus patronage. The timetables for implementation of bus lanes will vary according to regional situations.

Carpool Systems

Experience to date with carpool programs suggests that policies to encourage carpooling might double auto occupancy rates for downtown peak period work trips. If a 10 to 50 percent increase in auto occupancy is adopted as a realistic range of possible effects, the net effect of carpool policies on total urban area auto use might be a 5 to 10 percent reduction.

EPA is promulgating measures that provide computerized carpool matching programs and preferential carpool treatment programs. The matching program provides for the formation of carpools and the preferential treatment programs provide incentives such as free parking to encourage carpools. Under the measures included in some plans, disincentives such as parking space reduction or paid, rather than free parking, are included to discourage single occupancy on commuter trips.

In all Regions EPA is requiring the establishment of carpool matching systems to enable persons with similiar daily travel patterns to make contact with each other and arrange carpools. In some regions, pilot programs will be established prior to establishment of the system throughout the region. Such a measure is necessary if the restraints on individual vehicle use contained in this plan are to have the desired effect of reducing VMT.

The EPA Regional Office in San Francisco has contacted various Federal agencies in order to facilitate the implementation of the pilot programs called for in the regulation. The Regional Office has experienced initial success in its first contacts, and this effort is continuing. A detailed guide for the operation of a bus/carpool matching program, along with a discussion of a number of successful programs in operation in many areas of the country is found in a U. S. Department of Transportation Federal Highway Administration Publication "Carpool and Buspool Matching Guide (Second Edition)", May 1973. This report discusses the considerations involved in a successful program such as public information, incentives, data processing, and a continuing updating of the service, and is an excellent guide and reference for conducting such a program.

The EPA believes that this approach to reducing vehicle miles traveled is an excellent short-term strategy. It involves a minimum investment and deserves the active promotion and support of government and industry.

Employer Provisions for Mass Transit Priority Incentives

As was pointed out in the public hearings by some of those testifying, employer-paid privileges for employees tend to encourage employees to drive to their place of employment rather than use carpools or mass transit. The promulgated regulation therefore, provides for employer-paid mass transit fares and special parking privileges to those who travel in a carpool. It also requires that individuals who drive may not be provided with free unlimited parking, but must pay the prevailing surrounding parking rate.

This regulation will be implemented in stages, the first stage applicable to employers of 700 or more employees, and the second to employers of 70 or more.

The purpose of this regulation is to effect sizeable reductions in VMT caused by commuting, with appears to be the mode of travel most easily diverted to mass transit and car-pools.

<u>Control of Existing Parking Spaces</u>: <u>Surcharge on Parking</u>

The proposal that spaces in public parking facilities be reduced by 20 percent drew almost universal adverse comment during the rulemaking proceedings. At the same time, the use of regulatory fees to discourage pollution-causing activities was widely supported. In particular the use of fees to control parking was mentioned.

EPA also believes that the use of such parking fees has much to recommend as a matter of policy. Accordingly, EPA is not promulgating a reduction in publicly owned parking spaces and is instead promulgating a regulatory fee to increase the price of parking in, and so discourage traffic to, selected trip attraction centers in the three most heavily polluted AQCR's. The regulation's coverage will be increased in three phases. At least 50 percent of the revenues will be used for mass transit.

Several of the plans call for the imposition of regulatory fees on parking. In earlier Notices of Proposed Rulemaking, the Agency expressed some doubt about its authority to impose such fees. That legal question has been extensively reexamined, and EPA has now concluded that such a step is authorized by the statute. The transportation control measures promulgated by EPA will require a significant change in the driving habits of the American people. The use of fees can help to bring that change about with a minimum of social disruption of the wide latitude they leave to individual choice. Those whose needs or preferences are strongly in favor of using the single-passenger automobile may continue to do so, although at a somewhat higher cost; those who can easily adapt to the use of other modes of transportation have a financial incentive to do so. Many public comments supported the adoption of such fees. In addition, the enforcement of such fees will be less difficult than some other measures. Finally, such fees will be used to support mass transit. Expansion of mass transit is essential if the disin-centives to automobile use imposed by transportation control plans are to have the desired effect. Such a use of the proceeds will also greatly mitigate the potentially regressive nature of such fees.

In requiring the States and EPA to impose transportation controls where they are needed to meet air quality standards, the Congress imposed a regulatory task whose difficulty and complexity are virtually unparalleled. The legislative history shows that Congress fully recognized the magnitude of the problem. At the same time, the statute's description of the exact types of measures that may be imposed is extremely broad and general. In the face of this broad language, the Administrator concluded that the Congress intended him to impose the method of control that he determined was best able to achieve the purposes of the statute.

Parking Management Program

The proposal for review of new commercial parking facilities has been modified, from an earlier proposal, to allow a wider range of variables to be considered. In essence, the regulation promulgated today would forbid the construction of any facility that could be expected to lead to a VMT increase unless either (1) the application retired from service or caused the retirement from service of an equal number of spaces elsewhere in the AQCR, or (2) the applicant could show in a separate hearing devoted only to that question that the impact of the proposed facility on VMT, and thus air quality, would be insignificant.

The promulgated regulations will require that the appropriate local government submit to the Administrator a plan outlining the locally planned expansion of parking facilities for the next five years. If a submittal is not made that shows to the satisfaction of the EPA that such planned parking expansion does not conflict with the California State Implementation Plan, the EPA will review each proposed new parking facility individually. Such review by either the State or EPA will be consistent with the previously discussed complex sources regulations to be promulgated shortly.

Motorcycle Controls

In the July 16, 1973, proposal, regulations were included that would have restricted 2-stroke motorcycle operations during the "smog season" in California. This action was taken due to the very high pollution potential of the 2-stroke motorcycle. The average 2-stoke motorcycle emits approximately 31 times as much exhaust hydrocarbons per mile as a new California 1975 automobile will emit. Consequently, prevention of increases in the number of motorcycles was proposed to prevent counterproductive shifts from automobiles to motorcycle as a result of other elements of the control strategy. The Agency has evaluated the feasibility of establishing emission standards for new motorcycles and is currently evaluating the availability of motorcycle emission control technology for existing motorcycles to reduce emissions.

Based upon testimony presented by motorcycle manufacturers, testimony presented by motorcycle trade associations, and an independent analysis by the Environmental Protection Agency, it appears that significant reductions in the emissions from new motorcycles can be achieved.

Accordingly, the EPA is no longer requiring an unconditional ban on motorcycle operations. Instead, the ban regulation has been rewritten to provide that it will not go into effect in the event that nationally applicable Federal regulations are promulgated that require at least a 50 percent reduction of 2-stroke motorcycle emissions by 1976 and conformity with the 1976 automobile standards by 1979. Comparable emission reductions will be required of 4-stroke motorcycles.

Vehicle Free Zones - Not Promulgated

Traffic free zones are primarily promulgated to control local carbon monoxide problems. The zones are necessarily restricted in size (approximately ten blocks or less) in order to provide foot access. Consequently, the zones can be put into effect by 1975 since no additional transit facilities are required. Although increasing the size of the vehicle free zone tends to increase the potential air quality improvements, such action also increases the problems of access, circulation, and peripheral congestion and pollution.

Selective Vehicle Use Prohibitions - Not Promulgated

In several regions, EPA proposed a regulation under which the vehicle population would have been divided into five categories. Each category of vehicles would have been required to display prominently a tag of distinctive color; on one day of each working week vehicles marked with one such color would have been forbidden to operate.

Testimony at all the public hearings indicated that measures of this type so far proposed would be unenforceable because of their severeness and arbitrary nature. In addition, the number of additional enforcement personnel necessary to implement such a program would then have been so great as to preclude the reasonable availability of this measure. Were they to be implemented, many very workable methods of evading the requirements would doubtless be devised.

Gasoline Supply Limitations

The proposed transportation controls included measures to limit the gasoline supply in certain areas in order to reduce vehicle miles traveled. The measure included two types of regulations: (1) a gasoline supply lid that would become effective in 1974 to limit the quantity of gasoline sold to fiscal 1973 levels; and (2) a regulation to be implemented on May 31, 1977, to reduce an area's gasoline supply, and thus VMT, to the extent necessary to achieve the standards.

The gasoline supply requirement has been dropped as a primary measure. The Act requires that all "reasonably available" measures must be implemented by May 31, 1975, before granting an extension. Based upon the comments received at the public hearings on this measure and the Agency's evaluation of the feasibility of implementing and administering successful gasoline supply limitations, the Administrator has determined that a gasoline supply lid cannot be considered "reasonably available." The possibilities of evasion, the likelihood of noncompliance, and the difficulty of enforcement are too great to make this measure practicable at this time.

The gasoline supply reduction regulation to be implemented on May 31, 1977, however, has been retained in several plans. As was noted above, the Clean Air Act required air quality standards to be achieved by 1977 without regard to cost or social disorganization that may result as a by-product of achievement. If gasoline supply limitations are needed to achieve the standard, the "reasonableness" criteria is not a determining factor. Accordingly, the Administrator was obligated to use gasoline supply limitations as a final resort measure in certain areas with severe air pollution problems. Most of these areas required reductions in vehicle miles, traveled far in excess of 10 to 20 percent. In some regions, however, the required VMT reductions may well be accomplished through the specified VMT reduction measures. Gasoline supply limitations were required in these areas only to assure the attainment of the standards by 1977. If a review of air quality data and VMT reduction monitoring information prior to 1977 indicates that the gasoline reduction measure is not required, supply limitations will not be implemented.

ADDITIONAL VMT REDUCTION MEASURES - LOCAL PROPOSALS

State/Local Task Forces

State/local task forces have been formed in all AQCRs (except the Southeast Desert) covered by this promulgation to develop alternatives to the EPA-proposed control measures, with the goal of developing draft plans by mid-October 1973. Meetings were held between the task force and EPA representatives to discuss potential alternatives for inclusion in the EPA control plan promulgated for each AQCR. Although the EPA promulgations are not wholly comprised of recommendations of the task forces, EPA hopes that they will more properly reflect reasonable and locally acceptable measures to improve air quality in each AQCR. EPA also hopes that the recommended alternative plans being developed by the task forces later this fall will be approvable by EPA and will allow EPA to rescind its regulations.

The membership of the task forces follows:

Los Angeles: District VII Cal/Trans, California Air Resources Board, City and County of Los Angeles, California Highway Patrol, Southern California Association of Governments, Los Angeles County Air Pollution Control District, Southern California Rapid Transit District, South Coast Air Basin Coordinating Council, the League of California Cities.

San Francisco: District IV Cal/Trans, California Air Resources Board, San Francisco Bay Area Metropolitan Transportation Commission, Association of Bay Area Governments, and the Bay Area Pollution Control District.

San Diego: District XI Cal/Trans, California Air Resources Board, San Diego Comprehensive Planning Organization (CPO), San Diego County Office of Environmental Management, San Diego County Pollution Control District, City of San Diego, the San Diego Unified Port District, and San Diego Rapid Transit District.

San Joaquin Valley: Cal/Trans, California Air Resources Board, County, City, Regional, Fresno Community Council, local transit officials, and county, city, and governmental bodies including the Fresno County Air Pollution Control District.

Sacramento Valley: Cal/Trans, California Air Resources Board, Sacramento Regional Area Planning Commission, county, city and regional governmental bodies, and the Sacramento Regional Transit District.

Four-Day Work Week Schedule

The four-day week would reduce VMT generated in work commute travel. Like staggered work hours, this would be a useful measure if there were a localized, temporal problem in employment concentration areas. However, indications are that increased recreational and other non-work travel will fully replace if not exceed the reductions in VMT resulting from decreased work commuting. Thus, this measure does not respond well to hydrocarbon emission problems.

Staggered Work Hours

Changes in work schedule by staggering work hours have been proposed as a control measure in some cities as they tend to produce some flow improvements by reducing commute period traffic congestion. This measure, however, would produce only marginal reduction in emissions.

Staggered work hours do not decrease total daily VMT but simply spreads the time of VMT generation. Such a strategy is most applicable when the problem is a short duration, localized concentration of pollutant, which results from temporal concentration of traffic flow. High concentrations of carbon monoxide are most typical of this type of problem. Staggered work hours, however, also tend to reduce the potential for car pooling, a measure which relates well to hydrocarbon emission reduction, since it tends to directly reduce VMT.

Traffic Flow Improvements

Measures to achieve emission reductions through improved traffic flow fall into two categories: construction of new major traffic facilities (freeways, expressways and major arterial linkages); and operational improvements to existing streets and highways. The emission reductions are brought about by increases in vehicle speeds, reduced idling, and a general shortening of trip times.

Major facility construction normally enables significant increases in vehicle travel speed in the corridors affected but also tends to activate latent travel demand. In the long run this reinforces auto dependence and increases vehicle miles traveled. Over the short-range time frame of primary concern in this study, the air quality impacts of new traffic facilities can be assumed positive.

Operational improvements to existing streets and highways cover a broad range of programs. These include freeway improvements such as ramp metering and removal of bottlenecks; and surface street improvements such as area wide signal system integration, intersection channelization, minor widening of streets and intersection approaches, institution of one-way street systems, and the like. Because they do not produce dramatic shifts in accessibility, operation improvements generally do not lead to activation of latent travel demand and their near-term impact on emissions and air quality is assessed as positive but their specific contribution to areawide emission reduction is small and difficult to quantify. At best, the planned operational improvements can be expected to accommodate an ever increasing amount of travel without decrease in the level of service.

Ramp Metering

Ramp metering is used to optimize the efficiency of traffic movement in a freeway corridor. Metering also has potential utility for shutting down the freeway for episode control, and as a means to provide preferential entry for vehicles that have a higher utilization (car pools, buses).

Mass Transit Improvements

Since personal travel requirements cannot be diminished, some form of transportation alternatives must be provided if vehicle use is to be reduced, particularly if vehicle restraints are implemented. One form for these alternatives is public transit.

Improvements to public transit systems include both extensions and/or upgrading of bus systems and provision of rapid transit on separate rights-of-way. In conventional bus operation, improvements include level of service (area of coverage, headway, etc.) betterment and amenity promotions (air conditioning, bus stop shelters, etc.). Most of the urban areas already have or are in the process of setting up transit districts to expand public transit service. These could result in significant patronage increases, but it is unlikely that such improvements would induce major shifts of choice riders from auto to transit without a system of concurrent disincentives for single occupancy use of the automobile.

Fringe Parking, Dial-A-Ride, Jitneys

Fringe park and ride facilities could allow suburban commuters to park their cars on the peripheries of urban areas and then take either mass transit or carpools into the central business district. To have significant impact on lowering emissions, local meterological conditions in a specific geographical area would have to be suitable. For instance, if such a facility were in a basin, the amount of pollution reduced would be diminished. Dial-a-ride and jitney service could serve as feeders to either mass transit or carpool rendezvous points, in addition to serving as a primary means of transit.

Network of Bicycle Paths and Facilities

Greater use of bicycles could be encouraged through designation and protection of bicycle lanes and incorporating bike/pedestrian paths in new developments. A recent EPA study suggested that increased use of bicycles in urban commuting could reduce auto vehicle miles traveled by as much as three percent in some areas particularly amenable to bicycle travel.

Imposition of restraints on auto usage, particularly measures like gas pricing and rationing, could be expected to encourage bicycle use. The greatest increase in bicycle ridership would probable occur for children in getting to school, recreation, etc., as parents pre-empt the car for more essential functions. Work trips by bicycle could be encouraged by providing exclusive bike lanes in city streets and a carefully laid out bicycle grid system.

Free or Lower Transit Fares

Lowering the fare is one of the more effective means of improving the competitive position of transit vis a vis the automobile, particularly for intercity travel. However, very little travel diversion from auto could be expected from short trips, or from longer trips where time is valued over price (see TRW and DOT travel demand elasticities models).

Accompanied by auto use time penalty strategies or mass transit time savings measures, lower fares could play a more important role in reducing VMT.

Tax Disincentives

A "pollution" tax could be charged in direct ratio to the emission rate and mileage of each motor vehicle or to increase the tax on gasoline (consumption varies directly to mileage). Schemes to reduce vehicle mileage through gasoline pricing may be very effective if prices are set high enough. If imposed indiscriminately on all segments of society, the largest impact is felt by limited income groups.

Various taxes on automobiles have been proposed. Low fees are not effective in reducing VMT and high fees are extremely regressive. Substantial registration fees on second or third family autos might provide reductions in VMT and still avoid some of the more regressive elements of this type of taxation.

Tolls

The imposition of tolls on freeways is a potential method of regulating road use. It is possible, however, that a high percentage of those priced off the freeways by tolls may drive on surface streets rather than shifting to car pools or transit. This could produce increased emissions as a result of reduced travel speed and idling on surface streets. Tolls also tend to be regressive since many of those priced off the roads will be low income persons.

Gasoline Limitation

Recent increasing fuel demands and the predicted fuel shortages may cause some gas rationing in the near future, and therefore result in a VMT reduction. However, this would be a by-product, and not a TCP stragegy. Administrator Train recently announced a decision not to use gasoline limitation as a TCP strategy, if possible. Studies have been done evaluating the impact of schemes to raise the price of gasoline and thus reduce consumption. The use of gasoline is inelastic in lower price ranges and more elastic with higher prices with increased effects if accompanied by a range of other VMT reduction incentives. Experience in European countries shows that even when a gallon of gasoline is priced as high as $1.50 a gallon, VMT rates continue to grow. TRW [Ref. 1] estimates that it would take two years to evaluate the effects of raising the price of gasoline. However, a gas tax accompanied by other pricing penalties on private use of the automobile - parking surcharge, tolls, high registration fees on second and third cars, emission taxes - would help decrease VMT as well as contribute funds to mass transit.

II. ANALYTIC BASIS OF VMT REDUCTION ESTIMATES

To evaluate the relative effectiveness of various VMT reduction strategies, it is necessary to have analytical methodology which can predict the potential transit ridership of average automobile occupancy rates for a set of critical variables. Unfortunately, it is very difficult to quantitate the factors people use to rate the attractiveness of car pools relative to driving alone or riding in a bus. Many of the measures EPA and the local task forces have designed to reduce VMT are untried. EPA has gathered the available data and studies that analyze the range of VMT reductions possible from various transportation controls. Analysis has included surveys to measure public attitude and anticipated behavior, pilot studies conducted in specific areas to gain better understanding of carpool modal splits, and modeling to estimate the proportion of total trips between two geographical locations that will be made via mass transit (see Appendix 1 for listing of studies).

A Federal Department of Transportation draft report indicated some important relationships between increased use of mass transit and total auto travel.[1] The following quotes from that study illustrate the difficulties in achieving shifts away from personal use of the car by only providing improved transit incentives:

> "(a) The price elasticity of demand for transit work trips is only -0.19. This means that a one percent change in price will only result in .19 percent change in demand for transit work trips. Therefore, a 20 percent decrease in transit fares would only increase transit ridership by 3.8 percent."

> "(b) The price elasticity or demand for transit shopping trips is only -.323. Therefore, a 20 percent reduction in price will result in an increase in shopping trip ridership of 6.5 percent."

1/ Alternative Transportation Investments and/or Controls for Reduction of Air Pollution in Major Metropolitan Areas, U. S. Department of Transportation, 1972, page 10.

"(c) The time elasticity of demand for transit work trips is -.709. Therefore, a 20 percent decrease in travel time will increase the work trip ridership by 14 percent. (Note that time elasticity of demand is about 3.7 times the price elasticity.)"

"(d) The time elasticity of demand for transit shopping trips is -.593. Therefore, a 20 percent reduction in transit time will increase ridership by about 12 percent. (Note that time elasticity of demand for shopping is about twice as responsive to changes in travel time as it is to changes in fare: -.593 compared to -.323.)"

In addition, the cross elasticity for mass transit may be low without accompanying disincentives and penalties on personal use of the automobile.

EPA has funded studies to assess the possible impact of a range of incentives and disincentives to achieve VMT reductions in five of the California AQCR's. TRW has conducted studies for the Los Angeles Basin, San Francisco Bay Area, San Joaquin and Sacramento Valley. A joint IREM/Rand project [Ref. 12, 14] studied San Diego. Each region's transportation patterns can be applied to a model that can reasonably estimate the proportion of total trips between two geographical locations that will be made via alternate means other than private automobile when different incentives or disincentives are applied (Appendix 2 displays the various models and calculations used to arrive at the VMT reduction estimates). The model that has been applied to most of the California transportation studies was developed by Alan M. Voorhees and Associates (San Francisco).

The Voorhees Model

1. A "marginal utility" function is calculated for a typical trip between the two sub-areas between which projections are being made. "Marginal utility" is defined as a measure of the advantages of the private automobile over public transit. Therefore, higher marginal utilities will result in lower levels of transit ridership and vice versa.

2. Diversion curves are developed empirically for each regional area, which specifically relate transit ridership to marginal utility.

3. The diversion curves are used to predict the expected transit ridership for any calculated marginal utility. It is important to remember that the utility curves were derived empirically, and hence subject to uncertainties. It would be a mistake to view the model as an absolute predictor. Since the model has inherent uncertainties, any values calculated have the same uncertainties plus the additional uncertainties associated with various assumptions made.

There are a number of variables which can be used to measure the relative advantage the private auto has over public transit. Voorhees related marginal utility to nine variables, which fall into two classes - time and money. Within the group of nine variables used to formulate the marginal utility function, certain variables are more susceptible to change than others. Variables which are susceptible to change in the direction of decreasing marginal utility are the ones which hold most potential for decreasing VMT. Appendix 2 includes tables of the nine parameters and some implications associated with changing their marginal utility.

Theoretically, some or all of the nine parameters can be modified in hopes of affecting increases in transit ridership. Application of the model invariably shows that demand for public transit will increase if the marginal utility of the automobile is decreased.

4. Transit ridership estimates are extrapolated for different marginal utilities. They reflect three levels of optimism for what transit ridership might become under rather ideal conditions. The patronage level of forecast used depends on the transportation characteristics of the region in which the model is applied.

5. Within the defined patronage level of a region, the Voorhees curves are drawn for three different levels of income. Various income groups will exhibit different responses to, or perceive differing marginal utility changes to a uniform change in actual conditions. This is explained by the differing values placed on time and money within each economic class. Low income drivers will probably divert to public transit more rapidly than middle income drivers in the event a substantially increased cost penalty is associated with driving. However, since more low income people ride transit now, the percentage increase in transit ridership within each income level could be about the same. Appendix 2 shows the expected changes in transit ridership for various parameters as a function of three income levels.

For each region in which the model is used data is collected and typical values assumed for each parameter needed to simulate conditions experienced during a commute type trip. Using the assumed values and the variables curves can be generated for estimating the percent transit ridership as a function of each of the variables. Marginal utility is determined by holding all but one of the variables constant as one is allowed to change.

Conclusions From Applied Model

In comparison to transit variables, controls aimed at penalizing the automobile, are more effective. Theoretically, if the penalty placed on the auto is severe enough, high transit ridership and therefore, large VMT reductions are possible. However, the measures necessary to achieve large VMT reductions have to be very drastic.

A fairly consistent finding is that the private auto user is more affected by time loss and inconvenience than by monetary considerations. To achieve large VMT reduction by economic means alone would necessitate severe economic penalties for private auto use. The impact would be very inequitable affecting the lower classes the most.

An example from the TRW study for the L.A. Basin shows the degree of impedence necessary in money or time to achieve a VMT reduction response. Assuming no transit operation improvement, the combined vehicle operating and parking cost would have to be raised to approximately $4.00 per day ($2.00 per trip), an increase of 14 cents per mile in order to get to the saddle-point of the curve that separates the flat portion from the steeper, more responsive section. Similarly, if varied alone, the automobile travel time would have to be lengthened to more than 80 minutes (an average speed of approximately eight miles per hour) or the parking terminal time lengthened to 30 minutes to reach the same saddle point (present commute time is 23 minutes).

Unfortunately, attempts to use time to penalize the private auto are often counterproductive to reducing pollution. It has been shown that cars tend to emit less hydrocarbons and carbon monoxide at higher levels of speed than when idling or crawling in congested traffic. Therefore, the closest alternative is to implement measures that achieve great time savings for modes of travel (bus or carpool) other than the auto. Even this incentive does not achieve the same level of possible VMT reduction that a direct private auto time penalty would achieve.

To lenghten the parking terminal time implies the need to eliminate present parking spaces, a measure that is considered infeasible in light of public testimony and comment received.* However, parking management will control the growth of available spaces and impose time penalties if there is a growth in private car VMT.

A combination of adequately severe economic disincentives and of improved mass transit incentives has been promulgated for the regions in California requiring VMT reduction measures. Estimates of the expected VMT reductions achievable have been made based on the best available data and its application to the Voorhees model, or, in the case of San Francisco, to a modified BATSC/MTC** model.

* Periphery parking cannot be expected to cause significant increases in parking terminal time, since one would be able to take advantage of improved local transit or minibus to get into the CBD.

**Model designed by Bay Area Transportation Study Commission (BATSC) to estimate transportation modal choice in Bay Area. The Metropolitan Transit Commission (MTC) updated this modal to reflect recent conditions in the Bay Area.

III. ESTIMATED IMPACT OF VMT REDUCTION MEASURES

A. Los Angeles Intrastate AQCR

The majority of the data derived for Southern California was derived from the California Division of Highways' ongoing Los Angeles Regional Transportation Study (LARTS). Although the geographic boundaries do not coincide exactly with the State's definition of the South Coast Air Basin, it is assumed by TRW and by the Department of Public Works that the study area is equivalent to the AQCR. An analysis of population figures for the two areas show them to be very comparable. The LARTS study provides the input data for the Voorhees model, discussed earlier.

Table A shows the VMT control measures that are to be implemented in the Region. Measures 8-10 are locally proposed measures that were not promulgated by EPA but are to be implemented upon their adoption as part of the State plan. All of the measures shown on the table are complementary to the goal of mutually reinforcing incentives and disincentives that promote the use of multi-occupancy vehicles and penalize driver-only cars. However, the reinforcing nature of many of the measures makes addition of their individual impacts difficult. However, estimates of ranges are possible, holding all parameters except one constant in testing a measure's potential impact in the Voorhees model.

This procedure was followed by TRW in estimating approximate impacts of various VMT control measures. Table A shows the results in the column under TRW. Estimates have also been calculated for some of the measures by other sources. Differences in estimates for the same measure may occur because assumptions used in applying the model can vary, as explained in the preceding section on the Voorhees model. A percent transit mode split required to achieve specified total daily VMT reduction goals is given in the TRW study. In order to achieve a 10 percent reduction in VMT the percent commute transit ridership would have to be 38 percent, or a 30 percent increase over present levels. (8 percent now) A 66 percent ridership would be necessary to achieve a 20 percent VMT reduction. (Estimates assume a constant trip demand and no change in the level of car pooling).

Bus Improvements--

Projections of increased bus patronage by the Southern California Rapid Transit District (SCRTD) show low VMT reduction potential. A Mini-bus Project and the San Bernardino Busway Project with park and ride facilities are estimated to reduce VMT by only .5 percent. However, the study points out that projecting the 1977 ridership is very speculative at this point because the attractiveness of systems of this type in the Los Angeles travel context is unknown. Combined with other VMT reduction measures, the potential of the bus system may be as effective as the Shirley Highway Busway Project in Washington D.C. (Demand increased by 50% in one year).

Park and Ride--

A park and ride express bus service along the Santa Ana Freeway is estimated to reduce the area's VMT by .5 percent. TRW estimates for the combined impact of the programs planned before EPA promulgation (of the measures listed in Table A) is about 1.3 percent VMT reduction. It is unclear whether this reduction has been accounted for in estimates of reductions due to bus lanes and transit improvement, or whether it is in addition to the present estimates.

Results of the Voorhees model for L.A. data has given more encouraging estimates of VMT reduction. Even with no measures penalizing the auto, a reduction in transit ride time can attract 15 percent additional transit ridership. A free transit would attract less than 10 percent ridership. As indicated in Section II of this report, time turns out to be more important than money as a variable. Using very optimistic assumptions in the Voorhees model which would make transit service free and as fast as the private auto, one might be able to achieve an overall 10 percent VMT reduction. If more reasonable assumptions are used in the model, one achieves only a 3 percent VMT reduction in the Basin. These estimates are shown in the table.

Parking Surcharge--

When a surcharge on parking is brought in as a variable, holding transit riding time equal to the auto, approximately 75 cents per trip (making the combined costs equal to $1.25 per trip) is necessary to reach the elastic portion of the curve. Elasticity occurs at about 20 percent transit demands. A 20 percent ridership during commute periods would get a 4 percent VMT reduction in the basin. If the surcharge were raised to $2.00 per trip (making the combined costs equal to $2.50 per trip) a reduction of over 10 percent could be achieved.

The impact of increased parking costs is mitigated because only six percent of the commuters presently pay for parking. In order for parking surcharges to be effective, a massive program will have to be undertaken to substantially increase the percentage of drivers who pay for parking. This could possibly be achieved in conjunction with incentives for employees measures initiated by employers. Free parking would only be made available to car pools. This would probably help diminish the effect of the many parking lots that are free and in private (employer?) ownership. Pricing schemes would have to be worked out so that penalties don't tend to be regressive.

The Impact of Increased Car Pools--

Since the auto occupancy rate is so low for work trips (1.1), significant VMT reductions can be achieved through increased car pool activity. To get a 10 percent reduction in VMT by car pools the commuting auto occupancy would have to increase from 1.1 to 1.7. The freeway commuting auto occupancy would have to increase from 1.1 to 2.1. Commute travel by freeway users accounts for less than 25 percent of daily VMT. If all such commuters were in car pools of three and no additional VMT were generated by car pool assembly and dispersal, the maximum VMT reduction possible would be 17 percent. This result is not shown in Table A because the additive breakdown attributable to various car pool incentive measures is not clear. However, in estimating a total range of VMT reduction percents, this figure should be kept in mind. On the <u>optimistic</u> side of the tally one would be able to at least say that 17 percent is a bottom estimate of VMT reduction achievable.

Exclusive Bus and Car Pool Lanes on the Freeway--

A study by Voorhees and Associates for the U.S. Department of Transportation on reserved freeway lanes for buses and car pools estimates that this measure would create a 3 percent shift into buses and a 3 percent shift into car pools. With an increased bus ridership obtained through increased bus service on existing routes and establishment of new routes in the corridor, shifts greater than 5 percent into buses 5 percent into car pools would not be unrealistic. It is unclear whether the study anticipated the possibility that the 5% increase to buses due to transit improvements would partially come from the 3% shift to car pools, thereby not increasing total VMT reduction but shifting the proportion of car pools to buses. Table A reflects the predicted 6 to 10 percent range.

TRW's study arrives at a lower estimate of the bus/car pool lane's potential effect. By generously assuming a twenty minute travel time advantage over automobile travel maintained by the buses or car pools in the special lanes, a 15 percent ridership could be assumed, giving a 2.5 percent reduction in daily VMT. If this measure achieved a 1.5 persons per vehicle occupancy on the L.A. freeway system during commute hours, the VMT reduction would be about 4.4 percent of the daily Basin-wide VMT.

Impact of Local Task Force Measures--

The task force recommended a series of measures to speed the flow of traffic and avoid the bottlenecks and stop-and-go driving that are both polluting and wasteful of energy. These measures include: automated and interconnected traffic signals, freeway ramp metering, expanded fringe park-and-ride facilities, and other traffic flow improvements. The task force estimates that these measures will total an additional 5.3 percent reduction in pollution.

Total Ranges of VMT Reductions--

Using the TRW based estimates, one can expect about a 12.5 to 30.5 percent reduction in VMT plus whatever additional percent reductions can be calculated from parking supply management, and non-overlap mass transit incentives for employees, etc. Also added on to the sum would be the extra VMT reduction achieved by local traffic flow improvements, if any, and mass transit improvements. Substituting the DOT bus/car pool lane estimates the sum increases to 13.5 to 34.5 percent.

TABLE A

LOS ANGELES - VMT REDUCTION MEASURES

Control Measures	Promul-gated by EPA	Proposed by Local & Cal/Trans	Estimated percent Reduction in Daily Vehicle Miles Traveled - DVMT: Local Agencies Task Force	Cal DOT	Voorhees Study for DOT	EPA-TRW Study (LARTS Data)	Dept Pub Works
1. Exclusive Bus/Car Pool Lanes	X	X		4	6-10	2.5-4.4	2-3
2. Bus/Car Pool Matching (not necessarily additive with measure 1)	X					5-6	
3. Mass Transit Incentive for Employees	X					*** 1-2	
4. Parking Supply Management	X					*** 1-2	
5. Parking Surcharge	X					4-10	
6. VMT/Air Quality Improvement Monitoring Program	X						
7. Gasoline Limitations	X					****	
8. Mass Transit Improvements and Development		X				3-10	
9. Bicycle Network & Facilities		X					
10. Traffic Flow Improvements *		X	** 5.3			*** 0-1	
11. Fringe Parking for Park and Ride		X	** .3			.5-4	
12. Dial-a-Ride		X				*** .1-4	

* Traffic flow improvements may awaken the latent demand for increased use of the less congested facilities. Therefore, caution must be taken in calculating the VMT reduction for this measure.

** Estimates are for the percent of pollution reduced, not VMT

*** Estimate by EPA, Region IX

**** Amount necessary to meet air quality standards in 1977.

APPENDIX I

References

1. TRW, Transporation Control Strategy Development for the Metropoliton Los Angeles Region, December 1972

2. TRW, Transportation Control Strategy Development for Sacramento Valley

3. TRW, for San Joaquin

4. TRW, for San Francisco

5. TRW, Air Quality Implementation Plan Development for Central California Regions: Summary Report July 1973

6. State of California, Department of Public Works, for Air Resources Board, Can Vehicle Travel Be Reduced 20% in South Air Basin? January 1973.

7. California Institute of Technology, EQL, SMOG: A Report to the People of the South Coast Air Basin, January 1972

8. DOT, a Computer Simulation Model for Evaluating Priority Operations on Freeways June 1973.

9. Alan M. Voorhees and Associates, for Department of Transportation(DOT), Summary Report: Feasibility and Evaluation Study of Reserved Freeway Lanes for Buses and Car Pools, January 1971.

10. MTC, Proposed Regional Transportation Plan and Revisions: Improvement Proposals, June 1973.

11. Local Agencies Plan for LA Basin, Clean Air, August 9, 1973.

12. San Diego Air Pollution Control Task Force Report, Local Transporation Control Plan for the San Diego Basin, October 5, 1973.

13. San Diego Air Pollution Control Task Force, Evaluation of EPA's Proposed Air Pollution Control Plan with Alternatives

14. Rand Corporation, A Policy Oriented Urban Transportation Model: Notes on the Rand Approvals, March 9, 1973.

15. TRW, Report on the IREM/RAND Clean Air Project.

16. EPA Region IX, Technical Support Document for LA Basin, July 31, 1973

17. Federal Register, Proposed Regulations for California Air Quality Control Districts, Vol. 38, No. 126, Monday, July 2, 1973

18. Federal Register, Promulgation for Transportation Control Plans for California, Vol. 38, No. 217, Part I, November 12, 1973

APPENDIX 2a

VOORHEES MODEL

$$\text{Marginal utility} = U = 2.5\ (Ta + Tw) + Tr - (2.5\ At + Ar) + \frac{F - (Ao + Ap)}{0.251} \quad (1)$$

where : Ta = transit access time in minutes (i.e. the time to walk to the bus stop)

Tw = transit wait time in minutes

Tr = transit riding time in minutes

At = automobile parking access time in minutes (i.e., the time necessary to find parking and walk to destination)

Ar = automobile riding time in minutes

F = transit fare in cents

Ao = automobile operating costs in cents (excluding depreciation and insurance)

Ap = automobile parking cost in cents (averaged over the round trip)

I = mean income of the home based zoned in cents per minute

TABLE 7.4

Control of Marginal Utility Parameters

Marginal Utility Parameter [a]	Potential for Control	Example(s) of Control Aimed at Decreasing Marginal Utility
Ta	Low	More bus stops and/or routes
Tw	Medium	Improved frequency of service
Tr	Medium	Exclusive busways for freeway lanes
At	Low	Peripheral parking, auto free zones
Ar	High	Ramp metering
F	High	Lowered fares
Ao	High	Gasoline tax, "smog" tax, tolls
Ap	Medium	Increased parking costs
I	Very low	Lower personal income levels

a - see Equation 1

TABLE 7.5

ASSUMED VALUES OF MARGINAL UTILITY PARAMETERS

FOR A TYPICAL COMMUTE TRIP

Variable	Assumed Value	Source
Trip Length	10.5 miles	Table 5.4 (EPA publication APTD-1372)
Ta	5 minutes	Generally accepted value
Tw	7 minutes	15 minute headway, no transfer
Tr	48 minutes	LARTS, 1971 Travel Time Study
F	38 cents	30¢ basic fare + 8¢ for one additional zone
Ao	50 cents	4.8¢ per mile - assumed by Voorhees
Ap	2.5 cents	90¢ per day for estimated 5.8 percent who pay See Table 7.7.
I	8.3 cents/minute	$10,000 per year
At	2 minutes	A. M. Voorhees & Associates
Ar	23 minutes	Table 5.4 (EPA publication No. APTD-1372)

TABLE 7.6

MARGINAL UTILITY PARAMETER COMBINATIONS

Marginal Utility Variables	Symbol	Potential for Control	Relative Effectiveness
Transit fare (one way)	F	High	Low
Transit access and waiting time	T_a+T_w	Medium	Medium
Transit riding time	T_r	Medium	High
Auto operating and parking cost (one way)	A_o+A_p	Medium	High
Auto riding time	A_r	Medium	Low
Auto terminal time	A_t	Low	Low

NOTE: Income is considered a constant throughout, primarily because it is virtually impossible to control.

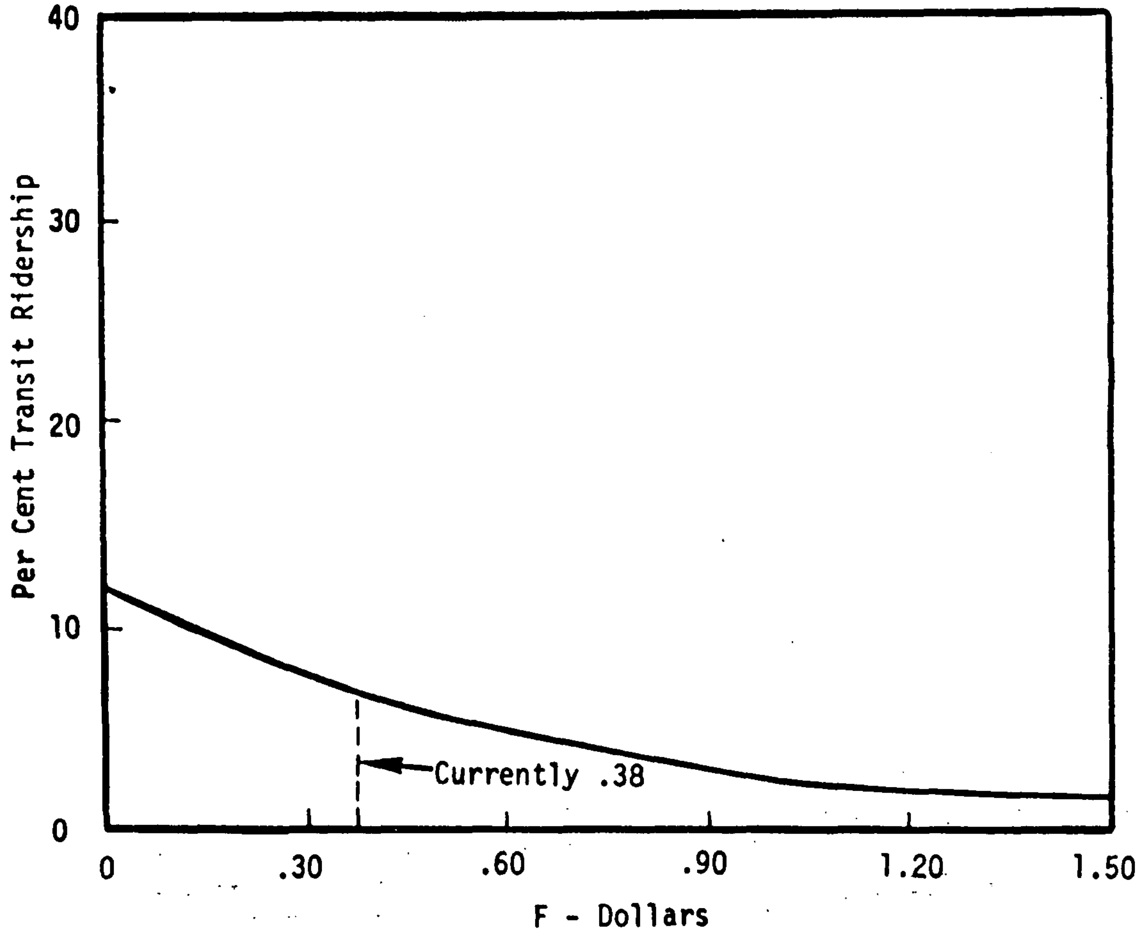


Figure 7.3. Transit Fare (One Way) vs. Per Cent Transit Ridership.

Source: Developed from the Los Angeles Metropolitan Area Mode Choice Model.

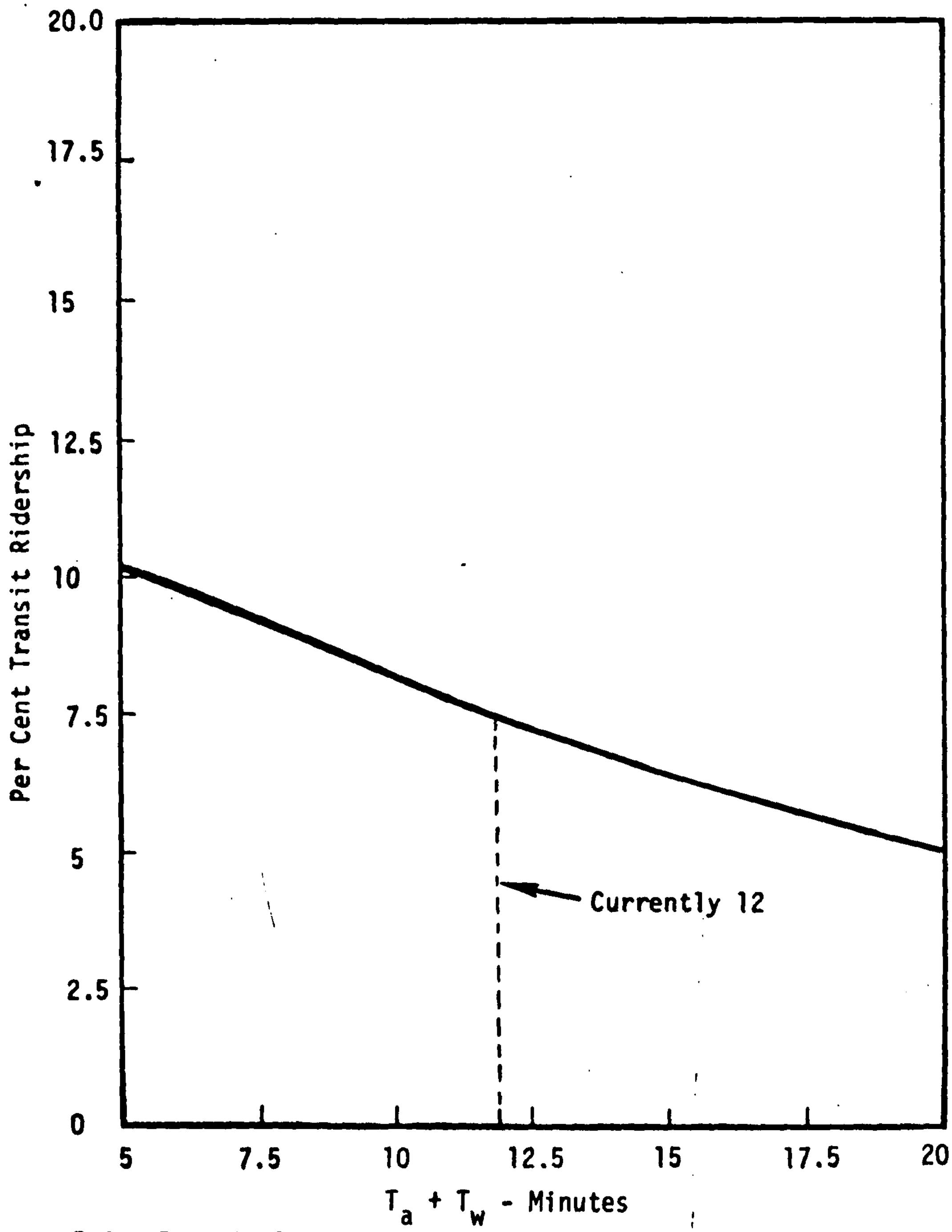


Figure 7.4. Transit Access and Waiting Time vs. Per Cent Transit Ridership.

<u>Source</u>: Developed from the Los Angeles Metropolitan Area Mode Choice Model.

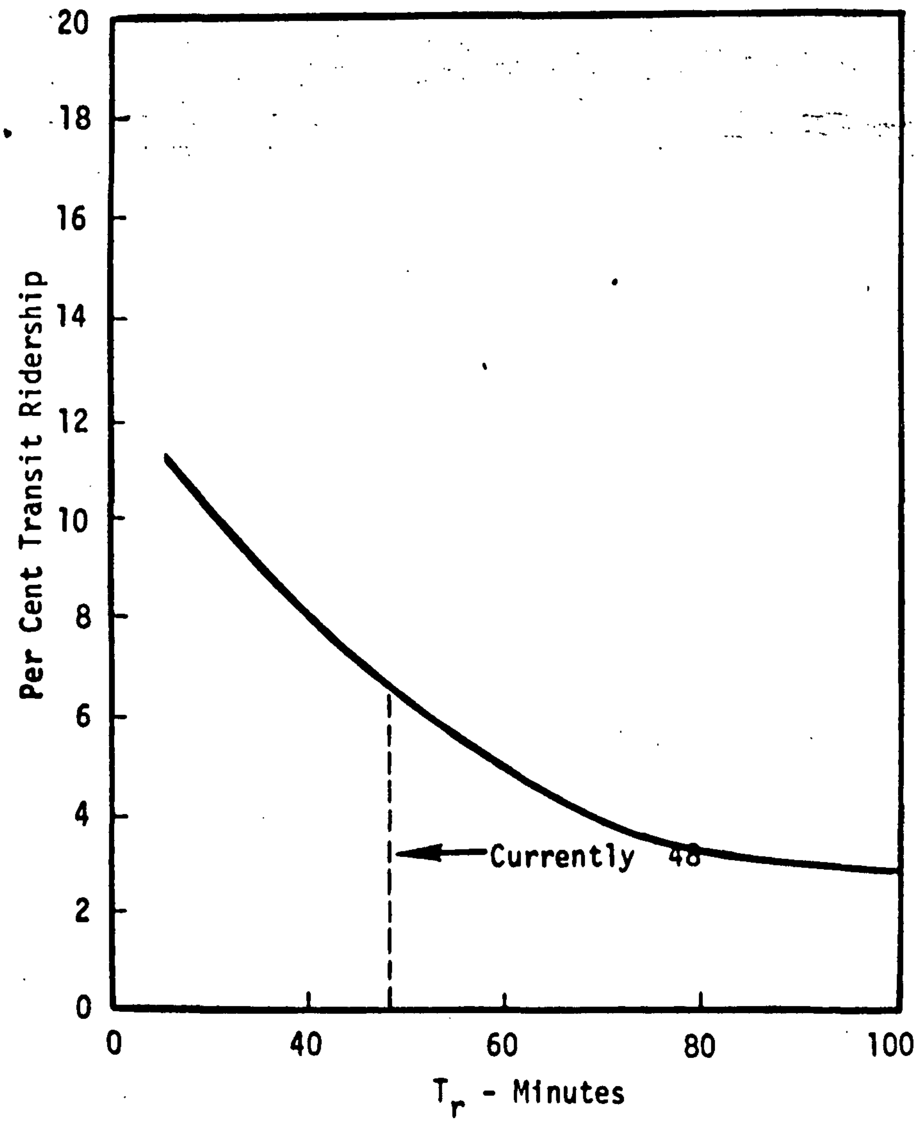


Figure 7.5. Transit Riding Time vs. Per Cent Transit Ridership.

Source: Developed from the Los Angeles Metropolitan Area Mode Choice Model.

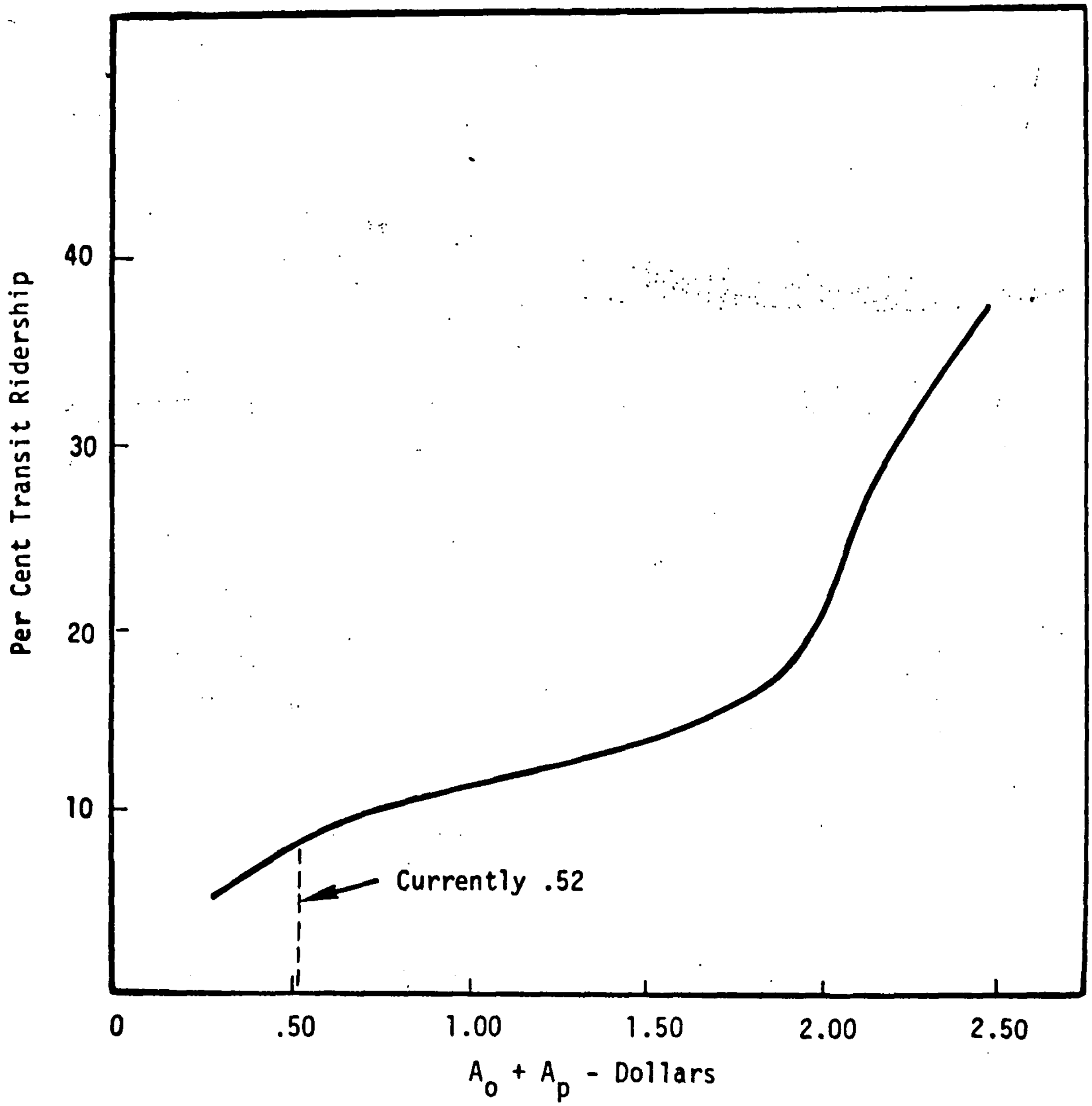


Figure 7.6. Automobile Operating and Parking Cost (One Way) vs. Per Cent Transit Ridership.

Source: Developed from the Los Angeles Metropolitan Area Mode Choice Model.

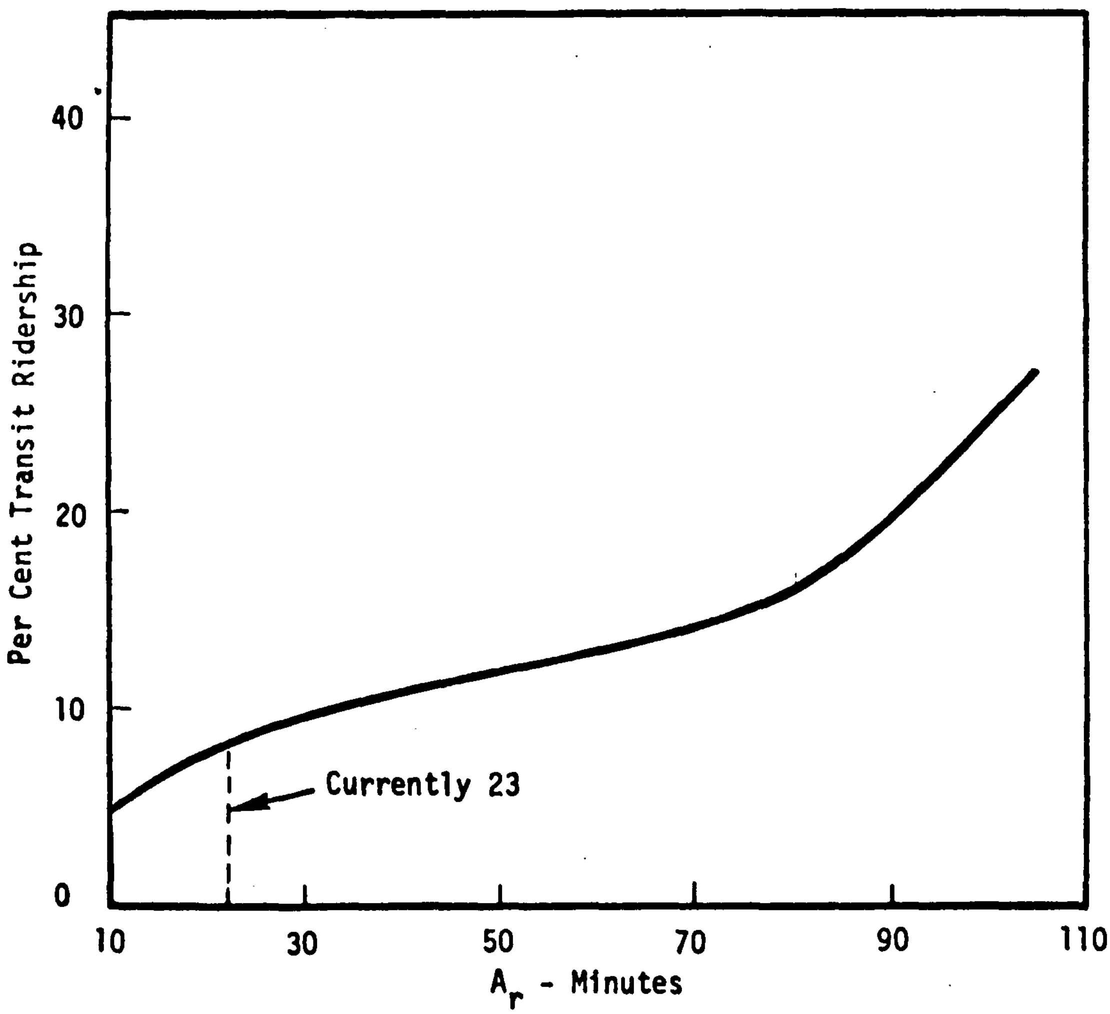


Figure 7.7. Automobile Riding Time vs. Per Cent Transit Ridership.

Source: Developed from the Los Angeles Metropolitan Area Mode Choice Model.

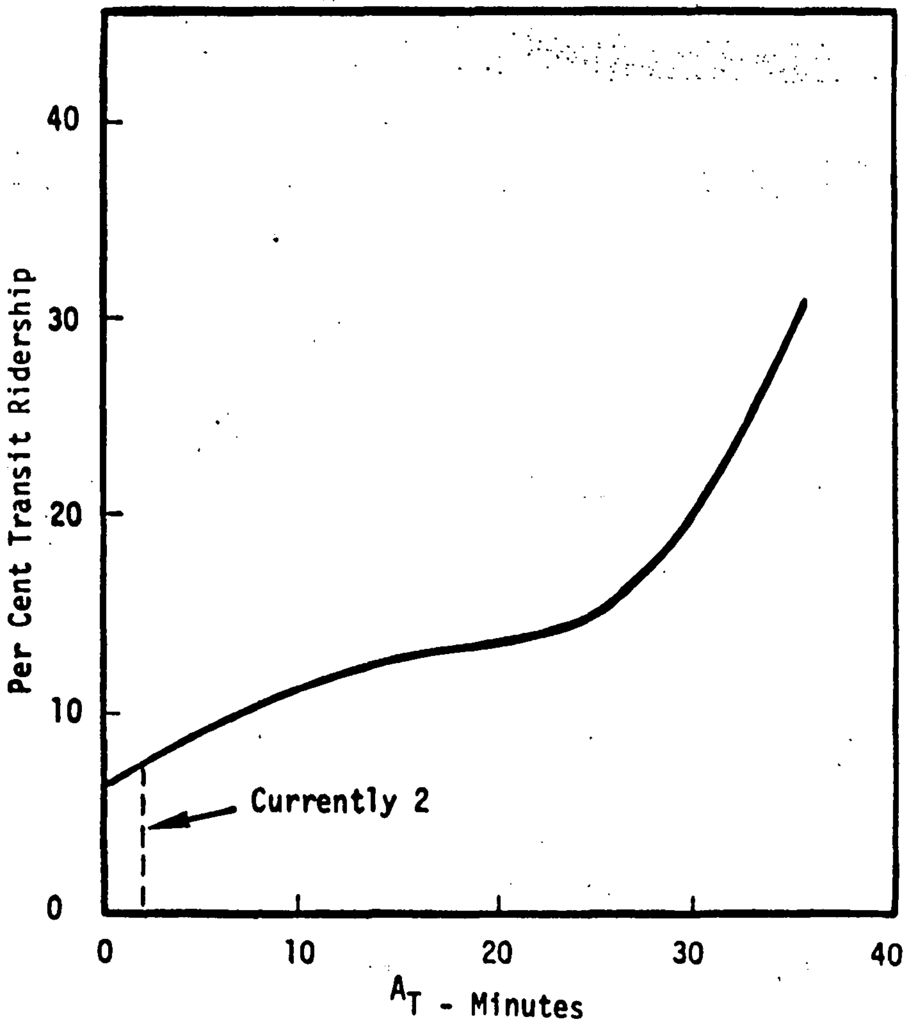


Figure 7.8. Automobile Terminal Parking Time vs. Per Cent Transit Ridership.

<u>Source</u>: Developed from the Los Angeles Metropolitan Area Mode Choice Model.

Sample Calculation #9

Impact of Exclusive Bus-Carpool Lane

Assumptions:

	Source
1) Trip length = 10.1 miles	See Appendix G, Table G-8. (Trip to freeway is excluded.)
2) 20 minute travel time advantage for users of the lane	San Bernardino Busway will have 18 minute advantage; Shirley Highway Busway has 30 minute advantage.
3) Values of Voorhees parameters	
T_a = 2 minutes	Assumed
T_w = 3 minutes	5 minute headway for correct bus
F = 46¢	Basic 30¢ fare + 2 zones
A_o = 48¢ (or 78¢)	4.8¢ per mile (+3¢ per mile "tax")
A_p = 2.5¢	Assumed
A_t = 2 minutes	See Reference E-5
T_r-A_r = 20 minutes	20 minute time advantage
I = 8.3¢/minute	$10,000 per year

$$U = 2.5\ (T_a+T_w) + T_r - (2.5A_t+A_r) + \frac{F - (A_o+A_p)}{0.25\ I}$$

U = -15 (-29 with 3¢ per mile "tax")

Based on the above assumptions and Figure 7.2, the estimated transit patronage is approximately 15 percent without the tax and 20 percent with the tax.

Sample Calculation #9 (Cont'd)

$$\% \text{ VMT Reduction} = 100-100 \left\{ \frac{OCB(1-F_T) + OCA(F_T)}{OCB(1-F_{T_o}) + OCA(F_{T_o})} \right\}$$ (Eq.(7),Sample Calculation #1)

The percentage of total commute VMT which is travelled on the freeway system in the Basin is approximately 17 percent (see Appendix G, Table G-8); therefore,

$$\% \text{ VMT Reduction} = .17 \left\{ 100-100 \left[\frac{OCB(1-F_T) + OCA(F_T)}{OCB(1-F_{T_o}) + OCA(F_{T_o})} \right] \right\}$$

Assume:

1) OCB = 50 persons per bus
2) OCA = 1.1 persons per car
3) F_{T_o} = negligible on freeways presently
4) F_T = .15 (.20 with "tax")

% VMT Reduction = 2.5 (or 3.2 with "tax")

To achieve an occupancy of 1.5

Assume:

1) During commute periods, average volume per lane of traffic of 1500 vehicles per hour
2) Carpool is three or more people per automobile
3) Negligible carpooling on the freeway presently
4) Eight lane freeway (four in each direction)
5) Capacity of freeway lanes is 1800 vehicles per hour
6) No diversion to transit
7) Total person trips on freeway is constant

Let N = Number of cars in carpool lane (three persons per car) when all other lanes are at capacity and the resultant average automobile occupancy is 1.5 persons per vehicle.

Then $$\frac{(3)(1800 \text{ veh./ln-hr})(1.1 \text{ persons/veh.}) + N(3 \text{ persons/veh.})}{(3)(1800) + N \quad \text{veh./ln-hr}} = 1.5$$

$\rightarrow$ N = 1440 veh./ln-hr

Persons diverting to carpools = 1440 x 3 = 4320

Total number of person trips = (3)(1800)(1.1) + (1440)(3) = 11,340

% of freeway commuters shifting to car pools = $\frac{4,320}{11,340}$ = 38%

Impact of Shifts in Carpools

Assume occupancy can be increased to 1.5 persons per vehicle.

From Sample Calculation #2 for commute periods periods,

$$\% \text{ VMT Reduction} = 32.4 \left(1 - \frac{1.21}{\text{OCA}}\right)$$

This strategy impacts 72.5 percent of the commute VMT (see Appendix G, Table G-8).

$$\% \text{ VMT Reduction} = .725(32.4)(1 - \frac{1.21}{\text{OCA}})$$

$$= 23.5 \ (1 - \frac{1.21}{1.5})$$

$$= 4.4\%$$

APPENDIX D

EXAMINATION OF THE PHOTOCHEMICAL AIR POLLUTION PROBLEM IN THE SOUTHERN CALIFORNIA AREA

E. A. Schuck and R. A. Papetti

I. INTRODUCTION

Many areas of the world which are highly urbanized experience two types of major air pollution problems. The first is due to direct emission into the air we breathe of a variety of components mainly from energy producing and related activities associated with the use of fossil fuels. Many of these exhaust components such as carbon monoxide, sulfur dioxide, and particulate matter produce significant deleterious health and welfare effects at the concentration observed in urban areas. Others such as most unburned or partially oxidized hydrocarbons, carbon dioxide, water, and nitric oxide have no significant direct health effects at observed ambient concentrations. Certain of the hydrocarbon products do, however, result in significant welfare effects. A major example is the vegetation damage resulting from the hydrocarbon automobile exhaust component, ethylene.

Some of these largely innocuous exhaust components, especially the hydrocarbons and nitric oxide, react after emission into the atmosphere to produce new products thus leading to the second type of major pollution problem, termed "smog," or more specifically photochemical air pollution. Many of the major products of these sunlight induced atmosphere reactions, i.e., ozone, peroxyacyl nitrates, nitrogen dioxide, and certain aldehydes, pose a serious health problem and in addition many of these secondary products are deleterious to vegetation growth and some such as the peroxyacyl nitrates and certain aldehydes produce eye irritation. To further compound the effects these atmospheric reactions also result in the rapid oxidation of part of the sulfur dioxide present and thus to the production of sub-micron sulfuric acid aerosols which result in greatly reduced visibility as well as further increasing the health problem resulting from particulate matter.

There has been a tendency in recent years to sharply differentiate cities into those whose air pollution problem is due to primary emissions, i.e., sulfur dioxide and particulates, and those whose problems are due to the secondary effects of photochemical air pollution. Such categorization, while correctly identifying the immediate most pressing problem of a given urban area nevertheless also tends to suggest that photochemical air pollution is unique to certain areas in the world. This concept is incorrect since chemical processes which lead to photochemical air pollution takes place during daylight hours wherever there are atmospheres containing hydrocarbons and oxides of nitrogen. Indeed the chemical reactions involved are an essential part of the oxidative processes which prevent the buildup of hydrocarbons in the earth's atmosphere. In lieu of such reactions the overall carbon dioxide cycle would be interrupted and the air we breathe in all probability would contain concentrations of certain hydrocarbons which would produce deleterious health effects. Thus, if urban areas concentrate all their efforts on the immediate obvious problems, such as excess concentrations of sulfur oxides or directly emitted particulate matter, they will, after resolution of these factors, be faced with the more insiduous problems resulting from photochemical air pollution. Whether recognized or not the presence and therefore detrimental effects of photochemical air pollutants exist in all urban areas and will continue to be a mojor problem as long as our energy base is dependent on the use of fossil fuels.

Areas in the United States where the effect of photochemical air pollution was early recognized as a major problem are located on the western edge of California. Because of such early recognition an extensive monitoring network for both precursors and products has been in use for the past 15-20 years. The most extensive of these multistation networks, and the one whose records are examined here, exists in the Southern California area surrounding Los Angeles and known as the South Coast Air Basin (SCAB). Into the common air mass covering this region the ten million inhabitants dump approximately

20,000 tons of pollutants each day. The semi stagnant characteristics of this air mass leads to the mild weather conditions which the population finds desirable but also results in restrictive dilution and dispersion of pollutants therefore creating a severe air pollution problem.

The magnitude and extent of the resulting health and welfare effects is impressive and alarming. Imagine if you will an area of one thousand square miles on a typical morning with 50 mile visibility. Four hours later the visibility has been reduced to less than a mile, not by direct emission of particulates, but rather by chemical reactions in the atmosphere which have created a submicron aerosol containing as its principal constituent sulfuric acid. Furthermore, as the day progresses one can visually trace this pollution cloud for hundreds of miles downwind. This visibility reduction, although physcologically depressing, is the least of the problem. This visually apparent air mass contains many substances which are detrimental to all forms of biological life. As an example, consider that certain types of sensitive commercial crops can no longer be grown in or near the SCAB. Millions of trees in the surrounding mountains are also being destroyed. Yet these effects are minor compared with the human health aspects. On as many as 250 days per year from 7 to 9 million of the local citizens must breathe air for several hours which, along with other deleterious components, contains oxidants (ozone) above the level of the health related national air quality standard (0.08 ppm for one hour). Furthermore, between 1 and 3 million of these citizens are breathing air which contains oxidant concentrations above the point where medical authorities advise against engaging in physical activities (above 0.27 ppm for one hour).

Since the early 1950's many local governmental agencies and in particular the Los Angeles County Air Pollution Control District have pursued an active and successful program to reduce the amounts of pollutants being dumped into this air basin. Without a doubt the automobile is the greatest contributor to ambient concentrations of carbon monoxide and to the precursors of photochemical air pollution, i.e., hydrocarbons and oxides of nitrogen. Following California's lead additional restrictions on the amounts of hydrocarbons and carbon monoxide in new motor vehicle exhaust were instituted by the federal government starting in 1968. It is the purpose of this discussion to examine the air monitoring data base of the SCAB in order to show what changes have occurred during the past several years and to explore the reasons for these changes. An auxillary purpose in this examination is to update the relationships between ambient early morning concentrations of precursors and subsequent oxidant values.

II. The Data Base and its Analysis

Since the early 1960's, at between 8 and 20 locations, oxidants and their precursors have been continuously measured in the South Coast Air Basin. This is particularly true for total oxidants, nitric oxide and nitrogen dioxide. Measures of total hydrocarbons being more difficult to obtain, were until recently only measured at one or two locations. Starting in 1971 however, continuous hydrocarbon measurements have been available from eight locations. This hydrocarbon measure contains an appreciable quantity of methane which does not participate in the oxidant forming reactions. Direct methods of measuring non-methane hydrocarbons are not in widespread use. In lieu thereof the Division of Chemistry and Physics, EPA, has on the basis of detailed chromatographic analysis of ambient hydrocarbons developed an empirical formula for converting the total hydrocarbons measurement to a non-methane hydrocarbon measurement.

This formula is:

$$\text{Non-methane hydrocarbon (ppmC)} = 0.7(\text{THC}-1.3)$$

where THC is the total hydrocarbon measurement (ppmC) and the 1.3 represents the average background methane concentration. Unless otherwise stated the hydrocarbon values cited in this discussion have been derived by application of this formula.

Since a major objective is to quantitate changes in air quality the data base consisting of hourly average frequency distributions at 8 stations for oxidant and at 11 stations for nitrogen dioxide were examined. Specifically examined were the hourly frequency distributions during the 1963 through 1967 time period as compared with the distributions observed during the 1968 through 1971 time period. Essentially the earlier time period represents a pre-automotive exhaust control period while the 1968-1971 data is a post-control period in which substantial changes in emissions were predicted as a result of increasing impact of automotive emission controls. The oxidant comparison was made to determine what effect if any the automotive hydrocarbon control program has produced. The nitrogen droxide comparison was made because the method chosen to control automotive hydrocarbons also resulted in substantial increases in nitric oxide. This latter comparison thus was made to determine the effect of such increases of nitric oxide emissions on subsequent nitrogen dioxide concentrations.

III. Discussion of Results

A. Ambient Oxidant Changes.

In table I are listed the changes observed in hourly average oxidant concentrations at eight stations when comparing the noted post automotive control period with the pre-control period. Substantial reductions in hourly average oxidants have occurred at all stations

Table I

Change in Hours Per Year - Average Hourly Oxidant Concentrations

Comparision of 1968 - 1971 Data With 1963 - 1967 Data

Station and Code	Percent Change in Stated Concentration Ranges (pphm)		
	1-8	8-25	25+
North Long Beach 72	+3	-57	-67
Downtown Los Angeles 1	+3	-42	-83
West Los Angeles 71	+6	-29	-78
Reseda 74	+18	-27	-65
Pomona 75	+13	-25	-28
Riverside 126	+6	-14	-26
Azusa 60	0	-3	-21
Burbank 69	+1	+3	-60
Average Change for All Stations	+6	-20	-39

with the greatest reductions occurring in the higher concentration range (i.e., 25 pphm and above). Two items are worthy of note. First these reductions are much greater than could be expected from hydrocarbon control alone since the maximum hydrocarbon reduction from the pre-control to post-control period is 8-10%. Second the stations with greatest upwind contributions, i.e., Riverside, Azusa, Pomona, show the smallest reductions. This is in line with previous determinations that in general the concentrations of any given pollutant at a specific location is proportional to number of and intensity of sources over which the air mass has passed. The noted increases in the 1-8 pphm range are discussed under Section III-C.

B. Nitrogen Dioxide Changes

As shown in Table 2 for 11 stations hourly average nitrogen dioxide above a value of 25 pphm demonstrate substantial increases except for the Riverside and Lennox sites. Why these latter sites exhibit a decrease is not known however, it will be noted that this decrease is not reflected in total exposure or in the yearly mean values. For that matter there is no ready explanation for the very substantial increase noted in hours above 25 pphm for the Basin as a whole (+42%) since the projected increases in nitric oxide emission are only about 16-20% which is more in line with the noted changes in basin wide total exposure and yearly mean.

Table 2
Observed Changes in Selected Hourly Average
Nitrogen Dioxide Concentrations and Total
Nitrogen Dioxide Exposrue During
1963-1971 in the South Coast Air Basin

Station and Code	Hours Per Year Above 25 pphm		Percent Change in 1968-1971 Compared to 1963-1967		
	1963-1967	1968-1971	Hours Above 25 pphm	Total Exposure (Conc. X Time)	Yearly Mean
Anaheim 176	1	20	+520	+40	+25
Riverside 126	25	12	-52	+16	+25
West Los Angeles 71	70	88	+26	+33	+40
Reseda 74	41	70	+71	+35	+40
Pomona 75	25	81	+220	+17	+14
North Long Beach 72	88	114	+30	+17	+33
Downtown Los Angeles 1	114	131	+15	+13	0
Lennex 76	140	61	-56	+8	+17
Burbank 69	96	254	+165	+38	+43
Azusa 60	6	29	+380	+26	+20
San Bernardino 151	0	2	--	+45	0
Average Percent Change (All Stations)			+42	+23	+23

It is probably more correct to say there is no precise quantifiable explanation for these changes rather than implying an area of unknown factors. From a diverse and substantial data base generated in environmental chambers it is quite apparent that the relationship between oxidant and oxidant precursors is quite complex. As long as ten years ago, Dr. Philip A. Leighton pointed out the danger of changing the ambient hydrocarbon to oxides of nitrogen ratio. He did in fact predict that reductions in hydrocarbon without an attending reduction in oxides of nitrogen would lead to some reductions in peak nitrogen dioxide concentrations and also to an increase in nitrogen dioxide total exposure. This effect observed at two stations in Table 2 may in fact be more general however, it is not possible from this data base to substantiate such an effect since it is difficult to seperate the effects due to the substantial increase in nitric oxide emissions from those due strictly to hydrocarbon reductions.

One positive effect of the increase in nitric oxide emissions has been the depressant effect on oxidant concentrations. Nitric oxide and ozone react extremely rapidly in the atmosphere to produce nitrogen dioxide and oxygen. Thus the substantial decreases in oxidant shown in Table I are as much if not more due to increases in nitric oxide emissions as they are due to reductions in emissions of hydrocarbons. Obviously the tradeoff is that in the process the ambient nitrogen dioxide concentrations have increased. While it is highly desirable to continue taking advantage of the presence of excess nitric oxide, the positive effects on oxidant reduction must be balanced against the negative effects of increased nitrogen dioxide since the latter also has health implications as well as resulting in coloration of the atmosphere. Moreover, nitrogen dioxide is the principal light absorber leading to the formation of photochemical air pollution.

C. Frequency Distribution Changes

Of particular interest are the changes in hourly average oxidant and nitrogen dioxide as a function of concentration range. A summary of these changes for the Basin air mass is shown in Table 3. It will be noted that a reversal in the sign of change occurs for both components at about 5pphm. Thus the reductions in oxidants observed previously lead to increases in hours of oxidant in the 1-5 pphm range. The reverse is true for nitrogen dioxide concentrations. The reason for these reversals is that for any given pollutant the frequency distribution is primarilly determined by meteorological variables. Thus in the case of nitrogen dioxide the increases in hours above 5 pphm have to be accounted for somewhere in the frequency distribution. Many of the hours that formerly contributed to hours in the 1 to 5 pphm range have becasue of increases in nitric oxide emissions moved up to higher concentration ranges. The reverse is true for the oxidant

Table 3
Observed Changes in Frequency Distributions
of Hourly Average Concentrations of
Oxidant and Nitrogen Dioxide
1963 through 1971 (1)

Hourly Average Concentration Range (pphm)	Percent Change in Hours Per Year in 1968-1971 Compared to 1963-1967		Average Number of Hours Per Year in 1968-1971	
	Oxidant	Nitrogen Dioxide	Oxidant	Nitrogen Dioxide
1-2	+8	-46	1630	575
2-3	+9	-23	952	935
3-4	+15	-11	617	1070
4-5	+5	-7	426	1020
5-6	-9	+16	259	930
6-8	-6	+21	456	1400
8-10	-16	+31	279	900
10-15	-20	+49	409	1050
15-20	-23	+63	192	348
20-25	-27	+52	88	123
25-30	-39	+41	34	48
30-40	-14	+38	16	26
40-60	-8	+7	3	6

(1) Oxidant data at 8 South Coast Air Basin Stations. Nitrogen dioxide data at 11 South Coast Air Basin Stations.

frequency distribution. Depending on weither the interest is peak valves or dosage these frequency shifts will have a decided effect on calculated changes. Thus if total oxidant dosage should become an important health factor the change in dosage over all concentration ranges would lead to a much less dramatic reduction than that shown in Table 3 as contrasted to the case where only peak valves above 8 pphm are important.

D. Relationship of Oxidant to Precursors

Since ambient concentrations are a complex function of the precursor hydrocarbons and oxides of nitrogen there have been various attempts to quantify this relationship for control purposes. The simplest such approach, termed linear rollback, assumes a one to one relationship between oxidant and precursors. Taking the highest oxidant valve observed in an area one can calculate what percent reduction in oxidant is required to reach a lower oxidant value such as the national air quality standard. It is then assumed that this same calculated reduction will apply to the precursors. Most frequently this is applied to hydrocarbon control alone although the implication is for equal control of both precursors. Data from environmental chambers however, as well as observations of ambient atmospheres consistently show that the oxidant precursor relationship is not linear even when the hydrocarbon to oxides of nitrogen ratio is held constant. The available data suggests that the linear - rollback technique tends to underestimate the degree of precursor control required.

A second approach is to use the relationship as determined in atmospheric simulations in environmental chamber studies. Unfortunately, at least until very recently, the walls of these chambers have caused fluctuations in the results and also the investigators have been forced by limitations of measurements to operate at precursor concentrations well above those found in real atmospheres. While all such studies are in qualitative agreement no quantitative projection can be made from this data base. What does become clear from these environmental chamber studies is that hydrocarbon control alone will in all cases lead to reductions in oxidants. These studies further show that oxides of nitrogen reductions can lead to both increases and decreases in oxidants depending to a large extent on what hydrocarbon to oxides of nitrogen ratio are being investigated. Investigation of early morning ambient atmospheres indicate an existing hydrocarbon to oxides of nitrogen ratio in the vicinity of about 10 to 1. Given this fact the chamber studies suggest the following guidelines for oxidant control in the South Coast Air Basin.

(1) Hydrocarbon control is the prime consideration for oxidant control.

(2) Oxidant control will be enhanced if the ratio of hydrocarbons to oxides of nitrogen decreases. This can be accomplished by (a) not controlling oxides of nitrogen or (b) controlling oxides of nitrogen at a slower rate than hydrocarbons. Partial oxides of nitrogen control appears necessary in view of the health and welfare effects of nitrogen dioxide.

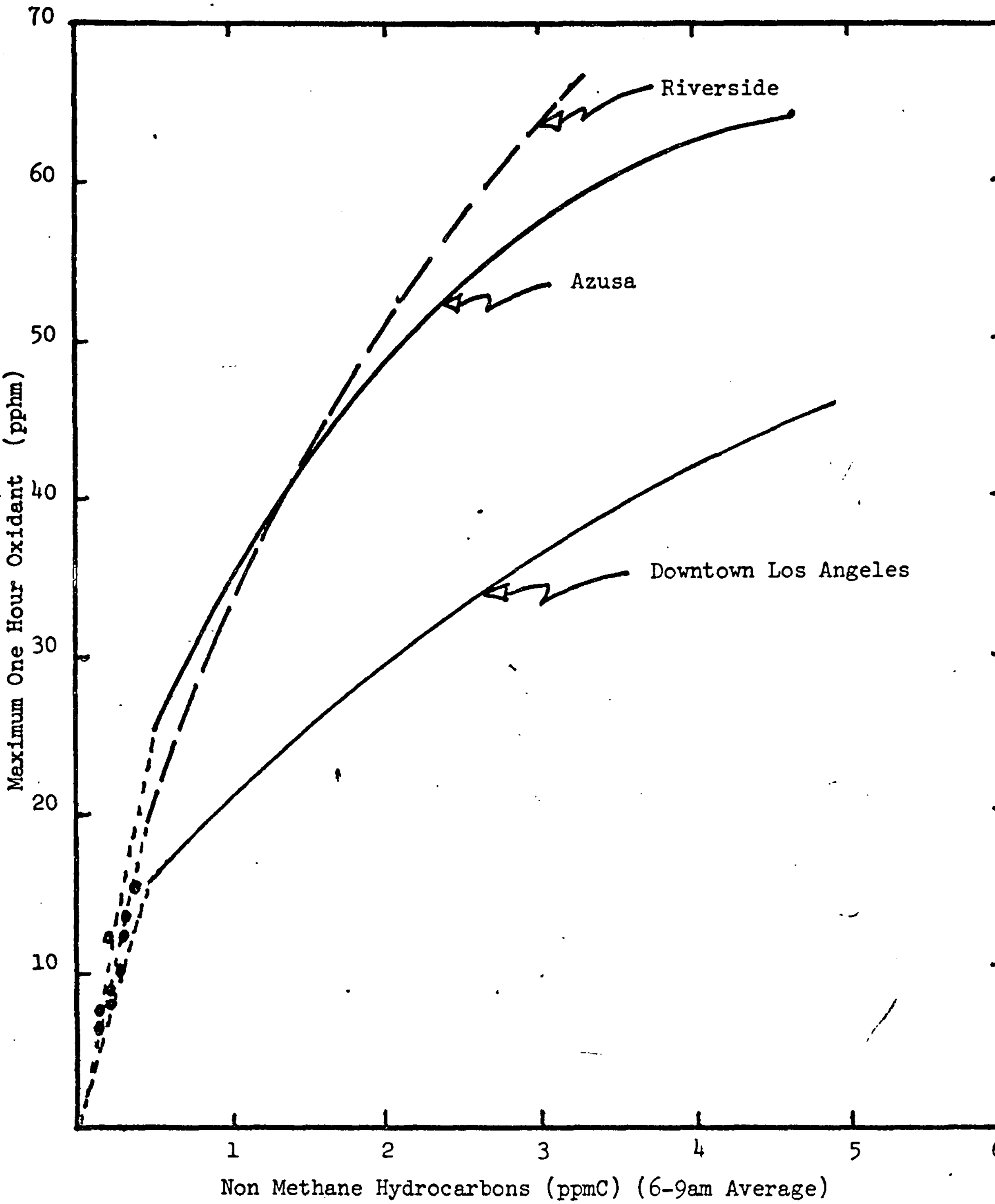
(3) If the hydrocarbon to oxides of nitrogen ratio is permitted to increase to 20 to 1 then hydrocarbon control will not be as effective in oxidant control. This event is not likely to happen since for most areas only minimal control of oxides of nitrogen is required in order to meet the national air quality standard for nitrogen dioxide.

The third approach to delineation of the oxidant-precursor relationship involves equating early morning precurson levels to subsequent oxidant peaks. The method chosen by the Environmental Protection Agency in 1970 was to equate the highest observed oxidant for a given day with the 6 - 9 am hydrocarbon peak. This has been termed the upper limit concept since for any given early morning hydrocarbon valve there will exist a range of subsequent oxidant valves from zero up to an observed maximum. This method has been severely criticized as being non statistical however, as we will discuss the more recent application of regression analysis has validated this upper limit concept.

Since 1970 the body of applicable data has increased making it possible to redefine the upper limit curves for multiple stations in the South Coast Air Basin. Three such curves based on 1968-1971 data are shown in Figure 1. Since little data exists in this Basin below 0.5 ppmC of hydrocarbon the curves have been extropolated to zero. The data points indicated in the vicinity of these extropolation are those obtained from other large U.S. cities where actual measurement of non-methane hydrocarbons as well as peak oxidants were observed. At first glance one might expect substantial differences between stations in projected degree of hydrocarbon reductions to reach a given oxidant valve. In reality the projections from the highest oxidant observed at each station give quite similiar projections. In order to reach the 8 pphm one hour standard the three curves in Figure I gives a valve of 93± 3% for hydrocarbon control. Again, as in the case of linear rollback the curves shown in Figure 1 assume equal control of the two precursors. Thus while linear rollback tends to underestimate the degree of control the use of the curves in Figure 1 tends to overestimate the degree of control since we know that the hydrocarbon to oxides of nitrogen ratio will decrease thus enhancing oxidant control.

As previously noted the 1971 data base includes 8 stations in

Figure 1



UPPER LIMIT ONE HOUR OXIDANT CURVES FOR
SELECTED SOUTH COAST AIR BASIN STATIONS

1968-1971 DATA

the Basin where hydrocarbons as well as oxidants were measured. This permits comparing the average 6-9 am hydrocarbon value for the Basin (as measured by these eight stations) with the highest oxidant observed at any of the stations in the Basin. This Basin average hydrocarbon value should provide a more direct link to emission inventories since these latter are also on a Basin wide basis. The resulting upper limit curve developed from this 1971 data base is shown in Figure II. Using the highest oxidant observed during that year suggests a 91% reduction in hydrocarbons in required in order to attain the national air quality standard of 8 pphm for one hour once per year. Again since the data base explores only the existing ambient precursor ratios it must be assumed to be an overestimate of the degree of hydrocarbon control required.

A fourth approach to determination of the oxidant-precursor relationship is the use of regression analysis. The specific relationship used both by EPA researchers and independent investigators at the Chevron Research Company assumes peak daily oxidant to be proportional to power functions of early morning hydrocarbon and oxides of nitrogen values. Unfortunately such assumed proportionality cannot take into account the complex chemistry involved. The resulting relationships correctly identify the direct or inverse relationship to hydrocarbon but cannot agree on a direct or inverse relationship to oxides of nitrogen. These analysis do however provide a

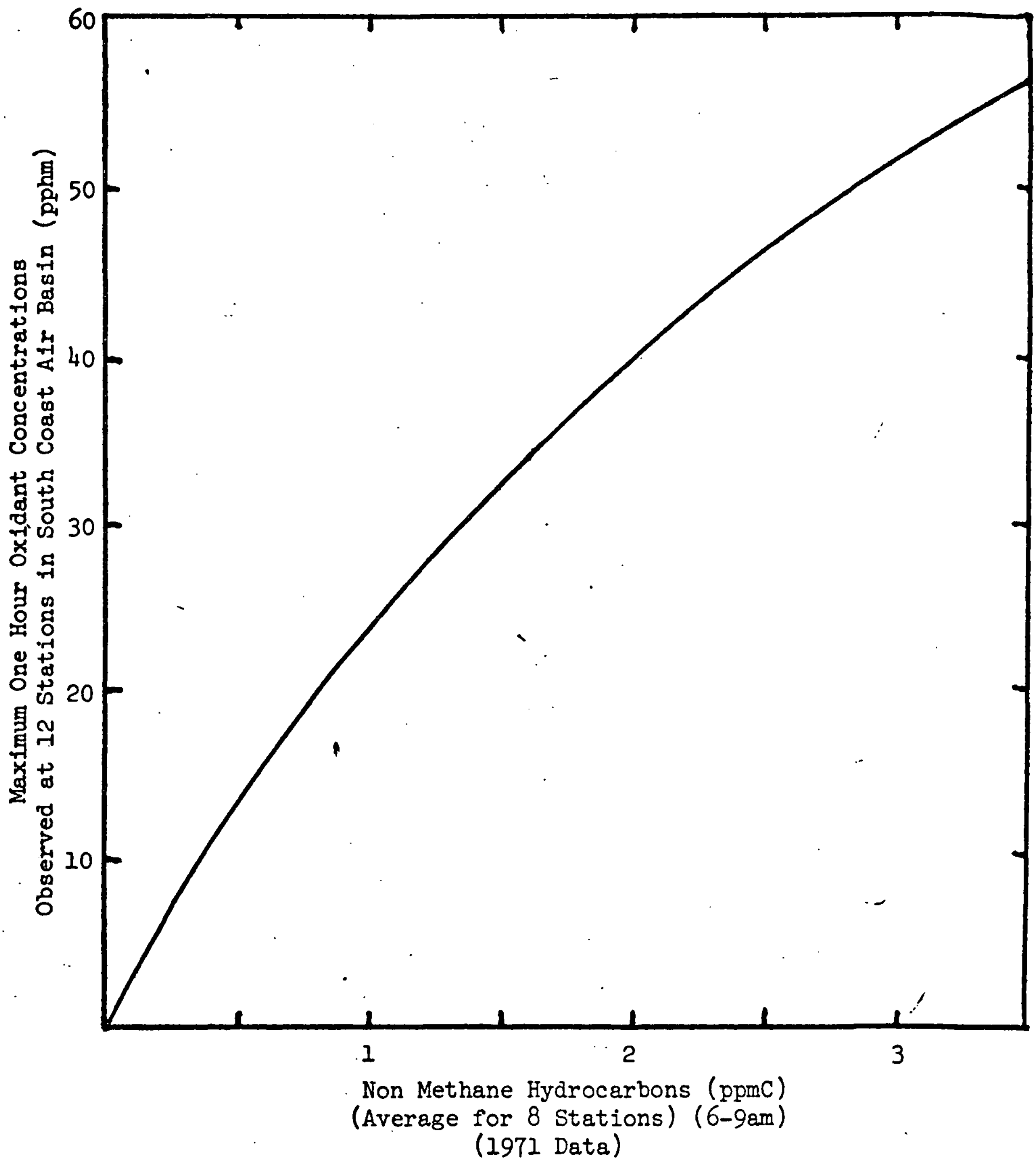


Figure 2

UPPER LIMIT OXIDANT VALUES IN THE SOUTH COAST AIR BASIN AS A FUNCTION OF AVERAGE 6-9am HYDROCARBON CONCENTRATIONS AT 8 STATIONS statistical check on the validity of the upper limit approach. Thus if the Chevron or EPA regression expression for the Downtown Los Angeles location are projected to the once per year event they duplicate the curve shown in Figure 1 for that station.

IV. Summary

Comparing a pre-automotive control period (1963-1967) with a post-control period (1968-1971) shows that changes in automotive emissions patterns have resulted in substantial changes in subsequent photochemical air pollutant concentrations in the South Coast Air Basin. Projection by the Los Angeles County Air Pollution Control District suggests that the post-control period is characterized by an 8-10% reduction in hydrocarbon emissions and a 16-20% increase in nitric oxide emissions when compared with the pre-control period. Examination of the air monitoring data from 8-11 stations in this 1000 square mile area shows that during this same time period the average number of hours of oxidant concentrations above 25 pphm has decreased by 39% and the average number of hours of nitrogen dioxide concentrations above 25 pphm has increased by 42%. The reduction in oxidant concentration is partially due to the decrease in hydrocarbon emissions and partly due to the increase in the nitric oxide emissions. These latter react instantaneously with oxidant (ozone) to form oxygen and nitrogen dioxide. Thus increased nitrogen dioxide concentrations is the resulting trade-off for much of the observed oxidant reductions. Nevertheless the essential point is that peak oxidant values are on the decrease as a direct result of control on automotive emissions. Furthermore these reductions are occurring in spite of a substantial population growth. To what extent we can continue to take advantage of the depressant effect of excess nitric

oxide emissions on peak oxidant concentrations will be a function of the health and welfare effects of the resulting increased nitrogen dioxide concentrations. As of this point in time in the South Coast Air Basin the health threat from oxidants would appear to be greater than that from nitrogen dioxide.

Reevaluation of the relationship between ambient oxidants and their early morning precursors in the light of an expanded air monitoring data base shows no essential change over previously developed relationships. The expanded data base does permit relating Basin wide average hydrocarbon concentrations to observed Basin wide peak oxidant rather than using such relationships at individual stations. The result of such a Basin wide relationship should permit a more direct connection to emission levels since the latter are also on an area basis. The results of this newly developed oxidant-precursor relationship are not significantly different than that obtained at single stations. This is not an unexpected result since the stations in this 1000 square mile area are highly interrelated because of gross meteorological factors. As an example, if the average daily peak oxidant for all stations is known, it is possible to calculate the Basin wide maximum peak within a deviation of 10%.

The Basin wide oxidant-precursor relationship predicts a need for 91% control of ambient hydrocarbons in order to reach the national air quality standard of 8 pphm for one hour once per year.

Use of a linear rollback technique, which is an underestimate, suggests a hydrocarbon control value of 85%. Both methods assume equal control of both hydrocarbon and oxides of nitrogen. This is not likely to occur, i.e., nitric oxide will persist in the emission and thus the depressant effect of these latter emissions will probably lead to the need for a hydrocarbon control somewhere between 85% and 91%. It will be noted, however, that these projections do not take into account expected growth in emissions. If such growth continues, a degree of hydrocarbon control greater than 91% will eventually be required.

V. Acknowledgments

The authors wish to express their appreciation to D. L. Worley and R. I. Larsen for their expert assistance in analysis of the air monitoring data base. Additionally, the suggestions and assistance of A. P. Altshuller and J. L. Horowitz proved invaluable to this study.