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# THE APPLICATION OF REPRO-MODELING TO THE ANALYSIS OF A PHOTOCHEMICAL AIR POLLUTION MODEL

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## Abstract

Several physical models which simulate the impact of emissions and meteorology on the creation and dispersion of photochemical smog have been developed. Characteristics of most of these models are that they are highly computational and require a great deal of input data; hence, it is generally difficult to systematically explore the implications of the models or to use them in a planning context where many model runs are required. This paper explores "repro-modeling," the analysis and replication of the input/output characteristics of the model, as a means of meeting these objectives. A study of the application of repro-modeling to the SAI model developed for the Los Angeles Basin is described. The major objectives of the study were threefold: (1) a feasibility test of the repro-modeling approach; (2) a limited interpretation of the implications of the model; and (3) an efficient repro-model program which duplicates input/output relationships of the original model. The repro-model developed is analyzed in a particular application context (i.e., transportation emission control policy evaluation) and its general implications are discussed. Examples of use of the repro-model, which requires orders of magnitude less computer time than the original model, are provided.

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## 1.0 INTRODUCTION

In recent years several researchers have developed complex physical models of the chemistry and dispersion of photochemical pollutants [e.g., 1,2,3,4]. The major motivation for the models initially was to aid in the evaluation of detailed plans for implementation of the Clean Air Act. For an application of this sort, where a few complex strategies are to be evaluated, the large amount of time required for data preparation and the high computer cost per run of such models are justified by the resulting benefits.

There are other uses for a pollution model, however, in which the computational burden and complexity of data input are significant impediments. Such uses include (a) gaining detailed insight into the impact of changes in emission levels and in ratios of pollutants as an aid to judgment in designing policies; (b) estimating the air pollution impact in a large-scale planning model measuring many environmental and socio-economic impacts; and (c) rapidly evaluating hundreds or even thousands of alternative policies as part of an optimization process, e.g., in developing an optimal fuel allocation plan.

Repro-modeling has been suggested as an approach to extending the utility of complex models to such uses [5]. Briefly, repro-modeling consists of using input/output data generated by the model to understand its implications and to develop an efficient "model of the model" for limited purposes. This final report on contract number 68-02-1207 with the Environmental Protection Agency explores the utility of repro-modeling through application to a photochemical pollutant model developed by Systems Applications, Inc.

## 1.1 Major Objectives

The major objectives of the present study are threefold:

(1) Feasibility of the repro-modeling approach--A major objective of the study was a demonstration of the repro-modeling approach and a test of its feasibility in application to a photochemical pollution model. Questions in this regard include the following: Is the input/output structure of the model sufficiently simple to allow repro-modeling that relationship with a small number of input/output samples of the model? Is the particular technical approach to the problem of modeling that relationship practical? Can the implications of the model be extracted from those input/output samples through the technical approaches proposed?

(2) Limited interpretation of the present model--Can the results of the study be phrased so that the implications of the model are made clear? The interpretation of the relationship between those input parameters changed and output variables measured for the present version of the model provides insights into the implications of the physical relationships embodied in the model and, to the degree of validity of the model, those embodied in the real world. Since a further version of the model is currently under development, any intuitively unreasonable implications of the present version may lead model developers into opportunities for further model improvement.

(3) An efficient repro-model--We wish to summarize the input/output implications of a model in relatively efficient equations which, to the degree of accuracy of the model, yield the same results as running the original model. This working repro-model, which can be embodied in a relatively simple computer program, should run orders of magnitude faster than the original model. These differences between the original model and the repro-model are illustrated in Figure 1.1.

## 1.2 Limitations of the Present Study

The present study has limited objectives and should be interpreted in that light. Major limitations on the generality of the results include the following: (a) the original model is calibrated for Los Angeles and the meteorology was fixed; (b) not all aspects of the original model are exercised; and (c) relationships implied by the original model are valid aids for policy design only to the extent that the model represents reality. Let us discuss these points in turn.

The model utilized was developed by Systems Applications, Inc., under contract to the Environmental Protection Agency [1]. It was designed from physical principles to be applicable to many regions, but has been calibrated and to some degree validated for the Los Angeles Basin. The study is limited to one particular high pollution day which is reasonably well documented and was included in the SAI study; our analysis is particular to the meteorology on that day. This limitation is not as restrictive as it might seem. One is usually interested in reducing pollution levels on extreme days, not average days. In fact, the "rollback" model used in designing many Clean Air Act implementation plans in effect chooses a

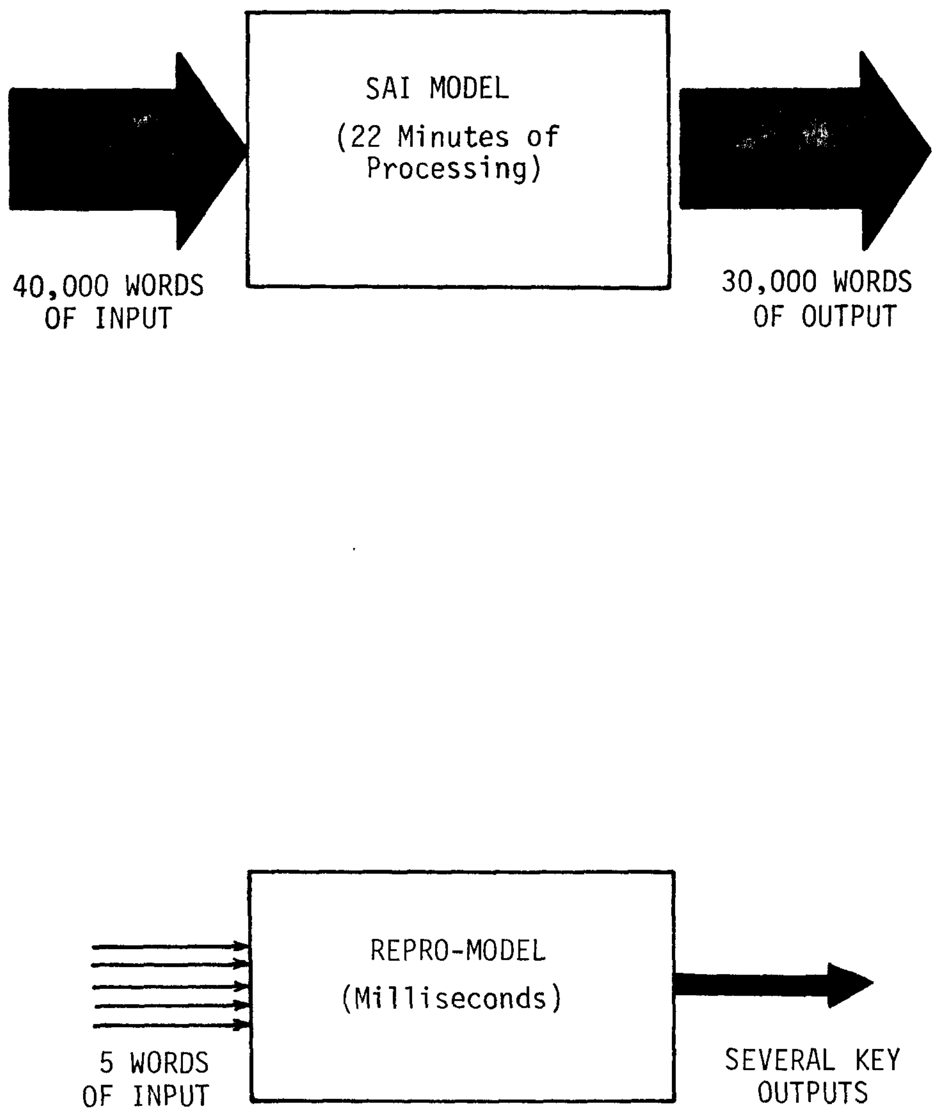


FIGURE 1.1

INPUT-OUTPUT STRUCTURE OF THE
ORIGINAL MODEL AND THE REPRO-MODEL

a single high pollution day as the point from which to roll back.

Consistent with the philosophy of repro-modeling, the number of variables varied in the repro-model is orders of magnitudes less than the number of variables which can be varied in the original model; however, the repro-model variables are aggregate variables which vary many of the original model inputs concurrently. The results must hence be qualified in the sense that all the degrees of freedom of the model have not been exercised and that the particular means chosen to aggregate the input variables involve several assumptions. For example, in defining variables such as the percent reduction in total reactive hydrocarbons emitted, the assumption was made that basic items such as time and space distribution of vehicular traffic would not change. Such assumptions, discussed in further detail in the body of this report, limit the number of alternative policies which can be evaluated by the repro-model, but are not inconsistent with a large number of policies. It should be noted that the validity of such assumptions depends to a large degree upon the outcome of the study; that is, if the input/output structure of the model is sufficiently simple, then more detailed assumptions probably are not justified.

An important limitation of the study that should be emphasized at the outset is that we are modeling a model, and only indirectly the physical system. Hence, the utility of the results in policy planning is determined by the validity of the original model. Tests of model validity will not be evaluated here, but it should be noted that those tests performed were related to forecasting absolute pollution levels. The repro-model is oriented more toward determining relative effects of changing different variables than predicting absolute pollution levels. If the major characteristics of the physical system are embodied reasonably in the model, then the relative effects and nonlinearities involved in the process should be modeled adequately. However, the original model is still under continuing development, and implications of future versions of the model may differ. On the positive side, an important aspect of working with models rather than directly with data from the physical system is that all variables can be controlled. The physical system is not so cooperative; the difference in pollution levels from one day to another is due to a large number of factors including changing traffic distributions and meteorology. In the physical model we can hold traffic distribution and meteorology constant while manipulating other factors. Hence, for the exploration of the relative effects of a large number of alternatives, modeling the model might in some cases be more to the point than a direct model of the physical world. From another point of view, the investigation of the implications of the model in terms of general effects is another form of model validation. If the model predicts effects which are strongly counter-intuitive and difficult to justify, this suggests that the components of the model contributing to those effects be examined carefully to suggest improvements in the model.

### 1.3 Outline

In Section 2.0 the photochemical pollutant model under study is described briefly. Section 3.0 discusses the application context for the repro-model; that is, the aggregate input variables and output variables chosen are described, the policies to which they correspond are indicated, and the ranges of the policy variables are specified. Section 4.0 contains discussion of the repro-models created, the accuracy achieved, and the form of the results produced by the repro-model program. Section 5.0 discusses the general implications of the model revealed by the analysis and exemplifies the use of the repro-model to examine policy tradeoffs. Section 6.0 reviews and summarizes the results of the study.

# 2.0 THE PHOTOCHEMICAL POLLUTION MODEL

## 2.1 Overview

The photochemical pollution model developed at Systems Applications, Inc.,* was the focus of analysis in this study. The purpose of the SAI model is, given emission levels, meteorology, and other data, to accurately predict pollutant concentration over a wide area (to date, the Los Angeles area). The model, as used in this study, divides the region into 625 2x2 mile squares, the atmosphere above ground level and below the inversion into five vertical strata and time into five minute intervals with hourly summaries. A ten-hour simulation was used in this study. Figure 2.1 illustrates the positioning of the model region over the Los Angeles Basin.

The SAI model is one of the most comprehensive photochemical pollution models developed. Based on the Eulerian (fixed coordinate) approach, the SAI model repeatedly solves the conservation of mass differential equations for the whole basin. A total of six atmospheric pollutants are simulated with a fifteen-step photochemical reaction model. These pollutants are reactive and unreactive hydrocarbons, nitrogen dioxide, nitric oxide, carbon monoxide, and ozone. The model requires two types of inputs: meterological inputs such as wind speed and direction and inversion heights, and emission inputs such as hydrocarbon and $NO_x$ production from both fixed and mobile sources. Outputs of the model take the form of estimates of the six pollutants' hourly average concentrations in most

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*The SAI model is documented in great detail in a lengthy report. The reader should consult this report for a complete description of the SAI model [1].

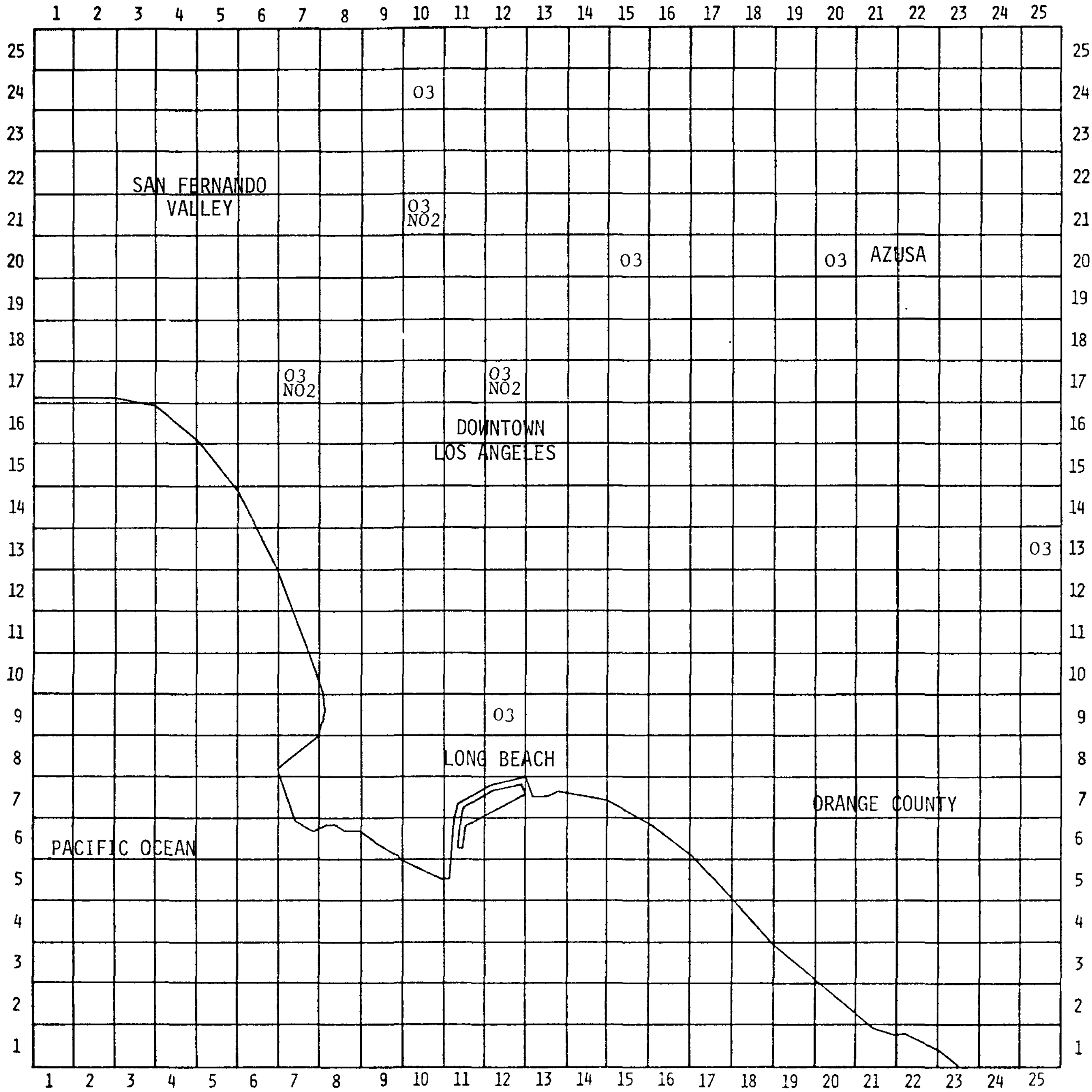


FIGURE 2.1

THE SAI COORDINATE SYSTEM
AND LOCATIONS OF REPRO-MODELS

of the four-square-mile zones. The SAI model can be characterized, therefore, as a transfer function between very detailed and complex inputs and very comprehensive outputs.

The SAI model is undergoing further development. The latest available version [1] of the model was used in this study. As newer versions of the SAI model are released, we can expect improvements in accuracy and possibly in computational efficiency.

## 2.2 Input Requirements of the SAI Model

Raw emissions and meteorological data are preprocessed before they are input into the model. Parts of this preprocessing are accomplished by hand; however, much of the data preparation procedure has been computerized in the current version.

The SAI model requires a complete and detailed emissions inventory for any day that is simulated. Traffic volumes on all surface streets and speeds and volumes of traffic on all freeways are used to obtain emissions from mobile sources. Cold start information, the temporal distribution of traffic, ground operations at airports are also used. Fixed source emissions are aggregated for each of the 625 zones. Stack emission information is also required. Approximately 15,000 words of emission input is used to simulate a single day in Los Angeles.

The SAI model further requires a complex statement of the simulated day's meteorology. Unlike emission inventories which can remain useful for several months, meteorological data can change drastically from one day to the next. Besides demanding wind speed and direction and inversion height in each zone for each hour, the SAI model requires initial and boundary condition concentrations of all the pollutants. In all, approximately 25,000 words of meteorological input must be respecified for each day simulated.

2.3 Outputs of the SAI model

In the course of one model run, approximately 37,500 words of output are generated. This breaks down into six pollutant concentrations in 625 zones for 10 hours. Each output is the average of several concentrations computed for each zone and each hour. Only ground level concentrations are normally reported, although the average concentrations in each of the four highest strata are also available. Additionally, the SAI model interpolates to obtain the expected concentrations at each of the air pollution monitoring station locations within the simulation boundaries.

In order not to convey the misleading impression that the SAI model is extremely accurate, the outputs are presented as rounded integers. The units of concentration for each pollutant are chosen such that the results contain about two digits of information. Where the results involve only one digit (e.g., 6 pphm) the error introduced by rounding can be a significantly high fraction of the pollution level. This feature of the model presents little problem to the typical user, since the accuracy of the model simply does not warrant more significant figures.

The rounding, however, presents a problem when doing statistical analyses of the model: it adds a pseudo-random component to the model output. This problem will be discussed in more detail later in this report.

## 2.4 Computational Requirements of the Model

The SAI model requires a computer with approximately 300K bytes of memory. The ten-hour simulation takes about seventy-three minutes [1] on the IBM 370-155 and about twenty-two minutes on the IBM 370-165. Furthermore, the program requires computer facilities which have available a minimum of three disk or tape drives, with two additional disk areas needed for full utilization.

In the course of this study, the SAI model was executed one hundred times. These computations were carried out by the staff at the Environmental Protection Agency on an IBM 370-165, according to specifications developed jointly by Technology Service Corporation and EPA personnel. Only the emission input data was modified in this study. Otherwise, the model was run exactly as specified by SAI. The results of the model runs were analyzed at TSC.

All the SAI model runs used the meteorological conditions of September 30, 1969. The test day had high average oxidant readings (36 pphm at Pasadena) and was typified by slight winds and a strong inversion.

Total $NO_x$ emissions for the test day were 772 tons in Los Angeles County and 119 tons in Orange County. Approximately 62% of the emissions were from motor vehicles. Los Angeles County contributed 1237 tons of high-reactivity organic gases and 804 tons of low-reactivity organic gases. Orange County was responsible for 220 tons of high-reactivity organic gases and 79 tons of low-reactivity organic gases. Motor vehicles were the cause of approximately 84% of these emissions.

A detailed breakdown of emission by sources can be obtained in the appendix to an early SAI report [1].

# 3.0 AN APPLICATION CONTEXT

## 3.1 A Repro-Model for Evaluating Effects of Transportation Control Strategies

The SAI model (as with any comprehensive model) lends itself to analysis from many different viewpoints. The number and variety of repro-models that could be constructed from any model of this size are virtually infinite. The content of a repro-model's input/output relationships can be defined by first delineating a decision or analysis context. Once this context has been carefully defined a repro-model can be built which specifically answers certain pre-specified questions.

The application context chosen for this study centers around transportation control strategies. The objective of the application is to gain insight into how across-the-board emission controls affect overall air quality. The inputs to the repro-model are aggregate emission measures. The outputs of the repro-model are selected measures of pollution concentration at various locations in the South Coast Air Basin.

The relationship between the SAI model and the repro-model was illustrated in Figure 1.1. While the SAI model represents an indirect relationship between tens of thousands of disaggregated variables, the repro-model selects only a few aggregated inputs and directly produces several meaningful outputs. Within its limited scope, the repro-model is in effect equivalent to the original SAI model.

The repro-model deals in the language of the decision-maker or planner rather than the language of the environmental engineer or meteorologist. For example, when the planner wishes to test the impact of a certain percentage reduction in vehicle miles of travel (VMT) in a specified year, the repro-model will accept this input with very little preprocessing. The outputs of the repro-model are phrased to convey the maximum of information to the decision-maker. Instead of producing volumes of uninterpreted data, the repro-model's results are phrased for comparison with the national ambient air quality standards.

3.2 The Policy Region

Because only one hundred air pollution model runs were made, the number of decision variables and their ranges were carefully selected.* For this repro-model, the variables were restricted to those which describe short-run emission reduction policies.

This repro-model is directed, particularly, toward changes in pollutant production from motor vehicles. Two control variables for primary motor vehicle pollutants ($NO_x$,HC), two variables for initial and boundary pollution concentration ($NO_x$,HC), and one variable for area source hydrocarbons have been defined. Meteorological, geographical, and developmental variables have all been assumed constant and equal to the values for the test day.

Each variable is defined in terms of the fraction of the values used for the selected test day. The oxides of nitrogen variable, for instance, is the fraction of $NO_x$ emitted from each zone as compared with the actual values for the test day. The fraction is specified constant over all zones. That is, a fifty percent reduction in $NO_x$ emissions implies a fifty percent reduction in every zone. The initial condition variables specify the

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*The "curse of dimensionality" makes careful choice necessary; for example, if one simply looked at combinations of 5 values of each of 5 variables, the number of model runs required would be $5^5 = 3{,}125$.

initial and boundary pollutant concentrations as a fixed fraction of the test day's initial and boundary concentrations.

While this variable set may seem somewhat restrictive, the number and types of policy alternatives which can be investigated in this manner is quite large. Table 3.1 on the following page shows which of the most commonly suggested control strategies the repro-model can handle. Of the short-run control measures only those which imply a transportation demand change or deal in an unmodeled pollutant cannot be analyzed using the repro-model.

Most commonly applied control measures do not radically reduce one pollutant while leaving all other pollutants unchanged. For example, if fuel was rationed we might expect to see emissions of all pollutants decrease roughly in proportion to the decrease in fuel consumption. Over the short run, one would not expect to see great variations between pollutants in the amount of reduction. Under a fifty percent gas rationing proposal, for instance, we would not expect to see in the short run a seventy percent reduction in HC and only a thirty percent reduction in $NO_x$ from mobile sources.

The policy region has been defined assuming that reductions in mobile source emissions will be highly correlated. A thirty percent variation from an equal reduction rule is permitted for control strategies which do not greatly affect the status quo, and as much as a two hundred percent variation off the equal reduction line is permitted for radical policy alternatives. A projection of the feasible policy region is shown in Figure 3.1. The equal reduction line is the set of points such that: $x_1 = x_2$, where $x_1$ is the $NO_x$ mobile source emission variable and $x_2$ is the hydrocarbon mobile source emission variable.

TABLE 3.1

POLICIES WHICH CAN BE EVALUATED USING THE REPRO-MODEL

| Short-Run Control Measures | Can repro-model aid decision making? |
|---|---|
| A. Inspection Maintenance | Yes |
| B. Retrofit | Yes |
| C. Fuels Modification | |
| 1. Lowering Reid Vapor Pressure | Yes |
| 2. Replacing Reactive Hydrocarbons | Yes |
| 3. Lead Removal | No |
| 4. Gaseous Fuel Conversion | Yes |
| D. Traffic System Improvements | Yes |
| E. Vehicle Exchange | Yes |
| F. Vehicle Travel Reduction | |
| 1. Limited Registration | Yes |
| 2. Fuel Rationing | Yes |
| 3. Travel Rationing | Yes |
| 4. Parking Limitations | No |
| 5. Free Zones | No |
| 6. Work Schedule Shifts | No |
| G. Pricing | |
| 1. Increase Cost of Ownership | Yes |
| 2. Increase Fuel Taxes | Yes |
| H. Demand Shift | |
| 1. Improve Mass Transit | No |
| 2. Slow Traffic Improvement | No |
| J. Household and Industrial Emission Reduction | No |
| Long-Run Control Measures | |
| K. Land Use Planning | |
| 1. Population Shifts Due to Transportation Improvement | Long-run strategies must be tested with a new repro-model designed to handle the specific problem. |
| 2. Population Increases | |
| 3. Green Belts--Open Space | |
| 4. Industrial Location/Stationary Source Location | |

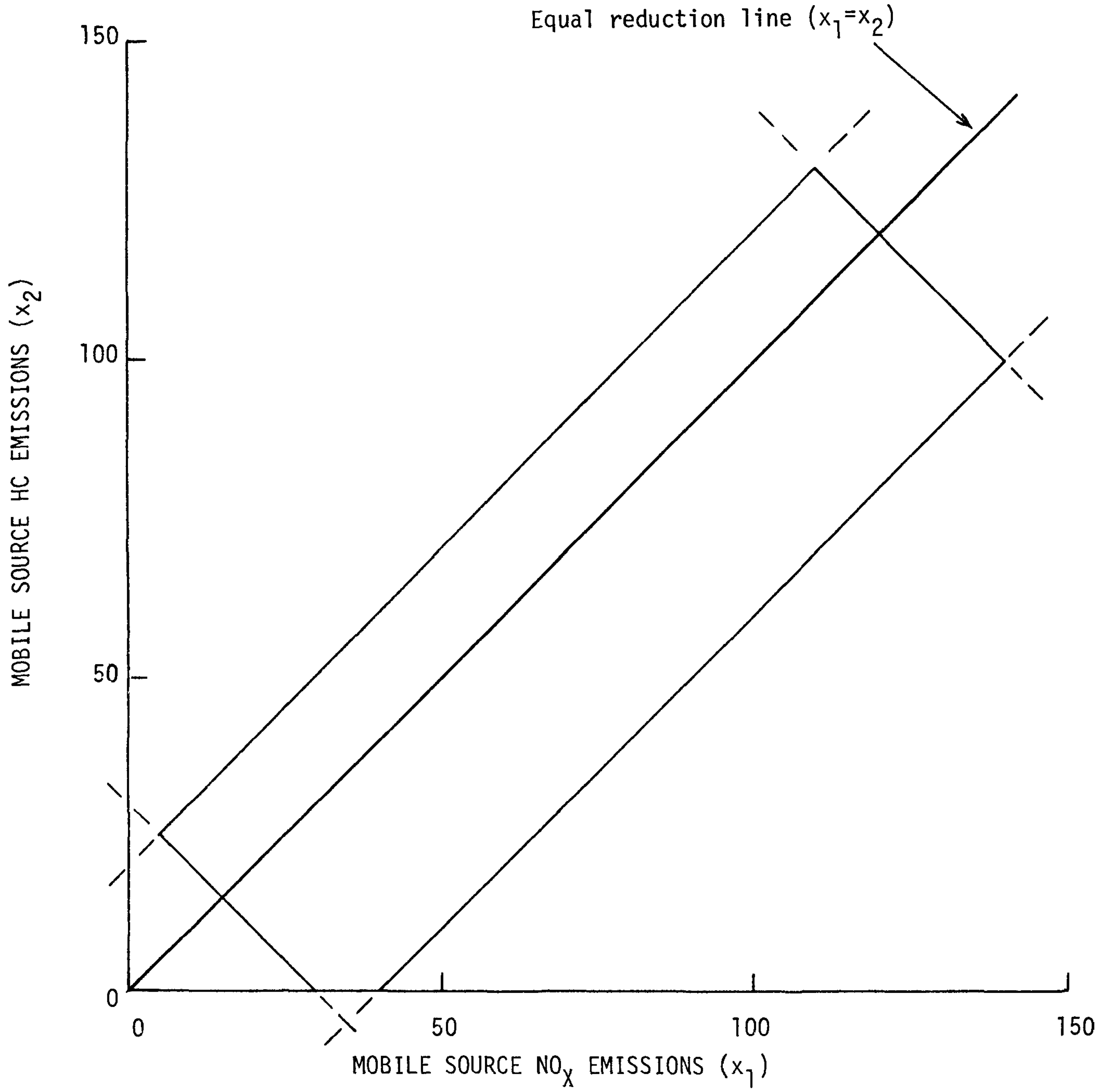



FIGURE 3.1

A PROJECTION ON THE ($x_1$,$x_2$) AXES OF THE FIVE-DIMENSIONAL POLICY REGION

The initial condition variables adjust both the initial conditions and boundary conditions together. These variables are permitted to vary around the values that would typically be found under the various emission control strategies. That is,

$$x_4 = 38 + 0.62x_1 + \delta \qquad (3.1)$$

$$x_5 = 0.84x_2 + 0.16x_3 + \delta \quad , \qquad (3.2)$$

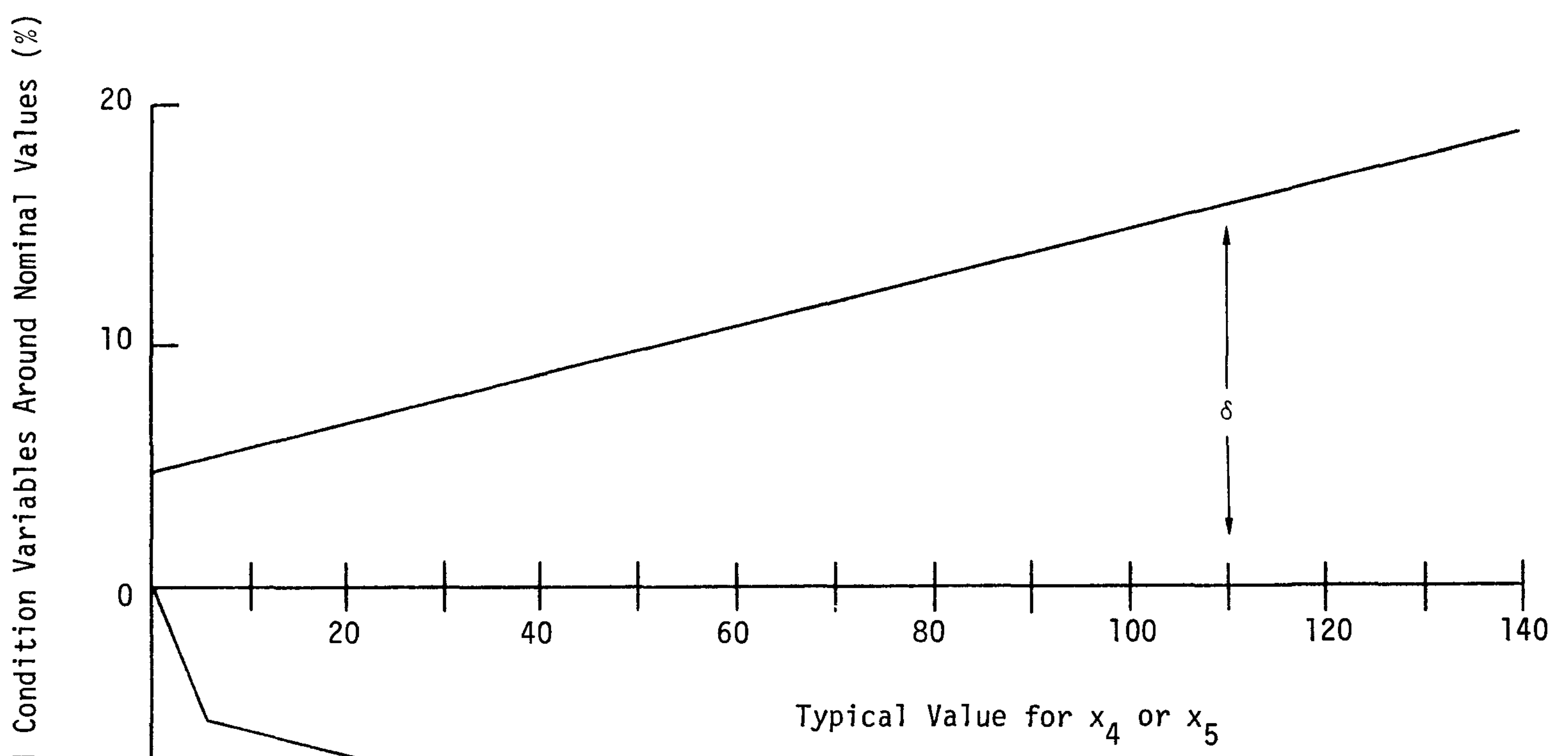
where $x_4$ is the $NO_x$ initial condition variable, $x_5$ is the hydrocarbon initial condition variable, and $x_3$ is the fixed source hydrocarbon-emission control variable.* Figure 3.2 shows the range ($\delta$) that the initial condition variables may be varied around their typical values. The relationship between $x_4$ and $x_1$ is shown in Figure 3.3.

The formal statement of the policy region constraints is provided in Table 3.2.

Carbon monoxide concentration does not greatly affect the reaction equation. CO production from automobiles has, therefore, been made an endogenous variable in this model. Because CO emissions are expected to vary roughly with $NO_x$ and HC emissions, we assume CO reduction is proportional to the average reduction in HC and $NO_x$.

The two-dimensional projection of the policy region with respect to $NO_x$ and HC mobile source emissions is a rectangle tilted at 45°. In

*The coefficients in these two equations result from the 62 percent contribution of $NO_x$ from mobile sources and the 84 percent contribution of HC from mobile sources.




Typical Value: $x_4' = 38 + 0.62x_1$ , $x_4 = x_4' + \delta$

$x_5' = 0.84x_2 + 0.16x_3$ , $x_5 = x_5' + \delta$

FIGURE 3.2

THE RANGE OF THE INITIAL CONDITION VARIABLES

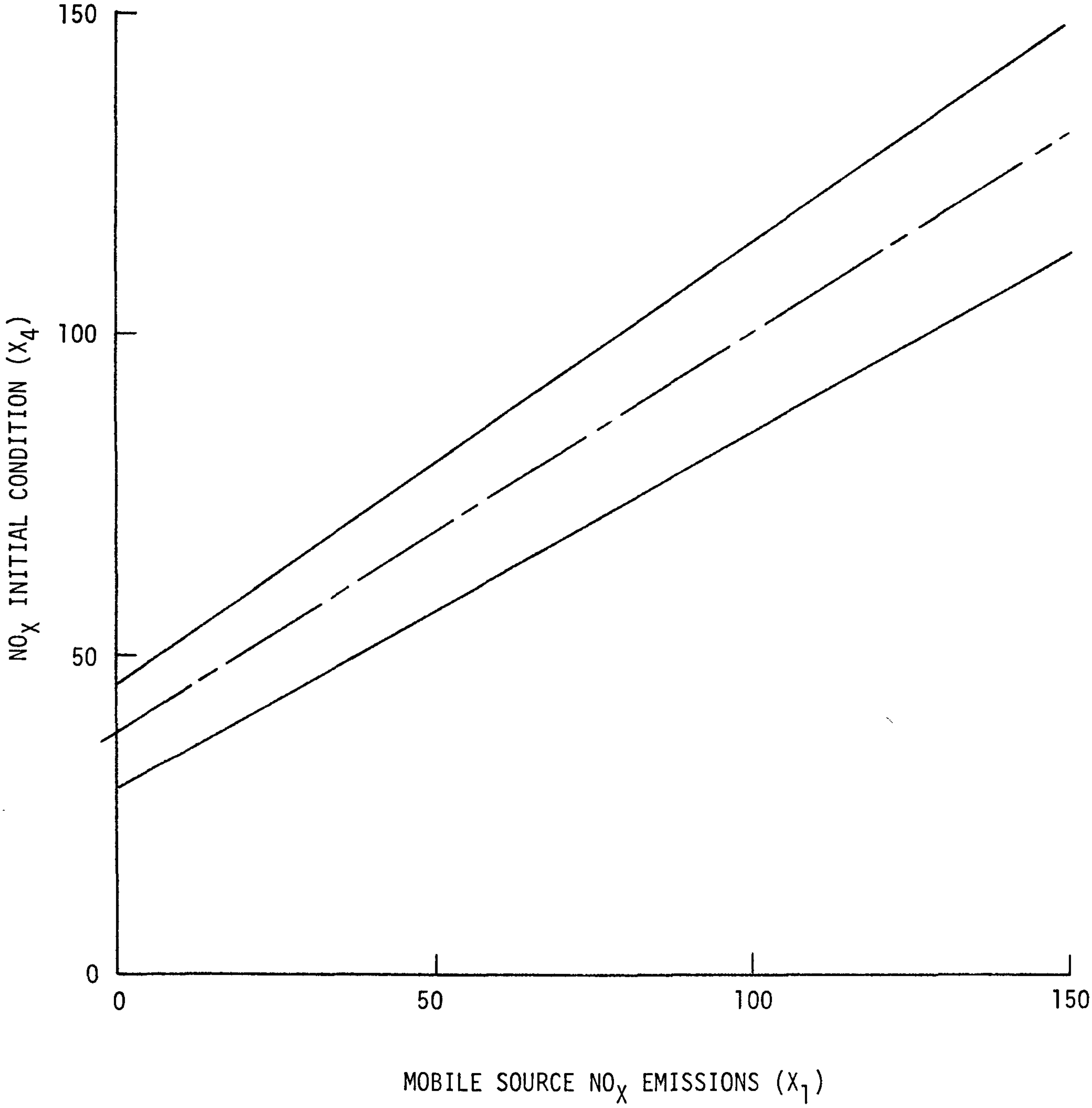



FIGURE 3.3

RELATIONSHIP BETWEEN $NO_X$ MOBILE SOURCE EMISSION

AND INITIAL CONDITION VARIABLES

TABLE 3.2

POLICY REGION CONSTRAINTS

$x_1 + x_2 > 30$ (1)

$x_1 + x_2 < 240$ (2)

$x_1 - x_2 < 40$ (3)

$-x_1 + x_2 < 20$ (4)

$x_2 > 0$ (5)

$x_3 > 0$ (6)

$x_3 < 100$ (7)

$x_4 - 0.558x_1 > 29.2$ (8)

$x_4 - 0.682x_1 < 46.8$ (9)

$-x_5 + 0.756x_2 + 0.144x_3 < 5$ (10)

$x_5 - 0.924x_2 - 0.176x_3 < 5$ (11)

$x_5 > 0$ (12)

---

$x_1$ = % of test day's mobile source $NO_x$ emissions

$x_2$ = % of test day's mobile source hydrocarbon emissions

$x_3$ = % of test day's fixed source hydrocarbon emissions

$x_4$ = % of test day's initial and boundary conditions for $NO_x$

$x_5$ = % of test day's initial and boundary conditions for hydrocarbons

Figure 3.4 the policies representing vehicle emission controls has been superimposed on the policy region [8]. The resulting curve falls well within the policy region. While Figure 3.4 holds vehicle miles of travel (VMT) constant, Figure 3.5 shows the effects of VMT changes in any year between 1969 and 1980. While these curves do not take into consideration secondary reductions or increases in emissions due to vehicle speed changes, all but very radical VMT change policies fall within the policy region. By varying both the VMT and the emission control policy, and adjusting for secondary effects, an infinite variety of control policies can be simulated within the specified policy region.

As insurance, two vectors well outside the policy region were included in the repro-model design to improve the accuracy of extrapolation beyond the chosen policy region.

### 3.3 Outputs of the Repro-Model

The outputs of the SAI model provide the ability to construct literally thousands of repro-models. We are given the concentrations of six pollutants, ten time periods, and six hundred and twenty-five zones. Not all of this information is particularly useful for present purposes, and the number of relevant dependent variables can be quite small.

The pollutant which violates national primary and secondary ambient air quality standards most frequently in the Los Angeles Basin is photochemical oxidant. While the eight-hour average carbon monoxide standard is often exceeded, photochemical oxidant is considered the critical pollutant for air quality control in Los Angeles. The repro-model accordingly emphasizes measures of peak one-hour average oxidant. Time average nitric oxide concentrations are also studied, but to a lesser extent.

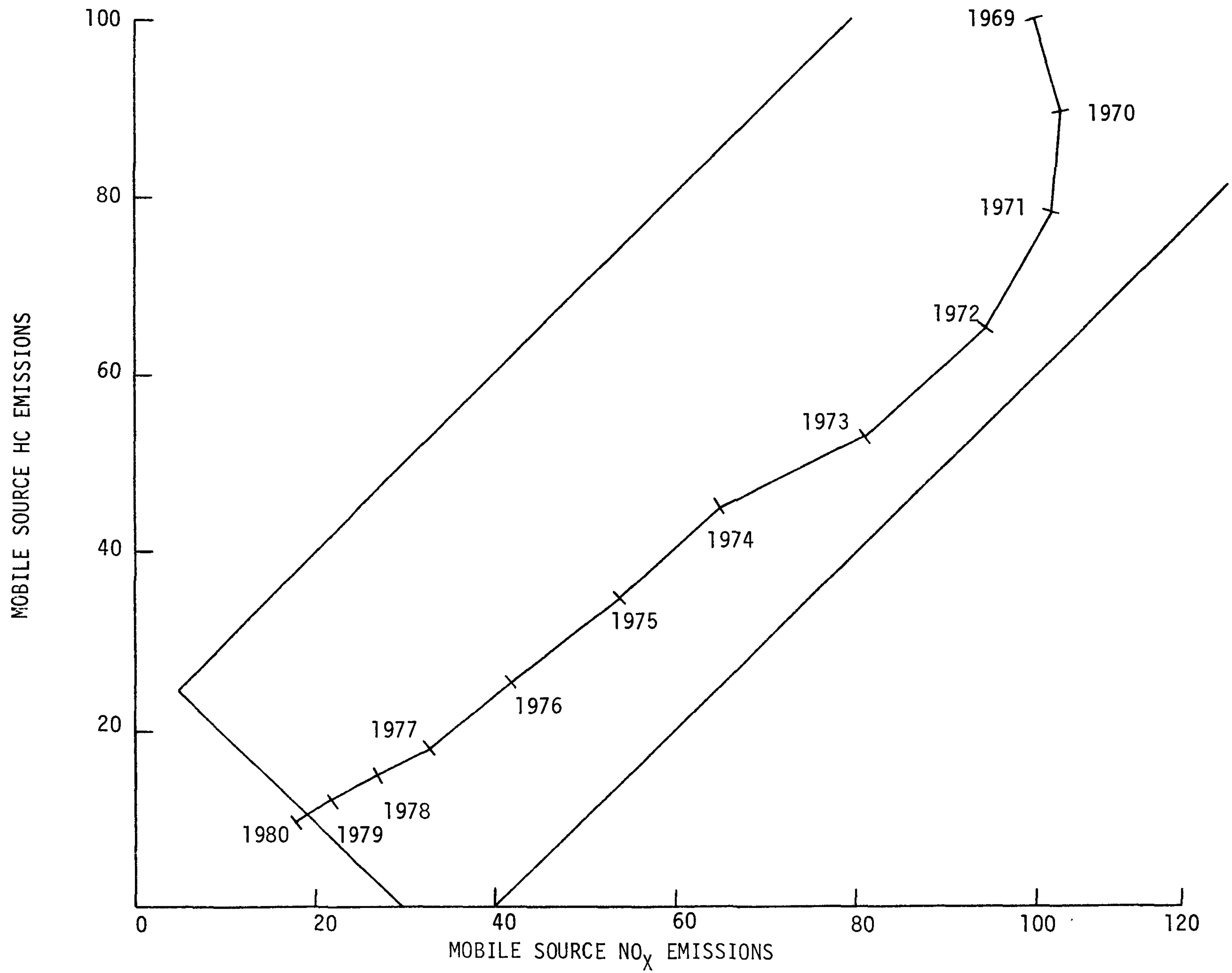



FIGURE 3.4
1969 VMT WITH VEHICLE MIX OF YEARS 1969-1980

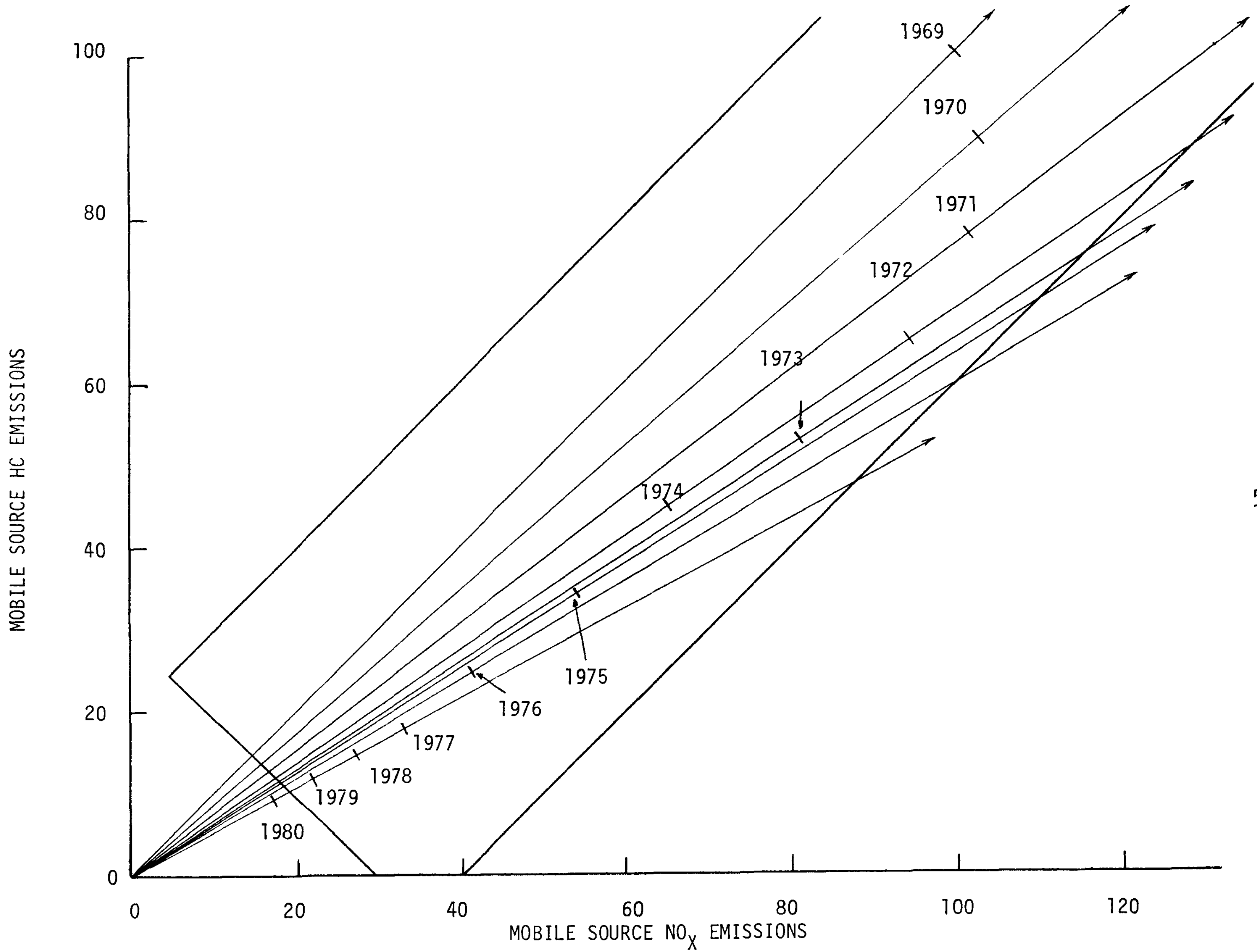



FIGURE 3.5

EFFECT OF VMT CHANGES ON MOBILE SOURCE EMISSIONS

Two classes of peak oxidant readings are considered in this modeling effort. First, we consider the peak one-hour average for eight selected zones in the basin, no matter when these peaks occur. Second, one repro-model will predict peak one-hour concentrations no matter where or when this peak occurs. These types of models are designed to answer the question of whether a particular control strategy will produce sufficiently reduced oxidant readings to satisfy air quality standards. Further, these repro-models will indicate where the oxidant concentration is expected to be a problem in a day similar to the conditions of the test day.

For three locations on the 625-zone grid, repro-models were constructed for ten-hour average $NO_2$. The time averaging phrases the $NO_2$ concentration in similar terms as the national ambient air quality standards, helps overcome roundoff error problems, and allows some determination of the ease of repro-modeling average pollutant concentrations.

The eight zones which were used for the repro-models were spread over the basin. Four of the zones correspond to the location of monitoring stations. Four of the zones were selected because of particularly interesting repro-model features. The eight zones are:

1. Sunland (10,24).* This zone consistently yielded levels near the peak oxidant value for runs which simulated high emissions. ($O_3$)
2. Pasadena (15,20). Location of monitoring station 75. ($O_3$)
3. Burbank (10,21). Location of monitoring station 69. ($O_3$ and $NO_2$)
4. Downtown Los Angeles. Location of monitoring station 1. ($O_3$ and $NO_2$)

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*In the zone designation (a,b), "a" refers to the east-west coordinate and (b) refers to the north-south coordinate. See Figure 2.1.

5. Duarte (20,20). Example of a high pollution area east of downtown Los Angeles. ($O_3$)

6. Carbon Canyon (25,13). Easternmost high pollution zone considered. ($O_3$)

7. West Los Angeles (7,17). Typical of many low pollution zones. Located near monitoring station number 71. ($O_3$ and $NO_2$)

8. North Long Beach (12,9). A low pollution zone located in the industrialized South Bay area.

A separate repro-model was constructed of the peak oxidant value whenever and wherever it occurred.

## 3.4 SAI Model Runs

One hundred well-spaced points within the policy region were used as a basis for the SAI model runs. These points are listed in the Appendix.

The first run is referred to as the "baseline." It represents the 100% case, and it uses the data exactly as provided by SAI for September 30, 1969. A peak oxidant "histogram" for this baseline case is shown in Figure 3.6. The boundaries of the simulation are clearly defined, especially along the coastline. Two local maximums are evident. One maximum occurs in the Northeast San Fernando Valley near Sunland. A second maximum occurs along the eastern boundary of the 25x25 grid. In general, this "histogram" and others for different runs exhibit a continuity in the peak oxidant function with a noticeable absence of isolated peaks and steep troughs. High concentration gradients visible in the northern portion of the graph indicate the model's sensitivity to meteorological factors.

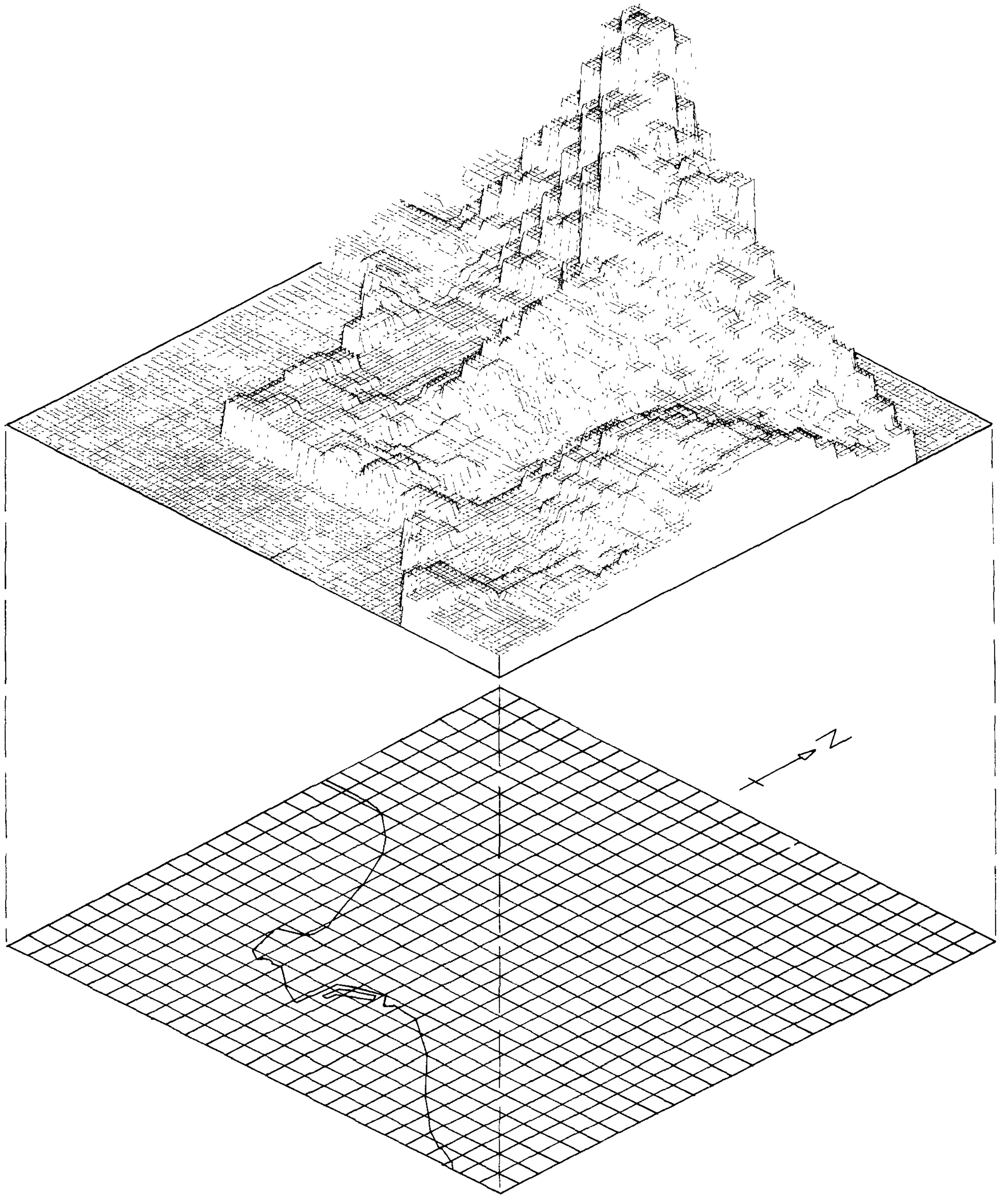


FIGURE 3.6

A PEAK OXIDANT "HISTOGRAM"
FOR THE BASELINE RUN

The shape of the peak oxidant function remains nearly the same throughout all the runs. This characteristic of the SAI model can be more precisely stated by the correlation matrix shown in Table 3.3. Each term in the matrix represents the correlation between the peak oxidant readings at two zones over ninety* of the one hundred runs. The near perfect correlations found in most of the table demonstrate this shape-retaining property of the SAI model. The last row on the table is the expected correlation between the particular peak oxidant readings and the same reading without any roundoff error, i.e., the value that would be obtained if the only source of error was roundoff error.** This row indicates that, after roundoff error is accounted for, zone (12,9) is behaving in nearly direct proportion to the other zones while zone (7,17) is not.

The column associated with the peak oxidant over all zones shows the typically high correlation with all other zones. Table 3.4 shows the proportionality constants between the peak zone and all other zones. Although only eight bivariate regressions were performed for this table, approximations of any peak oxidant reading can be arrived at in this manner. The fact that a simple linear relationship closely predicts the peak levels in most zones given the overall peak suggests that the aggregate output measures chosen summarize succinctly much of the model output.

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*Ten runs were removed at random for later independent tests.

**This effect of roundoff error is discussed further in Section 4.2.

TABLE 3.3

DEPENDENCE OF ZONE PREDICTIONS

Correlation Matrix (N=90)

| ZONE | PEAK | 10,24 | 10,21 | 15,20 | 20,20 | 7,17 | 12,17 | 25,13 | 12,9 |
|---|---|---|---|---|---|---|---|---|---|
| PEAK | 1.00 | | | | | | | | |
| 10,24 | .99 | 1.00 | | | | | | | |
| 10,21 | .98 | .97 | 1.00 | | | | | | |
| 15,20 | .99 | .98 | .99 | 1.00 | | | | | |
| 20,20 | .97 | .96 | 1.00 | .99 | 1.00 | | | | |
| 7,17 | .30 | .27 | .43 | .38 | .45 | 1.00 | | | |
| 12,17 | .94 | .91 | .98 | .96 | .98 | .51 | 1.00 | | |
| 25,13 | .98 | .97 | .99 | .98 | .99 | .39 | .96 | 1.00 | |
| 12,9 | .77 | .75 | .79 | .77 | .78 | .35 | .78 | .77 | 1.00 |
| LIMITING CORRELATION* | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | .85 | 1.00 | 1.00 | .71 |

*Correlation coefficient when the only degradation in perfect correlation is due to roundoff error.

TABLE 3.4

THE PEAK AS A PREDICTOR OF
OTHER CONCENTRATIONS (pphm)

[Zone level = SLOPE x Peak level + CONSTANT]

| ZONE | SLOPE | CONSTANT |
|---|---|---|
| 10,24 | 1.10 | -3.91 |
| 10,21 | 0.61 | -3.48 |
| 15,20 | 0.69 | -3.15 |
| 20,20 | 0.36 | -0.82 |
| 7,17 | 0.11 | 2.15 |
| 12,17 | 0.30 | -1.78 |
| 25,13 | 0.38 | -0.36 |
| 12,9 | 0.02 | 0.80 |

Three other points are of particular significance. One run of the SAI model represents the 87% hydrocarbon reduction control strategy for Los Angeles [9]. The results of this run were that over most of the basin the $O_3$ concentrations were between 1 and 3 pphm. Two other runs were made which represent points well outside the policy region. These points insure that the repro-model will extrapolate well in regions which are not completely explored.

## 4.0 REPRO-MODEL DEVELOPMENT

This section outlines the technical approach employed in creating the repro-models; discusses the limiting accuracy that can be achieved due to roundoff of the model output; lists the parameters of the repro-models developed; and discusses their accuracy, their efficiency, and the particular output format chosen for the delivered software. Discussion of the implications of the repro-models is postponed to section 5.0.

### 4.1 The Technical Approach

The general philosophy and approaches employed in repro-modeling have been discussed elsewhere [5]. Some discussion of the technical approach will aid exposition of the results of this study; however, the remainder of the report does not lean heavily on the present section.

In the 100 runs of the SAI model used in this study, five independent variables were varied. Each set of values of the independent variables produced a set of values of the dependent variables. Because a separate functional relationship is derived for each dependent variable, we will speak in terms of a repro-model with five independent variables and one dependent variable. In fact, the repro-model of the entire model is a collection of smaller repro-models having identical inputs (Figure 4.1). This semantic confusion will hopefully be unraveled through context.

The means by which these repro-models, i.e., functional forms modeling the input/output relationship implicit in the original model, are constructed is through the use of many samples of the input/output process. A hundred such samples were available for each repro-model; ninety were used to construct the repro-model, and ten set aside for a later test of consistency.

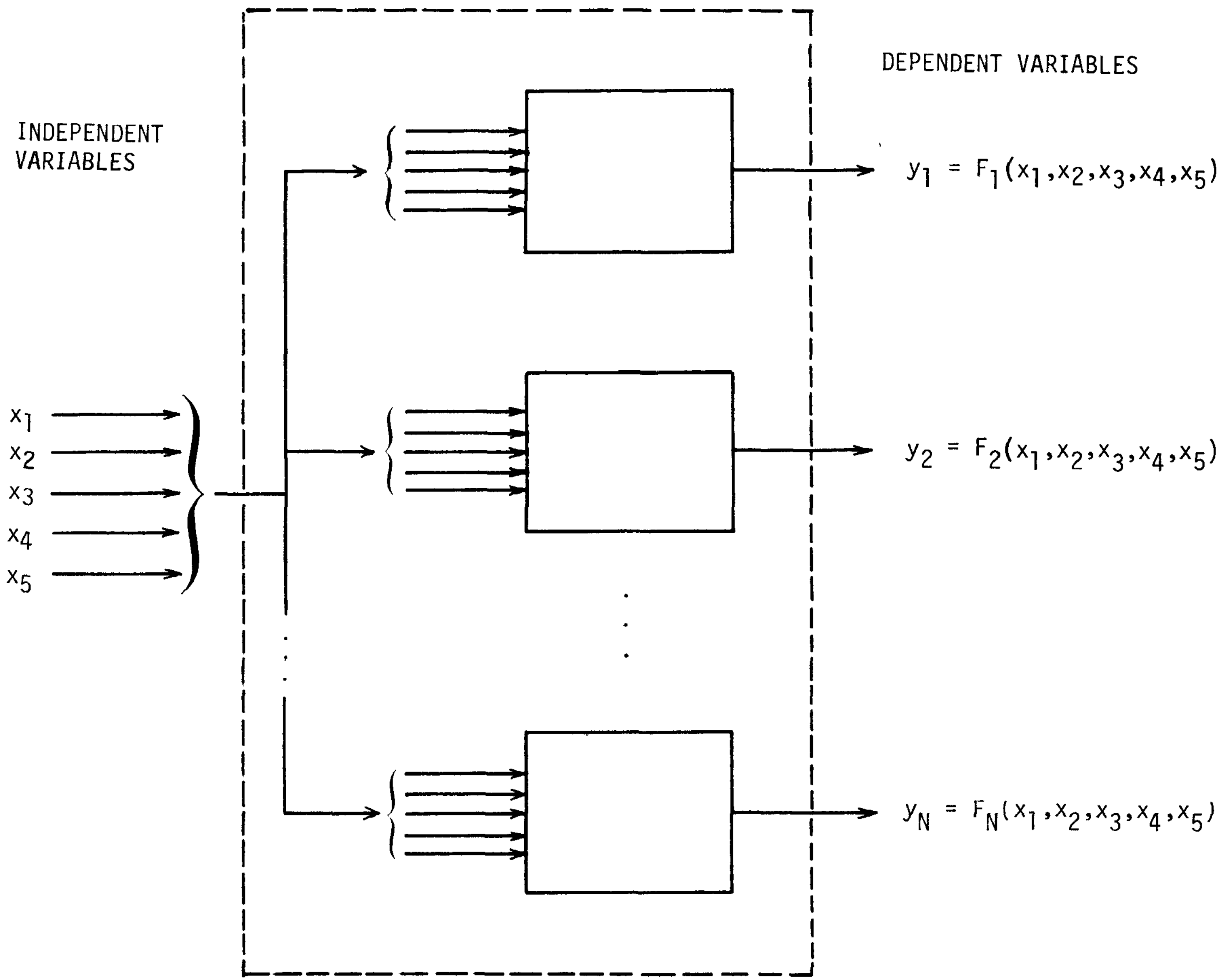


FIGURE 4.1
THE OVERALL REPRO-MODEL AS A COLLECTION OF
REPRO-MODELS FOR EACH DEPENDENT VARIABLE

Using a small set of multivariate samples to define a nonlinear relationship is a procedure which requires great care to avoid under-fitting (neglecting substantial information contained in the data) or over-fitting (imputing meaning to statistical fluctuations). This problem can be approached formally [7], but perhaps the most straight-forward way of expressing the objective of such a problem is in terms of the "efficiency" of the approximating functional form. The number of free parameters adjusted and the accuracy of fit resulting determine the efficiency of the functional form used in the approximation. The fewer parameters used to obtain a given degree of fit, the more efficient the approximation obtained. An efficient approximation minimizes the possibility of fitting statistical anomalies rather than fundamental relationships in the data.

### 4.1.1 Continuous Piecewise Linear Functions

Continuous piecewise linear functions have the potential of being a very efficient class of approximating functions, as well as other advantages in terms of interpretability. A piecewise linear function is a function for which one can find a partition of the space of independent variables such that the function is linear on every subregion. If the function is continuous piecewise linear, there are no discontinuities in the function at the boundaries between subregions. A continuous piecewise linear function of one variable is shown in Figure 4.2. Figures 4.3(a) and (b) illustrate continuous piecewise linear functions of two variables. In both cases the

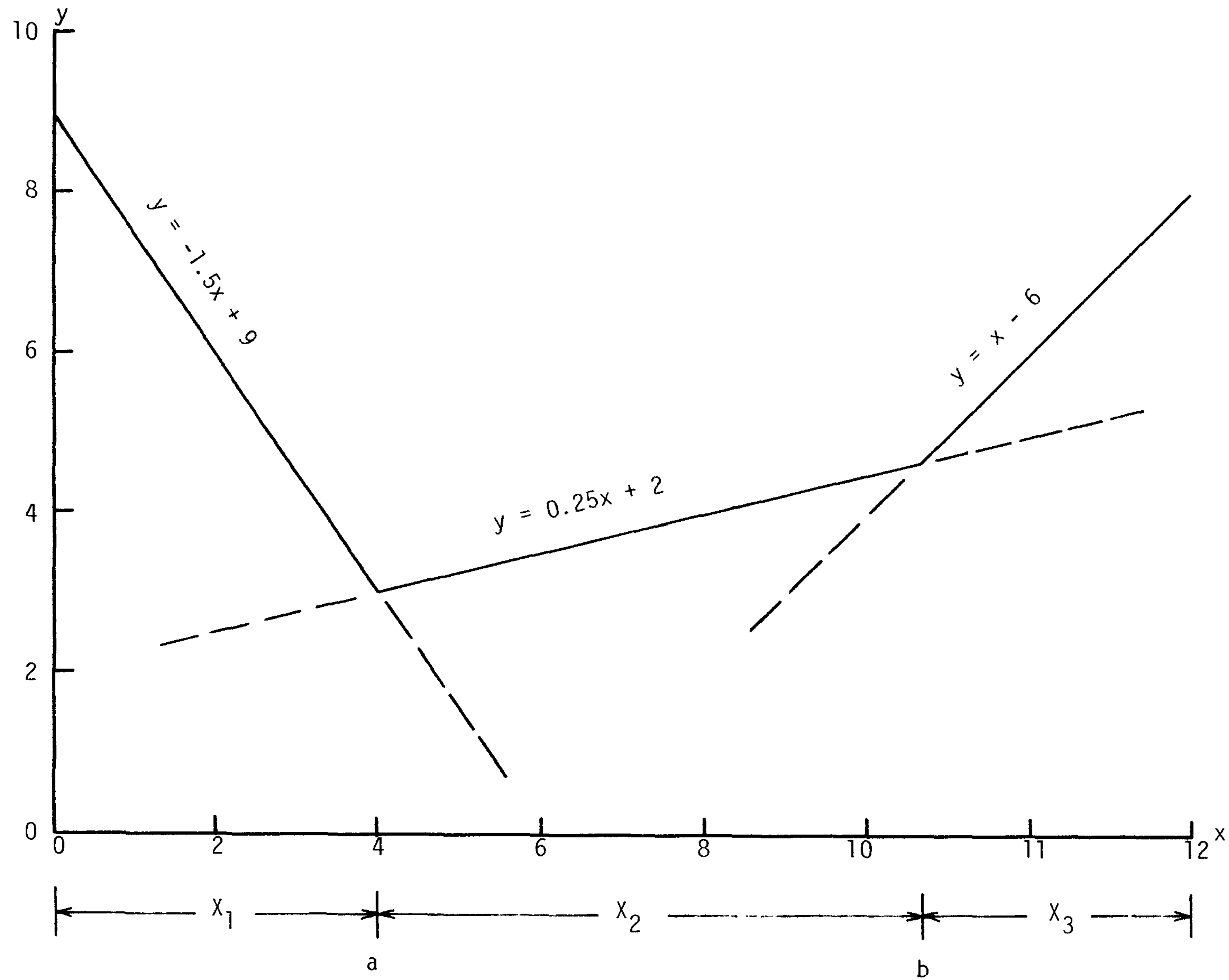


FIGURE 4.2

A CONTINUOUS PIECEWISE LINEAR FUNCTION OF ONE VARIABLE

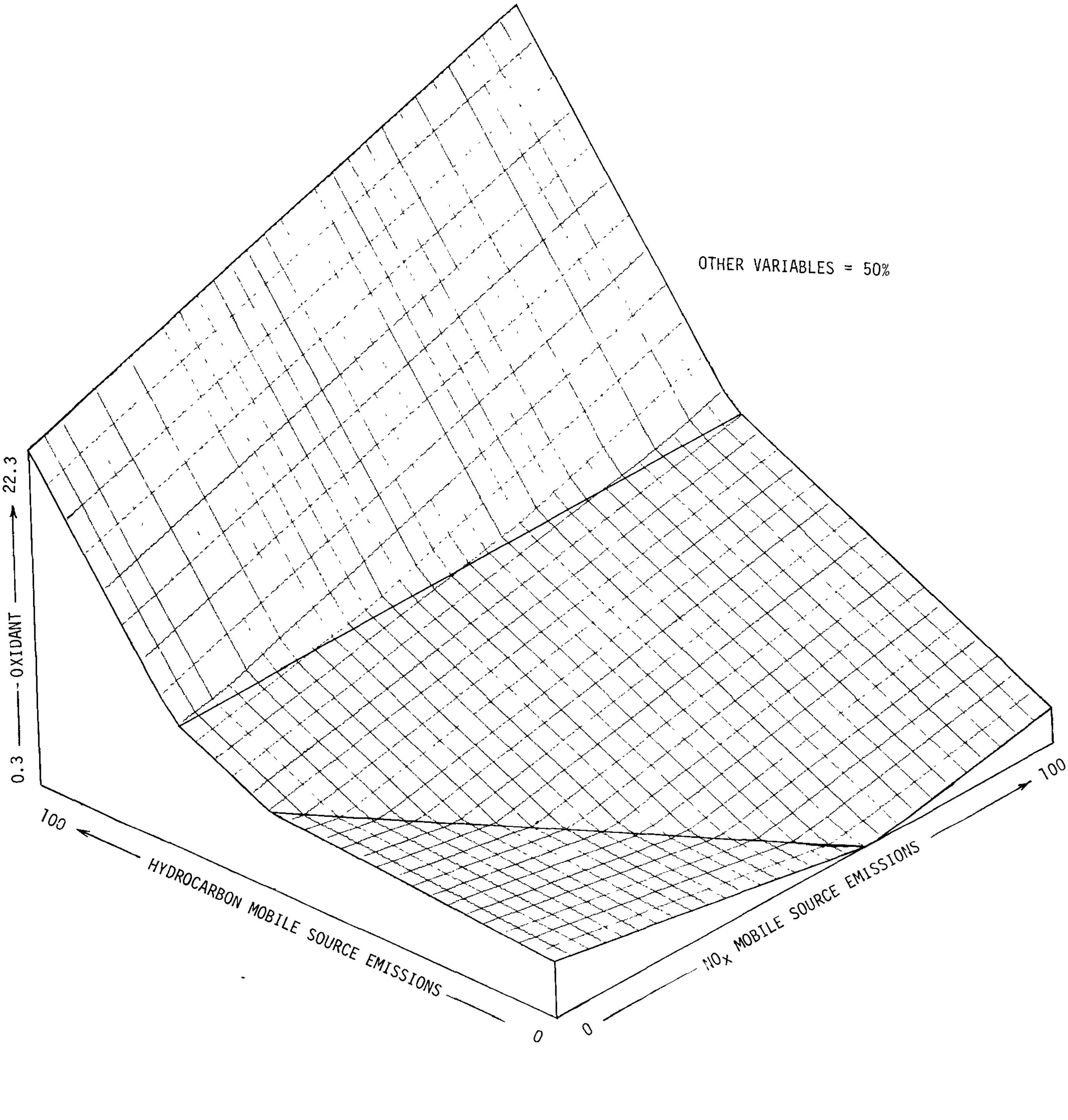


FIGURE 4.3(a)

AN EXAMPLE OF A CONTINUOUS PIECEWISE LINEAR FUNCTION IN TWO VARIABLES--AN OXIDANT REPRO-MODEL (10,24)

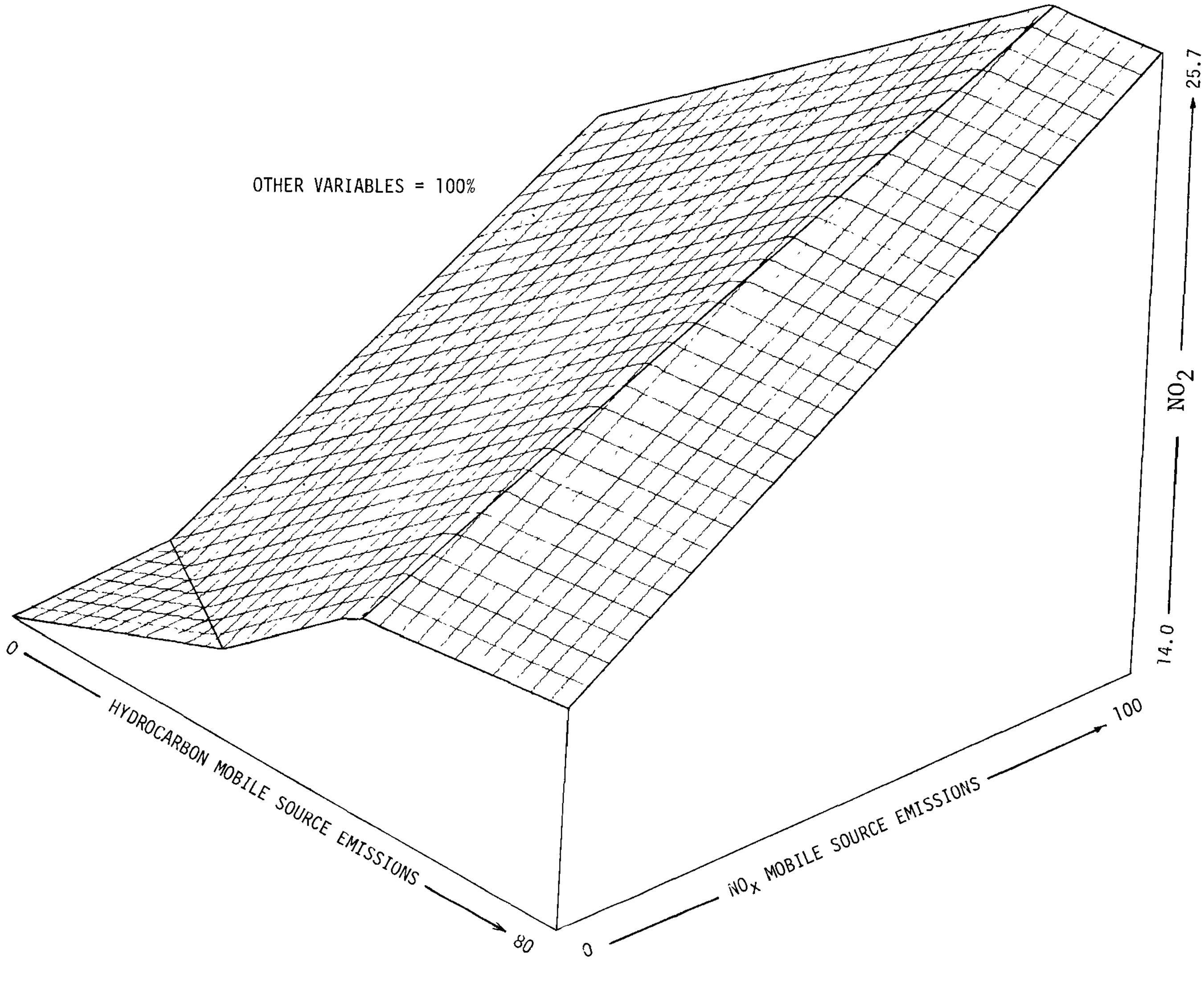


FIGURE 4.3(b)

AN EXAMPLE OF A CONTINUOUS PIECEWISE LINEAR FUNCTION IN TWO VARIABLES--AN $NO_2$ REPRO-MODEL (10,21) continuity constraint requires that the hyperplanes* defining the function in any subregion meet at the boundaries of the subregions. Thus, in Figure 4.2, the values of the linear functions on the first and second subregions must be the same at the boundaries between those subregions, i.e., the point a, and the values of the linear functions on the second and third subregions must be the same at the boundary between those subregions, i.e., the point b. In higher dimensions the subregions can become considerably more complex, as indicated in Figure 4.4, and the problem of ensuring continuity is a more difficult technical problem. The general formula for a piecewise linear function is given by

$$F(x_1,\ldots,x_n) = \begin{cases} \sum_{j=1}^{n} b_{1j}x_j + b_{1,n+1} & \text{for } \underline{x} \text{ in } X_1 \\ \vdots & \\ \sum_{j=1}^{n} b_{Rj}x_j + b_{R,n+1} & \text{for } \underline{x} \text{ in } X_R \end{cases} \tag{4.1}$$

where $\underline{x} = (x_1,x_2,\ldots,x_n)$ and $X_1,X_2,\ldots,X_R$ are subregions partitioning the space.

For any given set of subregions $X_1,X_2,\ldots,X_R$, one could (with difficulty) find the optimal coefficients $b_{ij}$ with a constraint of continuity at the boundaries. Since the choice of subregions is not obvious, the problem of simultaneously finding the optimal subregions makes the

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*A hyperplane is a generalization of lines in the two-dimensional case and planes in the three-dimensional case to any dimensionality.

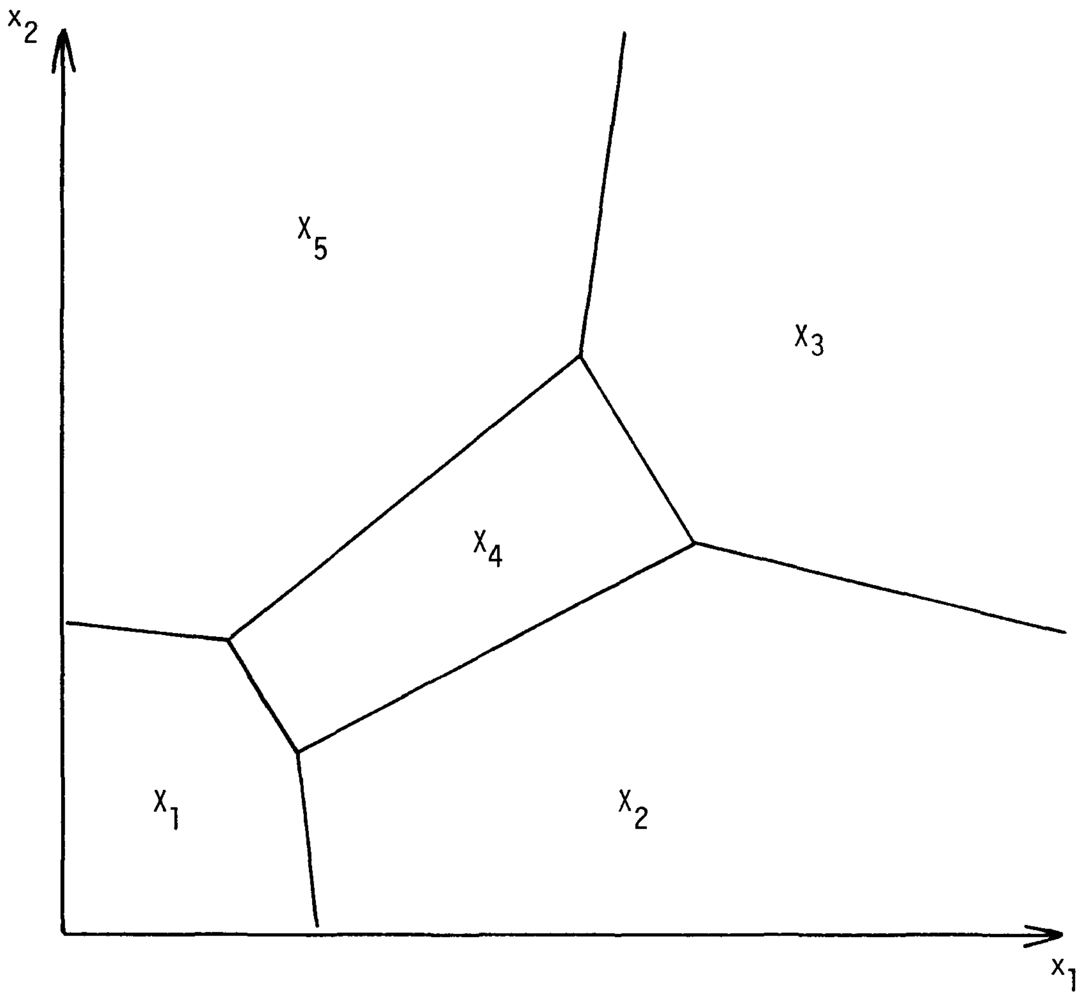



FIGURE 4.4

AN EXAMPLE OF POSSIBLE SUBREGIONS FOR A TWO-VARIABLE CONTINUOUS PIECEWISE LINEAR FUNCTION procedure quite difficult. The approach employed in the present work is the specification of the piecewise linear function in an alternate form which insures continuity as the parameters are varied and which defines the boundaries of the subregions implicitly as a function of the parameters defining the linear function on each subregion [5].

Specifically, equation (4.2) defines a continuous convex piecewise linear function:*

$$P(x_1,x_2,\ldots,x_n) = \max_{i=1,2,\ldots,K} \left\{ \sum_{j=1}^{n} a_{ij}x_j + a_{i,n+1} \right\} \tag{4.2}$$

Referring to equation (4.1), note that $F(x_1,\ldots,x_n) = P(x_1,\ldots,x_n)$ if $b_{ij} = a_{ij}$ and $X_i$ is the region where the $i^{th}$ hyperplane is largest, i.e.,

$$X_i = \left\{ \underline{x} = (x_1,x_2,\ldots,x_n) \,\middle|\, \sum_{j=1}^{n} a_{ij}x_j + a_{i,n+1} \geq \sum_{j=1}^{n} a_{kj}x_j + a_{k,n+1} \text{ for all } k \right\}.$$

Figures 4.2 and 4.3 (b) illustrate convex and non-convex piecewise linear functions respectively. Figure 4.2 illustrates this definition graphically. Note that the value of the function P(x) is obtained quite simply by calculating the values of the three linear functions

---

*A convex function is roughly, one which has the property that all the points on a line connecting two points on the surface of the function take values greater than or equal to the function.

$$g_1(x) = -1.5x + 9$$
$$g_2(x) = 0.25x + 2$$
$$g_3(x) = x - 6$$

and taking the largest value which results. The subregions are defined implicitly; for example, in Figure 4.2, $X_2$ is the region where

$$0.25x + 2 \geq x - 6$$

and

$$0.25x + 2 \geq -1.5x + 9 .$$

A simple extension of the approach will yield non-convex functions:

$$F(x_1,..,x_n) = \sum_{k=1}^{N} w_k P_k(x_1,\ldots,x_n) \quad , \qquad (4.3)$$

where

$$P_k(x_1,\ldots,x_n) = \underset{i=1,2,\ldots,K_k}{\text{Max}} \left\{ \sum_{j=1}^{n} a_{ij}^{(k)} x_j + a_{i,n+1}^{(k)} \right\} ,$$

i.e., F is a sum of functions of the form (4.2). The function F may be non-convex if the weights $w_k$ differ in sign. Note that F is a "parameterized" function: to fully specify F, we must choose the values $w_1,\ldots,w_N$ and $a_{ij}^{(k)}$ for $k=1,2,\ldots,N$; $i=1,2,\ldots,K_k$; and $j=1,2,\ldots,n$. Some of these parameters are redundant; the total number of free parameters is

$$(n+1)\left( \sum_{k=1}^{N} K_k \right) . \qquad (4.4)$$

The parameters $b_{ij}$ in equation (4.1) are related to the parameters $w_k$ and $a_{ij}$ by a linear equation on each subregion.

The procedure used was to test whether a convex function of the form in (4.2) was sufficient to represent the input/output relationship; this would be the case only if the relationship itself were convex or nearly so. If a convex function was insufficient, then a functional approximation of the form (4.3) was employed. This procedure yields the fringe benefit of detecting whether the model input/output relationship is itself essentially convex.

The means used to find the parameters of the function minimizing the least-mean-square error in the input/output approximation is not of particular concern here and is discussed elsewhere [5].

We note one important characteristic of continuous piecewise linear functions that makes them attractive for the present application. Since the functions are linear in any subregion, they will extrapolate linearly to points outside the region in which the input/output samples were taken; they can to some degree be trusted to extrapolate reasonably (particularly in comparison to other functional forms such as higher order multivariate polynomials).

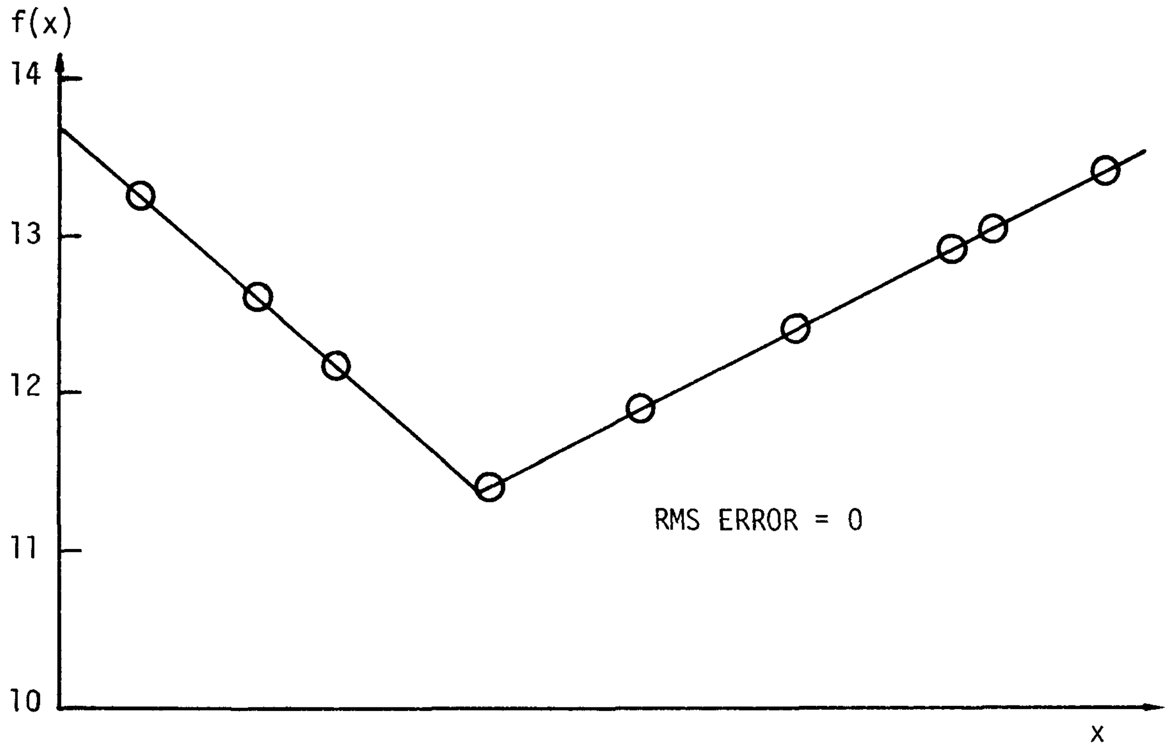
Another key characteristic of the continuous piecewise linear form is its ease of interpretability. In any small region (other than a point on the boundary between regions), the function is linear, and the relationship can be interpreted much as in linear regression. That is, in a particular region of space, the dependent variable is given by a linear function of the independent variables and the effect on the output of small changes in the independent variables is clearly evident. This approach to interpretation will be employed in Section 5.0.

## 4.2 Implications of the Precision of the SAI Model for Statistical Analysis

The SAI model reports its results to only one or two significant figures. The roundoff error due to this form of presentation can range from .5% to 50% of the reported concentration. The problem of statistically fitting this data is illustrated in Figures 4.5(a) and 4.5(b). In a set of data modeled perfectly by a piecewise linear function (Figure 4.5(a)), a rounding error has been introduced. The perfect fit which was achieved before rounding has an error associated with it after rounding. A perfect fit to the rounded data would clearly be distorted relative to the underlying physical relationship.

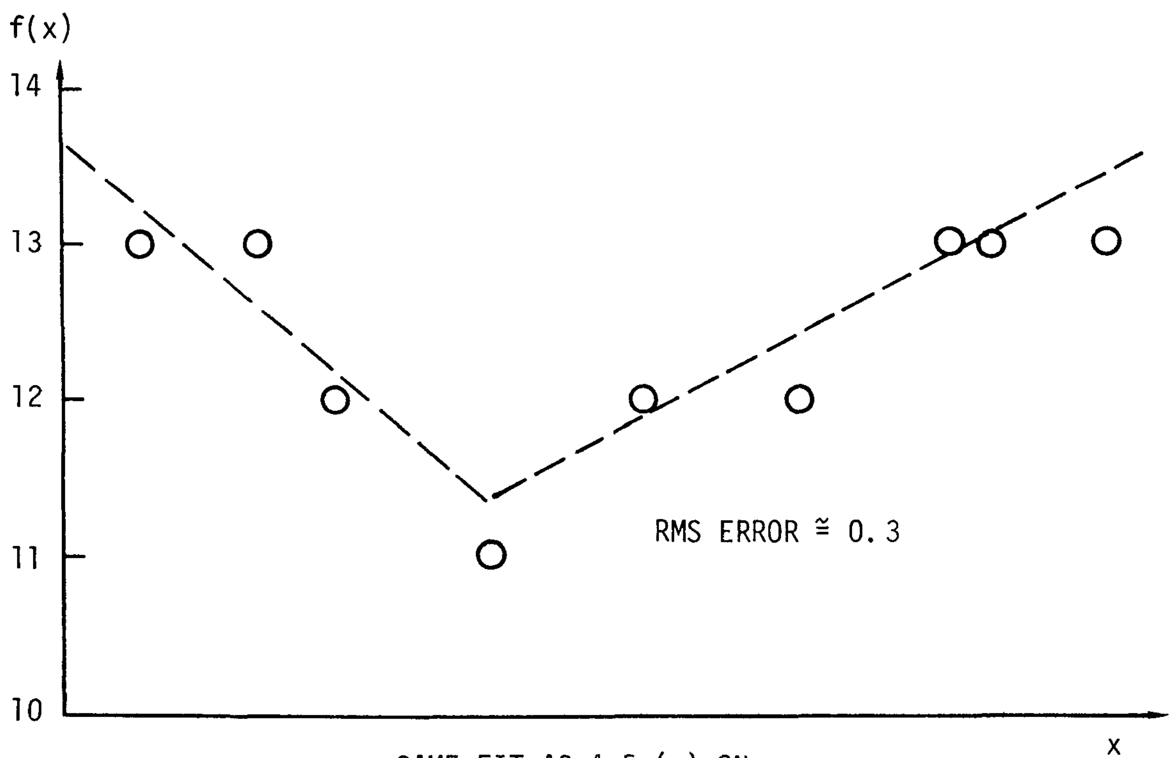
The rounding puts a lower bound on the error one should attempt to achieve with any functional fit. If an error of a fit less than this lower bound is achieved, there is a tendency for the resulting functional form to follow the error-distorted data rather than the original unrounded data. An attempt must, therefore, be made to choose the number of free parameters such that the resulting error of the fit approaches but does not become substantially less than a theoretical rounding error.

The theoretical RMS error of a perfect fit with only rounding errors introduced is 0.289. This assumes that the rounding error is uniformly and independently distributed over an interval of $\pm .5$ about the unrounded data, an assumption sufficiently representative for present purposes. In




FIT OF PERFECTLY PIECEWISE
LINEAR DATA

FIGURE 4.5 (a)




SAME FIT AS 4.5 (a) ON
DATA WITH ROUNDOFF
ERROR INTRODUCED

FIGURE 4.5 (b)

the case of the $NO_2$ data, however, ten numbers were averaged. This reduces the error somewhat, but only by a factor of $\sqrt{10}$. The theoretical RMS error of a perfect fit of ten averaged rounded numbers is 0.091. There is, of course, a logical upper bound on the fraction of variance explained by any statistical fit of rounded data. This fraction will vary, however, from one dependent variable to another. For unaveraged data however, this number is $1-(.289)^2/\sigma^2$ where $\sigma^2$ is the variance of the dependent variable. The "limiting correlation" coefficients used in Table 3.3 are the square roots of this fraction.

## 4.3 Repro-Models Created and Accuracy Achieved

The oxidant dependent variables as previously defined were statistically fit using three basic functional forms: linear, quadratic, and continuous piecewise linear. In all cases, ninety data points were used. Ten of the hundred data points (Table 4.1) were withheld at random for later testing.

A comparison of errors resulting from all these fits is shown in Table 4.2. The linear regression with six free parameters provided the worst error statistics in every instance. The 5-variable quadratic fit, which involved twenty-one free parameters, did consistently better than the linear regression (as it must), but still did not approach the roundoff error limit. The piecewise linear approximations, with 12 to 18 free parameters, performed better than either the quadratic or the linear fits. The improvements over the linear regression are by factors of between 2 and 8 and over the quadratic fit by factors of between 1.2 and 4. Since the error in the piecewise linear fit was uniformly smaller than the

TABLE 4.1

TEN POLICIES USED IN TESTING REPRO-MODELS

| | MOBILE $NO_x$ | MOBILE HC | FIXED HC | INITIAL $NO_x$ | INITIAL HC |
|---|---|---|---|---|---|
| 1. | 85.0 | 80.0 | 10.0 | 93.0 | 69.0 |
| 2. | 100.0 | 65.0 | 70.0 | 100.0 | 66.0 |
| 3. | 30.0 | 13.0 | 13.0 | 57.0 | 13.0 |
| 4. | 60.0 | 30.0 | 100.0 | 87.0 | 41.0 |
| 5. | 45.0 | 45.0 | 45.0 | 54.0 | 35.0 |
| 6. | 70.0 | 50.0 | 75.0 | 87.0 | 59.0 |
| 7. | 75.0 | 60.0 | 100.0 | 72.0 | 54.0 |
| 8. | 105.0 | 90.0 | 40.0 | 103.0 | 95.0 |
| 9. | 125.0 | 100.0 | 70.0 | 130.0 | 88.0 |
| 10. | 125.0 | 115.0 | 20.0 | 132.0 | 108.0 |

TABLE 4.2

COMPARISON OF CONTINUOUS PIECEWISE LINEAR FIT
WITH FIVE VARIABLE LINEAR AND QUADRATIC FITS (OXIDANT)

| | PEAK | 10,24 | 10,21 | 15,20 | 20,20 | 7,17 | 12,17 | 25,13 | 9,12 |
|---|---|---|---|---|---|---|---|---|---|
| RMS Error Piecewise Linear Fit | 0.48 | 0.55 | 0.68 | 0.56 | 0.41 | 0.22 | 0.54 | 0.44 | * |
| RMS Error Quadratic Fit | 2.12 | 1.91 | 0.80 | 0.95 | 0.59 | 0.30 | 0.70 | 0.53 | 0.22 |
| RMS Error Linear Fit | 3.70 | 4.69 | 4.40 | 3.94 | 2.62 | 0.43 | 2.71 | 2.35 | 0.30 |

*Linear fit used in this case.

quadratic fit, even though obtained with fewer free parameters, the piecewise linear form is clearly more efficient for this application and represents the model more naturally. Note that, in one case, a linear form was sufficient to achieve the limiting accuracy.

Table 4.3 and Table 4.4 provide the parameters of the twelve repro-models developed. The entries are labeled to correspond to equations (4.1) and (4.2). The number of free parameters on each piecewise linear approximation was adjusted separately. The numbers of hyperplanes that were used in each case were selected on the basis of the smoothness and convexity of the data being analyzed. Since there are six free parameters in each hyperplane, the number of free parameters for each repro-model ranged from six (counting the linear case) to twenty-four (including the $NO_x$ repro-models). In each case, care was taken not to "overfit" the data, that is, to allow the piecewise linear approximation to be strongly affected by the roundoff error.

The statistical characteristics of each of the twelve repro-models are shown in Tables 4.5 and 4.6. In each case the percent variance explained and the RMS error approached their respective practical limits. It should be noted that the averaging of the $NO_2$ data allowed a substantially better approximation to be calculated. The two $NO_2$ fits which required twenty-four free parameters behave very much like an eighteen parameter approximation. The nonconvexity of the data and the nature of the algorithm required the addition of a fourth hyperplane, although in both instances it explains an extremely small portion of the policy space (a point discussed further in section 5.0).

TABLE 4.3

REPRO-MODEL COEFFICIENTS FOR OXIDANT

| ZONE NAME | LOCATION | i | $NO_X$ MOBILE SOURCE EM. ($a_{i1}$) | HC MOBILE SOURCE EM. ($a_{i2}$) | HC FIXED SOURCE EM. ($a_{i3}$) | $NO_X$ INITIAL CONDITIONS ($a_{i4}$) | HC INITIAL CONDITIONS ($a_{i5}$) | CONSTANT ($a_{i6}$) |
|---|---|---|---|---|---|---|---|---|
| Peak of 625 Zones | | 1 | 0.0671 | 0.3418 | 0.1223 | 0.0974 | 0.2372 | -41.61 |
| | | 2 | -0.0053 | 0.0025 | 0.0007 | 0.0053 | 0.0012 | 6.86 |
| Sunland | (10,24) | | | | | | | |
| | | 1 | 0.0736 | 0.3426 | 0.1229 | 0.0969 | 0.2320 | -41.91 |
| | | 2 | -0.0403 | 0.0178 | 0.0021 | 0.0250 | 0.0243 | 0.22 |
| | | 3 | 0.0437 | 0.1150 | 0.0364 | 0.0085 | 0.1035 | - 9.97 |
| Pasadena | (15,20) | | | | | | | |
| | | 1 | 0.0064 | 0.2174 | 0.1234 | 0.0802 | 0.2357 | -36.45 |
| | | 2 | -0.0305 | 0.0460 | 0.0119 | 0.0439 | 0.0338 | - 2.45 |
| | | 3 | -0.1455 | 0.0610 | -0.016 | 0.0887 | 0.0544 | - 3.12 |
| Burbank | (10,21) | | | | | | | |
| | | 1 | 0.0001 | 0.2666 | 0.0932 | 0.1041 | 0.2391 | -45.14 |
| | | 2 | -0.0015 | 0.0298 | 0.0081 | -0.0026 | 0.0203 | 0.24* |
| | | 3 | 0.1834 | 0.0625 | -0.0213 | 0.0675 | 0.0572 | - 1.66 |
| Downtown L.A. | (12,17) | | | | | | | |
| | | 1 | -0.0076 | 0.0245 | 0.0041 | 0.0110 | 0.0067 | - 0.41 |
| | | 2 | -0.0315 | 0.1535 | 0.0806 | 0.1082 | 0.1915 | -36.68 |
| | | 3 | -0.1634 | 0.0506 | -0.0155 | 0.0440 | 0.0467 | - 1.52 |
| Duarte | (20,20) | | | | | | | |
| | | 1 | -0.0093 | 0.1260 | 0.0481 | 0.0644 | 0.1829 | -25.39 |
| | | 2 | -0.0133 | 0.0097 | 0.0025 | 0.0138 | 0.0226 | 0.89 |
| Carbon Canyon | (25,13) | | | | | | | |
| | | 1 | -0.0031 | 0.1055 | 0.0151 | 0.0666 | 0.1884 | -21.26 |
| | | 2 | -0.0038 | 0.0036 | -0.0010 | 0.0105 | 0.0431 | 0.66 |

TABLE 4.3 (CONTINUED)

REPRO-MODEL COEFFICIENTS FOR OXIDANT

| ZONE NAME | LOCATION | i | $NO_X$ MOBILE SOURCE EM. ($a_{i1}$) | HC MOBILE SOURCE EM. ($a_{i2}$) | HC FIXED SOURCE EM. ($a_{i3}$) | $NO_X$ INITIAL CONDITIONS ($a_{i4}$) | HC INITIAL CONDITIONS ($a_{i5}$) | CONSTANT ($a_{i6}$) |
|---|---|---|---|---|---|---|---|---|
| West L.A. | (7,17) | | | | | | | |
| | | 1 | -0.0045 | -0.0019 | -0.0008 | 0.0036 | 0.0047 | 1.95 |
| | | 2 | -0.0354 | 0.0018 | 0.0003 | 0.0077 | 0.0082 | 2.88 |
| | | 3 | -0.0209 | 0.0205 | 0.0084 | 0.0277 | 0.0385 | -4.64 |
| N. Long Beach | (12,9) | | | | | | | |
| | | 1 | 0.0047 | 0.0111 | 0.0015 | -0.0031 | 0.0008 | 0.1034 |

*Explains only a very small region of policy space.

TABLE 4.4

REPRO-MODEL COEFFICIENTS FOR $NO_2$

| ZONE NAME | LOCATION | i | k | $w^k$ | $NO_x$ MOBILE SOURCE EM. ($a^k_{i1}$) | HC MOBILE SOURCE EM. ($a^k_{i2}$) | HC FIXED SOURCE EM. ($a^k_{i3}$) | $NO_x$ INITIAL CONDITIONS ($a^k_{i4}$) | HC INITIAL CONDITIONS ($a^k_{i5}$) | CONSTANT ($a^k_{i6}$) |
|---|---|---|---|---|---|---|---|---|---|---|
| Burbank | (10,21) | | | | | | | | | |
| | | 1 | 1 | 3.599 | 0.0082 | 0.0098 | 0.0019 | 0.0349 | 0.0077 | -0.21 |
| | | 2 | 1 | | 0.0181 | 0.0217 | 0.0049 | 0.0542 | 0.0105 | -3.17 |
| | | 1 | 2 | -2.014 | 0.0017 | -0.0043 | -0.0018 | -0.0004 | -0.0059 | -6.97 |
| | | 2 | 2 | | -0.0049 | 0.0314 | 0.0077 | -0.0014 | 0.0147 | -11.95 |
| Downtown L.A. | (12,17) | | | | | | | | | |
| | | 1 | 1 | 2.714 | 0.0081 | 0.0111 | 0.0032 | 0.0321 | 0.0109 | -0.03 |
| | | 2 | 1 | | 0.0184 | 0.0235 | 0.0109 | 0.0507 | 0.0232 | -4.04 |
| | | 1 | 2 | -2.044 | 0.0024 | -0.0010 | -0.0010 | -0.0017 | -0.0044 | -5.19 |
| | | 2 | 2 | | -0.0115 | 0.0246 | 0.0111 | 0.0043 | 0.0078 | -10.19 |
| West L.A. | (7,17) | | | | | | | | | |
| | | 1 | 1 | 1.000 | 0.0180 | 0.0226 | 0.0077 | 0.1190 | 0.0371 | -6.17 |
| | | 2 | 1 | | 0.0101 | 0.0126 | 0.0030 | 0.0926 | 0.0124 | -0.88 |
| | | 3 | 1 | | 0.0416 | 0.0065 | 0.0037 | 0.0454 | 0.0183 | 0.33 |

TABLE 4.5

REPRO-MODEL SPECIFICATIONS

FOR OXIDANT

| CASE | ZONE ID | METHOD* | # FREE PARAMETERS | RMS ERROR | % $\sigma^2$ EXPLAINED | LIMITING % $\sigma^2$ EXPLAINED |
|---|---|---|---|---|---|---|
| 1 | PEAK | PLLS | 12 | 0.483 | 99.9 | 100.0 |
| 2 | 10,24 | PLLS | 18 | 0.549 | 99.9 | 100.0 |
| 3 | 10,21 | PLLS | 18 | 0.679 | 99.5 | 99.9 |
| 4 | 20,20 | PLLS | 12 | 0.406 | 99.5 | 99.8 |
| 5 | 15,20 | PLLS | 18 | 0.562 | 99.7 | 99.9 |
| 6 | 12,17 | PLLS | 18 | 0.542 | 98.9 | 99.7 |
| 7 | 7,17 | PLLS | 18 | 0.218 | 84.1 | 72.6 |
| 8 | 25,13 | PLLS | 12 | 0.441 | 99.5 | 99.8 |
| 9 | 12, 9 | MLR | 6 | 0.295 | 51.2 | 50.4 |

*PLLS: PIECEWISE LINEAR LEAST SQUARES
MLR: MULTIPLE LINEAR REGRESSION

RMS ERROR UNDER PERFECT FIT (A PRIORI): 0.289

TABLE 4.6

REPRO-MODEL SPECIFICATIONS FOR $NO_2$

| CASE | ZONE ID | METHOD* | NO. FREE PARAMETERS | RMS ERROR | % $\sigma^2$ EXPLAINED | LIMITING % $\sigma^2$ EXPLAINED |
|---|---|---|---|---|---|---|
| 10 | 10,21 | PLLS | 24 | 0.256 | 99.9 | 100.0 |
| 11 | 12,17 | PLLS | 24 | 0.231 | 99.9 | 100.0 |
| 12 | 7,17 | PLLS | 18 | 0.130 | 99.9 | 100.0 |

*PLLS: PIECEWISE LINEAR LEAST SQUARES
RMS ERROR UNDER PERFECT FIT (A PRIORI): 0.0913

The ten test policies were simulated on the repro-models. The results of these simulations were compared with the results of the SAI model for these policies. The RMS errors for each repro-model were calculated, and these are listed in Tables 4.7(a) and 4.7(b). For each of the twelve repro-models, the RMS error for the test cases was close to the error on the design set. This substantiates the expectation that the repro-models are valid for data points which were not among the set that was used to create the models in the first place.

It should be noted that the repro-models, to all intents and purposes, perfectly duplicate the behavior of the original model. This is a much better result than necessary in most repro-modeling applications, where it is usually assumed that it is sufficient to approximate only to the degree of accuracy with which the original model corresponds to reality. Since in the present application, validation results are often stated as the percentage of time the model is within a factor of two of reality, we have easily achieved this basic objective.

## 4.4 The Repro-Model Program

Since the repro-model requires no iterative calculation, it can run several orders of magnitude faster than the SAI model. Even with the relatively elaborate input/output routines of the repro-model package, the program will execute a single policy evaluation (twelve repro-models) in about 0.2 seconds.* If a single repro-model were to be embedded into an iterative calculation, such as an optimization routine, where the

---

*These runs were made on the CDC-6400.

TABLE 4.7(a)

RMS ERROR OVER TEN TEST POLICIES
$NO_2$

| Zone | RMS Error |
|---|---|
| 10,21 | .214 |
| 12,17 | .284 |
| 7,17 | .157 |

TABLE 4.7(b)

RMS ERROR OVER TEN TEST POLICIES
OXIDANT

| Zone | RMS Error |
|---|---|
| Peak | 0.47 |
| 10,24 | 0.48 |
| 15,20 | 0.51 |
| 10,21 | 0.79 |
| 12,17 | 0.60 |
| 20,20 | 0.40 |
| 25,13 | 0.37 |
| 7,17 | 0.24 |
| 12, 9 | 0.39 |

input-output overhead is minimal, the time of evaluation would be on the order of 10 milliseconds.

The repro-model package evaluates all twelve of the repro-models. On input it checks that all policy region constraints are satisfied and prints a specific warning message if one or more constraints are violated. After the policy is evaluated by the piecewise linear approximations, the program displays the linear sensitivities about the policy evaluated, i.e., indicates how small changes in policy variables would affect the result. An example of an output page from the repro-model is shown in Figure 4.6. A complete description of the repro-model program, a program listing, and an explanation of the output are found in the Appendix to this report.

*** TECHNOLOGY SERVICE CORPORATION -- REPRO MODEL -- NOVEMBER 1973 ***

*** POLICY 5 ***

| | | |
|---|---|---|
| NOX MOBILE SOURCE EMISSIONS | (MSE) = | 41.0 PCT OF TEST DAY |
| HC MOBILE SOURCE EMISSIONS | (MSE) = | 25.0 PCT OF TEST DAY |
| HC FIXED SOURCE EMISSIONS | (FSE) = | 100.0 PCT OF TEST DAY |
| NOX INITIAL CONDITIONS | (IC) = | 63.4 PCT OF TEST DAY |
| HC INITIAL CONDITIONS | (IC) = | 37.0 PCT OF TEST DAY |

| NAME | LOCATION EW | LOCATION NS | POLLUTANT | CONCENTRATION | | PERIOD | NET HYPERPLANE COEFFICIENTS NOX MSE | HC MSE | HC FSE | NOX IC | HC IC | CONSTANT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PEAK | | | OXIDANT | 7.0 | PPHM | PEAK HOUR | -0.00528 | 0.00246 | -0.00070 | 0.00531 | 0.00123 | 6.86122 |
| SUNLAND | 10. | 24. | OXIDANT | 2.7 | PPHM | PEAK HOUR | 0.04370 | 0.11500 | 0.03642 | 0.00852 | 0.10348 | -9.96756 |
| PASADENA | 15. | 20. | OXIDANT | 2.7 | PPHM | PEAK HOUR | -0.03049 | 0.04595 | 0.01190 | 0.04385 | 0.03381 | -2.44936 |
| BURBANK | 10. | 21. | OXIDANT | 2.3 | PPHM | PEAK HOUR | -0.00147 | 0.02977 | 0.00807 | -0.00262 | 0.02034 | 0.23634 |
| DOWNTOWN LA | 12. | 17. | OXIDANT | 1.2 | PPHM | PEAK HOUR | -0.00759 | 0.02453 | 0.00406 | 0.01102 | 0.00670 | -0.41179 |
| DUARTE | 20. | 20. | OXIDANT | 2.1 | PPHM | PEAK HOUR | -0.01334 | 0.00970 | -0.00247 | 0.01377 | 0.02260 | 0.89189 |
| CARBON CANYN | 25. | 13. | OXIDANT | 2.8 | PPHM | PEAK HOUR | -0.00381 | 0.00360 | -0.00096 | 0.01054 | 0.04310 | 0.65755 |
| WEST LA | 7. | 17. | OXIDANT | 2.3 | PPHM | PEAK HOUR | -0.03542 | 0.00177 | 0.00032 | 0.00770 | 0.00816 | 2.88111 |
| N LONG BEACH | 12. | 9. | OXIDANT | 0.6 | PPHM | PEAK HOUR | 0.00465 | 0.01107 | 0.00151 | -0.00305 | 0.00076 | 0.10340 |
| BURBANK | 10. | 21. | NO2 | 9.1 | PPHM | 10 HOUR AVE. | 0.02600 | 0.04373 | 0.01054 | 0.12485 | 0.03938 | -3.50897 |
| DOWNTOWN LA | 12. | 17. | NO2 | 7.1 | PPHM | 10 HOUR AVE. | 0.01696 | 0.03214 | 0.01068 | 0.09070 | 0.03859 | -2.61512 |
| WEST LA | 7. | 17. | NO2 | 6.5 | PPHM | 10 HOUR AVE. | 0.01007 | 0.01263 | 0.00299 | 0.09261 | 0.01238 | -0.87669 |

FIGURE 4.6

EXAMPLE OF AN OUTPUT TABLE
FROM ONE RUN OF THE REPRO-MODEL

## 5.0 IMPLICATIONS OF THE MODEL

In the previous section, the form, efficiency, and accuracy of the repro-model were discussed. The present section describes the implications of the repro-model, i.e., the implications of the SAI model. The discussion is in two parts: (1) an outline of the general conclusions implied by the input/output relationships of the model; and (2) several examples of the use of the repro-model to examine model implications for particular policy questions.

### 5.1 General Implications of the Model

One of the most valuable uses of an air pollution model is to provide qualitative insights and rough quantitative estimates about a process in general, rather than about the specific outcome of a particular policy. This type of information aids innovative policy design by indicating which variables have the most effect on pollutant levels and the approximate degree of that effect.

One means of studying the input/output relationship of the model is through graphical aids. Because the repro-model has five independent variables, however, one is limited to plots such as Figure 5.1, holding at least three variables constant. Similar information is displayed in 3-D plots holding three variables fixed, such as in Figures 4.3(a,b). While such plots do give some feel for overall model structure, one would be forced to look at a large number to fully explore the model; even then, it would be difficult to gain an intuitive feel for the five-variable relationship by such an approach. Graphical aids, however, are extremely useful in providing insight into particular questions, as will be illustrated in section 5.2.

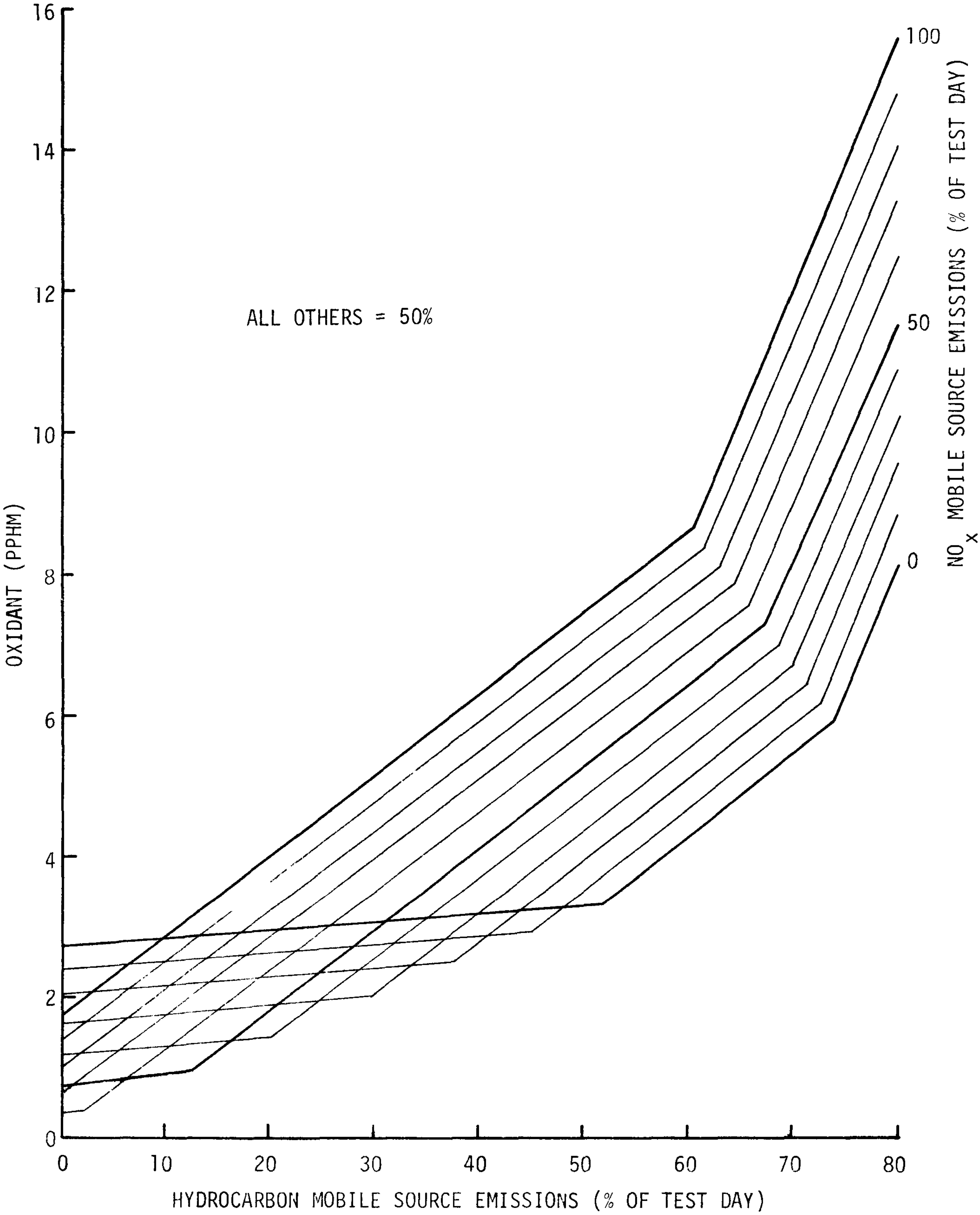



FIGURE 5.1

A "CUT" OF THE MODEL HOLDING THREE VARIABLES CONSTANT AT ZONE (10,24)

In this section we examine overall model implications by exploiting the piecewise-linear form of the repro-models.

We have previously noted that all the oxidant repro-models are convex. Thus, there is no tendency within the range of the repro-model for the process to saturate; as any emissions or initial condition variable is increased with the others held fixed, the rate of increase of oxidant will not decline, but will increase or stay constant. This is not the case for the $NO_2$ repro-models, two of which are non-convex.

We can examine the repro-models more deeply by noting once more that they are linear in large subregions of the space; for example, for the larger values of the variables, the oxidant level (in parts-per-hundred-million) for the repro-model at the peak is given by

$$\begin{aligned} \text{OXIDANT (pphm)} = {} & 0.067 \cdot \text{MSNO}_x + 0.342 \cdot \text{MSHC} + 0.122 \cdot \text{FSHC} + \\ & 0.097 \cdot \text{ICNO}_x + 0.237 \cdot \text{ICHC} - 41.6 \quad , \end{aligned} \tag{5.1}$$

where the independent variables are respectively mobile source $NO_x$, mobile source hydrocarbons, fixed source hydrocarbons, $NO_x$ initial conditions, and hydrocarbon initial conditions, all expressed in percent of test day. For example, setting all variables at 100% yields 45 pphm oxidant, which is indeed the peak predicted by the SAI model for the test day. It is easy to see from this equation that mobile source $NO_x$ and initial conditions for $NO_x$ have little effect on the oxidant level. Reducing both variables by 20% will reduce the oxidant level by only 3 pphm (a 7% reduction). On the other hand, the hydrocarbon variables have the predominant effect; reducing MSHC and ICHC by 20% (and leaving fixed sources unchanged) reduces the peak by 12 pphm (a 27% reduction). Hence, the oxidant level at the peak is dominated by hydrocarbon emissions.

The effect of the fixed source hydrocarbon variable is approximately one-third that of mobile source hydrocarbons (by the ratio of their coefficients), indicating that, while mobile sources have the predominant effect as usually assumed, reductions in fixed source emissions can have a significant impact.

A final point can be extracted from equation (5.1): assumptions regarding the levels of initial and boundary conditions have a major impact on model output. The coefficient of ICHC is comparable with the coefficient of MSHC and dominates that of FSHC; the coefficient of $ICNO_x$ is comparable with that of $MSNO_x$. Since initial and boundary conditions can be predicted only with a great deal of uncertainty, this uncertainty should be reflected in model use. For example, a change of $\pm$20% in initial/boundary condition assumptions for the 100% case would yield an estimate of 45 pphm $\pm$ 7 pphm.

At lower levels of emissions, the equation yielded by the repro-model at the peak is

$$\begin{aligned} OXIDANT = & -0.005 \cdot MSNO_x + 0.003 \cdot MSHC - 0.001 \cdot FSHC + \\ & 0.005 \cdot ICNO_x + 0.001 \cdot ICHC + 6.86 \quad . \end{aligned} \qquad (5.2)$$

At lower levels, the model indicates in effect a floor on oxidant levels of about 7 pphm; none of the variables have a significant effect on oxidant levels. By referring to the functional form of the repro-model, one can easily see that the boundary between the region where (5.1) holds and (5.2) holds is obtained by equating the two, i.e., (5.1) holds if

$$0.072 \cdot MSNO_x + 0.339 \cdot MCHC + 0.123 \cdot FSHC + 0.092 \cdot ICNO_x + 0.236 \cdot ICHC \geq 48.5 \quad , \qquad (5.3)$$

or, less precisely, when the oxidant level predicted by equation (5.1) is above 7 pphm.

The repro-model of the peak contains only two hyperplanes and hence is completely described by equations (5.1), (5.2), and, redundantly, (5.3). Table 5.1 lists the coefficients of the hyperplanes for all the oxidant repro-models with other pertinent data. The table includes the following aids to interpretation:

(a) Standard deviation of the dependent variable: This column lists the standard deviation of oxidant in parts per hundred million at the particular zone over all ninety points used in constructing the repro-model. This number in general is larger for the zones experiencing high pollutant levels. This standard deviation thus serves to characterize the zone and also measures the variability to be explained. Zones with little variability are typically low in oxidant and are of only minor interest because there is little change in the dependent variable under any condition.

(b) Subregion label: There may be several linear functions associated with each repro-model, depending upon its complexity. They are labeled simply for reference.

TABLE 5.1

ANALYSIS DATA FOR OXIDANT REPRO-MODELS

| Zone No. | Zone I.D. | S.D. of Oxidant (pphm) | Sub-Reg. I.D. | Pop. (%) | Average Policy $MSNO_x$ | MSHC | FSHC | $ICNO_x$ | ICHC | Coefficients of Linear Function $MSNO_x$ | MSHC | FSHC | $ICNO_x$ | ICHC | Const. | Normalized Coefficients $MSNO_x$ | MSHC | FSHC | $ICNO_x$ | ICHC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Peak | 15.7 | a | 60 | 91.9 | 86.4 | 54.3 | 94.0 | 83.0 | .0671 | .3420 | .1223 | .0974 | .2373 | -41.63 | .0043 | .0219 | .0078 | .0062 | .0152 |
| | | | b | 40 | 41.8 | 29.0 | 45.7 | 64.7 | 31.9 | -.0053 | .0025 | -.0007 | .0053 | .0012 | 6.86 | -.0003 | .0002 | 0.0000 | .0003 | .0001 |
| 2 | Sunland(10,24) | 17.4 | a | 59 | 92.3 | 86.8 | 55.2 | 94.4 | 83.4 | .0736 | .3426 | .1229 | .0969 | .2320 | -41.91 | -.0043 | .0198 | .0071 | .0056 | .0134 |
| | | | b | 18 | 57.5 | 40.9 | 47.2 | 73.1 | 44.3 | .0437 | .1150 | .0364 | .0085 | .1035 | -9.97 | .0025 | .0066 | .0021 | .0005 | .0060 |
| | | | c | 23 | 31.2 | 21.7 | 42.6 | 58.7 | 23.9 | -.0403 | .0178 | .0021 | .0250 | .0243 | 0.22 | -.0023 | .0010 | .0001 | .0014 | .0014 |
| 3 | Pasadena(15,20) | 11.0 | a | 50 | 95.7 | 90.9 | 59.7 | 95.8 | 87.7 | .0064 | .2174 | .1234 | .0803 | .2357 | -36.45 | .0006 | .0199 | .0113 | .0073 | .0215 |
| | | | b | 49 | 47.6 | 35.9 | 42.3 | 68.8 | 37.7 | -.1455 | .0609 | -.0163 | .0887 | .0544 | -3.12 | -.0133 | .0056 | -.0015 | .0081 | .0050 |
| | | | c | 1 | 65.0 | 40.0 | 30.0 | 70.0 | 29.0 | -.0305 | .0460 | .0119 | .0439 | .0338 | -2.45 | -.0028 | .0042 | .0011 | .0040 | .0031 |
| 4 | Burbank(10,21) | 9.8 | a | 42 | 99.3 | 96.3 | 58.0 | 98.9 | 92.8 | .0001 | .2666 | .0932 | .1041 | .2390 | -45.13 | .00001 | .0273 | .0095 | .0106 | .0244 |
| | | | b | 57 | 51.5 | 39.1 | 44.6 | 70.1 | 40.2 | -.1833 | .0625 | -.0213 | .0675 | .0572 | -1.66 | -.0187 | .0064 | -.0022 | .0069 | .0058 |
| | | | c | 1 | 65.0 | 55.0 | 95.0 | 72.0 | 56.0 | -.0015 | .0298 | .0081 | -.0026 | .0203 | 0.24 | -.0002 | .0030 | .0008 | -.0003 | .0021 |
| 5 | Carbon Cyn.(25,13) | 6.1 | a | 46 | 99.2 | 94.6 | 54.3 | 98.9 | 90.8 | -.0031 | .1055 | .0151 | .0666 | .1884 | -21.26 | -.0005 | .0173 | .0025 | .0109 | .0194 |
| | | | b | 54 | 49.0 | 37.4 | 48.0 | 68.4 | 39.0 | -.0038 | .0036 | -.0010 | .0105 | .0431 | 0.66 | -.0006 | .0006 | -.0002 | .0017 | .0071 |
| 6 | Duarte(20,20) | 5.8 | a | 42 | 99.3 | 96.3 | 58.0 | 98.9 | 92.8 | -.0093 | .1260 | .0481 | .0644 | .1828 | -25.39 | -.0016 | .0219 | .0084 | .0112 | .0318 |
| | | | b | 58 | 51.7 | 39.4 | 45.6 | 70.2 | 40.5 | -.0133 | .0097 | .0025 | .0138 | .0226 | 0.89 | -.0023 | .0017 | .0004 | .0024 | .0039 |
| 7 | *Downtown*(12,17) | 5.1 | a | 32 | 104.8 | 99.5 | 64.7 | 102.0 | 96.7 | -.0076 | .0245 | .0041 | .0110 | .0067 | -0.41 | -.0015 | .0048 | .0008 | .0022 | .0013 |
| | | | b | 67 | 54.9 | 45.6 | 43.8 | 72.0 | 45.7 | -.1634 | .0506 | -.0155 | .0440 | .0468 | -1.52 | -.0322 | .0100 | -.0031 | .0087 | .0092 |
| | | | c | 1 | 130.0 | 90.0 | 75.0 | 125.0 | 88.0 | -.0315 | .1536 | .0806 | .1082 | .1915 | -36.69 | -.0062 | .0303 | .0159 | .0213 | .0378 |
| 8 | West L.A.(7,17) | 0.5 | a | 20 | 106.7 | 107.5 | 68.6 | 103.5 | 105.2 | -.0209 | .0205 | .0084 | .0277 | .0385 | -4.64 | -.0382 | .0375 | .0154 | .0506 | .0704 |
| | | | b | 48 | 83.8 | 64.3 | 43.8 | 88.4 | 61.0 | -.0045 | -.0019 | -.0008 | .0036 | .0047 | 1.95 | -.0082 | -.0035 | -.0015 | .0066 | .0086 |
| | | | c | 32 | 32.4 | 34.8 | 50.2 | 60.0 | 38.5 | -.0354 | .0018 | .0003 | .0077 | .0082 | 2.88 | -.0647 | .0033 | .0005 | .0141 | .0150 |
| 9 | N. L. Beach(12,9) | 0.4 | | 100 | 71.8 | 63.4 | 50.8 | 82.3 | 62.6 | .0046 | .0111 | .0015 | -.0031 | .0008 | 0.10 | .0115 | .0271 | .0037 | -.0076 | .0020 |

(c) Population: This is the percentage of the 90 sample points which fell in the subregion where the particular linear function is active. Since the samples were uniformly distributed, this gives an estimate of the size of the subregion where the given linear function is used.

(d) Average policy: This is the average policy vector for the subregion corresponding to the given linear function, obtained by taking the mean of all policy vectors falling in the subregion. This data provides an insight into the typical policy for which the linear function is appropriate.*

(e) Linear coefficients and constant term: If the six entries in the table are $a_1$, $a_2$, $a_3$, $a_4$, $a_5$, $a_6$, then the equation for policies in the corresponding subregion is

$$\text{OXIDANT (pphm)} = a_1\text{MSNO}_x + a_2\text{MSHC} + a_3\text{FSHC} + a_4\text{ICNO}_x + a_5\text{ICHC} + a_6 \quad , \qquad (5.4)$$

where the variables are as before.

(f) Normalized coefficients: If $a_1$, $a_2$, $a_3$, $a_4$, $a_5$, $a_6$ are the entries discussed under (e), and $b_1$, $b_2$, $b_3$, $b_4$, $b_5$ are the entries in the columns presently under discussion, then

$$b_k = a_k/\sigma_{zone} \qquad (5.5)$$

*The subregions for the oxidant repro-models are themselves convex regions; hence, the mean policy vector is likely to fall near the centroid of the region.

where $\sigma_{zone}$ is the standard deviation of the dependent variable for the repro-model in question and is listed in the first column discussed [see (a)]. The constant term is not listed. These normalized coefficients use standard deviations as scale factors to provide a means of comparing coefficients between repro-models, i.e., between zones with differing ranges of dependent variable. The dependent variable predicted by the linear function corresponding to these coefficients can be thought of as the oxidant level stated in units of standard deviations particular to the zone rather than as an absolute level.

The reader will note several subregions with few sample points. The inclusion of a small subregion indicates that reduction of function parameters to eliminate the subregion resulted in a significant increase in approximation error; i.e., the subregion was necessary. Figure 5.2 indicates how such a situation might occur. Such subregions usually occur at transitions or extremes, and their location should be of interest as anomalies in model behavior. We will simply note here, however, that one should attribute little significance to the coefficients corresponding to a region with low population.

Let us use Table 5.1 to examine differences in the repro-models for different zones. Table 5.2 abstracts the most pertinent data for this purpose. Two sets of normalized linear function coefficients are listed, corresponding to higher emission levels and to intermediate or lower levels. Also listed is the standard deviation of the oxidant level for each zone. Where there existed multiple linear functions corresponding to intermediate or low emissions, the one corresponding to

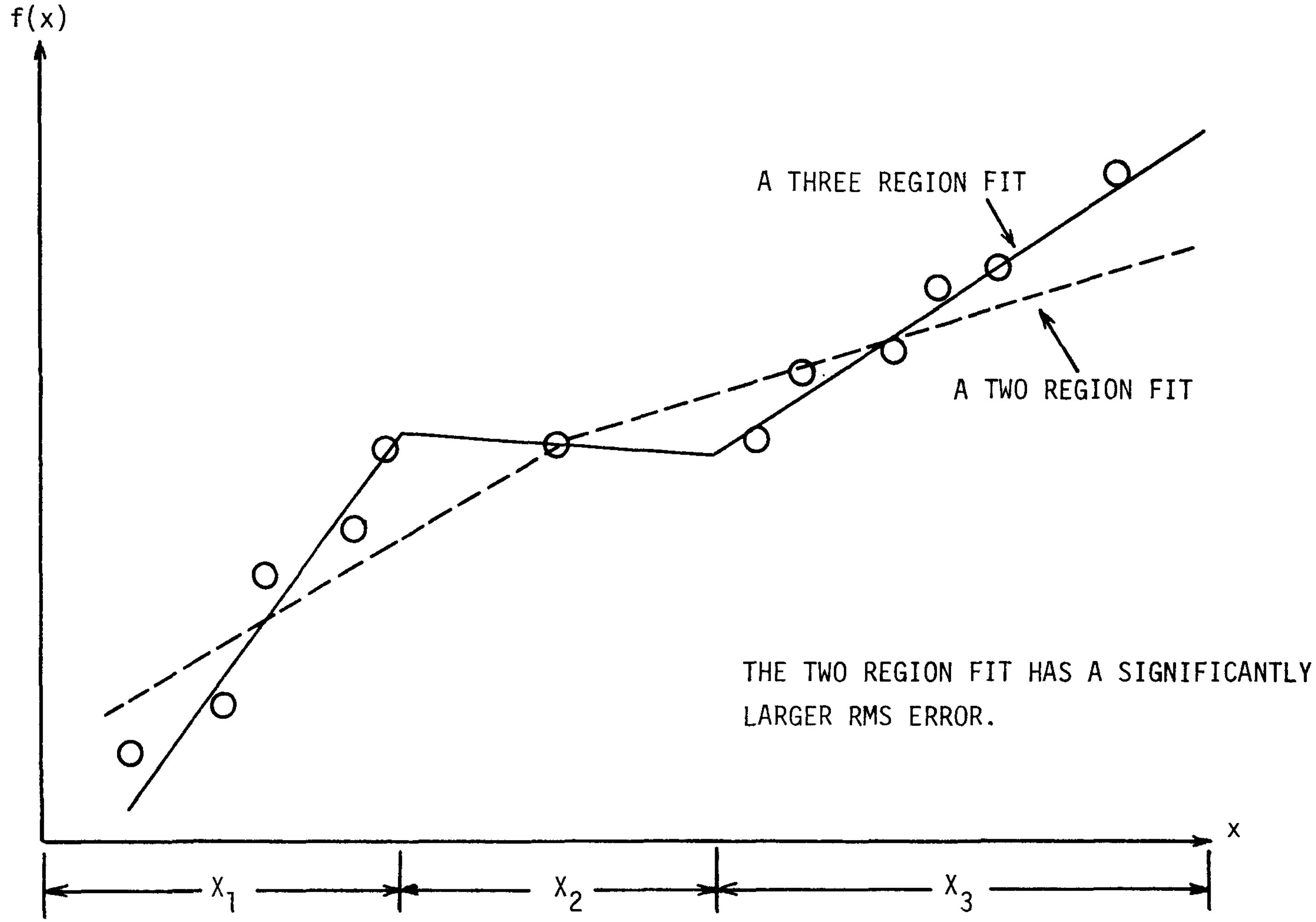



FIGURE 5.2

A SIMPLE ILLUSTRATION OF THE POSSIBLE
NEED FOR A TRANSITORY SUBREGION

TABLE 5.2

COEFFICIENTS OF LINEAR FUNCTIONS
FOR OXIDANT REPRO-MODELS

| Zone No. | Zone I.D. | S.D. of Oxidant in Zone | Normalized Coefficients (x1000) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | HIGH EMISSIONS | | | | | INTERMEDIATE/LOW EMISSIONS | | | | |
| | | | $MSNO_x$ | MSHC | FSHC | $ICNO_x$ | ICHC | $MSNO_x$ | MSHC | FSHC | $ICNO_x$ | ICHC |
| 1 | Peak | 15.7 | 4 | 22 | 8 | 6 | 15 | 0 | 0 | 0 | 0 | 0 |
| 2 | Sunland (10,24) | 17.3 | 4 | 20 | 7 | 6 | 13 | 3 | 7 | 2 | 1 | 6 |
| 3 | Pasadena (15,20) | 10.9 | 1 | 20 | 11 | 7 | 21 | -13 | 6 | -2 | 8 | 5 |
| 4 | Burbank (10,21) | 9.8 | 0 | 27 | 10 | 11 | 24 | -19 | 6 | -2 | 7 | 6 |
| 5 | Carbon Canyon (25,13) | 6.1 | -1 | 17 | 3 | 11 | 19 | -1 | 1 | 0 | 2 | 7 |
| 6 | Duarte (20,20) | 5.8 | -2 | 22 | 8 | 11 | 32 | -2 | 2 | 0 | 2 | 4 |
| 7 | Downtown L.A. (12,17) | 5.1 | -2 | 5 | 1 | 2 | 1 | -32 | 10 | -3 | 9 | 9 |
| 8 | West L.A. (7,17) | 0.5 | -38 | 38 | 15 | 51 | 70 | -8 | -4 | -2 | 7 | 9 |
| 9 | N. Long Beach (12,9) | 0.4 | 11 | 27 | 4 | 8 | 2 | | | | | |

highest emissions was chosen. (Linear functions corresponding to populations of 1 percent were ignored.)

Consider first the high emission case. Note that the coefficients for zone No. 2, where the peak most often occurs with high emissions, are essentially identical to those for the peak (zone No. 1). In fact, the coefficients have essentially the same implications for most of the zones with high and intermediate pollution levels (zones 2-6). These implications have been discussed in terms of the peak model. One exception to this consistency is a marked decrease in the value of the coefficient for mobile source $NO_x$ as the pollution level of the zone decreases; the coefficient even changes sign. This trend suggests that, in regions with higher pollution levels, an increase in $NO_x$ emissions results in an increase in oxidant, but at intermediate and lower levels results in no change or a decrease in oxidant levels.

The coefficients for $NO_x$ initial conditions are positive for all zones and of similar magnitudes. We thus have contradictory effects at the lower pollution levels: an increase in $NO_x$ initial/boundary conditions leads to an increase in oxidant concentrations, while an increase in mobile source $NO_x$ emissions leads to a decrease in oxidant concentrations. Having noted this characteristic, we shall leave its meaning an open question.

Marked differences in the effect of boundary conditions is consistent with the location of zones 6 and 7. The normalized coefficients for zones 8 and 9 are included for completeness, but there is too little variability in pollution levels in these zones to merit close examination.

At low emission levels, the variables have much less effect on oxidant concentrations, but one effect is consistent and pronounced. Except in zone No. 2, mobile source $NO_x$ becomes the prime determinant of oxidant level, with oxidant decreasing as mobile source $NO_x$ increases.

It remains to analyze the three $NO_2$ repro-models (Table 5.3). At the highest emission levels in the highest pollution zones, increasing any of the three hydrocarbon variables reduces average $NO_2$ (perhaps by converting it into oxidant). In all cases, the $NO_x$ initial and boundary conditions (and not mobile source $NO_x$) are the prime determinant of the average $NO_2$ levels.

We have outlined the predominant implications of the model; the energetic reader may wish to probe further into the data provided.

## 5.2 Examples of Repro-Model Use

The repro-model is intended to aid transportation control policy evaluation. Three sets of examples of repro-model runs presented in this section illustrate the usage of the model. It should be emphasized that these examples represent a small fraction of the types of questions that can be addressed using the model. The repro-model program is designed to permit rapid evaluation of many more control policies. In the following analyses and in using the repro-model, the reader should recall the limitations of the repro-model (section 1.0).

### 5.2.1 Impact of Emission Controls on Motor Vehicles

Several repro-model evaluations were produced which simulate the change in air quality due to changes in the motor vehicle emission standards. The policies shown in Figure 3.5 and listed in Table 5.4 were used as input to the repro-model. Fixed source emissions of all types and VMT were held

TABLE 5.3

ANALYSIS DATA FOR $NO_2$ REPRO-MODELS

($NO_2$ in pphm)

| Zone No. | Zone I.D. | S.D. of $NO_2$ (pphm) | Sub-Reg. I.D. | Pop. (%) | Average Policy | | | | | Coefficients of Linear Function | | | | | | Normalized Coefficients | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | $MSNO_x$ | MSHC | FSHC | $ICNO_x$ | ICHC | $MSNO_x$ | MSHC | FSHC | $ICNO_x$ | ICHC | Const. | $MSNO_x$ | MSHC | FSHC | $ICNO_x$ | ICHC |
| 10 | Burbank (10,21) | 8.17 | a | 40 | 96.3 | 90.4 | 55.4 | 95.4 | 87.0 | .0393 | -.0280 | -.0085 | .1285 | -.0020 | 6.53 | .0048 | -.0034 | -.0010 | .0157 | -.0002 |
| | | | b | 39 | 65.0 | 51.9 | 44.1 | 79.0 | 51.8 | .0618 | .0865 | .0212 | .1941 | .0498 | -14.15 | .0076 | .0106 | .0026 | .0238 | .0061 |
| | | | c | 20 | 32.8 | 29.7 | 52.2 | 59.3 | 33.2 | .0260 | .0437 | .0105 | .1249 | .0394 | -3.51 | .0032 | .0053 | .0013 | .0153 | .0048 |
| | | | d | 1 | 135.0 | 105.0 | 95.0 | 138.0 | 90.0 | .0752 | .0147 | .0022 | .1978 | .0084 | -4.11 | .0092 | .0018 | .0003 | .0242 | .0010 |
| 11 | Downtown (12,17) | 6.58 | a | 1 | 110.0 | 100.0 | 65.0 | 106.0 | 80.0 | .0454 | -.0202 | -.0141 | .0783 | -.0107 | 7.59 | .0069 | -.0031 | -.0021 | .0119 | -.0016 |
| | | | b | 38 | 92.1 | 89.4 | 59.0 | 95.4 | 86.6 | .0734 | .0135 | .0069 | .1288 | .0229 | -3.29 | .0112 | .0021 | .0010 | .0196 | .0035 |
| | | | c | 47 | 65.7 | 52.6 | 43.5 | 77.1 | 52.1 | .0449 | .0658 | .0317 | .1412 | .0721 | -13.50 | .0068 | .0100 | .0048 | .0215 | .0110 |
| | | | d | 14 | 35.8 | 27.7 | 52.3 | 62.7 | 32.3 | .0170 | .0322 | .0107 | .0907 | .0386 | -2.62 | .0026 | .0049 | .0016 | .0138 | .0059 |
| 12 | West L.A. (7,17) | 3.79 | a | 45 | 99.4 | 92.2 | 53.8 | 99.2 | 88.9 | .0180 | .0226 | .0077 | .1190 | .0370 | -6.16 | .0047 | .0060 | .0020 | .0314 | .0098 |
| | | | b | 47 | 46.0 | 38.7 | 46.8 | 68.2 | 39.7 | .0101 | .0126 | .0030 | .0926 | .0124 | -0.87 | .0027 | .0033 | .0008 | .0244 | .0033 |
| | | | c | 8 | 65.7 | 43.6 | 57.9 | 67.7 | 46.0 | .0416 | .0065 | .0037 | .0454 | .0183 | 0.34 | .0110 | .0017 | .0010 | .0120 | .0048 |

TABLE 5.4

IMPACT OF FEDERAL EMISSION CONTROL STANDARDS
MOBILE SOURCES*--OXIDANT (in pphm)

| YEAR | $NO_x$ MOBILE** SOURCE EM. | HC MOBILE SOURCE EM. | PEAK | 10,24 | 10,21 | 15,20 | 20,20 | 7,17 | 12,17 | 25,13 | 12,9 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1969 | 100 | 100 | 45 | 45 | 25 | 30 | 16 | 3 | 14 | 16 | 2 |
| 1970 | 103 | 90 | 40 | 40 | 21 | 26 | 13 | 2 | 11 | 12 | 1 |
| 1971 | 102 | 78 | 33 | 33 | 15 | 21 | 10 | 2 | 7 | 10 | 1 |
| 1972 | 95 | 65 | 25 | 25 | 8 | 15 | 6 | 2 | 2 | 7 | 1 |
| 1973 | 81 | 53 | 17 | 17 | 4 | 9 | 3 | 2 | 2 | 4 | 1 |
| 1974 | 65 | 45 | 11 | 11 | 3 | 5 | 3 | 2 | 2 | 4 | 1 |
| 1975 | 54 | 35 | 7 | 5 | 3 | 3 | 3 | 2 | 2 | 3 | 1 |
| 1976 | 42 | 25 | 7 | 3 | 2 | 3 | 3 | 2 | 1 | 3 | 1 |
| 1977 | 33 | 18 | 7 | 2 | 2 | 2 | 2 | 2 | 1 | 2 | 0 |
| 1978 | 27 | 15 | 7 | 2 | 2 | 2 | 2 | 3 | 1 | 2 | 0 |
| 1979 | 22 | 12 | 7 | 2 | 2 | 2 | 2 | 3 | 1 | 2 | 0 |

*Vehicle Miles of Travel held at 1969 level.

**Fixed source hydrocarbons held at 100%. All initial conditions set at values typical for the mobile source emission control policy (See equations 3.1 and 3.2).

constant at the 1969 level, and initial conditions were varied to correspond to levels normally expected under the particular control policy. The policies were derived from calculations performed by the Los Angeles Air Pollution Control District [8] assuming federal standards are met on schedule. The calculations included changes in vehicle mix over the years and automobile aging and mortality.

The results of the repro-model evaluations are shown in Table 5.4. This table indicates that if VMT were to be held at the 1969 level, the peak concentration of oxidants on a day similar to the test day, as predicted by the SAI model, would dip below 8 pphm by the year 1975. Table 5.4 demonstrates a relatively early predicted improvement in air quality as emissions are reduced. This improvement can be considerably reduced, however, by increases in VMT and fixed source emissions and by delays in implementing emission controls. A planner or engineer interested in evaluating other alternative policies, such as effects of delays in control implementation or changes in VMT, can do so easily using the repro-model.

Note that the results of the model do not correspond to the assumptions of the rollback model; e.g., a reduction in hydrocarbon emissions of 55% results in a reduction in peak oxidant of 76% rather than 55%.

### 5.2.2 Ratio of Hydrocarbon Emissions to $NO_x$ Emissions

The California mobile source emission standards differ from those of the federal government. The principal difference between the standards is California's higher permissible $NO_x$ emissions. The Los Angeles APCD asserts [8] that the California standards provide a more favorable <u>ratio</u> of $NO_x$ to hydrocarbons than the federal standards. An exploratory investigation as to the importance of this ratio at a particular location on air quality was made using the repro-model for Sunland (10,24). While holding fixed source emissions constant and while varying $NO_x$ emissions, constant hydrocarbon contours were generated using the repro-model. Figure 5.3 displays the contours. The "HC = 70" contour, for example, fixes all hydrocarbon emissions at the 70% level and fixed source $NO_x$ at the test day level and varies $NO_x$ mobile source emissions between 10% and 140%. The hash marks on the contours denote the boundaries of the policy region.

Over most of the policies, especially with high hydrocarbon emissions, the SAI model, as interpreted by the repro-model, behaves very regularly. At a constant hydrocarbon emission level, for the most part, reducing $NO_x$ causes a linear reduction in $O_3$. At lower emission levels, however, the behavior of the SAI model changes. As the hydrocarbon emissions are reduced to the 50% level, the rate of reduction in $O_3$ concentration with respect to a reduction in $NO_x$ is smaller. At the 40% level, the slope of the contour starts to become negative. At lower hydrocarbon levels, a decrease in $NO_x$ emissions causes an increase in the $O_3$ concentration.

This analysis would normally be carried out for the Peak model. The interesting effects, however, are hidden in the case of the Peak repro-model by the fixed source contributions. Therefore, zone (10,24), the zone which seems most affected by mobile source emissions, was used instead.

This discussion by no means resolves the controversy; however, the SAI model behaves such that at low emissions the ratio of $NO_x$ to hydrocarbons is very important. For low levels of hydrocarbon emissions there appears to be an optimum level (other than zero) of $NO_x$ emissions for maximum oxidant reduction.

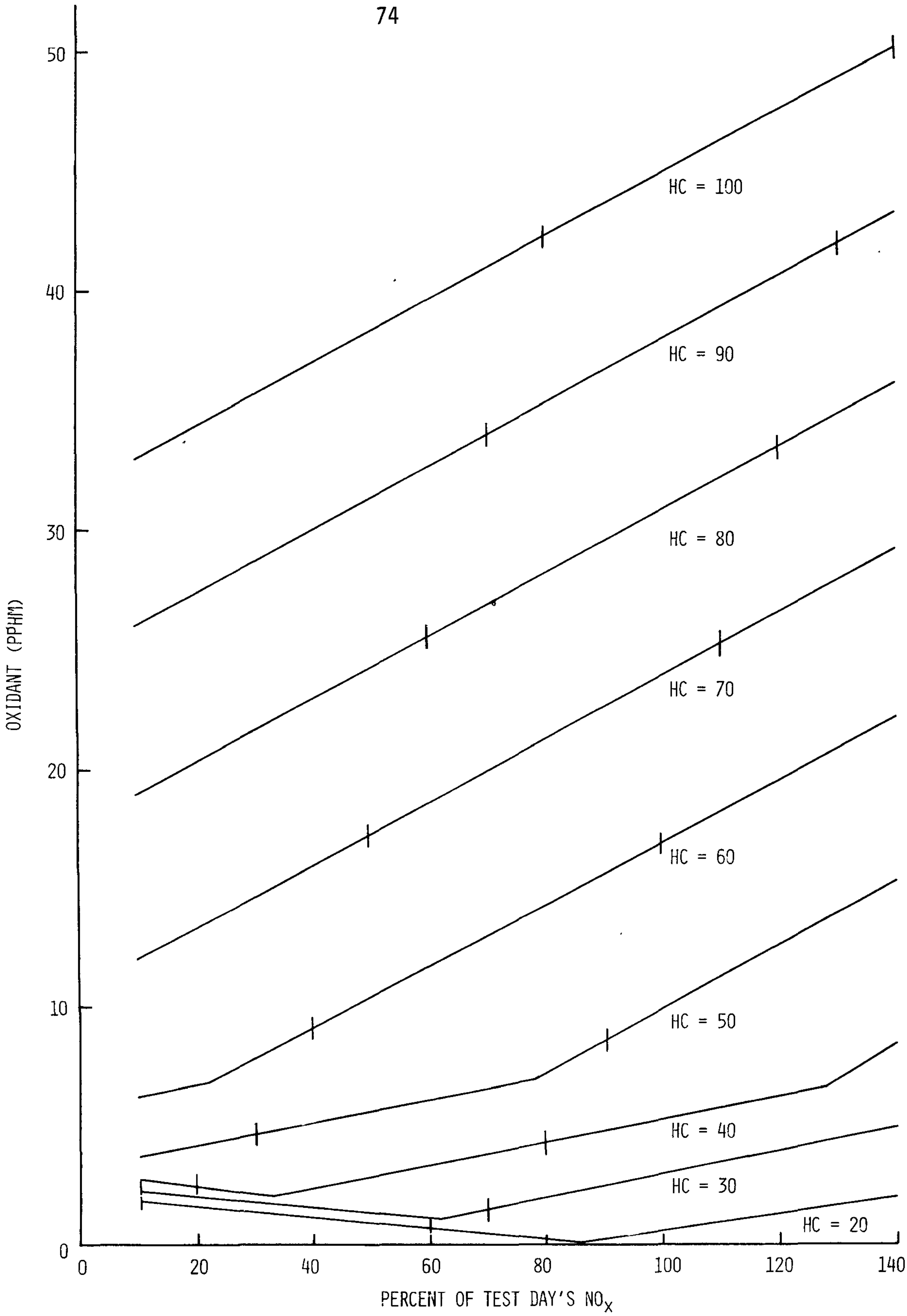



FIGURE 5.3

EFFECT OF VARYING $NO_X$ WHILE
HOLDING HYDROCARBONS CONSTANT

The well-behaved nature of the repro-model for oxidant at Sunland at high pollution levels allows for the derivation of a simple alternative to the rollback model. If HC and NOX are derived variables, where HC represents the appropriate policy for an across-the-board decrease in hydrocarbon emissions and where NOX represents the appropriate policy for an across-the-board decrease in mobile source $NO_x$ emissions, the oxidant concentration at Sunland can be represented by the equation:

$$\text{OXIDANT} = 0.70 \cdot \text{HC} + 0.13 \cdot \text{NOX} - 38 \quad . \qquad (5.6)$$

The region where this linear equation remains valid can be clearly seen in Figure 5.3. Both the derived variables, HC and NOX, are expressed in percent of the test day.

The dependence on the test day can be lessened somewhat by expressing equation 5.6 in terms of percent reduction.* That is,

$$\text{\% REDUCTION in } O_3 = -1.55 \cdot \text{HC} - 0.30 \cdot \text{NOX} + 185 \quad . \qquad (5.7)$$

When NOX and HC are both set at 100, the percentage reduction in oxidant is, of course, zero. We see that this simple model predicts a 1.6% reduction in oxidant concentration for each 1% decrease in the hydrocarbon emissions variable and a 0.3% reduction in oxidant concentration for each 1% decrease in the $NO_x$ emissions variable. This linear equation holds up to about an 80% reduction. Also, the coefficients for the Sunland model and the peak model are almost identical for this range.**

---

*See Section 2.4 for a listing of test day emission levels.

**Specifically, the appropriate constants for the peak model are -1.56, 0.28, and 184.

### 5.2.3 Effects of Single Day Emission Reduction

Control policies have been proposed for Los Angeles whereby air quality standards are achieved by cutting VMT for a single day. Two scenarios which are representative of such policies were simulated using the repro-model. The first case was that of a twenty percent reduction in mobile source emissions while initial conditions remain at their original level. When compared with the "baseline" (100%) case, this one day emission reduction produced approximately a 20% overall reduction in oxidant concentrations. (See Table 5.5.) When a twenty percent decrease in emissions was tried at a lower emission level, some reductions in oxidant concentrations were achieved. In this case the reductions were not as dramatic.

TABLE 5.5

EFFECTS OF SINGLE DAY TRAFFIC REDUCTION POLICY
ON AIR QUALITY (OXIDANT, pphm)

| Zone | Baseline[1] | 20% Reduction in Mobile Source Emissions[2] | 50% of Baseline[3] | 20% Reduction of Mobile Source Emissions from 50% Base[4] |
|---|---|---|---|---|
| Peak | 45 | 37 | 7 | 7 |
| 10,24 | 45 | 37 | 6 | 4 |
| 10,21 | 25 | 20 | 3 | 3 |
| 15,20 | 30 | 25 | 4 | 3 |
| 20,20 | 16 | 13 | 3 | 3 |
| 7,17 | 3 | 3 | 2 | 2 |
| 12,17 | 14 | 11 | 2 | 1 |
| 25,13 | 16 | 14 | 3 | 3 |
| 12, 9 | 2 | 1 | 1 | 2 |

[1]Policy: 100,100,100,100,100 ($NO_x$ and HC mobile source emissions, HC fixed source emissions, and $NO_x$ and HC initial condition, respectively.)

[2]Policy: 80, 80,100,100,100

[3]Policy: 50, 50, 50, 69, 50. The 69% value for $NO_x$ initial condition variable results from the uncontrolled $NO_x$ fixed sources.

[4]Policy: 40, 40, 50, 69, 50

## 6.0 CONCLUSION

In the introduction, we listed three objectives: (1) a feasibility test for repro-modeling in the context of pollution models; (2) an interpretation of some of the implications of the SAI model; and (3) the creation of an efficient repro-model to allow further analysis. The following is a review of the study in the light of these objectives.

Since the SAI model had tens of thousands of numbers constituting input and thousands of numbers as output, it was neither feasible nor desirable to explore the input/output relationships of the model in full variety. Five aggregate input variables were defined: mobile source $NO_x$, mobile source hydrocarbon, fixed source hydrocarbon, $NO_x$ initial/boundary conditions, and hydrocarbon initial/boundary conditions. These independent variables were expressed as percent of level on test day. Twelve outputs (dependent variables) were examined: the peak one-hour-average oxidant concentration over the Los Angeles basin, the peak one-hour-average at eight specific locations in the basin, and $NO_2$ ten-hour-average concentrations at three specific locations. Twelve repro-models, each relating the five independent variables to one of the dependent variables, were constructed to create the overall repro-model. Ninety model runs were used to create the repro-models; ten additional runs were used for independent testing.

The feasibility of the approach was clearly demonstrated. The input/output relationship implied by the SAI model was relatively simple and fully defined by the set of model runs. The resulting repro-models essentially duplicated the SAI model output; accuracy of approximation was close to the limiting accuracy with which the output was reported and certainly well within the accuracy with which the model corresponds to reality. The continuous piecewise linear functional form used to represent the input/output relationship proved to be efficient relative to multivariate polynomials. The independent test on ten model runs provided convincing verification of the repro-models.

The objective of efficiency was clearly met. While a run of the original model took 22 minutes of computer time, the repro-models took milliseconds on a comparable computer. A computer program was developed and delivered to the Environmental Protection Agency.

The study yielded an extensive interpretation of the implications of the SAI model regarding the relationship between the five aggregate input variables and the twelve output variables. Characteristics noted included the following:

(1) The oxidant models were convex; the rate of increase of oxidant concentration never decreased with increasing values of the independent variables. Two of the three $NO_2$ repro-models were non-convex.

(2) Over most of the policy region hydrocarbon emissions are significantly more important than $NO_x$ emissions in the formation of ozone.

(3) Assumptions on the magnitude of initial and boundary conditions have a major impact on the predicted air quality.

(4) As emissions are reduced the impact on oxidant formation of $NO_x$ emissions becomes relatively less. In fact, increasing $NO_x$ emissions reduces oxidant concentration for very low emission policies.

(5) At low pollution levels, increasing mobile source $NO_x$ emissions decreases oxidant concentrations, but increasing $NO_x$ initial/boundary

conditions increases oxidant concentrations.

(6) The major determinant of average $NO_2$ concentrations in the model is $NO_x$ initial and boundary conditions and <u>not</u> mobile source $NO_x$ emissions.

(7) Simplified models to aid planning may be extracted by exploiting the locally linear nature of the repro-model form. For example, in the limited context of this study, the results suggested the following rule-of-thumb relationship between the percent reduction of peak oxidant concentration and the level of fixed and mobile-source hydrocarbon emissions (HC) and mobile source $NO_x$ emissions (NOX), expressed as percent of test day:

$$\%\ \text{REDUCTION in } O_3 = -1.55 \cdot \text{HC} - 0.30 \cdot \text{NOX} + 185 \quad .$$

This formula holds up to about an 80% reduction and indicates the predominant effect of hydrocarbons. (Section 5.2 details the assumptions involved.)

It is appropriate to conclude this report by referring the reader to the limitations, discussed in the introduction, on the generality of the repro-model and the generality of its implications. In particular, we have been discussing the characteristics of a model, and it is not our purpose to make a judgment on the correspondence of the model characteristics to reality. We have hopefully demonstrated that repro-modeling is a powerful tool for understanding the implications and extending the utility of complex physical models.

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# APPENDIX

## A.1 Repro-Model Documentation

The several piecewise linear representations of the SAI model have been included in a repro-model computer program. The program is user-oriented and is suitable for both batch and on-line processing. A listing of the program appears at the end of this documentation.

The policies which are to be evaluated are input after the program deck. One policy (five numbers) is punched on a card. The format is 5F10.1. The five fields contain the information in Table A.1. The program will accept up to 500 different policies (i.e., 500 cards). The program will cease reading policy cards when it reaches an end-of-file. (An end-of-file card must follow the last policy.)

Figure 4.6 shows a typical page of output from the repro-model program. The policy variables are printed first. Also, if any policy region constraints are violated by that particular policy, these violated constraints are listed. The table contains the repro-model results. The first column is the name of the zone, and the next two columns list the east-west and north-south coordinates of that zone, corresponding to Figure 4.5. The pollutant name appears in the fifth column. The repro-model results are printed in the next column, followed by a time period designation. The remainder of the page contains a listing of the net hyperplanes which were used to obtain the concentration estimates and indicate the sensitivity of the result for small changes in the independent variable.

The formula,

$$y = \sum_{i=1}^{5} a_i x_i + a_6$$

TABLE A.1

REPRO-MODEL POLICY INPUT FORMAT

| VARIABLE | COLUMNS |
|---|---|
| Percent of Test Day* Mobile Source $NO_x$ Emissions | 1-10 |
| Percent of Test Day Mobile Source Hydrocarbon Emissions | 11-20 |
| Percent of Test Day Fixed Source Hydrocarbon Emissions | 21-30 |
| Percent of Test Day Initial Conditions for $NO_x$. If set equal to 0 or left blank, the typical value will be assumed. | 31-40 |
| Percent of Test Day Initial Conditions for $NO_x$. If set equal to 0 or left blank, the typical value will be assumed. | 41-50 |

*The test day used in constructing the repro-model was September 30, 1969.

can be used to compute the pollutant concentration, where the $a_i$'s are respective net hyperplane coefficients ($a_6$ is the constant term).

## A.2 Program Listing

The following is a FORTRAN listing of the repro-model program.

```
C
C POLICY ARRAY CONTAINING POLICIES OF VARYING EMISSIONS
C ZONE   ARRAY CONTAINING ALPHAMERIC LABELLING INFORMATION
C HOUR   ARRAY CONTAINING ALPHAMERIC LABELLING INFORMATION
C NPFUNC ARRAY CONTAINING NUMBER OF PIECEWISE-LINEAR FUNCTIONS USED IN EACH
C        POLICY-ZONE EVALUATION
C NHYPER ARRAY CONTAINING NUMBER OF HYPERPLANES PER P-FUNCTION PER ZONE
C XCOORD, YCOORD ARRAYS DESCRIBING ZONE LOCATION ON GRID
C
C                    VARIABLE LIST AND DESCRIPTION OF PURPOSE OF EACH VARIABLE
C POLLUT ARRAY CONTAINING ALPHAMERIC LABELLING INFORMATION DESCRIBING TYPE OF
C        POLLUTANT
C CONCEN ARRAY CONTAINING ALPHAMERIC LABELLING INFORMATION DESCRIBING UNITS OF
C        CONCENTRATION OF POLLUTANT
C PFUNCW ARRAY CONTAINING PIECEWISE-LINEAR FUNCTION WEIGHTS
C PFUNCC ARRAY CONTAINING PIECEWISE-LINEAR FUNCTION CONSTANTS
C HYPER  ARRAY CONTAINING HYPERPLANES
C K      VARIABLE CONTAINING NUMBER OF ZONES INPUT
C POLCON ARRAY CONTAINING CALCULATED POLLUTION CONCENTRATION FOR THE
C                    ZONE UNDER CONSIDERATION
C HYPMAX ARRAY CONTAINING MAXIMUM HYPERPLANE FOR THE ZONE UNDER CONSIDERATION
C
C                    DRIVER FOR REPRO MODEL POLICY EVALUATION PROGRAM
C
C                    INPUT POLICY VARIABLES X1 TO X5
      DO 1000 I=1,500
      CALL INPOL
C                    CALCULATE REPRO MODELS
      CALL CALC
C
      CALL HEADER(I)
1000  CONTINUE
      END
      SUBROUTINE CALC
C
C                    SUBROUTINE TO CALCULATE CONCENTRATION OF POLLUTANT IN A GIVEN
C                    ZONE FOR A PARTICULAR SET OF VALUES OF POLLUTANT SOURCES
C
      COMMON/TACTIC/POLICY(5)
      DIMENSION NPFUNC(20), NHYPER(20), PFUNCW(20,3),PFUNCC(20),
     1   HYPER(180,6)
      COMMON/RESULT/POLCON(20),HYPMAX(20,6)
      DATANPFUNC/1,1,1,1,1,1,1,1,1,2,2,1,0,0,0,0,0,0,0,0/
      DATANHYPER/2,3,3,3,3,2,2,3,1,2,2,3,0,0,0,0,0,0,0,0/
      DATAPFUNCW( 1,1)/12.83 /
      DATAPFUNCW( 2,1)/ 6.545/
      DATAPFUNCW( 3,1)/ 5.293/
      DATAPFUNCW( 4,1)/ 5.770/
      DATAPFUNCW( 5,1)/ 4.694/
      DATAPFUNCW( 6,1)/ 3.514/
      DATAPFUNCW( 7,1)/ 2.749/
      DATAPFUNCW( 8,1)/ .9727/
      DATAPFUNCW( 9,1)/ 1.000/
      DATAPFUNCC( 1)/   9.195/
      DATAPFUNCC( 2)/  11.860/
      DATAPFUNCC( 3)/   6.120/
      DATAPFUNCC( 4)/   3.205/
      DATAPFUNCC( 5)/   0.2909/
      DATAPFUNCC( 6)/   3.0660/
      DATAPFUNCC( 7)/   4.2340/
      DATAPFUNCC( 8)/   1.8160/
```

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      DATAPFUNCC(10)/16,77 /
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      DATAPFUNCC(12)/ 9,833/
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      DATAHYPER( 23,5)/ ,00765800/,HYPER( 23,6)/-4,8730000/
      DATAHYPER( 24,1)/ ,01814000/,HYPER( 24,2)/ ,02165000/
      DATAHYPER( 24,3)/ ,00488100/,HYPER( 24,4)/ ,05418000/
      DATAHYPER( 24,5)/ ,01054000/,HYPER( 24,6)/=7,8290000/
      DATAHYPER( 25,1)/ ,00173100/,HYPER( 25,2)/=,00426500/
      DATAHYPER( 25,3)/=,00178900/,HYPER( 25,4)/ ,00044590/
      DATAHYPER( 25,5)/-,00587000/,HYPER( 25,6)/ 1,3610000/
      DATAHYPER( 26,1)/=,00489500/,HYPER( 26,2)/ ,03137000/
      DATAHYPER( 26,3)/ ,00765400/,HYPER( 26,4)/=,00137500/
      DATAHYPER( 26,5)/ ,01466000/,HYPER( 26,6)/=3,6260000/
      DATAHYPER( 27,1)/ ,00805600/,HYPER( 27,2)/ ,01110000/
      DATAHYPER( 27,3)/ ,00315100/,HYPER( 27,4)/ ,03211000/
      DATAHYPER( 27,5)/ ,01087000/,HYPER( 27,6)/-4,8720000/
      DATAHYPER( 28,1)/ ,01835000/,HYPER( 28,2)/ ,02350000/
      DATAHYPER( 28,3)/ ,01090000/,HYPER( 28,4)/ ,05071000/
      DATAHYPER( 28,5)/ ,02322000/,HYPER( 28,6)/=8,8820000/
      DATAHYPER( 29,1)/ ,00239800/,HYPER( 29,2)/-,00098670/
      DATAHYPER( 29,3)/=,00104200/,HYPER( 29,4)/=,00173700/
      DATAHYPER( 29,5)/-,00444600/,HYPER( 29,6)/ 1,2390000/
      DATAHYPER( 30,1)/=,01152000/,HYPER( 30,2)/ ,02460000/
      DATAHYPER( 30,3)/ ,01110000/,HYPER( 30,4)/ ,00431900/
      DATAHYPER( 30,5)/ ,01964000/,HYPER( 30,6)/=3,7560000/
      DATAHYPER( 31,1)/ ,00636800/,HYPER( 31,2)/ ,00799100/
      DATAHYPER( 31,3)/ ,00189000/,HYPER( 31,4)/ ,05858000/
      DATAHYPER( 31,5)/ ,00783300/,HYPER( 31,6)/=6,7740000/
      DATAHYPER( 32,1)/ ,01139000/,HYPER( 32,2)/ ,01432000/
      DATAHYPER( 32,3)/ ,00488900/,HYPER( 32,4)/ ,07528000/
      DATAHYPER( 32,5)/ ,02344000/,HYPER( 32,6)/=10,120000/
      DATAHYPER( 33,1)/ ,02629000/,HYPER( 33,2)/ ,00412000/
      DATAHYPER( 33,3)/ ,00236000/,HYPER( 33,4)/ ,02871000/
      DATAHYPER( 33,5)/ ,01155000/,HYPER( 33,6)/=6,0090000/
      K=12
C
C                ARRAY POLCON CONTAINS THE POLLUTION CONCENTRATION FOR THE
C                J=TH ZONE IN CELL POLCON(J)
      DO 1006 J=1,20
      POLCON(J)=0
1006  CONTINUE
C
      MM=0
C                FOR EACH ZONE CALCULATE POLLUTION CONCENTRATION AND MAXIMUM
C                HYPERPLANE
      DO 1007 KK=1,K
      DO 1005 I=1,6
      HYPMAX(KK,I)=0
1005  CONTINUE
      CUMHYP=0
C                ITERATE ON PIECEWISE-LINEAR FUNCTIONS
      NPFUNK=NPFUNC(KK)
      DO 1000 L=1,NPFUNK
      HYPIJ==1,E+50
C                ITERATE ON HYPERPLANES
      NHYPK=NHYPER(KK)
C                FORM DOT PRODUCT OF HYPERPLANE AND POLICY
      DO 1001 M=1,NHYPK
      SUM=0
      DO 1003 NN=1,5
```

```
      SUM=SUM + POLICY(NN) * HYPER(MM+M,NN)
1003  CONTINUE
      SUM=SUM + HYPER(MM+M,6)
      IF(HYPIJ .LE. SUM) MAXHYP=MM+M
      HYPIJ=AMAX1( SUM,HYPIJ )
1001  CONTINUE
C
      MM=MM + NHYPK
      DO 1004 I=1,6
      HYPMAX(KK,I)=HYPMAX(KK,I) + PFUNCW(KK,L)*HYPER(MAXHYP,I)
1004  CONTINUE
C
      CUMHYP=CUMHYP + HYPIJ*PFUNCW(KK,L)
1000  CONTINUE
C
      HYPMAX(KK,6)= HYPMAX(KK,6)+ PFUNCC(KK)
      POLCON(KK)=CUMHYP + PFUNCC(KK)
1007  CONTINUE
1002  CONTINUE
      RETURN
      END
      SUBROUTINE EVAL
C
C                SUBROUTINE TO DETERMINE POSSIBLE VIOLATION OF POLICY
C                CONSTRAINTS
C
      COMMON/TACTIC/POLICY(5)
      DIMENSION FLAG(12)
      LOGICAL FLAG,VIOLAT
100   FORMAT(/10X,43H*** VIOLATED POLICY REGION CONSTRAINT(S)---)
101   FORMAT( 21X,17HX1 + X2  .GE.  30 )
102   FORMAT( 21X,17HX1 + X2  .LE. 240 )
103   FORMAT( 21X,17HX1 - X2  .LE.  40 )
104   FORMAT( 21X,17HX2 - X1  .LE.  20 )
105   FORMAT( 21X,15HX2       .GE. 0 )
106   FORMAT( 21X,15HX3       .GE. 0 )
107   FORMAT( 21X,17HX3       .LE. 100 )
108   FORMAT( 21X,24HX4 - 0.558X1  .GE. 29.2 )
109   FORMAT( 21X,24HX4 - 0.682X1  .LE.  46.8 )
110   FORMAT( 21X,30H0.756X2 + 0.144X3 - X5  .LE. 5)
111   FORMAT( 21X,30HX5 - 0.924X2 - 0.176X3  .LE. 5)
112   FORMAT( 21X,11HX5  .GE. 3 )
C
      VIOLAT=.FALSE.
      DO 1000 J=1,12
      FLAG(J)=.FALSE.
1000  CONTINUE
C                LOGICAL CASCADE TO EVALUATE INEQUALITIES
C
      DO 1001 J=1,12
C
      IF((POLICY(  1) + POLICY(  2)) .LT. 30. )  FLAG( 1)=.TRUE.
      IF((POLICY(  1) + POLICY(  2)) .GT.240. )  FLAG( 2)=.TRUE.
      IF((POLICY(  1) - POLICY(  2)) .GT. 40. )  FLAG( 3)=.TRUE.
      IF((POLICY(  2) - POLICY(  1)) .GT. 20. )  FLAG( 4)=.TRUE.
      IF( POLICY(  2) .LT.  0)                   FLAG( 5)=.TRUE.
      IF( POLICY(  3) .LT.  0)                   FLAG( 6)=.TRUE.
      IF( POLICY(  3) .GT.100.)                  FLAG( 7)=.TRUE.
      IF((POLICY(  4) - .558*POLICY(  1)) .LT. 29.2) FLAG( 8)=.TRUE.
      IF((POLICY(  4) - .682*POLICY(  1)) .GT. 46.8) FLAG( 9)=.TRUE.
      IF((.756*POLICY(  2)+.144*POLICY(  3)-POLICY(  5)).GT.5)
     *FLAG(10)=.TRUE.
      IF((POLICY(  5)-.924*POLICY(  2)-.176*POLICY(  3)).GT.5)
     *FLAG(11)=.TRUE.
      IF(POLICY(  5) .LT. 0)                     FLAG(12)=.TRUE.
C
```

```
1001  CONTINUE
C
      DO 1002 J=1,12
      IF( FLAG(J) ) VIOLAT=.TRUE.
1002  CONTINUE
      IF( VIOLAT ) GOTO 1
      RETURN
1     WRITE(6,100)
      IF( FLAG(1) ) WRITE(6,101)
      IF( FLAG(2 )) WRITE(6,102)
      IF( FLAG(3))WRITE(6,103)
      IF( FLAG(4))WRITE(6,104)
      IF( FLAG(5))WRITE(6,105)
      IF( FLAG(6))WRITE(6,106)
      IF( FLAG(7))WRITE(6,107)
      IF( FLAG(8))WRITE(6,108)
      IF( FLAG(9))WRITE(6,109)
      IF(FLAG(10))WRITE(6,110)
      IF(FLAG(11))WRITE(6,111)
      IF(FLAG(12))WRITE(6,112)
      RETURN
      END
      SUBROUTINE HEADER(I)
C
C                 SUBROUTINE TO OUTPUT POLICY-ZONE RELATIONSHIPS AND POLLUTION
C                 CONCENTRATIONS RESULTING FROM GIVEN POLICY
C
      COMMON/TACTIC/POLICY(5)
      COMMON/RESULT/PULCON(20),HYPMAX(20,6)
      DIMENSION ZONE(20,3),HOUR(20,3),XCOORD(20),YCOORD(20),POLLUT(20,3)
     1   ,CONCEN(20,3)
      INTEGER ZONE,HOUR,POLLUT,CONCEN
C           NBLANK IS USED TO BLANK OUT COORDINATE FIELD
      DATA NBLANK/4H    /
      DATAZONE( 1,1)/4HPEAK/,ZONE( 1,2)/4H    /,ZONE( 1,3)/4H    /
      DATAZONE( 2,1)/4HSUNL/,ZONE( 2,2)/4HAND /,ZONE( 2,3)/4H    /
      DATAZONE( 3,1)/4HPASA/,ZONE( 3,2)/4HDENA/,ZONE( 3,3)/4H    /
      DATAZONE( 4,1)/4HBURB/,ZONE( 4,2)/4HANK /,ZONE( 4,3)/4H    /
      DATAZONE( 5,1)/4HDOWN/,ZONE( 5,2)/4HTOWN/,ZONE( 5,3)/4H LA  /
      DATAZONE( 6,1)/4HDUAR/,ZONE( 6,2)/4HTE  /,ZONE( 6,3)/4H    /
      DATAZONE( 7,1)/4HCARB/,ZONE( 7,2)/4HON C/,ZONE( 7,3)/4HANYN/
      DATAZONE( 8,1)/4HWEST/,ZONE( 8,2)/4H LA  /,ZONE( 8,3)/4H    /
      DATAZONE( 9,1)/4HN LO/,ZONE( 9,2)/4HNG B/,ZONE( 9,3)/4HEACH/
      DATAHOUR( 1,1)/4HPEAK/,HOUR( 1,2)/4H HOU/,HOUR( 1,3)/4HR   /
      DATAHOUR( 2,1)/4HPEAK/,HOUR( 2,2)/4H HOU/,HOUR( 2,3)/4HR   /
      DATAHOUR( 3,1)/4HPEAK/,HOUR( 3,2)/4H HOU/,HOUR( 3,3)/4HR   /
      DATAHOUR( 4,1)/4HPEAK/,HOUR( 4,2)/4H HOU/,HOUR( 4,3)/4HR   /
      DATAHOUR( 5,1)/4HPEAK/,HOUR( 5,2)/4H HOU/,HOUR( 5,3)/4HR   /
      DATAHOUR( 6,1)/4HPEAK/,HOUR( 6,2)/4H HOU/,HOUR( 6,3)/4HR   /
      DATAHOUR( 7,1)/4HPEAK/,HOUR( 7,2)/4H HOU/,HOUR( 7,3)/4HR   /
      DATAHOUR( 8,1)/4HPEAK/,HOUR( 8,2)/4H HOU/,HOUR( 8,3)/4HR   /
      DATAHOUR( 9,1)/4HPEAK/,HOUR( 9,2)/4H HOU/,HOUR( 9,3)/4HR   /
      DATACONCEN( 1,1)/4HPPHM/,CONCEN( 1,2)/4H    /,CONCEN( 1,3)/4H    /
      DATACONCEN( 2,1)/4HPPHM/,CONCEN( 2,2)/4H    /,CONCEN( 2,3)/4H    /
      DATACONCEN( 3,1)/4HPPHM/,CONCEN( 3,2)/4H    /,CONCEN( 3,3)/4H    /
      DATACONCEN( 4,1)/4HPPHM/,CONCEN( 4,2)/4H    /,CONCEN( 4,3)/4H    /
      DATACONCEN( 5,1)/4HPPHM/,CONCEN( 5,2)/4H    /,CONCEN( 5,3)/4H    /
      DATACONCEN( 6,1)/4HPPHM/,CONCEN( 6,2)/4H    /,CONCEN( 6,3)/4H    /
      DATACONCEN( 7,1)/4HPPHM/,CONCEN( 7,2)/4H    /,CONCEN( 7,3)/4H    /
      DATACONCEN( 8,1)/4HPPHM/,CONCEN( 8,2)/4H    /,CONCEN( 8,3)/4H    /
      DATACONCEN( 9,1)/4HPPHM/,CONCEN( 9,2)/4H    /,CONCEN( 9,3)/4H    /
      DATAXCOORD( 1)/ 0./,YCOORD( 1)/ 0./
      DATAXCOORD( 2)/10./,YCOORD( 2)/24./
      DATAXCOORD( 3)/15./,YCOORD( 3)/20./
      DATAXCOORD( 4)/10./,YCOORD( 4)/21./
      DATAXCOORD( 5)/12./,YCOORD( 5)/17./
```

```
      DATAXCOORD( 6)/20,/,YCOORD( 6)/20,/
      DATAXCOORD( 7)/25,/,YCOORD( 7)/13,/
      DATAXCOORD( 8)/ 7,/,YCOORD( 8)/17,/
      DATAXCOORD( 9)/12,/,YCOORD( 9)/ 9,/
      DATAPOLLUT( 1,1)/4HOXID/,POLLUT( 1,2)/4HANT /,POLLUT( 1,3)/4H    /
      DATAPOLLUT( 2,1)/4HOXID/,POLLUT( 2,2)/4HANT /,POLLUT( 2,3)/4H    /
      DATAPOLLUT( 3,1)/4HOXID/,POLLUT( 3,2)/4HANT /,POLLUT( 3,3)/4H    /
      DATAPOLLUT( 4,1)/4HOXID/,POLLUT( 4,2)/4HANT /,POLLUT( 4,3)/4H    /
      DATAPOLLUT( 5,1)/4HOXID/,POLLUT( 5,2)/4HANT /,POLLUT( 5,3)/4H    /
      DATAPOLLUT( 6,1)/4HOXID/,POLLUT( 6,2)/4HANT /,POLLUT( 6,3)/4H    /
      DATAPOLLUT( 7,1)/4HOXID/,POLLUT( 7,2)/4HANT /,POLLUT( 7,3)/4H    /
      DATAPOLLUT( 8,1)/4HOXID/,POLLUT( 8,2)/4HANT /,POLLUT( 8,3)/4H    /
      DATAPOLLUT( 9,1)/4HOXID/,POLLUT( 9,2)/4HANT /,POLLUT( 9,3)/4H    /
      DATAZONE(10,1)/4HBURB/,ZONE(10,2)/4HANK /,ZONE(10,3)/4H    /
      DATAZONE(11,1)/4HDOWN/,ZONE(11,2)/4HTOWN/,ZONE(11,3)/4H LA /
      DATAZONE(12,1)/4HWEST/,ZONE(12,2)/4H LA /,ZONE(12,3)/4H    /
      DATAHOUR(10,1)/4H10 H/,HOUR(10,2)/4HOUR /,HOUR(10,3)/4HAVE,/
      DATAHOUR(11,1)/4H10 H/,HOUR(11,2)/4HOUR /,HOUR(11,3)/4HAVE,/
      DATAHOUR(12,1)/4H10 H/,HOUR(12,2)/4HOUR /,HOUR(12,3)/4HAVE,/
      DATACONCEN(10,1)/4HPPHM/,CONCEN(10,2)/4H    /,CONCEN(10,3)/4H    /
      DATACONCEN(11,1)/4HPPHM/,CONCEN(11,2)/4H    /,CONCEN(11,3)/4H    /
      DATACONCEN(12,1)/4HPPHM/,CONCEN(12,2)/4H    /,CONCEN(12,3)/4H    /
      DATAXCOORD(10)/10,/,YCOORD(10)/21,/
      DATAXCOORD(11)/12,/,YCOORD(11)/17,/
      DATAXCOORD(12)/07,/,YCOORD(12)/17,/
      DATAPOLLUT(10,1)/4HNO2 /,POLLUT(10,2)/4H    /,POLLUT(10,3)/4H    /
      DATAPOLLUT(11,1)/4HNO2 /,POLLUT(11,2)/4H    /,POLLUT(11,3)/4H    /
      DATAPOLLUT(12,1)/4HNO2 /,POLLUT(12,2)/4H    /,POLLUT(12,3)/4H    /
      K=12
C
109   FORMAT( 54X,11H*** POLICY ,I3,4H ***,/ )
111   FORMAT( 35X,36HNOX MOBILE SOURCE EMISSIONS (MSE) = ,F5.1,
     *            16H PCT OF TEST DAY)
112   FORMAT( 35X,36HHC  MOBILE SOURCE EMISSIONS (MSE) = ,F5.1,
     *            16H PCT OF TEST DAY)
113   FORMAT( 35X,36HHC  FIXED  SOURCE EMISSIONS (FSE) = ,F5.1,
     *            16H PCT OF TEST DAY)
114   FORMAT( 35X,36HNOX INITIAL CONDITIONS       (IC) = ,F5.1,
     *            16H PCT OF TEST DAY)
115   FORMAT( 35X,36HHC  INITIAL CONDITIONS       (IC) = ,F5.1,
     *            16H PCT OF TEST DAY)
116   FORMAT(1H1,3(1X/),27X,74H*** TECHNOLOGY SERVICE CORPORATION  --  R
     1EPRO MODEL  --  NOVEMBER 1973 ***,//)
      WRITE(6,116)
      WRITE(6,109) I
C
      WRITE(6,111) POLICY(  1)
      WRITE(6,112) POLICY(  2)
      WRITE(6,113) POLICY(  3)
      WRITE(6,114) POLICY(  4)
      WRITE(6,115) POLICY(  5)
C                  PRINT EFFECTS OF IMPLEMENTATION
      CALL EVAL
C
      WRITE(6,100)
100   FORMAT(//10X,117(1H*))
      WRITE (6,101)
101   FORMAT(24X,8HLOCATION,54X,27HNET HYPERPLANE COEFFICIENTS/
     1 14X,4HNAME,7X,2HEW,2X,2HNS,3X,9HPOLLUTANT,2X,13HCONCENTRATION,
     2  2X,6HPERIOD,8X,7HNOX MSE,
     33X,6HHC MSE,3X,6HHC FSE,3X,6HNOX IC,4X,5HHC IC,2X,8HCONSTANT/10X,
     4 117(1H*))
117   FORMAT(/10X,3A4,2X,F3.0,F4.0,4X,2A4,3X,F4.1,2X,A4,3X,3A4,1X,
     1  5(1X,F8.5),1X,F9.5)
118   FORMAT(/10X,3A4,2(1X,A4  ),3X,2A4,3X,F4.1,2X,A4,3X,3A4,1X,
     1  5(1X,F8.5),1X,F9.5)
```

```
C
C                   PRINT (K) ZONES FOR I-TH POLICY
      DO 1000 J=1,K
      IF((XCOORD(J).LE.0).OR.(YCOORD(J).LE.0))   GO TO 10
      WRITE(6,117) (ZONE(J,L),L=1,3),XCOORD(J),YCOORD(J),(POLLUT(J,L),
     1 L=1,2),POLCON(J),CONCEN(J,1),(HOUR(J,L),L=1,3),(HYPMAX(J,L),L=1
     2 ,6)
      GO TO 1000
10    WRITE(6,118) (ZONE(J,L),L=1,3),NBLANK   ,NBLANK   ,(POLLUT(J,L),
     1 L=1,2),POLCON(J),CONCEN(J,1),(HOUR(J,L),L=1,3),(HYPMAX(J,L),L=1
     2 ,6)
1000  CONTINUE
      WRITE(6,100)
      RETURN
      END
      SUBROUTINE INPOL
C
C                   SUBROUTINE TO INPUT POLICIES TO BE USED IN DETERMINING AIR
C                   POLLUTION CONCENTRATIONS FOR ZONES UNDER CONSIDERATION
C
      COMMON/TACTIC/POLICY(5)
C
100   FORMAT(5F10.0)
C
      READ(5,100,END=1) (POLICY(J),J=1,5)                                    C
C                   INSERTION OF INITIAL CONDITIONS
4     IF(POLICY(4) .LE. 0) POLICY(4)=.62*POLICY(1)+38
      IF(POLICY(5) .LE. 0) POLICY(5)=.84*POLICY(2)+.16*POLICY(3)
C
      RETURN
1     CONTINUE
      STOP
      END
```

A.3 One Hundred SAI Model Runs

The five input variables used for each of the SAI model runs are listed in the following table.

## Independent Variables

| | $x_1$ | $x_2$ | $x_3$ | $x_4$ | $x_5$ |
|---|---|---|---|---|---|
| 1 | 100 | 100 | 100 | 100 | 100 |
| 2 | 25 | 5 | 20 | 58 | 13 |
| 3 | 20 | 10 | 40 | 45 | 9 |
| 4 | 15 | 15 | 60 | 57 | 15 |
| 5 | 10 | 20 | 80 | 54 | 30 |
| 6 | 5 | 25 | 100 | 34 | 43 |
| 7 | 30 | 13 | 13 | 57 | 13 |
| 8 | 35 | 10 | 25 | 65 | 15 |
| 9 | 30 | 15 | 45 | 46 | 27 |
| 10 | 25 | 20 | 65 | 49 | 22 |
| 11 | 20 | 25 | 85 | 60 | 35 |
| 12 | 15 | 30 | 10 | 47 | 27 |
| 13 | 40 | 5 | 30 | 73 | 9 |
| 14 | 45 | 15 | 50 | 78 | 13 |
| 15 | 40 | 20 | 70 | 62 | 24 |
| 16 | 35 | 25 | 90 | 65 | 44 |
| 17 | 30 | 30 | 15 | 48 | 36 |
| 18 | 25 | 35 | 35 | 50 | 27 |
| 19 | 20 | 40 | 55 | 60 | 42 |
| 20 | 50 | 10 | 75 | 61 | 16 |
| 21 | 50 | 25 | 95 | 62 | 40 |
| 22 | 45 | 30 | 0 | 66 | 18 |
| 23 | 40 | 35 | 20 | 63 | 28 |
| 24 | 35 | 40 | 40 | 70 | 49 |
| 25 | 30 | 45 | 60 | 46 | 57 |
| 26 | 55 | 20 | 80 | 71 | 32 |
| 27 | 60 | 30 | 100 | 87 | 41 |
| 28 | 55 | 35 | 5 | 72 | 30 |
| 29 | 50 | 40 | 25 | 74 | 42 |
| 30 | 45 | 45 | 45 | 54 | 35 |
| 31 | 40 | 50 | 65 | 57 | 47 |
| 32 | 35 | 55 | 85 | 68 | 71 |
| 33 | 65 | 25 | 10 | 84 | 23 |
| 34 | 65 | 40 | 30 | 70 | 29 |
| 35 | 60 | 45 | 50 | 75 | 46 |
| 36 | 55 | 50 | 70 | 78 | 58 |
| 37 | 50 | 55 | 90 | 63 | 55 |
| 38 | 45 | 60 | 15 | 77 | 63 |
| 39 | 70 | 35 | 35 | 70 | 28 |
| 40 | 75 | 45 | 55 | 84 | 47 |
| 41 | 70 | 50 | 75 | 87 | 59 |
| 42 | 65 | 55 | 95 | 72 | 56 |
| 43 | 60 | 60 | 0 | 87 | 50 |

Independent Variables (Cont.)

| | $x_1$ | $x_2$ | $x_3$ | $x_4$ | $x_5$ |
|---|---|---|---|---|---|
| 44 | 55 | 65 | 20 | 84 | 69 |
| 45 | 50 | 70 | 40 | 58 | 55 |
| 46 | 80 | 40 | 60 | 88 | 49 |
| 47 | 80 | 55 | 80 | 94 | 54 |
| 48 | 75 | 60 | 100 | 72 | 54 |
| 49 | 70 | 65 | 5 | 74 | 61 |
| 50 | 65 | 70 | 15 | 89 | 70 |
| 51 | 60 | 75 | 30 | 75 | 80 |
| 52 | 85 | 50 | 45 | 104 | 49 |
| 53 | 90 | 60 | 60 | 80 | 60 |
| 54 | 85 | 65 | 75 | 91 | 67 |
| 55 | 80 | 70 | 85 | 94 | 77 |
| 56 | 75 | 75 | 95 | 99 | 65 |
| 57 | 70 | 80 | 5 | 77 | 62 |
| 58 | 65 | 85 | 25 | 90 | 87 |
| 59 | 95 | 55 | 45 | 88 | 53 |
| 60 | 95 | 70 | 65 | 82 | 57 |
| 61 | 90 | 75 | 85 | 99 | 77 |
| 62 | 85 | 80 | 10 | 93 | 69 |
| 63 | 80 | 85 | 30 | 82 | 83 |
| 64 | 75 | 90 | 50 | 85 | 71 |
| 65 | 100 | 65 | 70 | 100 | 66 |
| 66 | 105 | 75 | 90 | 118 | 90 |
| 67 | 100 | 80 | 15 | 85 | 80 |
| 68 | 95 | 85 | 35 | 97 | 65 |
| 69 | 90 | 90 | 55 | 80 | 84 |
| 70 | 85 | 95 | 75 | 91 | 106 |
| 71 | 80 | 100 | 95 | 100 | 99 |
| 72 | 110 | 70 | 0 | 116 | 59 |
| 73 | 110 | 85 | 20 | 110 | 74 |
| 74 | 105 | 90 | 40 | 103 | 95 |
| 75 | 100 | 95 | 60 | 93 | 97 |
| 76 | 95 | 100 | 80 | 110 | 96 |
| 77 | 90 | 105 | 100 | 85 | 89 |
| 78 | 115 | 80 | 5 | 93 | 68 |
| 79 | 120 | 90 | 25 | 112 | 93 |
| 80 | 115 | 95 | 45 | 96 | 100 |
| 81 | 110 | 100 | 65 | 106 | 80 |
| 82 | 105 | 105 | 85 | 117 | 102 |
| 83 | 100 | 110 | 10 | 104 | 94 |
| 84 | 95 | 115 | 30 | 90 | 108 |
| 85 | 125 | 85 | 50 | 115 | 79 |
| 86 | 125 | 100 | 70 | 130 | 88 |
| 87 | 120 | 105 | 90 | 98 | 118 |
| 88 | 115 | 110 | 15 | 93 | 109 |
| 89 | 110 | 115 | 35 | 106 | 112 |
| 90 | 105 | 120 | 55 | 103 | 110 |

Independent Variables (Cont.)

| | $x_1$ | $x_2$ | $x_3$ | $x_4$ | $x_5$ |
|---|---|---|---|---|---|
| 91 | 130 | 90 | 75 | 125 | 88 |
| 92 | 135 | 105 | 95 | 138 | 90 |
| 93 | 130 | 110 | 0 | 110 | 92 |
| 94 | 125 | 115 | 20 | 132 | 108 |
| 95 | 120 | 120 | 40 | 100 | 123 |
| 96 | 115 | 125 | 60 | 100 | 109 |
| 97 | 110 | 130 | 80 | 113 | 139 |
| 98 | 135 | 100 | 100 | 97 | 100 |
| 99 | 100 | 20 | 50 | 100 | 25 |
| 100 | 20 | 100 | 50 | 50 | 92 |

## TECHNICAL REPORT DATA

*(Please read Instructions on the reverse before completing)*

| | | |
|---|---|---|
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16. ABSTRACT

Several physical models which simulate the impact of emissions and meteorology on the creation and dispersion of photochemical smog have been developed. Characteristics of most of these models are that they are highly computational and require a great deal of input data; hence, it is generally difficult to systematically explore the implications of the models or to use them in a planning context where many model runs are required. This paper explores "repro-modeling," the analysis and replication of the input/output characteristics of the model, as a means of meeting these objectives. A study of the application of repro-modeling to the SAI model developed for the Los Angeles Basin is described. The major objectives of the study were threefold: (1) a feasibility test of the repro-modeling approach; (2) a limited interpretation of the implications of the model; and (3) an efficient repro-model program which duplicates input/output relationships of the original model. The repro-model developed is analyzed in a particular application context (i.e., transportation emission control policy evaluation) and its general implications are discussed. Examples of use of the repro-model, which requires orders of magnitude less computer time than the original model, are provided.

17. KEY WORDS AND DOCUMENT ANALYSIS

| a. DESCRIPTORS | b. IDENTIFIERS/OPEN ENDED TERMS | c. COSATI Field/Group |
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