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COMPUTER MODELING OF TRANSPORTATION-GENERATED AIR POLLUTION

State-of-the-Art Survey, II

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16. Abstract

This report updates an earlier DOT survey (14) on the mathematical modeling of air pollution from transportation sources. Up-to-date information is furnished on two subjects: (1) the characteristics of currently operational air pollution dispersion models suitable for analyzing transportation-generated pollutants -- 22 such models are covered and (2) the availability of air quality data acquired in the vicinity of transportation systems (e.g., highways and airports) -- 24 such data samples are identified.

The computer modeling of inert gases, particulates, and reactive pollutants is discussed with emphasis on model types, implementation (i.e., input data, computer requirements, output) applications, model validation and availability. It is concluded that, although some progress has been registered in model development during the past 5 years and despite the fact that limited validation of some models has been achieved, no model in current use has been adequately tested and evaluated.

Air quality data near transportation systems are categorized by type of site, dates of data acquisition, funding source, and data availability. The quality of the 24 data samples reported here is unknown.

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PREFACE

This report is an updated version of Report No. DOT-TSC-OST-72-20 entitled, "Computer Modeling of Transportation Generated Air Pollution: A State-of-the-Art Survey" by Eugene M. Darling, Jr., published in June 1972.

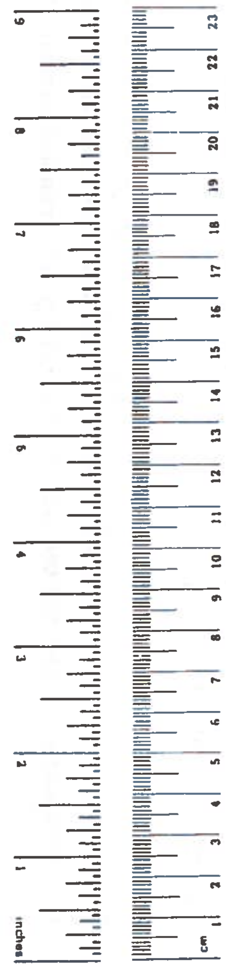
The objectives of this report are: (1) to furnish up-to-date information on current operational air pollution dispersion models suitable for analysis of transportation-source pollutants, and (2) to document available air quality data acquired in the vicinity of transportation systems.

Both this survey and the earlier one were prepared under the Technology for Environmental Analysis Program, directed by Dr. Richard L. Strombotne of the Office of the Secretary of Transportation, TST-46.

METRIC CONVERSION FACTORS

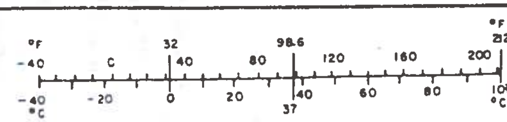
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



1. INTRODUCTION

1.1 BACKGROUND

Under a series of laws which relate to the preservation of environmental quality, the Secretary of Transportation must take certain actions aimed at curbing the impact of transportation-generated air pollution on the environment. Since knowledge of these environmental laws is essential to a proper understanding of the role of the Secretary in air pollution abatement, a brief summary of amendments to the environmental laws since the initial 1972 report has been included and is followed by a section on recent court decisions under the National Environmental Policy Act.

The Introduction concludes with a section on the content and structure of this report.

1.2 AMENDMENTS TO PUBLIC LAWS GOVERNING THE ENVIRONMENTAL IMPACT OF TRANSPORTATION

Recent amendments to two major public laws, the Clean Air Act and the National Environmental Policy Act, are summarized below.

1.2.1 Clean Air Act (42 U.S.C. 1857 et seq., as amended by PL 93-319, June 24, 1974)

The final version of amendment HR 14368-93-319 delayed, for one year (until September 30, 1977), final automobile emission standards for carbon monoxide and hydrocarbons. Other provisions of the amendment barred the EPA from using parking surcharges as an air pollution control measure and gave the Federal Energy Administration (FEA) broad powers to gather the information needed to make energy policy.

1.2.2 Clean Air Act Amendments of 1977 (PL 95-564, August 3, 1977)

The Clean Air Act Amendments of 1977 contain a number of provisions that deal with transportation-generated air pollution.

A new schedule of emission standards for motor vehicles was established (see Table 2.1). The new schedule requires that:

(1) "The Administrator [EPA] . . . shall conduct a study and investigation of emissions of air pollutants from railroad locomotives, locomotive engines, and secondary power sources on railroad rolling stock . . ."

(2) "The Administrator, in conjunction with the Secretary of Transportation, shall study the problem of carbon monoxide intrusion into sustained-use motor vehicles" (e.g., buses, taxicabs, police vehicles)."

(3) "The Administrator shall conduct a study concerning the effects on health and welfare of particulate emissions from motor vehicles or motor vehicle engines."

(4) "Any regulations in effect . . . with respect to aircraft shall not apply if disapproved by the President, after notice and opportunity for public hearing, on the basis of a finding by the Secretary of Transportation that any such regulation would create a hazard to aircraft safety."

(5) "The Administrator shall, after consultation with the Secretary of Transportation . . . publish guidelines on the basic program elements for the transportation planning process . . . Such guidelines shall include information on methods to identify and evaluate alternative planning and control activities." Another subsection states that "The Administrator shall publish and make available to appropriate Federal agencies, States, and air pollution control agencies . . . information prepared, as appropriate, in cooperation with the Secretary of Transportation, regarding processes, procedures, and methods to reduce or control each such pollutant . . ."

1.2.3 The National Environmental Policy Act (42 U.S.C. 4341; Amended by PL 94-83, August 9, 1975)

As signed into law, The National Environmental Policy Act, PL 94-83, was amended to state "that an Environmental Impact Statement required by the law for major federal actions . . . was not legally insufficient just because it had been prepared by a state agency or official if the state official had statewide jurisdiction and responsibility for the action dealt with by the impact statement and if the responsible federal official guided and participated in such preparation, and independently evaluated the statement before it was approved and adopted." This amendment enabled state officials to participate in the preparation of Environmental Impact Statements for federally funded projects. This amendment was designed to end confusion over the permissible extent of state agency participation in the writing of (environmental impact) statements.

1.3 COURT DECISIONS UNDER THE NATIONAL ENVIRONMENTAL POLICY ACT (NEPA) OF 1969

Recent court cases under NEPA have treated the subject of the preparation of National Environmental Policy Act Environmental Impact Statements. Section 102(c) of NEPA requires that an Environmental Impact Statement be prepared for ". . . major Federal actions significantly affecting the quality of the human environment. . ." The question of what constitutes "major Federal actions" and the interpretation of the phrase "significantly affecting the quality of the human environment" have played a major role in recent court cases under NEPA.

Three decisions which are pertinent to the subject of environmental impact statement preparation follow.

(1) The National Environmental Policy Act requires the Department of Transportation to file an Environmental Impact Statement on the California "diamond lane" freeway project (partially funded by federal grant) since the commitment of funds contingent upon the undertaking of an entire project is a major Federal action which significantly affects the quality of the human environment. (Case: Pacific Legal Foundation v. Burns 9 ERC 1399-1414 (CA DC CCalif 1976)).

(2) The expenditure of Federal funds which were subsequently repaid by the state for the preliminary engineering studies on a state highway project is a *de minimus* federal involvement and does not constitute a major Federal action that would make the project subject to the Environmental Impact Statement requirements of the National Environmental Policy Act. (Case: Scottsdale Mall v. State of Indiana 9 ERC 1532-38 (CA DC SInd 1976)).

(3) The transportation plan for the Atlanta metropolitan region which was funded and approved by the Federal Government but formulated in such a way that the Government did not actually participate, is not a major Federal action requiring a National Environmental Policy Act Environmental Impact Statement. (Case: Atlanta Coalition on the Transportation Crisis v. Atlanta Regional Commission 8 ERC 1116-21 (DC NGa 1975)).

1.4 THIS REPORT

The material for this report was obtained from an extensive survey of the literature, as well as from responses to the following Commerce Business Daily (CBD) announcement placed by the Transportation

Systems Center (TSC). This announcement appeared in the CBD issue of August 26, 1976.

> "SOURCES SOUGHT: OPERATIONAL AIR POLLUTION DISPERSION MODELS FOR ANALYZING TRANSPORTATION-GENERATED POLLUTANTS; AIR POLLUTION DATA FROM TRANSPORTATION SYSTEMS (i.e., HIGHWAYS, AIRPORTS). As part of its Technology for Environmental Analysis Program the Transportation Systems Center (TSC) is planning to publish a detailed technical survey of Transportation Source Air Pollution Dispersion Models and Transportation Air Pollution Data. TSC invites firms with operating computer programs either developed for, or readily adaptable to, the modeling of transportation-source air pollution to submit their program specifications to the Center for use in preparing this survey. TSC also solicits information about air quality data measured in the vicinity of transportation systems (such as highways, airports, and railyards) for inclusion in the survey. TSC acts as advisor to the Office of the Secretary of Transportation, the DOT operating administrations, Environmental Protection Agency (EPA), state departments of transportation, and other agencies on questions relating to the analysis of transportation-generated air pollution. In this capacity, TSC intends to widely circulate this survey among Federal, regional, state and local agencies concerned with transportation-source air pollution. The Center will only consider information which is submitted on a TSC questionnaire which can be obtained from:
>
> U. S. Department of Transportation
Transportation Systems Center
Data Technology Branch, Code 622 [now Environmental Technology Branch, Code 331]
Kendall Square
Cambridge, MA 02142
>
> For identification purposes refer to Form MD-01.

The respondent is required to state that the information submitted on the questionnaire is not proprietary and to agree that the Government is free to make any use of said information it deems appropriate, including publication with proper acknowledgements in Government technical reports.

This is not a request for proposal. Firms which are deemed qualified to support DOT's Technology for Environmental Analysis Program will be considered if and when future requests for proposals are solicited. No formal evaluation of the information submitted on questionnaires will be furnished."

The questionnaire cited was used in order to assure that the same information would be obtained from each respondent. This questionnaire consisted of two parts: Part I, Transportation Source Air Pollution Dispersion Model, and Part II, Transportation Air Pollution Data. In order to clarify the level of detail and the format desired, a completed sample questionnaire for Part I for the TSC/EPA model was furnished to each firm responding to the announcement (as well as to other firms to which the questionnaire was mailed without request). Appendix A contains both the questionnaire and completed sample questionnaire.

Fifty firms requested copies of the TSC questionnaire. Seven questionnaires completed for Part I and thirteen questionnaires completed for Part II were returned to TSC. A total of twelve firms made one or more submissions for each part. Forty-nine firms were sent copies of the TSC questionnaire without request. These firms were sent questionnaires because TSC was familiar with the work they had done in the field of air pollution modeling. Thirteen questionnaires completed for Part I and eleven questionnaires completed for Part II were returned to TSC by seven of the forty-nine firms. One firm completed Part II of the questionnaire, but it completed only two sections of Part I of the TSC questionnaire because it felt that Part I of the questionnaire was not totally applicable to its organization which used models supplied by three other organizations in its work. Another firm completed only Part II of the TSC questionnaire. The Environmental Protection Agency (EPA) highway air-pollution-dispersion model (HIWAY) as modified by TSC (the TSC/EPA model) is also discussed in this survey.

The body of this current report consists of seven sections. Section 2 deals with transportation emission products. Section 3 deals with dispersion models which have been used to analyze air pollution. Section 4 treats the computational aspects of computer programs developed for the modeling of transportation-source air pollution, including input, output, software and hardware requirements. Section 5 describes applications of the models to both transportation and non-transportation pollution problems. Section 6 deals with the validation of dispersion models with real-world data, the comparison of a model's predictions with those of other dispersion models, and the availability of dispersion models to the public. Section 7 discusses the acquisition of measured air quality data by some firms, as well as the availability of these data. Finally, Section 8 contains a summary and conclusions.

2. TRANSPORTATION EMISSION PRODUCTS

This Section deals with two kinds of air pollution standards: (1) light duty vehicle emission standards and (2) ambient air quality standards.

2.1 LIGHT DUTY VEHICLE STANDARDS

Vehicle emission standards have been established by law for the following pollutants: Carbon Monoxide (CO), Oxides of Nitrogen (NO_x), and Hydrocarbons (HC). These three pollutants occur in tailpipe emissions from motor vehicles.

In comparing implementation dates for light duty vehicle emission standards under the Clean Air Act Amendments of 1970 and 1977 (Table 2.1), it should be noted that the dates for attaining the various standards have been delayed from 1 to 4 years under the 1977 Act. Furthermore, the earlier 0.4 grams per vehicle per mile standard for NO_x (required in 1978 under the 1970 Act) has been abandoned under the 1977 Act and replaced by a requirement for EPA to study the feasibility of such a standard.

2.1.1 Carbon Monoxide, CO

Carbon Monoxide is derived from the incomplete combustion of organic materials and is emitted into the atmosphere in greater quantities than any other urban air pollutant discussed here. In an internal combustion engine, the two factors that determine total CO emissions are the concentration of CO in the exhaust and the exhaust volume.[2] These two factors combine in such a way that, in general, total CO emissions decrease as average route speed increases. Carbon monoxide (CO) in the urban air is due almost entirely to emissions from automobiles. High levels of CO are related to vehicle congestion and certain local meteorological conditions.[1]

TABLE 2.1

Emission Standards for Light Duty Motor Vehicles

Model Year When the Standard Becomes Effective

POLLUTANT	CARBON MONOXIDE			HYDROCARBONS		NITROGEN OXIDES				
Emissions Standard (grams per vehicle per mile)	15.0	7.0	3.4	1.5	0.41	3.1	2.0	1.5	1.0	0.4
Clean Air Act Amendment of 1970	1976		1977	1976	1977	1976	1977			1978
Clean Air Act Amendment of 1977	1977	1980	1981 (1)	1977	1980		1977	(2)	1981	(3)

(1) Waiver from 3.4 to 7.0 grams per vehicle per mile can be requested for 1981-82.

(2) Waiver from 1.0 to 1.5 grams per vehicle per mile for the period 1981-84 can be requested under certain circumstances to permit the use of new technology.

(3) EPA is to conduct a study of the public health implications, cost and technology of implementing a 0.4 grams per vehicle mile standard for NO_x (Report to Congress, July 1, 1980).

The Clean Air Act (CAA) Amendments of 1977 (Table 2.1) mandate a progressive reduction in the CO emission standard for light duty vehicles (LDV) from 15.0 grams per vehicle per mile (gvm) for 1977 model vehicles to 3.4 gvm for 1981 model vehicles.

2.1.2 Oxides of Nitrogen, NO_x

The oxides of nitrogen which cause pollution occur as nitric oxide (NO) and nitrogen dioxide (NO_2).[3] Nitric oxide, the main nitrogen-based compound emitted from both mobile and stationary sources, causes pollution in two ways. As nitric oxide, it participates in photochemical oxidant formation; when converted to nitrogen dioxide, it is harmful to human health.[1] The high combustion temperatures in automobile engines enhance the production of nitric oxide which is then oxidized to nitrogen dioxide by chemical reactions with O_2, NO_3, complex organic compounds, etc. During daylight hours, the atmospheric NO_2 photolytic cycles govern the interactions between NO_x and active HC under the influence of solar ultraviolet energy to produce photochemical oxidants and smog.

The CAA Amendments of 1977 require a reduction in LDV NO_x emissions from the present 2.0 gvm to 1.0 gvm for 1981 model year vehicles (Table 2.1). In addition, EPA is to study the implications of health, cost and technology involved in implementation of a 0.4 gvm standard in the future. In addition, a 4-year waiver (1981-84) of the 1.0 gvm standard to 1.5 gvm is allowed under certain circumstances to permit the use of new technology.

2.1.3 Hydrocarbons, HC

It is important to recognize that the criteria for non-methane hydrocarbons as pollutants rest almost entirely on their role as precursors of other compounds formed in the atmospheric photochemical system and not upon direct effects of the hydrocarbons themselves. The ultimate products of photooxidation of hydrocarbons in urban air, after sufficient irradiation by sunlight, would be carbon dioxide and water vapor.[4]

Hydrocarbon exhaust emissions originate primarily from the inefficient combustion of volatile fuels, especially gasoline. In automobiles without emission controls, 60% of the unburned hydrocarbons come from exhaust, 20% from crankcase blowby and 20% from fuel tank and carburetor evaporation.[5] The control of hydrocarbon emissions rests upon the basic principles of: (1) combustion process optimization, (2) recovery by mass transfer principles, (3) restriction of evaporative loss, and (4) process material and fuel substitution. The first three principles have all been applied with varying degrees of success to control automobile emissions.

Table 2.1 shows that the CAA Amendments of 1977 mandate that LDV HC emissions be reduced from the current 1.5 gvm to 0.41 gvm for 1980 model year vehicles.

2.2 AIR QUALITY STANDARDS

Table 2.2 lists the six pollutants for which national ambient air quality standards have been established: (1) Particulate matter; (2) Sulfur oxides (SO_x); (3) Carbon monoxide (CO); (4) Nitrogen dioxide (NO_2); (5) Photochemical oxidants; and (6) Hydrocarbons (HC). Among these, the pollutants having vehicle emission standards (i.e., carbon monoxide, nitrogen dioxide and hydrocarbons) were discussed in subsection 2.1.1. The remaining three pollutants will be considered here.

TABLE 2.2

National Ambient Air Quality Standards[1]

Pollutant	Averaging time	Primary standards	Secondary standards
Particulate matter	Annual (geometric mean)	75 μg/m³	60 μg/m³
	24 hour[b]	260 μg/m³	150 μg/m³
Sulfur oxides	Annual (arithmetic mean)	80 μg/m³ (0.03 ppm)	—
	24 hour[b]	365 μg/m³ (0.14 ppm)	—
	3 hour[b]	—	1300 μg/m³ (0.5 ppm)
Carbon monoxide	8 hour[b]	10 mg/m³ (9 ppm)	10 mg/m³ (9 ppm)
	1 hour[b]	40 mg/m³ (35 ppm)	40 mg/m³ (35 ppm)
Nitrogen dioxide	Annual (arithmetic mean)	100 μg/m³ (0.05 ppm)	100 μg/m³ (0.05 ppm)
Photochemical oxidants	1 hour[b]	160 μg/m³ (0.08 ppm)	160 μg/m³ (0.08 ppm)
Hydrocarbons (nonmethane)	3 hour (6 to 9 a.m.)	160 μg/m³ (0.24 ppm)	160 μg/m³ (0.24 ppm)

[a] The air quality standards and a description of the reference methods were published on April 30, 1971, in 42 C.F.R. 410, recodified to 40 C.F.R. 50 on July 1, 1975.

[b] Not to be exceeded more than once per year.

2.2.1 Particulate Matter

Particulate air pollution refers to any matter dispersed in the air whether solid or liquid, in which the individual particles are larger than small molecules but smaller in diameter than 500μ (one μ is one millionth of a meter). Particles in this size range stay in the air anywhere from a few seconds to several months.[6] The particulate matter commonly found dispersed in the atmosphere is composed of a large variety of substances. Some of these - beryllium, lead, and asbestos, for example - are known to be directly toxic, although not necessarily at levels routinely found in the atmosphere today.[6] Particles occuring in motor vehicle exhaust include lead compounds, carbon particles, motor oil, and nonvolatile products formed from motor oil in the combustion zone.[7] Two of the most important particulates are lead and sulfates (see subsection 2.2.2).

Lead was listed by the Environmental Protection Agency on April 8, 1976 as an air pollutant for which air quality criteria and ambient air quality standards must be developed under the Clean Air Act (41 FR 14921). The listing was made in response to a March 1, 1976 order of the U. S. District Court for the Southern District of New York, which ruled that the EPA has a nondiscretionary duty to list lead under Section 108 (8 ERC 1695).[8] The EPA was required to develop an air quality criteria document for lead by a decision upheld in the U. S. Court of Appeals for the Second Circuit on November 10, 1976 (9 ERC 1425).[9] Subsequently, the EPA prepared and circulated for comment a draft of "Air Quality Criteria for Atmospheric Lead."[10] Citing "inadequate scholarship" and "apparent biases", a subcommittee of the Environmental Protection Agency's Science Advisory Board recommended by a narrow margin on January 31, 1977 that this draft document be withdrawn from consideration in order to allow for the development of a new, more accurate document.[11]

As shown in Table 2.2, there are two standards for total particulate matter: (1) an annual primary standard of 75 $\mu g/m^3$ and a secondary standard of 60 $\mu g/m^3$; and (2) a 24-hour primary standard of 260 $\mu g/m^3$ and a secondary standard of 150 $\mu g/m^3$.

2.2.2 Sulfur Oxides, SO_x

Transportation sources are not a major contributor to the total sulfur oxide concentration measured in urban areas. However, gasolines contain trace amounts of sulfur (typically 0.03% by weight) which are converted to SO_2 during the combustion process. In catalyst-equipped autos, a portion of the SO_2 is subsequently oxidized to sulfur trioxide (SO_3) by the converter; ultimately sulfuric acid aerosols are released by the reaction of SO_3 with water vapor. (Automobile manufacturers selected catalytic converters for incorporation in vehicle exhaust systems in order to reduce hydrocarbon and carbon monoxide emissions. This action was judged necessary in order to meet federal and state emission standards.[12])

As shown in Table 2.2, sulfur oxides have an annual primary standard of 80 $\mu g/m^3$ (0.03 ppm) and a 24-hour primary standard of 365 $\mu g/m^3$ (0.14 ppm).

2.2.3 Photochemical Oxidants

Photochemical oxidants result from a complex series of atmospheric reactions initiated by sunlight. When reactive organic substances and nitrogen oxides accumulate in the atmosphere and are exposed to the ultraviolet component of sunlight, the formation of new compounds including ozone and peroxyacetyle nitrate takes place.[13] Ozone is the predominant chemical constituent in the family of compounds called photochemical oxidants. Hydrocarbons and nitric oxide emitted by automotive and by stationary sources participate in the complex atmospheric reactions that form ozone as a product.[1] Table 2.2 shows that photochemical oxidants have a 1-hour primary standard of 160 $\mu g/m^3$ (0.08ppm) and the same 1-hour secondary standard.

3. MODELING THE DISPERSION OF POLLUTANTS

A dispersion model may be defined as a mathematical structure which accepts data on source emissions, meterological conditions, and geographic boundaries as inputs; it computes the dispersion of pollutants by the atmosphere (as well as chemical reactions and removal by sinks where appropriate); it also produces output data on the concentration of pollutants over the area of interest for specified time periods. The model is thus a mechanism for translating emission data into air quality data and, as such, is an invaluable tool for environmental impact analysis.

3.1 TYPES OF MODELS

This section will discuss mathematical modeling of the atmospheric dispersion of inert gases, particulates and reactive products. Two types of air pollution dispersion models are used in almost all applications which involve inert gases: (1) Gaussian models which assume that the dispersion of pollutants can be represented by a Gaussian process; and (2) conservation of mass models which require the solution of the partial differential equations which govern turbulent diffusion.

For particulates, a mathematical transport model has been formulated. This model will be discussed in section 3.2.2.

Models of the conservation of mass type can be used to model reactive products. In this type of modeling, the conservation of mass equation explicitly treats the rate of generation and the source strength of each reactive species.

Table 3.1, which summarizes the dispersion models reported in Part I of the TSC questionnaire, shows that 14 of these models are Gaussian and 6 are conservation of mass models. (Therefore, most of the models reported herein are of the Gaussian type, as was the

TABLE 3.1

Dispersion Models Currently Operating

Company	Type of Model: Gaussian	Type of Model: Conservation of Mass	Emission Source
AeroVironment, Inc.	X		Point, Line, Area
California D.O.T.	X		Line
Close, Jensen and Miller	X[1]		Highway, Airport
Dept. of Atmospheric Sciences, U. of Washington	X[2]		Highway
Environmental Research and Technology, Inc. (1)		X	Highway, Airport
Environmental Research and Technology, Inc. (2)	X		Line
Lockheed, Huntsville		X	Highway
Mathematical Sciences N.W.	X		Point, Line, Area
Ministry of the Environment		X	Area
MSA Research Corp.		X	Tunnels
Northern Research and Engineering Corp.	X		Airport
Pacific Environmental Services Inc.		X	Any Vehicle, Area
Pandullo Quirk Associates	X		Area
Parsons, Brinckerhoff, Quade, Douglas, Inc.	X		Point, Line
Scott Environmental Technology Inc.	X		Point, Line
Stanford Research Institute (1)	X		Line, Area
Stanford Research Institute (2)	X		Area, Point
Stanford Research Institute (3)	X		Line, Area
Systems Applications Inc.	X		Point
TRW Inc.	X		Area
TSC/EPA	X		Highway
Xonics Inc.		X	Highway

[1] Firm has not developed its own air pollution dispersion model, but it has a program whose results are used by a companion program, based on the Gaussian plume model, to predict CO levels.

[2] Firm has not developed its own air pollution dispersion model, but it used several Gaussian plume models in a study it conducted for Washington State Highway Department.

case in the 1972 report.) One firm has not developed its own dispersion model but has used several Gaussian models in a study which it conducted. Another firm has not developed its own dispersion model, but has a program the results of which are used by a companion program which is Gaussian.

3.2 MODELING OF POLLUTANTS

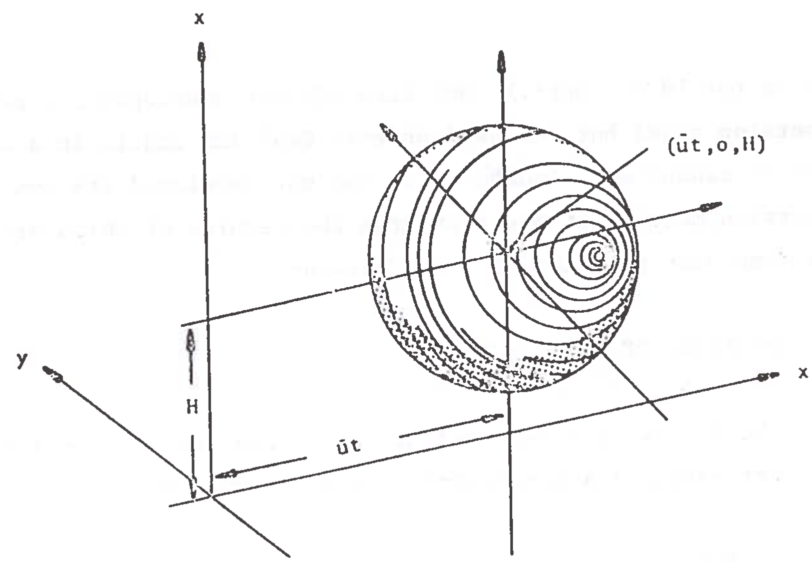
The following three sections will treat the modeling of: (1) inert gases, (2) particulates, and (3) reactive products.

3.2.1 Modeling of Inert Gases

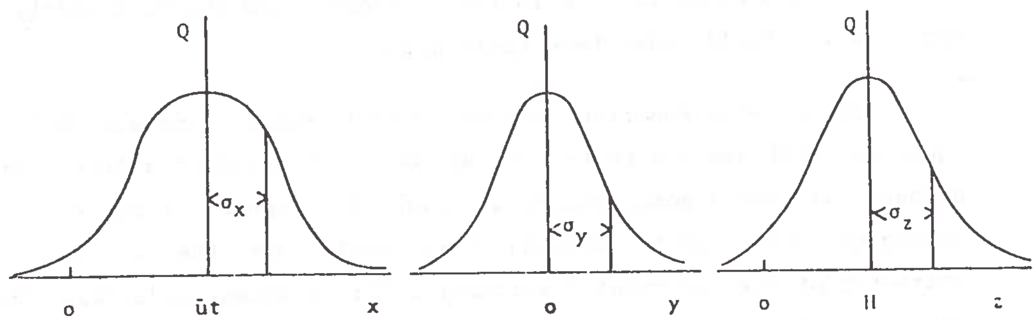
As mentioned above, the Gaussian and conservation of mass models may be used to model inert gases. Gaussian techniques for modeling the dispersion of pollutants in the atmosphere are the most widely used tools in the field today (see Table 3.1).

All Gaussian equations can be derived from the Gaussian Puff equation which deals with the instantaneous emission of a finite puff of material from a point source at height H. Figure 3.1 shows a conceptual sketch of the Gaussian Puff model. Note the Gaussian character of the component distributions of pollutant material. The Gaussian Puff equation is discussed in the 1972 report.

The Gaussian Plume equation is the steady state version of the Gaussian Puff equation; it can be modified readily to handle both linear and area sources.



A. Three Dimensional Puff of Material



B. Component Distributions of Material about Axes through ($\bar{u}t$,o,H)

FIGURE 3.1

Schematic Representation of the Gaussian Puff Model

3.2.2 Modeling of Particulates

A mathematical model for atmospheric particulate transport has been formulated as part of a study of toxic metals in the environment.[15] The basis of the model is the analytical solution to the equations governing the transport of particulates from a point source. From this solution general expressions were obtained which determine the distribution of pollutants emitted from a finite length source at an arbitrary angle to the wind direction. This model is general and can be applied to any region of flat terrain.

3.2.3 Modeling of Reactive Pollutants

As mentioned in Section 3.1, the conservation of mass model may be used for the modeling of reactive products as well as for the modeling of inert gases. The conservation of mass equation, with the inclusion of the R_i (rate of generation) and S_i (source strength of reactive species) terms on the right-hand side of the equation, is used in the modeling of reactive products.[16]

The following section describes a photochemical air quality simulation model.

Photochemical Air Quality Simulation Models (PAQSM)[17]

In order to develop a mathematical relationship that will simulate the transport, dispersion, and transformation of pollutant emissions into the atmosphere, it is essential to consider the following:

1. Chemical Transformations - To understand the relationship between HC-NO_x emissions and photochemical oxidant formation, a chemical mechanism must be formulated which describes the complex processes that occur in a sunlight-irradiated atmosphere.

2. Source Emissions Inventory - Model performance is critically related to the accurate description of emission rates of pollutant species in space and time.

3. Meteorological Factors - Methodologies must be developed for the treatment of the meterological variables which affect pollutant transport and dispersion. The complexity of the methodology used will depend upon the mathematical detail considered in describing the transport and dispersion processes in the turbulent planetary boundary layer.

The research and development in each of these three areas represents a formidable task in itself. The even greater problem of coupling them together via mathematical relationships which describe the physical and chemical dynamics of the atmosphere is the goal of the photochemical air quality simulation model.

No analytic solutions to the mathematical relationships which describe the physical and chemical dynamics of the atmosphere have been achieved to date. Instead, simplified approaches have been adopted for treating the fundamental physical and chemical processes which occur in the atmosphere. Specifically, all of the currently available PAQSM use mathematical relationships which are derived from the conservation of mass equation and are based on K-diffusivity theory.

Three classes of current operational photochemical models are considered here. In decreasing order of complexity, these are the grid point, trajectory and box models.

The working equation for the grid point model is shown in equation (1).

$$\frac{\partial c_i}{\partial t} + u \frac{\partial c_i}{\partial x} + v \frac{\partial c_i}{\partial y} + w \frac{\partial c_i}{\partial z}$$

$$= \frac{\partial}{\partial x} K_H \frac{\partial c_i}{\partial x} + \frac{\partial}{\partial y} K_H \frac{\partial c_i}{\partial y} + \frac{\partial}{\partial z} K_V \frac{\partial c_i}{\partial z}$$

$$+ S_i(x,y,z,t) + R_i(c_1,c_2,\ldots,c_N) , \; i = 1, 2, \ldots, N , \qquad (1)$$

where

- N = number of pollutant species.
- c_i = mean concentration of pollutant species i.
- x, y. z = Cartesian coordinates
- u, v, w = mean wind speeds in the x, y, and z directions, respectively.
- K_H, K_V - horizontal and vertical turbulent eddy diffusivities, respectively.
- S_i - emission source strength for species i.
- R_i - rate of production (or consumption) of species i through chemical reactions.

To derive equation (1) the following assumptions were made:

1. Pollutant species do not affect atmospheric temperature and velocity, and thus the equations of conservation of species can be solved independently of the equations of momentum and energy.
2. Molecular diffusion is negligible.
3. Atmospheric flow is incompressible.
4. The system is isothermal.
5. Wind velocities and pollutant concentrations can be represented as the sum of deterministic and stochastic components.

6. The average value of the stochastic components of concentration is zero.

7. The turbulent fluxes are linearly related to the gradients in the mean concentrations.

8. Terms involving the stochastic component of interactions between chemical components are negligible.

In the case of the moving cell or trajectory approach, equation (1) reduces to equation (2).

$$\frac{\partial c_i}{\partial t} = \frac{\partial}{\partial z} K_V \frac{\partial c_i}{\partial z} + S_i(x,y,z,t) + R_i(c_1,c_2,\ldots,c_N) \ , \ i = 1,2,\ldots,N \tag{2}$$

with the following additional assumptions:

1. The motion of an air parcel corresponds to the local surface wind velocities in the modeling region.

2. Horizontal transport of materials across cell boundaries does not occur.

3. Variation in wind velocity with height is neglected.

Finally, the box model approach, which assumes constant wind velocity and mixing height and does not consider diffusional effects, is expressed by equation (3).

$$\frac{d(c_i)}{dt} = \frac{S_i}{Z} - \frac{uc_i}{\Delta x} - R_i(c_1,c_2,\ldots,c_N) \ , \ i = 1,2,\ldots,N \tag{3}$$

Where

Z = depth of mixing layer

Δx = box width

u = wind speed

4. IMPLEMENTATION OF THE MODELS

This section examines, in detail, how dispersion equations are solved, starting with input data, proceeding to the software and hardware requirements, and ending with the output.

The process of solving the dispersion equations is depicted in the simplified block diagram in Figure 4.1. Note that neither source emission factors nor meteorological data are entered directly into the model which computes pollutant dispersion and photochemical reactions. Instead, both are input to preprocessing routines which generate the data required by the dispersion model. The output consists of listings and graphical representations of the input data, the results of intermediate computations, and calculated concentrations at specified time intervals.

4.1 INPUT

The TSC questionnaire (Part I) asks for specific information on the following kinds of input data: (1) emission data which specify source characteristics; and (2) meteorological data which depict the state of the atmosphere. The specific types of emission and meteorological data which the various firms used as input to their models are discussed below.

4.1.1 Emission Data

The questionnaire (in Appendix A) asks each firm to state whether it has used as input to its highway air pollution model any of the following kinds of data for calculating emissions: traffic distribution, traffic estimates, vehicle mix, or traffic speed. Table 4.1 is an illustration of the format for reporting such data. The columns represent types of data; the rows represent specifications; X's mark the

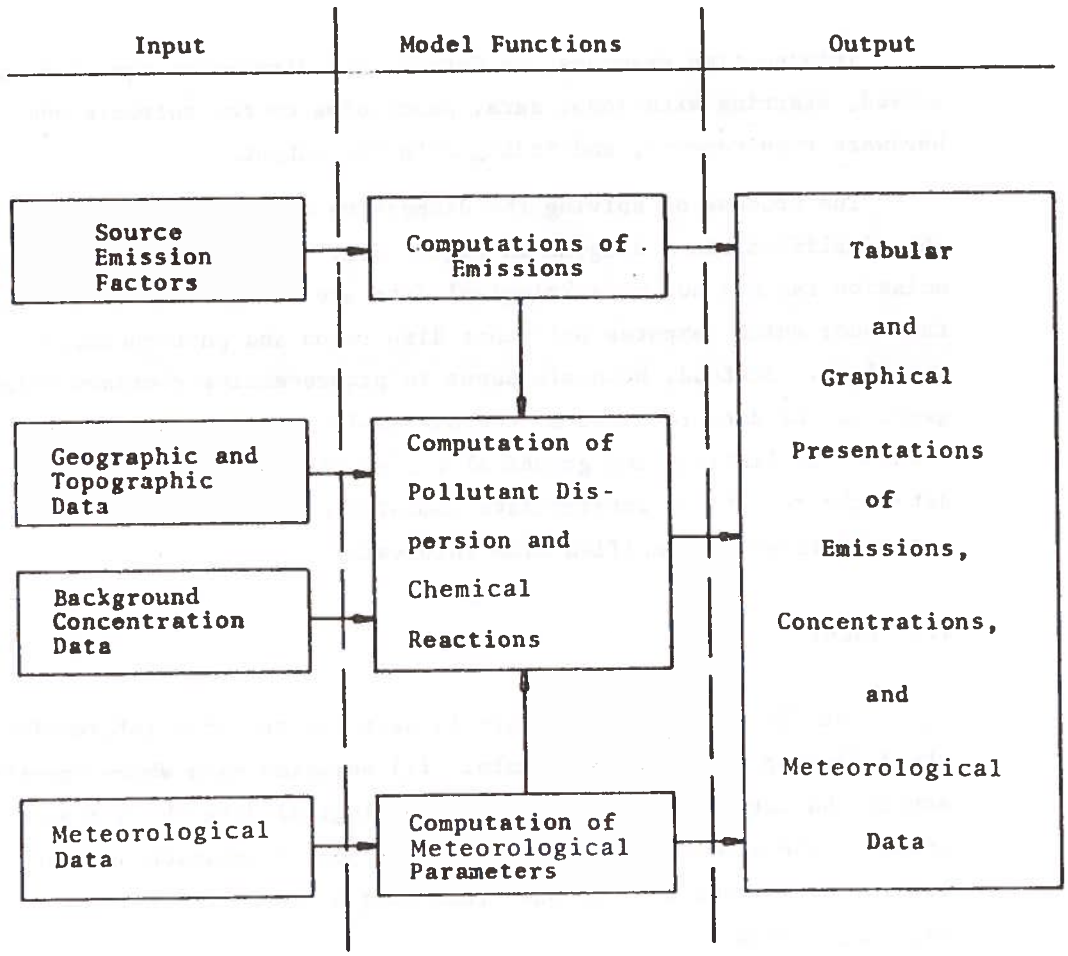


FIGURE 4.1

Solution of Dispersion Equations

TABLE 4.1

Highway Emission Data Format*

	Traffic Distribution	Traffic Estimates	Vehicle Mix	Year Being Analyzed	Traffic Speed	Emission Factors
Entire Road	X				X	
By Lane	X				X	
By Direction	X				X	
Average Daily Traffic		X				
Average Hourly Traffic		X				
% Heavy Duty Vehicles			X			
% Buses, Separately			X			
% Trucks, Separately			X			
Age Distribution			X			
EPA, National						X
State						X
Other[1]	X	X	X	X	X	X

* X's mark appropriate options.

[1] As specified by firm.

appropriate options. For example, traffic distribution data might be for an entire road, by lane, by direction or by some other method as specified by the firm.

According to the responses of firms to questions on highway traffic data, a majority used: (1) traffic distribution for an entire road (rather than by lane or by direction); and (2) traffic estimates averaged hourly. An almost equal number of firms used data on traffic speed for an entire road, a lane, or for a traffic direction.

Airport air pollution models required automobile traffic estimates (within the airport) averaged daily, hourly, or per passenger. Other data used to calculate airport emissions include the vehicle mix (i.e., types of vehicles, number of each type, and age of each vehicle), and aircraft activity data describing the operating mode of each aircraft an any given time.

The questionnaire asks for information on the methods which the firms used to obtain emission factors. Many firms used EPA emission factors in their highway models to calculate pollutant concentration from traffic speed. Some firms used AP-42 Supplement 5 (a report issued by the Office of Air Programs, Environmental Protection Agency) to compute emission factors for transportation systems accommodated by their models. Other firms had their models compute the emission factors using their own methodologies.

4.1.2 Meteorological Data

The questionnaire asks for specific information on the following types of meteorological data: winds, both at the surface and aloft; observations of cloud cover; general parameters (e.g., temperature, pressure, humidity); stability class; and mixing height.

A majority of the firms used a mean hourly wind speed and wind direction. Two methods for determining the wind shear were reported: (1) calculation by a power law function at the upwind boundary of the wind field based on measured or input value and reference height; and (2) determination from anemometer wind speed, surface roughness, and stability, using surface layer similarity theory.

Firms that used stability class as an input to their dispersion models were asked to state their methodology for determining it and the number of classes used. Many used Pasquill's stability class structure with a total of six classes; a few used the method in Turner's Workbook,[21] involving estimates of surface wind speed with incoming solar radiation (day) or with cloud cover (night), to determine stability class; some firms had their dispersion model compute the stability.

The most common parameter used was temperature; other parameters commonly used were pressure, pressure height, relative humidity, mixing height and insolation. (One firm calculated the mixing height from the vertical temperature structure.) Meteorological parameters used less frequently were initial vertical dispersion, measured diffusivity coefficients, heat flux (ratio of vertical to horizontal dispersion speeds), and ground roughness.

4.2 SOFTWARE AND HARDWARE REQUIREMENTS

The characteristics of the computer programs and systems required to run the twenty two dispersion models* listed in Table 3.1 will now be examined. The bulk of the information on this subject is contained in Tables 4.2 and 4.3. All of the material in this section is taken from completed questionnaires (Part I) returned to TSC.

4.2.1 Software Requirements

Table 4.2 shows the programming language used and the program size for the models developed and/or used by the companies listed. All of these models are currently operational on the computers named in Table 4.3. The prevalence of FORTRAN IV as the favored language is immediately apparent (as was the case with the models reported in the 1972 report.)

The size of the FORTRAN program is a rough measure of its complexity which, in turn, gives some indication of how readily the program can be modified. Program size can be gauged by the following rule of thumb:

Program Size

		Models Reported	
Magnitude	Lines of Code	Number	Percent
Small	< 1000	9	45
Medium	1000 - 1999	5	25
Large	≥ 2000	6	30

---

* The Department of Atmospheric Sciences, University of Washington, is not included here because the Department has not developed a model, but has used the models of others, instead. Also, the Stanford Research Institute Model (3) is not a computer model and hence is not included here.

TABLE 4.2

Software Implementation of Dispersion Models

COMPANY	PROGRAMMING LANGUAGE			PROGRAM SIZE (Lines of Source Code)		
	FORTRAN IV	PL/1	OTHER	<1000	1000-1999	≥2000
AeroVironment, Inc.			HPL	X		
California D.O.T.	X		BASIC	X		
Close, Jensen and Miller			BASIC	X		
Environmental Research and Technology, Inc. (1)	X					X
Environmental Research and Technology, Inc. (2)	X					X
Lockheed, Huntsville	X			X		
Mathematical Sciences N.W.	X				X[1]	
Ministry of the Environment	X			X		
MSA Research Corp.	X			X		
Northern Research and Engineering Corp.	X				X	
Pacific Environmental Services, Inc.	X				X	
Pandullo Quirk Associates	X			X		
Parsons, Brinckerhoff, Quade, Douglas, Inc.	X					X
Scott Environmental Technology, Inc.	X				X	
Stanford Research Institute (1)	X					X

1 Including plot generating software.

TABLE 4.2 (Continued)

Software Implementation of Dispersion Models

COMPANY	PROGRAMMING LANGUAGE: FORTRAN IV	PL/1	OTHER	PROGRAM SIZE (Lines of Source Code): <1000	1000-1999	≥2000
Stanford Research Institute (2)	X					X
Systems Applications, Inc.	X			X		
TRW, Inc.	X					X
TSC/EPA	X			X		
Xonics, Inc.	X				X	

It is apparent that most of these programs can be classified as small or large in size. Most of the programs reported in the 1972 report could be classified as small or medium in size, which may indicate an increase during the past 5 years in the size of computer program required to run dispersion models.

4.2.2 Hardware Requirements

In Table 4.3 the computer hardware and program memory requirements of the models are summarized. Of the twenty models, eight (40%) have been programmed for (or have subsequently been reprogrammed for) IBM computers while seven other models (35%) have been programmed for (or have subsequently been reprogrammed for) CDC computers. In the 1972 report, 68% of the models were originally programmed for (or subsequently reprogrammed for) IBM computers, which indicates a decrease in the use of IBM computers and an increase in the use of CDC computers for the running of air pollution dispersion models.

Again, a rule of thumb will be used to categorize the program memory requirements.

Program Memory

Magnitude	Requirements (K bytes)	Models Reported Number	Models Reported Percent
Small	< 100	10	50
Medium	100 - 199	4	20
Large	≥ 200	6	30

The picture here is similar to the case for source program size in that most of the program memory requirements fall into the small or

TABLE 4.3

Hardware Implementation of Dispersion Models

COMPANY	COMPUTER	PROGRAM MEMORY REQUIREMENT (Kbytes)			PERIPHERAL EQUIPMENT							
		<100	100-199	≥200	Card Reader	Card Punch	Line Printer	Disk Drive	Magnetic Tape	Drum	Plotter	Other
AdroVironment, Inc.	ROM Controlled minicomputer	X									X	
California D.O.T.	IBM 370/168		X		X	X	X	X				
Close, Jensen and Miller	Wang 2200 B, 16K	X					X	X			X	
Environmental Research and Technology, Inc. (1)	IBM OS 360			X	X	X	X	X				
Environmental Research and Technology, Inc. (2)	IBM OS 360			X	X		X	X	X			
Lockheed, Huntsville	UNIVAC 1108		X		X		X				X	
Mathematical Sciences N.W.	CDC-6400			X	X		X				X	
Ministry of the Environment	IBM 360	X					X					
MSA Research Corp.	PDP8L with deck tape	X										X[1]
Northern Research and Engineering Corp.	CDC-6600[2]	--[3]			X		X					

[1] Teletype.

[2] Or any equivalent scientific computer.

[3] 22 K words.

TABLE 4.3 (Continued)

Hardware Implementation of Dispersion Models

COMPANY	COMPUTER	PROGRAM MEMORY REQUIREMENT (Kbytes)			PERIPHERAL EQUIPMENT							
		<100	100-199	≥200	Card Reader	Card Punch	Line Printer	Disk Drive	Magnetic Tape	Drum	Plotter	Other
Pacific Environmental Services, Inc.	IBM 370/158[4]	X			X	X	X	X			X	
Pandullo Quirk Associates	--[5]	--[6]					X					X[7]
Parsons, Brinckerhoff, Quade, Douglas, Inc.	IBM 370/135 or IBM 360/91			X	X		X					
Scott Environmental Technology, Inc.	1108 Exec/8		X		X		X					
Stanford Research Institute (1)	CDC-6400			X	X	X	X	X	2			
Stanford Research Institute (2)	CDC-6400			X	X		X					
Systems Applications, Inc.	CDC-7600	X			X		X					

[4]Or any computer with 250K memory.

[5]Standard Fortran computer.

[6] 64 K words.

[7]Any type of mass storage device which can be allocated at run time.

TABLE 4.3 (Continued)

Hardware Implementation of Dispersion Models

COMPANY	COMPUTER	PROGRAM MEMORY REQUIREMENT (Kbytes)			PERIPHERAL EQUIPMENT							
		<100	100-199	≥200	Card Reader	Card Punch	Line Printer	Disk Drive	Magnetic Tape	Drum	Plotter	Other
TRW, Inc.	CDC-6500 or CDC-7418	X			X		X	2			X	
TSC/EPA	IBM 370/155	X			X		X	2			X	
Xonics, Inc.	IBM, UNIVAC DEC, or CDC		X		X		X					

large categories. The 1972 report found that program memory requirements fell into the medium or large categories.

Table 4.3 also lists peripheral equipment. Most of the models require the standard peripherals which one would expect to find in medium to large batch processing centers, as was the case in the 1972 report. The only non-standard hardware called for is a plotter which is needed (or optional) for 33% of the models.

4.3 OUTPUT

The questionnaire asks for information about the output produced by the dispersion models developed and/or used by the companies. The information specifically asked for includes: output format, averaging interval of output, and output form. Possible output formats for pollutant concentrations are: (1) receptor points (fixed or selectable), (2) grid points (fixed or variable), and (3) contour map. Most of the models produced output: (1) with selectable receptor points, (2) for an hourly averaging interval, and (3) in the form of tabular (rather than graphical) data. Several of the firms attached samples of output to their questionnaires; the following pages contain some samples of this output. Figure 4.2, an example of output in the form of tabular data, shows the pollutant emissions of an airport and its surroundings according to source category. Figure 4.3, another example of tabular data, shows air pollution concentrations calculated at evenly spaced points for the Lincoln Tunnel - Westbound Tube. Figure 4.4 is a three dimensional graph of air quality concentrations over a region.

TOTAL EMISSIONS OF AIRPORT AND SURROUNDINGS IN TIME PERIOD, GMS

POLLUTANT	AIRCRAFT		NON-AIRCRAFT AIRPORT		AIRPORT SURROUNDINGS
	GROUND OPERATIONS	FLIGHT OPERATIONS	AUTO TRAVEL	OTHER	
1	1.062E+09	3.499E+08	4.011E+09	2.523E+04	3.447E+10
2	1.280E+07	5.183E+08	4.011E+08	6.623E+07	2.481E+09
3	6.716E+06	2.261E+08	7.878E+06	1.009E+08	6.528E+08
4	1.073E+07	1.390E+08	1.361E+07	5.046E+06	5.222E+08
5	0.	0.	0.	0.	0.
6	3.808E+08	2.423E+08	6.088E+08	2.838E+07	6.136E+09
7	3.712E+05	2.391E+06	0.	3.154E+06	0.
8	1.080E+07	2.845E+07	1.576E+07	6.307E+05	0.

FIGURE 4.2

Pollutant Emissions According to Source Category

Northern Research & Engineering Corporation

```
          0.7209 0.3341

TRANS AIR IN
TRANS AIR OUT 0.4684E6 0 0 0 0
0.264E6 0 0 0 0

END AIR IN TUNNEL LENGTH  TUNNEL DELT L26600 0.235 0.02

VEHICLES/HR; INLET, AMBIENT CONC 1160 352 0 0

CONT-1

TUNNEL POS        CONC
 0.200000E-1     0.850087E+1
 0.400000E-1     0.142818E+2    Section N4
 0.599999E-1     0.183770E+2             40 ppm
 0.800000E-1     0.213752E+2             CO Monitor Chart Reading
 0.999999E-1     0.236307E+2
 0.119999E+0     0.253666E+2
 0.139999E+0     0.267287E+2
 0.159999E+0     0.278155E+2
 0.179999E+0     0.286954E+2
 0.199999E+0     0.294170E+2
 0.219999E+0     0.300154E+2
 0.235000E+0     0.304023E+2
DISCHARGE FLOW 0.766339E+5
AVG CONC 0.235749E+2

TUNNEL CONC
POL. COEFS 0.9876 0.86

TRANS AIR IN
TRANS AIR OUT0.6011E6 0 0 0 0
0.6266E6 0 0 0 0

END AIR IN TUNNEL LENGTH  TUNNEL DELT L 0.76634E5 0.4868 0.05

VEHICLES/HR; INLET, AMBIENT CONC 1180 352 30.4 0

CONT-1

TUNNEL POS        CONC
 0.500000E-1     0.333033E+2
 0.100000E+0     0.354140E+2
 0.150000E+0     0.369414E+2    Section N3
 0.200000E+0     0.380414E+2             50 ppm
 0.250000E+0     0.388890E+2             CO Monitor Chart Reading
 0.300000E+0     0.393920E+2
 0.350000E+0     0.397909E+2
 0.399999E+0     0.400723E+2
 0.449999E+0     0.402698E+2
 0.486000E+0     0.403804E+2
DISCHARGE FLOW 0.642805E+5
AVG CONC 0.381655E+2

TUNNEL CONC
POL. COEFS 1.1944 2.7607

TRANS AIR IN
TRANS AIR OUT 0.8786E6 0 0 0 0
0.676E6 0 0 0 0

END AIR IN TUNNEL LENGTH  TUNNEL DELT L 0.642205E5 0.4621 0.05

VEHICLES/HR; INLET, AMBIENT CONC 1160 352 40.38 0

CONT-1
```

FIGURE 4.3

Portion of Computer Printout for Lincoln Tunnel-Westbound Tube

MSA Research Corporation

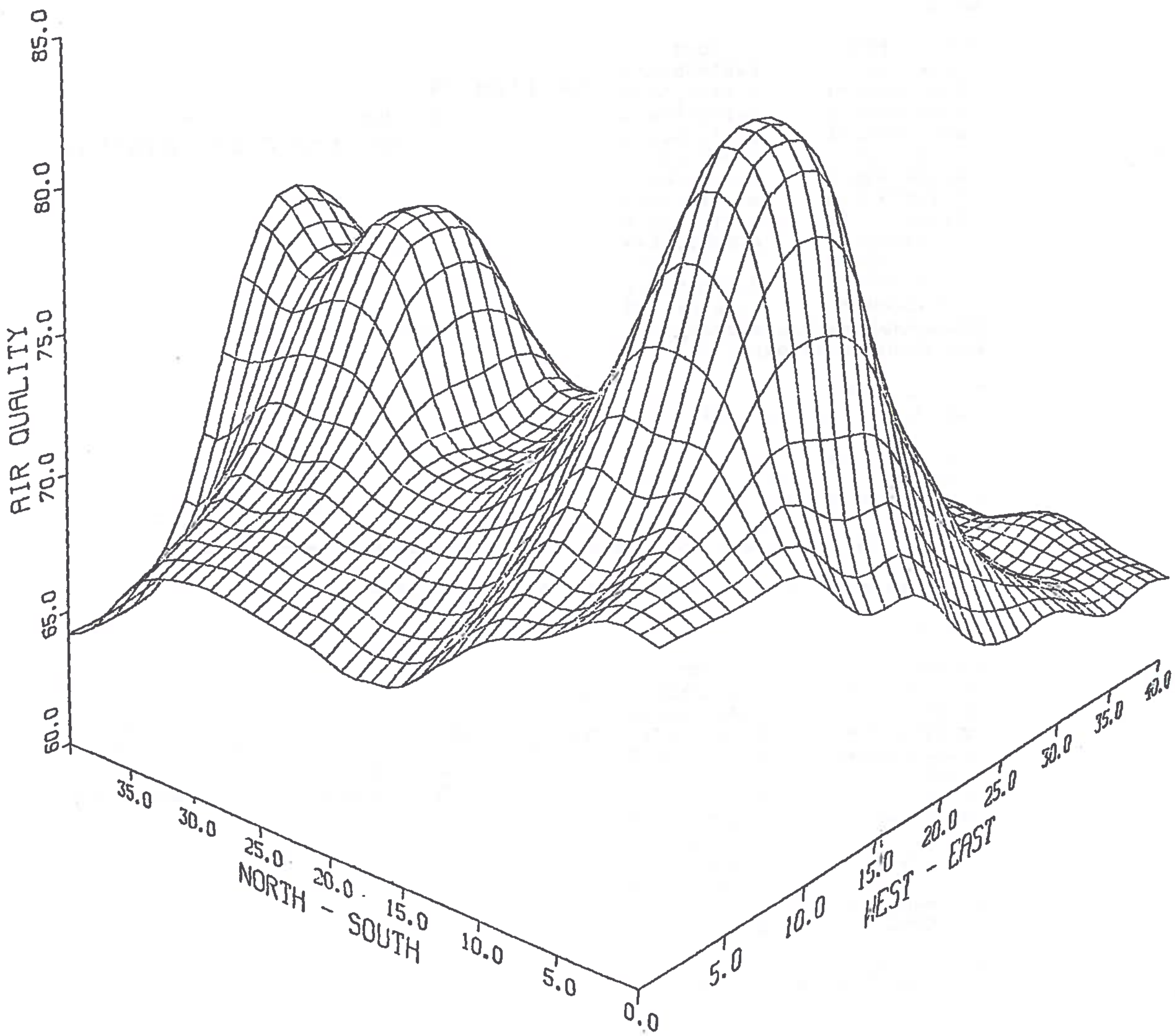


FIGURE 4.4

Three Dimensional Picture of Air Quality Concentrations over a Region

TRW, Inc.

5. APPLICATIONS OF THE MODELS

The TSC questionnaire (Part I) requested information as to how each firm's model had been used. In particular, each respondent was asked to describe a typical problem to which his model had been applied and to indicate both the time required to solve this problem and the approximate (computer) cost. Seventeen replies were received, 15 of which described transportation problems and two non-transportation problems. Since similar models were used for all of these problems, both the transportation (Section 5.1) and non-transportation (Section 5.2) applications are presented here. Each section contains brief edited statements made by the modelers about the problems they solved; a table follows which summarizes the computational aspects. Each firm was also asked to respond to the following questions about model applications: (1) the number of air quality analyses performed from 1970 to the present as part of an Environmental Impact Statement; (2) the number of air quality analyses of proposed or existing transportation systems performed between 1970 and the present (but which were not part of an Environmental Impact Statement); (3) the number of analyses from 1970 to the present performed to determine the impact on air quality of traffic control strategies, vehicle pollution control and other applications; (4) the number of micro-scale air quality analyses of a transportation system included in a regional air quality analysis performed by the firm from 1970 to the present; and (5) other types of analyses the firm may have performed as an application of its model. A table which summarizes the responses of firms to these questions and an accompanying discussion are presented in Section 5.3. The information provided in Tables 5.1 and 5.2, which summarize computational aspects of the models, should be regarded only as a sampling of typical running times and costs for a variety of air pollution modeling problems. Precise comparative performance measurements for individual models can be obtained only by controlled tests using a common set of input data.

5.1 TRANSPORTATION SOURCE PROBLEMS

1. Stanford Research Institute (see Table 3.1)

   A. Model 2 was used to compute air quality levels for a shopping center for eight one-hour periods with 150 links, 31 zones, 48 intersections and 26 receptors.

   B. Model 3 was applied to a problem where the geometric configuration consisted of one intersection with associated bi-directional roadways and several receptors.

2. Lockheed Missile and Space Company, Inc., Huntsville Research and Engineering Center

   The geometric set up consisted of a two lane highway with various median widths and three receptors located on each side. Concentrations of CO were computed at the downwind receptors for 275 cases comprising various emission rates and environmental conditions.

3. MSA Research Corporation

   An actual data computation is shown in Figure 4.3. The output data consists of columns which show concentration levels for a given pollutant at incremental distances along various sections of a tunnel. The exhaust air flow from the section is below the concentration/location columns followed by the average concentrations of the given pollutant in the exit air duct (where applicable).

4. Parsons, Brinckerhoff, Quade, Douglas, Inc.

The geometric set-up consisted of a straight six lane at-grade highway (three lanes in each direction) with one receptor location and hourly traffic and meteorological conditions for 12 hours per day for five years. Computations of maximum one-hour and eight-hour CO concentrations were made for each year.

5. Ministry of the Environment

The model was used to evaluate a four lane highway for one set of meteorological and traffic conditions.

6. California Department of Transportation

The model was applied to a proposed highway which would add 5,000 vehicles per day to a small area. The problem was to compute the resultant CO concentrations.

7. Xonics, Inc.

The model was used for the computation of aerosol production and fallout for a cut section of roadway.

8. Pacific Environmental Services, Inc.

The problem involved photochemical modeling of a proposed highway involving five different six-hour trajectories.

9. TRW, Inc.

CO concentrations due to highway traffic and selected fixed sources were calculated for a grid spanning Phoenix.

Three thousand highway links with volume, speed and length were input to the model.

10. Environmental Research and Technology, Inc. (Two models. See Table 3.1)

   A. Model 1 was applied to a problem where the geometric configuration consisted of a six lane divided highway depressed by approximately six meters. CO concentrations at 300 grid points encompassing a perpendicular cross-section extending 100 meters downwind and 30 meters vertically were calculated for eight cases (i.e., one complete set of input parameters).

   B. Model 2 was applied to a problem in which the geometric set-up consisted of an interchange for two freeways and an adjacent rapid transit parking facility. Concentrations of CO were calculated for each wind direction at 130 receptors and maximum values over all wind directions, at each receptor for one case (i.e., one complete set of input parameters).

11. AeroVironment, Inc.

   CO concentrations were computed at 200 receptors on both sides of a four lane freeway for 50 cases (one case denotes one hour).

12. Scott Environmental Technology, Inc.

   CO concentrations due to two segments of a four lane rural roadway (with median) were calculated along a line of 17 receptors and three different wind angles for one-hour and eight-hour periods. The eight-hour period had two different stability classes. The contribution from each segment and the total for the two segments were printed out for one-hour and eight-hour periods.

13. TSC/EPA

The geometric set-up consisted of a four lane highway (two lanes per direction) with three receptors located on each side. The problem was to compute the CO concentrations at the three downwind receptors for 220 cases. (A case is a complete set of input parameters for a particular hour.)

The computation and cost involved in running these problems ranged from $5 to $470 and are summarized in Table 5.1.

5.2 PROBLEMS NOT INVOLVING TRANSPORTATION SOURCES

1. Mathematical Sciences, North West, Inc.

   The model was used for a complex industrial facility with 29 point sources.

2. Pandullo Quirk Associates

   The geometric set-up consisted of a grid of 50 x 50 points, having a spacing of approximately 900 meters, and an assumed source and receptor at each point (i.e., calculations were made for 2500 x 2500 source-receptor pairs).

Table 5.2 summarizes the computations involved in solving these problems.

TABLE 5.1

Computations for Typical Transportation Source Air Pollution Modeling Problems

PROBLEM NUMBER	COMPANY	CPU TIME (minutes)	RUNNING TIME (minutes)	APPROXIMATE COST ($)
1 A	Stanford Research Institute	6.0	6.3	58
1 B	Stanford Research Institute[1]	--	--	--
2	Lockheed, Huntsville	13.3	13.3	178
3	MSA Research Corporation	--	5.0	5
4	Parsons, Brinckerhoff, Quade, Douglas, Inc.	5.0[2]	11.0[2]	40
5	Ministry of the Environment	0.3	5.0	23
6	California D.O.T.	< 0.02	--[3]	2-10
7	Xonics, Inc.	0.2	2.0	6
8	Pacific Environmental Services, Inc.	5.0	6.0	100
9	TRW, Inc.	0.6	2.0	7

[1] Firm's model is a hand methodology

[2] For the IBM 370/135

[3] Variable due to operating system environment

TABLE 5.1 (Continued)

Computations for Typical Transportation Source

Air Pollution Modeling Problems

PROBLEM NUMBER	COMPANY	CPU TIME (minutes)	RUNNING TIME (minutes)	APPROXIMATE COST ($)
10 A	Environmental Research and Technology, Inc.	1.7	1.8	56
10 B	Environmental Research and Technology, Inc.	3.3	3.7	36
11	AeroVironment, Inc.	--[4]	150.0 [5]	--[4]
12	Scott Environmental Technology, Inc.	0.9	1.7	8
13	TSC/EPA	38.3	40.0	470

[4] Negligible

[5] Inclusive of plotter outputs

TABLE 5.2

Computations for Typical Air Pollution Modeling Problems
Not Involving Transportation Sources

PROBLEM NUMBER	COMPANY	CPU TIME (minutes)	RUNNING TIME (minutes)	APPROXIMATE COST ($)
1	Mathematical Sciences N. W.	0.5	5.0	12
2	Pandullo Quirk Associates	--[1]	3.0	3

[1] 49.4 units (Rapidata DEC 70)

5.3 MODEL APPLICATIONS

Each firm was asked to respond to the questions stated at the beginning of this section that concerned their model applications. In addition to indicating the number of analyses performed from 1970 to the present, each firm was asked to indicate the locations of the air quality analyses it performed.

Tables 5.3 and 5.4 contain the responses of firms to the questions concerning model applications. Table 5.3 shows that the California Department of Transportation performed the greatest number of air quality analyses as part of an Environmental Impact Statement and also the largest number of air quality analyses of proposed or existing transportation systems. California D.O.T. performed thousands of both types of analyses throughout the state. Environmental Research and Technology, Inc. performed 31 analyses as part of an Environmental Impact Statement in several states throughout the country, while Northern Research and Engineering Corp. performed 22 air quality analyses of airports in a number of locations.

Table 5.4 summarizes air quality analyses performed from 1970 to the present (1) to determine the impact on air quality of traffic control strategies, vehicle pollution control, etc., and (2) microscale air quality analyses of a transportation system as part of a regional air quality analysis (i.e., a highway, airport or other transportation system specified by the firm). Again, the California Department of Transportation performed the largest number of analyses (e.g., thousands of microscale analyses); few microscale analyses were performed by any of the other firms reporting.

TABLE 5.3

Air Quality Analyses of Existing or Proposed Transportation Systems

	Analyses as Part of an Environmental Impact Statement		Analyses of Proposed or Existing Transportation System	
COMPANY	NUMBER	LOCATION	NUMBER	LOCATION
Stanford Research Institute (1)	--	--	1	Chicago, Illinois
Stanford Research Institute (2)	1	Independence Lake, California	--	--
Stanford Research Institute (3)	--	--	--	--
Mathematical Sciences, N.W.	2	Bellvue, Addy, Washington	2	Seattle, Washington; Regional segments in Washington state
Northern Research and Engineering Corp.	1	--[1]	22	Los Angeles International; Washington National; J. F. Kennedy International; O'Hare International; Van Nuys, CA; Tamiami, FL (Airports)
Lockheed, Huntsville	1	Washington, D.C.	--	--
MSA Research Corp.	1	New York City	1	New York City
Parsons, Brinckerhoff, Quade, Douglas, Inc.	1	New York City	--	--
Ministry of the Environment	~5	Metro Toronto	1	Metro Toronto
California D.O.T.	In the thousands	All over California	In the thousands	Throughout California
Xonics, Inc.	~20	Oregon, California, Nevada	~20	Oregon, California, Nevada

[1] No records could be maintained of applications of the model.

TABLE 5.3 (Continued)

Air Quality Analyses of Existing or Proposed Transportation Systems

COMPANY	Analyses as Part of an Environmental Impact Statement: NUMBER	Analyses as Part of an Environmental Impact Statement: LOCATION	Analyses of Proposed or Existing Transportation System: NUMBER	Analyses of Proposed or Existing Transportation System: LOCATION
Pacific Environmental Services, Inc.	3	Phoenix, Arizona; Santa Barbara and Long Beach, CA	--	--
TRW, Inc.	--	--	--	--
Environmental Research and Technology, Inc. (1)	31	(3) Washington State; (10) Maryland; (2) New Jersey; (1) New Hampshire; (1) New York; (9) Washington, D.C.; (4) Massachusetts; (1) Milwaukee, Wisconsin	10	(7) Maryland; (2) Massachusetts (1) Washington, D.C.
Environmental Research and Technology, Inc. (2)	17	(6) Maryland; (3) Washington State; (3) Massachusetts; (2) New Jersey; (3) Washington, D.C.	--	--
Systems Applications, Inc.	--[2]	--	--	--
Pandullo Quirk Associates	1	Cape May, New Jersey	--	--
AeroVironment, Inc.	11	(5) Las Vegas, Nevada; (3) Reno, Nevada; (2) Phoenix, Arizona; (1) Palmdale, California	1	San Jose, California
Scott Environmental Technology, Inc.	8	Philadelphia, PA; Baltimore, MD; State of Maryland; Chambersburg, PA	--	--
TSC/EPA	2	Baltimore, MD	5	Baltimore, MD

[2] Model currently under development, has not been applied operationally.

TABLE 5.4

Air Quality Analyses Performed as Applications of the Models

	Analyses to Determine Impact on Air Quality of Traffic Control Strategies, Vehicle Pollution Control, or Other[1]		Microscale Air Quality Analyses of a Transportation System as Part of a Regional Air Quality Analysis (Highway, Airport, or Other[1])	
COMPANY	NUMBER	LOCATION	NUMBER	LOCATION
Stanford Research Institute (1)	4	Seattle and Spokane, Washington Kansas City, Missouri St. Louis, Missouri San Jose, California	--	--
Stanford Research Institute (2)	1	Marina Del Ray, California[2]	--	--
Stanford Research Institute (3)	--	--	--	--
Mathematical Sciences, N.W.	--	--	--	--
Northern Research and Engineering Corp.	8	Los Angeles International (Airport)	--	--
Lockheed, Huntsville	--	--	--	--
MSA Research Corp.	--	--	--	--
Parsons, Brinckerhoff, Quade, Douglas, Inc.	--	--	--	--
Ministry of the Environment	1	Metro Toronto		
California D.O.T.	200±	Los Angeles, San Francisco, Sacramento	In the thousands	Throughout California

[1] As specified by firm.

[2] Additions to a shopping center.

(Continued)

TABLE 5.4 (Continued)

Air Quality Analyses Performed as Applications of the Models

	Analyses to Determine Impact on Air Quality of Traffic Control Strategies, Vehicle Pollution Control, or Other[1]		Microscale Air Quality Analyses of a Transportation System as Part of a Regional Air Quality Analysis (Highway, Airport, or Other[1])	
COMPANY	NUMBER	LOCATION	NUMBER	LOCATION
Xonics, Inc.	5	Oregon	~20	Oregon, California, Nevada
Pacific Environmental Services, Inc.	--	--	--	--
TRW, Inc.	4	Albuquerque, NM; Trenton, NJ; Newark, NJ; Camden, NJ	--	--
Environmental Research and Technology, Inc. (1)	3	Washington, DC; New York City; Lawrence, MA	1	Washington, D.C.
Environmental Research and Technology, Inc. (2)	--	--	--	--
Systems Applications, Inc.	--[3]	--	--	--
Pandullo Quirk Associates	1	--[4]	--	--
AeroVironment, Inc.	--	--	--	--
Scott Environmental Technology, Inc.	--	--	--	--
TSC/EPA	--	--	--	--

3 Model currently under development, has not been applied operationally.

4 Regional growth, including vehicular pollution.

It is apparent from these two tables that the principal applications of air pollution dispersion models are in the preparation of Environmental Impact Statements and in microscale analyses of transportation systems as part of a regional air quality analysis - the latter performed mainly by the California Department of Transportation.

6. MODEL VALIDATION AND COMPARISON

The TSC questionnaire (Part I) asks the following questions with respect to the validation of models:

> "Has the model been validated with real-world data? If so, indicate the period of time, sample size, geographical area, site geometry, and the results of such validation(s)."

Of the 22 responses to this question, 12 reported that their model had been validated to some extent and eight stated that validation had not yet been undertaken. (The responses of two firms who have not developed their own models are not included in the following sections.) Of the 12 positive responses, nine reported validation on transportation source problems, and one on a non-transportation problem. (Two firms reported that their models had been validated to some extent but did not state the specific details of their validations.) The results are reported in three sections, one for transportation (Section 6.1), one for non-transportation (Section 6.2), and one for unclassified validations (Section 6.3). The material in these three sections consists of edited quotes from individual company statements concerning the validation of their models.

6.1 VALIDATION OF TRANSPORTATION-SOURCE MODELS

1. Stanford Research Institute

A. A new version of the APRAC model has recently been developed (December 1976). However an earlier version of the model (APRAC-1A) was validated in San Jose, California and St. Louis, Missouri. In San Jose two months of data were recorded from about 0700 to 1800PST. Seven stations were operated in a two block downtown area to measure CO at five heights, as well as winds and temperature gradients. CO concentrations and temperatures were also measured by a helicopter and two vans. San Jose's automated downtown network provided traffic data. The model was evaluated through comparison of observed and predicted hourly concentrations of CO for eight days at two levels at each of five stations. Hourly predictions are well correlated (correlation coefficient of about 0.6 to 0.7) with observations, and about 80 percent of the calculated values are within three ppm of the observed (which ranged as high as 16 ppm). In St. Louis the experimental program was carried out for three months. Two adjacent downtown street canyons were instrumented to obtain measurements of CO concentrations at 30 points and winds at eight locations. Wind, temperature, and CO were also measured to a height of 130m above the site on a tower. The model was applied using only routinely available meteorological and traffic data. Concentrations were calculated for four locations in the canyons and two at roof level. The calculations were compared with about 600 hourly-averaged observations for each location. The predicted concentrations of CO had root-mean-square errors of 3-4 ppm. Linear regression (calibration) reduced the differences by an additional 1 ppm. Median and 90-percentile concentration errors were 2-3 ppm in the current model; these errors could be halved by the use of calibrated values. (Model 1, Table 3.1.)

B. The infinite line source portion of model 3 was validated with traffic and meteorological data obtained in January and February 1975 near the Bayshore Freeway in Santa Clara, California. The freeway is a six lane at-grade roadway. CO measurements from five samplers on each side of the roadway were used to evaluate the model for 18 one-hour periods; a total of 82 observations were considered. The root-mean-square difference between calculated ard observed values was 4.72 ppm, while the linear correlation coefficient was 0.56; the range of r at the 95-percent confidence interval was 0.41 to 0.68 Calibration of the model reduces the RMS difference to 1.43 ppm; the correlation coefficient was increased to 0.80 while the range of the 95-percent confidence interval was 0.70 to 0.87. (Model 3, Table 3.1.)

2. Mathematical Sciences North West, Inc.

The model, COMPLEX, in addition to several other models, was validated at several sites for a study conducted by the University of Washington, Department of Atmospheric Sciences and Civil Engineering (a firm which also participated in the survey but did not develop its own air pollution dispersion model). The sites selected for the study included freeway segments with the prevailing winds parallel to or across the highway and the intersection of a major arterial with a freeway. The general approach taken to evaluate the models was to supply the same emissions, meteorological, highway and receptor parameters to each of the models for each one-hour period sampled. The concentrations calculated at each of the receptor points from these inputs were then compared to the measured concentrations for that one-hour period. One of the performance measures used was the mean square difference, which measures the deviation between the actual and predicted values. Table 6.1 (supplied by MSNW) shows at the bottom of the table D^2, the mean square difference, for each

TABLE 6.1

<u>Summary of Calculations of the Mean Square Difference</u>

Department of Atmospheric Sciences, University of Washington

Site	Case	Stab.	Wind Spd	Wind Dir	HIWAY	MSNW	CALINE-1	CALINE-2
Renton	1	D	4-6	⊥	0.51	2.83	0.00	0.21
	2	D	7-10	⊥	4.26	0.63	5.67	8.62
Kirkland	1	C	4-6	||	21.48	4.37	229.32	11.00
	2	D	4-6	||	473.13	111.98	952.56	238.14
	3	C	7-10	||	69.81	13.41	108.48	20.96
Vancouver	1	B	0-3	||	96.12	6.91	57.74	7.40
	2	B	4-6	⊥	127.02	-----	267.45	276.94
	3	B	4-6	/	130.65	206.86	251.78	285.13
	4	B	4-6	||	4.25	99.88	16.81	204.69
	5	C	0-3	||	237.13	22.97	22.09	0.02
	6	C	4-6	/	0.00	9.80	22.90	26.91
	7	C	4-6	||	0.48	125.15	99.53	210.42
	8	C	7-10	||	234.00	500.64	538.79	781.98
	10	D	0-3	/	477.63	229.31	3.15	24.19
	11	D	0-3	||	1054.12	131.26	6.14	5.32
	12	D	4-6	/	68.89	105.06	209.70	246.49
	13	D	4-6	||	72.87	24.52	123.79	125.94
	14	D	7-10	||	0.19	45.47	171.36	174.23
Spokane	1	C	0-3	/	-----	7.61	4.32	6.70
	3	C	4-6	/	8.84	7.73	1.68	2.98
	4	D	0-3	||	192.47	87.12	-----	-----
	5	D	0-3	/	59.28	72.51	0.04	0.19
	6	D	4-6	/	-----	37.68	8.73	11.83
$\Sigma D_i N_i$					3333.11	1853.73	3102.03	2770.29
ΣN_i					1381	1530	1296	1296
D^2					2.41	1.21	2.39	2.14

⊥ Winds Perpendicular to Highway Axis
|| Winds Parallel to Highway Axis
/ Winds Oblique to Highway Axis

model. Note that MSNW, the model of Mathematical Sciences North West, has the smallest D^2 of the four models tested: (1) EPA HIWAY, (2) MSNW, (3) CALINE-I, and (4) the CALINE-II.

3. <u>Northern Research and Engineering Corporation</u>

Qualitative results obtained with the model, when properly interpreted, agreed well with real-world data acquired by the firm. The data measurements were taken at an airport during the following time periods: 8/1/72 - 8/31/72 (summer data) and 12/18/71 - 3/12/72 (winter data). Data were measured at seven receptors (one vertical level). Continuous strip chart recordings were made for gas analyzers, which were subsequently digitized to give hourly values. Daily values were obtained for particulates. A total of 25,650 measurements (i.e., digitized values) was taken, consisting of 9624 CO, 5400 HC, 5328 NO_x, 5112 SO_2, and 186 particulates.

4. <u>MSA Research Corporation</u>

Traffic counts were made in the north and center tubes of the Lincoln Tunnel with both one-way and two-way traffic. Figure 6.1 shows the results of the north tube calculation both with and without the piston effect. (It should be noted that the chart CO levels are averages for each section since the monitors are located in the exhaust ductwork.) The calculated results are in good agreement with the measured results and are within the accuracy of the CO monitors.

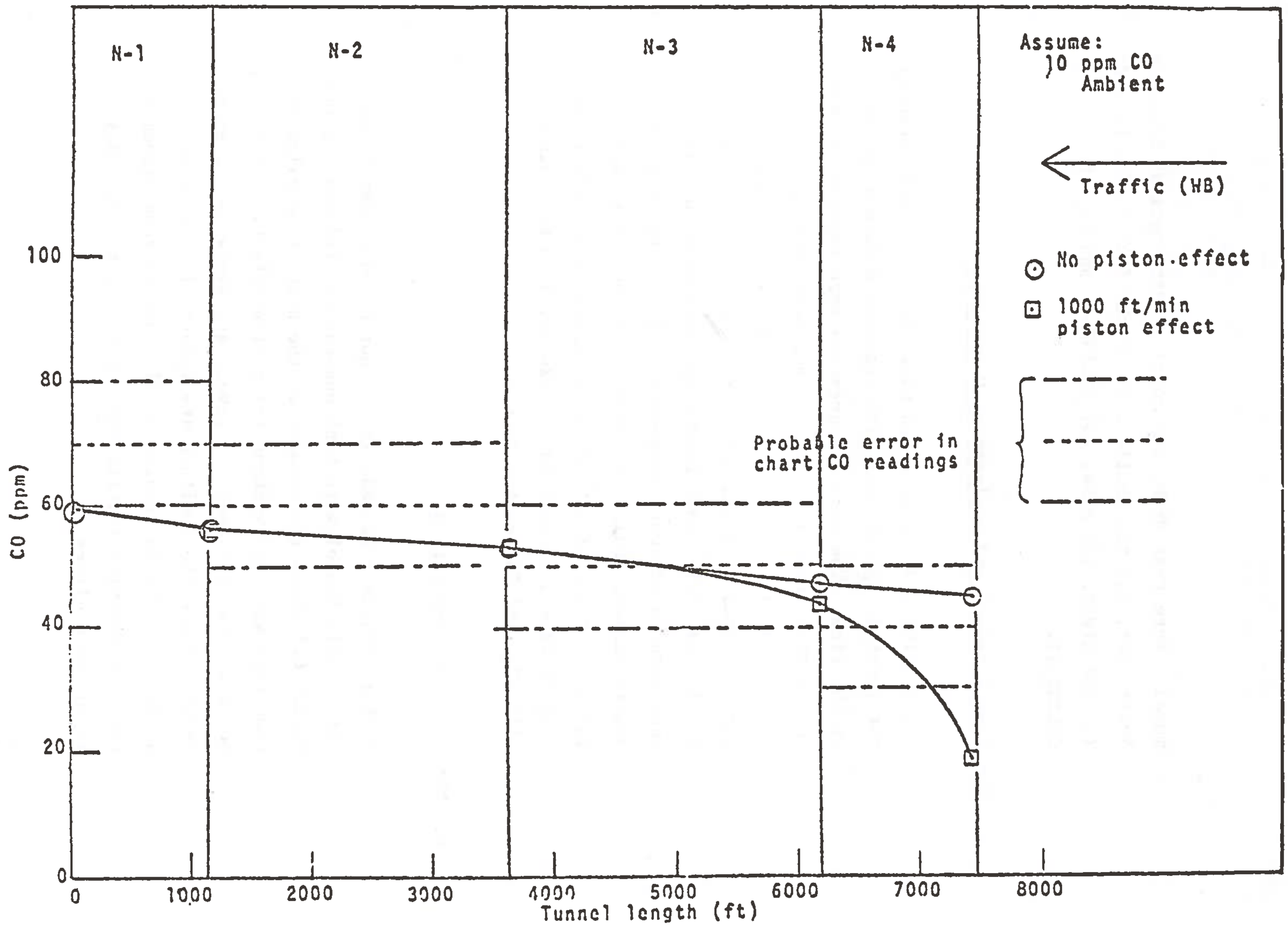


FIGURE 6.1

Actual and Calculated CO Values for the Lincoln Tunnel-North Tube

MSA Research Corporation

5. Parsons, Brinckerhoff, Quade, Douglas, Inc.

The CUES model was developed to predict CO concentrations resulting from complex geometric roadway configurations in urban areas such as New York City. The CUES model was validated with real-world data collected at primary sites along the existing West Side Highway in Manhattan. The validation procedure compares concentrations generated by CUES with actual measured concentrations recorded under conditions identical to those used as inputs to the model. Once CUES was shown to be statistically valid, it was then calibrated for prediction.

6. Ministry of the Environment

This model was designed to compute CO concentrations in a vertical plane orthogonal to Highway 401 at Keele Street in Toronto. The model was run for 22 cases, and a comparison was made between the actual concentration at the fixed Keele Street measuring station (48 feet north of the edge of the pavement and 7 feet above the ground) and the value predicted by the model at that location. The computed concentrations at the measuring site had a sample correlation coefficient of 0.82 with the observed concentrations. Table 6.2 summarizes the comparison between actual (C_o) and predicted (C_p) carbon monoxide concentrations at the fixed Keele Street site for 1969.

7. Environmental Research and Technology, Inc.

The EGAMA model was validated extensively at six highway sites in Washington, D.C. Continuous CO measurements were taken on both sides of the roadways and at three

TABLE 6.2

Comparison Between Actual (C_o) and Predicted (C_p) Carbon Monoxide Concentrations at the Fixed Keele St. Site.

Ministry of the Environment

Cold, neutral and warm air advection are denoted by C, N and W, respectively. Times are GMT. The year is 1969.

Time	C_o (ppm)	C_p (ppm)	n (cars hr^{-1})	h (m)	V_t (m sec^{-1})	u_t (m sec^{-1})	Advection
2030, Jul. 8	1	2.2	14080	1193	6.0	3.4	N
1230, Jul.14	2	0.1	13360	306	4.3	-4.2	W
1130, Aug. 1	10	6.2	13040	10	2.9	2.6	W
2030, Aug. 1	13	9.5	13790	10	2.7	1.7	W
1130, Aug. 7	14	7.1	12830	10	3.4	2.2	W
2030, Aug. 7	5	1.7	13730	359	7.8	6.3	W
1130, Aug.15	17	14.0	12750	10	1.3	1.1	W
2030, Aug.15	7	2.2	14710	1231	6.0	5.5	W
1130, Aug.18	13	14.1	13880	10	2.0	1.2	W
2030, Aug.18	6	2.9	13870	1481	5.1	2.2	W
1130, Aug.19	6	0.5	13210	10	2.9	-1.9	C
2030, Aug.19	1	0.0	13730	343	5.4	-5.2	C
1130, Aug.20	9	1.3	12580	10	1.6	-1.3	C
2030, Aug.20	2	0.1	13830	965	6.9	-6.1	C
1130, Aug.21	10	0.8	12880	10	2.0	-1.7	C
2030, Aug.21	1	0.0	13590	1360	6.5	-6.0	C
1130, Aug.25	8	1.3	13620	10	2.9	-1.0	N
2030, Aug.25	1	0.0	14110	1068	7.2	-5.9	N
1230, Aug.26	8	0.1	13260	10	4.7	-4.5	C
2030, Aug.26	2	0.0	14020	1367	6.7	-6.5	C
1130, Aug.28	13	11.9	12680	10	4.7	1.2	W
2030, Aug.28	8	2.6	14470	1587	6.3	4.4	W

heights, along with concurrent meteorological measurements and traffic observations. The study was conducted in 1973 and included at-grade, depressed, and elevated sites with multi-lane divided roadways. It was found that the model predicts CO concentrations within 20% of observed values. (Model 1, see Table 3.1.)

8. AeroVironment, Inc.

This model has been validated five times: at San Jose, Palmdale, Reno, Las Vegas and Phoenix. The data for San Jose were measured near a single highway (at-grade and cut) with 12 receptors, for CO, NO_x, particulates, ozone, lead and hydrocarbons. The data for Palmdale were measured at an airport with five receptors (one vertical level) for CO, NO_x, ozone and hydrocarbons (CH_4, THC). The Reno data were measured at a single highway (at-grade) with 15 receptors (one vertical level) for CO. Data for Las Vegas were measured near a city street and at the intersection of two city streets with a total of 28 receptors (one vertical level) for CO, particulates and lead. Finally, data measurements for Phoenix were taken for a single highway (cut and elevated) with eight receptors for CO.

9. TSC/EPA

Since air quality data suitable for model validation have not been available to the Transportation Systems Center (TSC), it has not been possible to validate the model. However, the Center has developed the Transportation Air Pollution Studies (TAPS) System, a package of computer programs for storing, manipulating and retrieving air quality data, coupled to routines for analyzing the performance of dispersion models with a wide variety of performance measures. The TAPS System is described in Report No. DOT-TSC-OST-73-24. This System will be used to test the model as soon as suitable air quality data are received.

6.2 VALIDATION OF MODELS FOR NON-TRANSPORTATION SOURCES

Pacific Environmental Services, Inc.

Since the necessary information for a useful validation study was available in the Los Angeles area, the REM model was initially designed for application to that area. The study which was supported by the Environmental Protection Agency, involved the use of meteorological and contaminant data gathered on an hourly basis for six typical episodes of photochemical air pollution observed in Los Angeles in the summer and fall of 1969.

These data included wind speed, wind direction, temperature, and humidity at each of twenty-five meteorological stations in the Los Angeles basin, as well as radiosonde measurements of the vertical temperature profile at Los Angeles International Airport. These data, together with information about the location and elevation of the various stations, permitted the calculation of air parcel trajectories with associated temperature, humidity, and mixing depth. Since validation requires the prediction of quality at places where measurements exist, the locations of various air monitoring stations were taken as terminal points for trajectories, and the trajectory starting points were calculated with the use of a "reverse trajectory" routine.

Atmospheric simulation runs were performed for each of the six smog episode days specified by EPA for four receptor locations. When the calculated ozone concentrations for these receptor locations were compared with the field observations, the calculated values were found to be slightly lower (about 20 percent on the average) The results for carbon monoxide were also about 20 percent lower, while nitrogen dioxide levels were overestimated about 25 percent.

Another way of expressing the results of the validation study is to report the fraction of all comparisons made in which the calculated value was more than half as large and less than twice as large as the observed value. For ozone, this fraction was 75%; for carbon monoxide, 80%; for nitrogen dioxide, 60%; and for nitric oxide, 75%. These results show that the accuracy of REM compared favorably with that of other air quality models, including those which require much more extensive input data and substantially greater computation times.

6.3 VALIDATION OF MODELS: PROBLEMS UNCLASSIFIED

1. California Department of Transportation

The model has been validated but no specific details of the validation were given in the firm's response.

2. Xonics, Inc.

The model, ROADS, has been validated, but no specific details of the validation were given by the firm.

6.4 COMPARISON OF MODEL PREDICTIONS

The TSC questionnaire (Part I) asks the following questions with respect to the comparison of models:

> "Have the model predictions been compared with those of other dispersion models? If so, describe the results of such comparisons."

Of the 22 responses to this question, the predictions of 10 models had been compared with those of other dispersion models.

The material in the following paragraphs consists of edited statements from individual companies concerning the comparison of their model's predictions with those of other dispersion models.

1. <u>Mathematical Sciences North West, Inc.</u>

   An earlier version of the model, COMPLEX, was tested by a University of Washington group for the Washington State Highway Department. The model outperformed three other models: EPA HIWAY, CALINE-I and CALINE-II, in the Mean Square Difference Statistic - a measure of how well the models predicted CO concentrations.

2. <u>MSA Research Corporation</u>

   The firm has not actually compared the predictions of its model with those of other models. However, a comparison was made between the firm's MSAR model and the PNYA model, a mathematical model of tunnel ventilation developed in 1965 by the R&D Division of the Port of New York Authority - Engineering Department. The results of the comparison are as follows: (1) instead of the finite difference equations used in the MSAR model, the PNYA model employs differential equations which are derived for both ventilation and contaminant profiles; (2) the MSAR model does not require derivation of differential equations; and (3) the data generated by both methods should be identical if a sufficiently small length derivative (dl) is chosen.

3. Parsons, Brinckerhoff, Quade, Douglas, Inc.

Table 6.3 shows the statistical results of a comparative evaluation of their CUES model with the California, Danard, and Ragland models. Each of the models in Table 6.3 was calibrated using the same data set, the same emission factors and making the same assumptions. (The CUES model was also analyzed by the Transportation Systems Center (TSC) of the United States Department of Transportation and was found to belong to a consensus group of models (see discussion in 11 below).) A model review and evaluation performed by the firm for the West Side Highway Project did not bring to light any available models with performance surpassing that of the CUES model.

4. Department of Atmospheric Sciences, University of Washington

The department has not developed its own dispersion model, but has compared the predictions of the following models: (1) EPA HIWAY, (2) CALINE-I, (3) CALINE-II, and (4) an

TABLE 6.3

Model Comparison

Parsons, Brinckerhoff, Quade, Douglas, Inc.

Prototype Site Location	Type of Site	CUES Model				California Model				Danard Model				Ragland Model			
		A	B	r	Sc/x	A	B	r	Sc/x	A	B	r	Sc/x	A	B	r	Sc/x
Bruckner Expressway at White Plains Road	At-grade	3.58	1.25	0.17	2.01	3.23	0.94	0.23	1.98	3.58	0.31	0.13	2.02	3.85	0.40	0.07	1.90
West Side Highway/West Street at Murray Street	Elevated	3.12	0.34	0.25	1.89	2.69	0.32	0.35	1.82	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
West Side Highway/West Street at Christopher St.	Elevated	1.35	1.97	0.60	1.67	2.55	0.15	0.29	1.99	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
West Side Highway/12th Avenue at 27th Street	Elevated	4.22	0.89	0.56	2.29	4.11	0.49	0.56	2.29	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
West Side Highway/12th Avenue at 41st Street	Elevated	5.92	0.50	0.45	3.67	5.37	0.24	0.49	3.57	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Grand Central Parkway at Parsons Boulevard	Depressed	5.23	0.16	0.25	3.66	4.88	0.07	0.29	3.61	N.E.	N.E.	N.E.	N.E.	N.A.	N.A.	N.A.	N.A.
Brooklyn-Queens Expwy at Hicks Street (BQE-71)	Depressed	4.40	2.08	0.30	5.26	6.85	0.07	0.07	5.50	7.18	0.00	0.01	5.51	N.A.	N.A.	N.A.	N.A.

N.A. = Not applicable.
N.E. = Not evaluated.

A = Population regression coefficient (intercept)
B = Population regression coefficient (slope)
r = Sample correlation coefficient
Sc/x = Sample standard error of estimate

earlier version of the model COMPLEX. The measures of comparisons used included the mean square difference between predictions and measurement, the amount of over or under prediction of maxima for critical cases, qualitative factors such as costs, level of support by issuing organization, and flexibility to model complex situations. Table 6.4 is a matrix table summarizing the preliminary results of a model of evaluation study.

5. California Department of Transportation

The predictions of the model CALINE-II were compared with those of the "HIGHWAY" and "EXPLOR" programs and were compared against real data. CALINE-II had the highest correlation with observed measurements. Also see 11 below.

6. Xonics, Inc.

The predictions of the ROADS model were compared with those of the EXPLOR model. No details of this comparison were given.

7. TRW, Inc.

The TRW model was compared with the Climatological Dispersion Model (CDM) output and with measured data for several Phoenix area receptors. No statistical analysis was made because the objective was to determine whether certain modifications to CDM would produce results compatible with other models. In this case, the modified APRAC was considered to be the standard.

TABLE 6.4

Matrix of Model Desirability

Department of Atmospheric Sciences, University of Washington

	HIWAY	CALINE-1	CALINE-2	MSNW
Intra-model variability analysis	1	4	2	2
Inter-model mean square difference analysis	4	3	2	1
Cost of obtaining computer program	1	1	1	2
Operating costs for computer programs	3	1	1	2
Model flexibility	1	4	3	2
"Support" level	1	4	2	3

KEY

1 Most desirable characteristics

2,3 In-between

4 Least desirable characteristics

8. Environmental Research and Technology, Inc.

See 11 below.

9. AeroVironment, Inc.

The calculations of the AVQUAL model have been compared with predictions of the CALINE I model. No further details are given of the comparison. Also see 11 below.

10. Scott Environmental Technology, Inc.

Some comparisons of the model, HIWAYS - Scott Version, have been made. No specific details of the comparisons have been given in the firm's response.

11. TSC/EPA

The TSC/EPA model has been compared with 12 other highway air pollution dispersion models[18], using the input parameters of a portion of the Airedale data from Washington, D.C. The following distance measures were calculated for the output of all 13 models in pairs: the average absolute difference, the 80th percentile difference and the correlation coefficient. Clusters of model predictions were formed by defining cluster diameters for each of the distance measures and determining which pairs of models had prediction distances less than these diameters for each measure separately and for all measures combined. The following five models (three Gaussian and two conservation of mass) were found to cluster consistently, and these were defined as the consensus models: AeroVironment, California Department of Transportation (CALINE I), Environmental Research and Technology, Walden Research, and TSC/EPA.

6.5 MODEL AVAILABILITY

The TSC questionnaire (Part I) asks each firm if the computer program for its model is in the public domain; and if so, in what form, with what documentation, and at what cost? Table 6.5 contains the responses of the firms to those questions. The table shows that: (1) computer programs for 11 of the models are in the public domain; (2) computer programs for 11 of the models are not available to the public; (3) the present version of one firm's program is available, but the newer version of that program is not in the public domain; and (4) the original version of the REM model is available through NTIS. However, the latest version of that model is proprietary and is accessible only by a contract with the company. Seven of the available models can be obtained for no cost. Also, most of the firms whose models are in the public domain are able to provide (at cost) card decks, computer listings and a user's manual.

TABLE 6.5

Model Availability

COMPANY	Model Available	Deck of Cards	Listing	User's Manual	Available on Time Sharing Computer System	Approximate Total Cost ($)	Model Not Available	Model is Proprietary, Can Only Be Accessed Via Contact with Firm	Model Under Development	Other[1]
Stanford Research Institute (1)	X	X	X	X^2	X^3	$ 75				
Stanford Research Institute (2)	X	X	X	X		100				
Stanford Research Institute (3)	X			X		0				
Mathematical Sciences, N.W.							X	X		
Northern Research and Engineering Corp.	X	X^4		X		1,500	X^5	X^5		
Lockheed, Huntsville	X	X^4	X	X		0				
MSA Research Corp.	X^6									
Parsons, Brinckerhoff, Quade, Douglas, Inc.	X	X	X	X		--[7]				
Ministry of the Environment	X		X			0				
California D.O.T.	X	X	X	X	X^8	0[9]				

1 As specified by firm.

2 To be available through National Technical Information Service (NTIS)

3 Original Version of APRAC-1A on EPA UNAMAP system

4 Or magnetic tape

5 New version of the program

6 Available through NTIS

7 Duplicating cost only

8 On TENET system, report on model also available

9 $80 for private firms

TABLE 6.5 (Continued)

Model Availability

COMPANY	Model Available	Deck of Cards	Listing	User's Manual	Available on Time Sharing Computer System	Approximate Total Cost ($)	Model Not Available	Model is Proprietary, Can Only Be Accessed Via Contact with Firm	Model Under Development	Other[1]
Xonics, Inc.	X				X[10]					
Pacific Environmental Services, Inc.							X[11]	X		
TRW, Inc.							X	X		
Environmental Research and Technology, Inc. (1)							X	X		
Environmental Research and Technology, Inc. (2)							X	X		
Systems Applications, Inc.							X		X[12]	
Close, Jensen and Miller							X	X		
Pandullo Quirk Associates							X	X		
AEROVIRONMENT, Inc.							X	X		
Scott Environmental Technology, Inc.							X	X		
TSC/EPA	X	X	X	X[13]		0				

10 On Infonet system, the model with modifications not available, is proprietary

11 Original version of REM (circa 1973) available through NTIS, present version with modifications not available to public

12 Expected to be available to public in June 1977

13 Report describing model applications also available at no cost

7. TRANSPORTATION AIR POLLUTION DATA

This section considers the measured air quality data which firms have acquired in the vicinity of transportation systems (such as highways, airports and railyards). These firms completed and returned Part II of the TSC questionnaire which requests specific information on the following topics:

I. Project name
II. Sponsor
III. Starting date of measurements
IV. Completion date of measurements
V. Site information
VI. Approximate number of measured data points
VII. Data acquired (pollutant, highway, airport, other)
VIII. Data availability

Of the 20 firms who responded to Part I and/or Part II of the TSC questionnaire, 10 reported that they had acquired air quality data. The following section will examine these data in detail (see Appendix A for a listing of those firms which completed and returned Part II of the TSC questionnaire.) All of the material in this section is taken from Part II of the completed questionnaires returned to TSC.

7.1 THE DATA

A total of 24 completed questionnaires for Part II were returned to TSC by 10 firms; five reported on more than one data sample. Table 7.1 contains the responses of the ten firms to the questions on site location,and the starting and completion dates of measurements. Note that: (1) the period of time in which measurements were taken ranges from 24 hours to one year; (2) the earliest starting date

TABLE 7.1

Site Information and Measurement Dates

COMPANY	SINGLE HIGHWAY	MULTIPLE HIGHWAY	COMPLEX INTER-CHANGE	CITY STREET	AIRPORT	OTHER[1]	DATES OF MEASUREMENT	
							STARTING	COMPLETION
Stanford Research Institute (1)	X						Jan. 17, 1975	Feb. 5, 1975
Stanford Research Institute (2)	X						July 2, 1975	July 22, 1975
Stanford Research Institute (3)	X						Aug. 12, 1975	Sept. 3, 1975
Northern Research and Engineering Corp.					X		Dec. 18, 1971 Aug. 1, 1972	Mar. 12, 1972[2] Aug. 31, 1972
MSA Research Corp.						X[3]	March 1971	Nov. 1971
Parsons, Brinckerhoff, Quade, Douglas, Inc. (1)		X					March 1976	April 1976
Parsons, Brinckerhoff Quade, Douglas, Inc. (2)		X					May 1976	June 1976
Parsons, Brinckerhoff Quade, Douglas, Inc. (3)		X		X		X[4]	----------	----------[5]

1 As specified by firm.

2 Winter and summer measurements taken.

3 5 Tunnels.

4 Tunnel portal areas.

5 Field measurement program was undertaken in late 1972 and early 1973.

(Continued)

TABLE 7.1 (Continued)

Site Information and Measurement Dates

COMPANY	SINGLE HIGHWAY	MULTIPLE HIGHWAY	COMPLEX INTER-CHANGE	CITY STREET	AIRPORT	OTHER[1]	DATES OF MEASUREMENT	
							STARTING	COMPLETION
Department of Atmospheric Sciences, University of Washington	X	X	X				Jan. 1974	Aug. 1974
California D.O.T. (1)						X[6]	Various	Various
California D.O.T. (2)		X					Sept. 1974	June 1975
Environmental Research and Technology, Inc. (1)						X[7]	April 29, 1974	May 24, 1974
Environmental Research and Technology, Inc. (2)	X	X	X	X			June 12, 1972	Nov. 14, 1972
Environmental Research and Technology, Inc. (3)						X[8]	May 1974	Sept. 1974
Environmental Research and Technology, Inc. (4)					X	X[9]	Dec. 1971	March 1972
Environmental Research and Technology, Inc. (5)						X[10]	Aug. 1975	Aug. 1975
Environmental Research and Technology, Inc. (6)					X		May 1976	May 1977

1 As specified by firm.

6 Regional air quality surveys of Fresno, San Diego, Sacramento and Bakersfield.

7 At grade signalized urban intersection.

8 Three toll plazas on the New Jersey Turnpike.

9 Airport access roads.

10 Two toll plazas on the New Jersey Turnpike.

(Continued)

TABLE 7.1 (Continued)

Site Information and Measurement Dates

COMPANY	SINGLE HIGHWAY	MULTIPLE HIGHWAY	COMPLEX INTER-CHANGE	CITY STREET	AIRPORT	OTHER[1]	DATES OF MEASUREMENT	
							STARTING	COMPLETION
GCA/Technology Division		X				X[11]	March 13, 1974	Apr. 13, 1974
AeroVironment, Inc. (1)	X						June 19, 1972 Aug. 28, 1972 Oct. 2, 1972	Oct. 7, 1972[12] Aug. 31, 1972[13] Oct. 5, 1972[13]
AeroVironment, Inc. (2)					X		Oct. 4, 1975	Oct. 5, 1975
AeroVironment, Inc. (3)	X						Nov. 19, 1974	Nov. 20, 1974
AeroVironment, Inc. (4)				X		X[14]	Jan. 7, 1975 Feb. 25, 1975	Jan. 8, 1975 Feb. 26, 1975
AeroVironment, Inc. (5)	X						March 4, 1976	March 5, 1976
Scott Environmental Technology, Inc.	X	X	X	X			June 6, 1974	July 9, 1974

1 As specified by firm.

11 Major intersection near a regional shopping center.

12 Field program.

13 Model Validation data.

14 Intersection of two city streets.

for measurements is March 1971 (MSA Research Corporation, whose completion date of measurements is November 1971); and (3) the most recent set of measurements was taken by Environmental Research and Technology, Inc., whose measurement gathering program began in May 1977. Several firms took more than one set of measurements. For example, Northern Research and Engineering Corporation took one set of winter and one set of summer measurements at an airport. AeroVironment, Inc., took one set of measurements as part of a field program, two sets for model validation data, as well as another two (near one city street and at the intersection of two other city streets).

As for the question of sites, Table 7.1 shows that most of the data samples were taken near single or multiple highways: 14 of 24 samples were taken near single and/or multiple highways, while four were taken at airports. Other sites measurement included complex interchanges, city streets, tunnels, toll plazas and several different types of intersections.

A total of 23 of the 24 data samples contained measurements of carbon monoxide (CO); 11, hydrocarbons (HC); and 11, oxides of nitrogen (NO_x). (Vehicle emission standards have been established for these three pollutants under the Clean Air Act.)

Eighteen of the 24 data samples contained highway measurements (average daily traffic, hourly traffic or other highway data) while two samples included airport measurements (aircraft, service vehicles, access vehicles or other airport data specified by the firms). Meteorological data (e.g., wind speed, wind direction, ambient temperature) were also acquired.

7.2 DATA AVAILABILITY

The questionnaire asks each firm the following questions: (1) Are these data currently available?; (2) If not, when will they become available?; and (3) Cite name and address where data can be obtained now or in the future. Table 7.2 shows the responses of firms to these questions.

In response to the first question, 18 of the 24 data samples are currently available, 4 are not available and 2 are available if consent is given by the New Jersey Turnpike Authority. Also, 4 data samples which are not now available will become available in early 1977. The third column of the table supplies names of agencies where data acquired can be obtained now or in the future. Federal agencies from which these data can be obtained include the Federal Highway Administration (FHWA), the Federal Aviation Administration (FAA) and the U. S. Environmental Protection Agency (EPA). Several of the data samples can be obtained directly from the firms acquiring them, while two of them are described in reports - one obtainable through the National Technical Information Service (NTIS), the other through the U.S. Environmental Protection Agency (EPA). Data can also be obtained from state agencies (e.g., the California and Nevada Departments of Highways and the Arizona and Pennsylvania Departments of Transportation).

7.3 PROJECT SPONSORS FOR DATA ACQUISITION

The questionnaire asks the name of the project and the sponsor of each air pollution data acquisition effort. Some of the sponsors were state agencies (e.g., the Pennsylvania, New York State and Arizona Departments of Transportation and the California and Nevada Departments of Highways); others were Federal agencies (e.g., U. S. Environmental Protection Agency, FAA and FHWA).

TABLE 7.2

Data Availability

COMPANY	DATA AVAILABLE	DATA NOT AVAILABLE	WHERE DATA CAN BE OBTAINED, NOW OR IN THE FUTURE
Stanford Research Institute (1)		X[1]	Office of Research, FHWA[2]
Stanford Research Institute (2)		X[1]	Office of Research, FHWA[2]
Stanford Research Institute (3)		X[1]	Office of Research, FHWA[2]
Northern Research and Engineering Corp.	X		DOT, Federal Aviation Administration, Office of Environmental Quality
MSA Research Corp	X		Report No. FHWA-RD-72-15, National Technical Information Service
Parsons, Brinckerhoff, Quade, Douglas, Inc. (1)	X		from this firm
Parsons, Brinckerhoff, Quade, Douglas, Inc. (2)	X		from this firm
Parsons, Brinckerhoff, Quade, Douglas, Inc. (3)	X		from this firm
Dept. of Atmospheric Sciences, U. of Washington	X		Department of Civil Engineering, University of Washington
California D.O.T. (1)	X		California Transportation Laboratory
California D.O.T. (2)	X		California Transportation Laboratory

1 Data will be available early 1977.

2 Federal Highway Administration.

(Continued)

TABLE 7.2 (Continued)

Data Availability

COMPANY	DATA AVAILABLE	DATA NOT AVAILABLE	WHERE DATA CAN BE OBTAINED, NOW OR IN THE FUTURE
Environmental Research and Technology, Inc. (1)	X		from this firm
Environmental Research and Technology, Inc. (2)	X		Transportation Systems Center
Environmental Research and Technology, Inc. (3)	X[3]		from this firm
Environmental Research and Technology, Inc. (4)	X		from this firm
Environmental Research and Technology, Inc. (5)	X[3]		from this firm
Environmental Research and Technology, Inc. (6)	X		Federal Aviation Administration
GCA/Technology Division	X		U. S. Environmental Protection Agency, Report No. EPA-450/3-74-058, November 1974
AeroVironment, Inc. (1)	X		California Department of Highways[4]
AeroVironment, Inc. (2)	X		Los Angeles Department of Highways
AeroVironment, Inc. (3)	X		State of Nevada Department of Highways
AeroVironment, Inc. (4)	X		State of Nevada Department of Highways
AeroVironment, Inc. (5)	X		Arizona Department of Transportation
Scott Environmental Technology, Inc.		X	Pennsylvania Department of Transportation[5]

[3] Data available if consent is given by New Jersey Turnpike Authority.

[4] District 4 (of the Department of Highways).

[5] District 6 (of the Department of Transportation).

8. CONCLUSIONS

Conclusions for the following six major areas were stated in the initial version of this survey published in 1972; these were:

1. Model Validation

   While many models are currently in use, none of them have been adequately validated.

2. Data

   Data for model validation are scarce, but new data gathering experiments are underway and should produce suitable data.

3. Photochemical Models

   The validation of photochemical models has barely begun.

4. Model Performance

   There is no proof that numerical conservation of mass models are superior to simple Gaussian models.

5. Meteorology

   Meteorological data lacks the resolution required for model input.

6. Emissions

   It is difficult to estimate source emissions due to the difficulty involved in making the required measurements.

Our current assessment of these six major areas is as follows:

1. Model Validation

Some progress has been registered in model validation during the past five years. Many of the models reported to TSC had been validated (or compared with other models) using one or more sets of air quality data. However, it is still our opinion that none of these models have yet been validated with a data base sufficiently large enough to provide confidence in the results.

2. Data

Twenty three currently available air quality data bases were reported to TSC: 15 highway, 4 airport and 4 other. In addition, data from four other major highway test sites are (or soon will be) available; these are California DOT (42-mile loop), General Motors Milford Proving Ground (sulfate experiment[19]), New York State Department of Environmental Conservation (Long Island Expressway), and St. Louis Air Pollution Studies (SLAPS) Project. It remains to be determined whether enough of these data are of sufficient quality to permit the comprehensive validation of models.

3. Photochemical Models

A few photochemical models are currently operational; the principal ones are LIRAQ[20] (Lawrence Livermore Laboratory), PAQSM[17] and SAI[16]. DOT and EPA have supported the development and testing of the SAI model during the past few years. However, none of these models have been adequately validated to date.

4. Model Performance

A preliminary evaluation of 13 highway air pollution models[18] conducted by TSC (using synthetic input data) showed that 5 models (3 Gaussian, 2 conservation of mass) produced predictions that clustered closely together. This study demonstrated that certain Gaussian and conservation of mass models would generate very similar predictions from a common set of input data. These results say nothing about the absolute accuracy of these predictions since valid air pollution measurements were not available for comparison.

5. Meteorology

Inadequate resolution of meteorological data remains a problem in model applications. Most firms having Gaussian models still use a single hourly mean transport wind in their models along with Pasquill stability class and mixing height. Conservation of mass models require a wind field over a grid as input. In general, a divergence-free wind field is generated from whatever wind observations are available; this approach is required in order to avoid spurious effects in the model solutions.

6. Emissions

Emission inputs to dispersion models have two components: the geometry of the source (i.e., point, line, volume, etc.), and the source strength (in mass per unit time, distance, volume, etc.). Progress has been made during the past few years in estimating both components. Detailed measurements of the emission distributions over a highway were made as part of the General Motors sulfate experiment[19]. It was found that these distributions were much more complicated than the uniform mechanical mixing cell that is often assumed. The emission source strength for CO has been back-calculated in experiments where a tracer gas was emitted along a highway at precisely known rates and then sampled downstream at positions colocated with CO samplers.

The following areas which were not included in the 1972 survey are covered in this report:

1. Particulate Dispersion Modeling

   Some progress has been registered in developing dispersion models for particulates; however, much remains to be done in this area.

2. Air Quality Analyses

   Numerous applications of models were reported; the largest number involved air quality analyses as part of Environmental Impact Statements (e.g., the California Department of Transportation has performed several thousand of these).

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APPENDIX A

LIST OF REQUESTERS AND RESPONDERS

THE TSC QUESTIONNAIRE

THE SAMPLE COMPLETED QUESTIONNAIRE

List of Companies Requesting and Returning the TSC Questionnaire

Name	Address	TSC Questionnaire Requested	Number Returned Part I	Number Returned Part II
Aero Vironment, Inc.	660 South Arroyo Parkway Pasadena, CA 91105	*		
Aeronautical Research Associates of Princeton	50 Washington Road Princeton, N.J. 08540	*		
AEROVIRONMENT, Inc.	145 Vista Avenue Pasadena, CA 91107	X	1	5
Allan M. Vorhees & Associates, Inc.	Westgate Research Park McLean, VA 22101	X		
AVCO Systems Division	Wilmington, MA 01887	*		
Battelle Columbus Labs	505 King Avenue Columbus, OH 43201	*		
Beak Consultants, Inc.	317 S. W. Alder Third Floor Portland, Oregon 97204	X		
Boeing Commercial Airplane Company, Mail Stop 77-76	P.O. Box 3707 Seattle, Washington 98124	X		
Boeing Computer Services	P.O. Box 24346 Seattle, Washington	*		
Bolt Beranek and Newman, Inc.	50 Moulton Street Cambridge, MA 02138	X		
California Department of Transportation	5900 Folsom Blvd. Sacramento, CA 95819	*	1	2
Center for Environmental Studies Argonne National Laboratory	9700 So. Cass Avenue Argonne, Illinois 60439	*		
Close, Jensen and Miller	449 Silas Deane Highway Wethersfield, Conn. 06109	X	1	

* Questionnaire was mailed without request to these organizations.

List of Companies Requesting and Returning the TSC Questionnaire (Continued)

Name	Address	TSC Questionnaire Requested	Number Returned Part I	Number Returned Part II
Community Research Associates, Inc.	245 Columbine Suite 206 Denver, Col. 80206	X		
Computer Science Corporation	1701 N. Fort Meyer Drive Arlington, Virginia 22209	*		
Computer Sciences Corporation	8728 Colesville Road Silver Spring, MD 20910	*		
CONSAD Research Corp.	121 No. Highland Avenue Pittsburgh, Penn. 15206	*		
Control Data Corp.	60 Hickory Drive Waltham, MA 02154	*		
Curran Associates, Inc.	182 Main Street Northampton, MA. 01060	X		
Dalton-Dalton-Little-Newport	3650 Warrensville Center Road Cleveland, Ohio 44122	*		
Delaware Valley Regional Planning Commission	Penn Towers Building 1819 J.F. Kennedy Blvd. Philadelphia, Penn. 19103	X		
Dept. of Atmospheric Sciences, University of Washington	Seattle, Washington	*	1	1
Dept. of Civil Engr., University of Tennessee	Knoxville, Tenn. 37916	X		
Dept. of Mechanical Engr., University of Wisconsin - Madison	1513 University Avenue Madison, Wisconsin 53706	*		
Doreen Pillie	P.O. Box 1887 Bellevue, Washington 98009	X		
Engineering - Science Air Quality Department	7903 Westpark Drive McLean, Virginia 22101	X		

* Questionnaire was mailed without request to these organizations.

List of Companies Requesting and Returning the
TSC Questionnaire (Continued)

Name	Address	TSC Questionnaire Requested	Number Returned Part I	Number Returned Part II
Environmental Research & Technology	429 Marett Road Lexington, MA	*		
Environmental Research & Technology, Inc.	696 Virginia Road Concord, MA 01742	X	2	6
Environmental Science and Engineering, Inc.	P.O. Box 13454 University Station Gainesville, FL 32604	X		
ESL, Inc.	495 Java Drive Sunnyvale, CA 94086	*		
Euclid Research Group	1760 Solano Avenue Berkeley, CA 94707	*		
GCA/Technology Division	Burlington Road Bedford, MA 01730	*		1
General Research Corp. Systems Research Division	P.O. Box 3587 Santa Barbara, CA 93105	*		
GEOMET, Inc.	50 Monroe Street Rockville, MD 20850	*		
GEOMET, Inc.	15 Firstfield Road Gaithersburg, MD 20760	X		
Grumman Aerospace Corporation	Bethpage, NY 11714	*		
Harbridge House, Inc.	Eleven Arlington Street Boston, MA 02116	X		
H. E. Cramer Co., Inc.	P.O. Box 8049 Salt Lake City, Utah 84108	X		
Houston Galveston Area Council	P.O. Box 22777 3701 West Alabama Houston, TX 77027	X		

* Questionnaire was mailed without request to these organizations.

List of Companies Requesting and Returning the
TSC Questionnaire (Continued)

Name	Address	TSC Questionnaire Requested	Number Returned Part I	Number Returned Part II
Hydroscience Environmental Systems	9041 Executive Park Drive Suite 226 P.O. Box 11685 Knoxville, TN 37919	X		
IBM-FSD	18100 Frederick Pike Gaithersburg, MD	*		
INTERA	200 West Loop South Houston, TX 77027	*		
Kaman Sciences Corp.	P.O. Box 7463 Colorado Springs, Col. 80907	*		
KAPPA SYSTEMS, INC.	1409 Potter Drive Colorado Springs, Col. 80909	X		
Kenvirons, Inc.	State National Bank Bldg. Frankfort, KY 40601	X		
Lirbitran Associates Transportation Urbanistics	101 Park Avenue New York, NY 10017	X		
Lockheed Missile & Space Co., Analysis & Test Aero-Thermo-Dynamics	Sunnyvale CA	*		
Lockheed Missiles & Space Co., Huntsville Research & Engineering Center	4800 Bradford Drive Huntsville, AL 35807	*	1	
Mathematical Sciences North West, Inc.	P.O. Box 1887 Bellevue WA 98009	*	1	
Midwest Research Institute	425 Volker Blvd. Kansas City, MO 64110	X		
Ministry of the Environment	135 St. Clair Street Suite 100 Toronto, Ontario Canada M4V 1P5	*	1	

* Questionnaire was mailed without request to these organizations.

List of Companies Requesting and Returning the TSC Questionnaire (Continued)

Name	Address	TSC Questionnaire Requested	Number Returned Part I	Number Returned Part II
MSA Research Corp.	Laboratory & Plant Evans City, PA 16033	*	1	1
Mt. Auburn Research Associates, Inc.	385 Elliot Street Newton, MA 02164	*		
Multisystems, Inc.	1050 Mass. Avenue Cambridge, MA 02138	*		
Northern Research and Engineering Corp.	219 Vassar Street Cambridge, MA 02134	*	1	1
NUS Corporation	4 Research Place Rockville, MD 20850	X		
Pacific Environmental Services, Inc.	P.O. Box 25925 W. Los Angeles, CA 90025	*	1	
Pandullo Quirk Associates	Gateway "80" Office Park Wayne, NJ 07470	X	1	
Parsons, Brinckerhoff, Quade, Douglas, Inc.	One Penn Plaza 250 West 34th Street New York, NY 10001	*	1	3
Peat, Marwick, Mitchell & Company	1025 Connecticut Avenue, N.W. Washington, D.C. 20036	X		
Potomac Research, Inc.	7655 Old Springhouse Road Westgate Research Park McLean, Virginia 22101	X		
Potomac Scheduling	6400 Goldsboro Road Washington, D.C. 20034	X		
QEI Incorporated	119 The Great Road Bedford, MA 01730	X		
Raytheon Service Co.	2 Wayside Raod Box 503 Burlington, MA 01803	X		
Resource Management Associates	3706 Mt. Diablo Blvd. Suite 200 Lafayette, CA 94549	X		

* Questionnaire was mailed without request to these organizations.

List of Companies Requesting and Returning the TSC Questionnaire (Continued)

Name	Address	Requested	TSC Questionnaire Number Returned Part I	Part II
Resource Science, Inc.	228 N. Cascade Avenue Suite 101 Colorado Springs, Col. 80903	*		
R J Associated	1018 Wilson Blvd. Arlington, VA 22209	X		
Rockwell International Atomics International Division	2421 W. Hillcrest Drive Newbury Park, CA 91320	X		
San Diego State University, San Diego State University Foundation	San Diego, CA 92182	X		
Science Applications, Inc.	1200 Prospect Street P.O. Box 2351 La Jolla, CA 92038	X		
Scott Environmental Technology, Inc.	Plumsteadville, PA 18949	X	1	1
Seton, Johnson & Odell, Inc.	317 S. W. Alder Street Portland, Oregon 97204	X		
Shell Engineering and Associates	1113 Fay Street Columbia, Missouri 65201	X		
Stanford Research Institute	Menlo Park, CA 94025	*	3	3
Stanford Research Institute, Contract Relations	333 Ravenswood Avenue Menlo Park, CA 94025	X		
System Sciences, Inc.	P.O. Box 2345 Chapel Hill, No. Carolina 27514	X		
Systems Applications, Inc.	9418 Wilshire Blvd. Beverly Hills, CA 90212	*		

* Questionnaire was mailed without request to these organizations.

List of Companies Requesting and Returning the
TSC Questionnaire (Continued)

Name	Address	TSC Questionnaire Requested	Number Returned Part I	Number Returned Part II
Systems Applications, Inc.	950 Northgate Drive San Rafael, CA 94903	X	1	
Systems Control, Inc.	1801 Page Mill Road Palo Alto, CA 94304	*		
Systems Science & Software	P.O. Box 1620 La Jolla, CA 92037	*		
Systems Technology Corporation	245 North Valley Raod Xenia, Ohio 45385	*		
Technology Inc., Instruments & Controls Division	P.O. Box 3036 Overlook Branch Dayton, Ohio 45431	X		
Technology Service Corporation	225 Santa Monica Blvd. Santa Monica, CA 90401	*		
Texas Instruments, Inc.	13500 No. Central Expressway Dallas, Texas	*		
The Center for the Environment & Man, Inc.	275 Windsor Street Hartford, Conn. 06129	X		
The Center for the Environment & Man, Inc.	275 Windsor Street Hartford, Conn. 06120	*		
The Pennsylvania State University	Research Building B University Park, PA 16802	X		
The Rand Corporation	2100 M Street, N.W. Washington, D.C. 20037	X		
The University of Oklahoma	1000 Asp Avenue Room 314 Norman, Oklahoma 73019	X		
TRC/The Research Corporation of New England	210 Washington Street Hartford, Conn. 06106	*		

* Questionnaire was mailed without request to these organizations.

List of Companies Requesting and Returning the TSC Questionnaire (Continued)

Name	Address	TSC Questionnaire Requested	Number Requested Part I	Number Requested Part II
TRW Inc., Mail Stop: Building R4/1136, Energy Systems Group	One Space Park Redondo Beach, CA 90278	*	1	
Vogt, Sage & Pflum Consultants	222 East Central Parkway Cincinnati, Ohio 45202	X		
Walden Research Corporation	359 Allston Street Cambridge, MA 02139	*		
Walden Research Division of Abcor, Inc.	850 Main Street Wilmington, MA 01887	*		
Wapora, Inc.	211 East 43rd Street New York, NY 10017	X		
Weiner & Associates, Inc.	1100 East 16th Avenue Denver, Colorado 80218	*		
Westinghouse Electric Corporation, Research & Development Center	Beulah Raod Pittsburgh, PA 15235	*		
Xonics, Inc.	6837 Hayvenhurst Avenue Van Nuys, CA 91406	*	1	
York Research Corp.	One Research Drive Stamford, CT 06906	X		

* Questionnaire was mailed without request to these organizations.

U.S. DEPARTMENT OF TRANSPORTATION

TRANSPORTATION SYSTEMS CENTER
KENDALL SQUARE
CAMBRIDGE, MASSACHUSETTS 02142

In reply
refer to: 622

Dear

Because of your past participation in the TSC Technology for Environmental Analysis Program, you are invited to assist the Center in preparing a detailed technical survey of Transportation Source Air Pollution Dispersion Models and Transportation Air Pollution Data.

TSC is interested in the up-to-date specifications of your operating computer programs developed for, or readily adapted to, the modeling of transportation-source air pollution. The Center also solicits information about measured air quality data which you may have acquired in the vicinity of transportation systems (such as highways, airports and railyards) for inclusion in this survey.

A general invitation for firms to participate in the preparation of this survey will appear in a forthcoming Commerce Business Daily Announcement.

As you know, TSC acts as advisor to the Office of the Secretary of Transportation, the DOT operating administrations, EPA, state departments of transportation and other agencies on questions relating to the analysis of transportation-generated air pollution. In this capacity, TSC intends to widely circulate this survey among Federal, regional, state and local agencies concerned with transportation-source air pollution.

The Center will only consider information submitted on TSC questionnaire MD-01, a copy of which is enclosed for your use. Completed questionnaires should be mailed to me at:

U.S. Department of Transportation
Transportation Systems Center, Code 622
Kendall Square
Cambridge, MA 02142

The closing date for mailing completed questionnaires to TSC is September 17, 1976.

You are asked to state that the information submitted on questionnaires is not proprietary and to agree that the Government is free to make any use of said information it deems appropriate, including publication with proper acknowledgements in Government technical reports.

This is not a request for proposal. However, you will be considered if and when future requests for proposals are solicited. No formal evaluation of the material furnished in your questionnaires will be furnished.

Your continued participation in the TSC transportation air pollution analysis program is greatly appreciated.

Sincerely,

Eugene M. Darling, Jr.
Chief, Data Technology Branch

Enclosure:
Questionnaire MD-01

U.S. DEPARTMENT OF TRANSPORTATION

TRANSPORTATION SYSTEMS CENTER
KENDALL SQUARE
CAMBRIDGE, MASSACHUSETTS 02142

In reply
refer to: 622

Dear

The questionnaire MD-01 which you requested in response to our Commerce Business Daily announcement of is enclosed.

Thank you for your interest in furnishing the Government with information about your air pollution models and/or data.

Please mail the completed questionnaire(s) to me no later than

Sincerely,

Eugene M. Darling, Jr.
Chief, Data Technology Branch

Enclosures

U.S. Department of Transportation

Transportation Systems Center

Cambridge, Massachusetts 02142

Transportation Air Pollution Model and Data Questionnaire MD-01

O.M.B. No. 004-S76008

Firm Name:

Firm Address:

Principal Investigators: Phone:

INSTRUCTIONS

This questionnaire consists of two parts: Part I, Transportation Source Air Pollution Dispersion Model, and Part II, Transportation Air Pollution Data. Each part may be filed separately. Please report on only one model in each Part I filed and on only one data sample in each Part II.

Much of the information called for in this questionnaire only requires the checking of appropriate choices under the various subject headings. It is estimated that the entire questionnaire can be completed in 1 to 2 hours. Where narrative information is requested, your response should be typed in the space provided. A sample completed Part I for the TSC/EPA model is furnished for your guidance. The narrative responses in this sample are at the desired level of detail.

You have been assigned model code I – 18 and data code II– 18. If you are reporting on more than one model, identify the first by your model code followed by A, the second by our model code followed by B, etc. Use the same procedure if you are reporting on more than one data sample.

Please enter the appropriate code in the space provided at the top of each page of the questionnaire.

Supplementary material is not required, but may be submitted at your option. However, such material will only be considered if accompanied by a completed questionnaire.

No formal evaluation of the information submitted on questionnaires will be furnished by the Government. The deadline for mailing model questionnaires is

DISCLAIMER

____ hereby states that the
Firm Name

information contained in the attached Part(s) I and/or II of questionnaire(s) MD-01 is not proprietary and further agrees that the Government is free to make any use of said information it deems appropriate, including publication with proper acknowledgements in Government technical reports.

____ _______________
Signature Date

____
Title

Model Code: I ______

DOT/TSC MD-01/1
O.M.B. No. 004-S76008

TRANSPORTATION AIR POLLUTION MODEL AND DATA QUESTIONNAIRE

PART I

TRANSPORTATION SOURCE AIR POLLUTION DISPERSION MODEL

I. GENERAL DESCRIPTION OF THE MODEL

A. Model Name:

B. Model Type:

_____ Gaussian

_____ Puff

_____ Plume

_____ Modified, explain:

_____ Conservation of Mass (Numerical)

_____ Other, explain:

C. Basic Equation (define model parameters):

I. GENERAL DESCRIPTION OF THE MODEL (continued)

D. Pollutants

_____ CO, units:

_____ HC, units:

_____ NOx, units:

_____ SOx, units:

_____ Particulates, units:

_____ Aerosols, units:

_____ Photochemical oxidants, units:

_____ Ozone, units:

_____ Lead, units:

_____ Other, list:

E. Other General Information

II. IMPLEMENTATION OF THE MODEL

A. Status

Is the model implemented in a working computer program?

_____ Yes

_____ No

_____ Other, explain:

B. In its existing form can the program be directly used for modeling air pollution from transportation sources?

_____ Yes

_____ No

_____ Other, explain:

C. Unique Features of the Model

II. IMPLEMENTATION OF THE MODEL (continued)

D. When was the model last used to calculate air pollution from a transportation source and for what type of project?

III. TRANSPORTATION SOURCES ACCOMMODATED

Highways

_____ Single lane

_____ Multiple lane

_____ Multiple lane with median strip

_____ Multiple highways

_____ Rising/descending road

_____ At-grade

_____ Elevated

_____ Viaduct

_____ Depressed

_____ Curved roads

_____ Other, specify:

III. TRANSPORTATION SOURCES ACCOMMODATED (continued)

Airports

_____ Gates

_____ Taxi Strips

_____ Runways

_____ Aircraft Mix

_____ Aircraft Operating Modes

_____ Service Vehicles

_____ Access Roads

_____ Parking Lots

_____ Power Plants

IV. MODEL INPUT

A. Emission

1. Highway

_____ Traffic Distribution

_____ Entire Road

_____ By Lane

_____ By Direction

_____ Other, specify:

Model Code: I _____

IV. MODEL INPUT

A. Emission

1. Highway (continued)

_____ Traffic Estimates

_____ Average Daily Traffic

_____ Average

_____ Hourly

_____ Other, specify:

_____ Vehicle Mix

_____ % Heavy Duty Vehicles

_____ % Buses, separately

_____ % Trucks, separately

_____ Age Distribution

_____ Other, specify:

IV. MODEL INPUT

A. Emission Computations

1. Highway (continued)

_____ Year Being Analyzed

_____ Traffic Speed

_____ Entire road

_____ By lane

_____ By direction

_____ Other, specify:

_____ Emission Factors

_____ EPA, national, specify:

_____ State, specify:

_____ Other, specify:

IV. MODEL INPUT

A. Emission Computations

1. Highway (continued)

_____ Other Factors, specify:

_____ Emission Equation or Model, specify:

2. Airport

_____ Aircraft Activity

_____ By hour

_____ By day

_____ By month

_____ By year

_____ Other, specify:

_____ Aircraft Classification

_____ By type

_____ None used

_____ Other, specify:

IV. MODEL INPUT

A. Emission Computations

2. Airport (continued)

____ Aircraft Operational Mode

____ Start-up

____ Idle

____ Shutdown

____ Taxi

____ Delay

____ Aircraft Operational Mode

____ Landing

____ Take-off

____ Approach

____ Climb-out

____ Other, specify:

____ Automobile Traffic Estimates (within airport)

____ Average Daily Traffic

____ Average Hourly Traffic

____ Average per passenger

____ Other, specify:

IV. MODEL INPUT

A. Emission Computations

2. Airport (continued)

_____ Vehicle Mix (within airport)

_____ % Heavy Duty Vehicles

_____ % Buses, separately

_____ % Trucks, separately

_____ Age Distribution

_____ Other, specify:

_____ Additional Airport Emission Sources

_____ Service & Auxilary Vehicles

_____ Type

_____ Operational mode

_____ Other, specify:

_____ Additional Airport Emission Sources

_____ Heating plant

_____ Fuel type

_____ Rating

_____ Operating cycle

_____ Other, specify:

IV. MODEL INPUT

A. Emission Computations

2. Airport (continued)

____ Fuel Storage Facility

____ Nearby Airport Surroundings

____ Roadways

____ Other, specify:

____ Other, specify:

3. Other, specify:

IV. MODEL INPUT (continued)

B. Meteorological Data

_____ Surface Wind

_____ Wind Rose

_____ Seasonal

_____ Annual

_____ Other, specify:

_____ Wind Speed

_____ Mean, period:

_____ Measured, frequency:

_____ Other, specify:

_____ Wind Direction

_____ Mean, period:

_____ Measured, frequency:

_____ Other, specify:

_____ Wind Variability, specify:

IV. MODEL INPUT

B. Meteorological Data (continued)

_____ Other, specify:

_____ Winds Aloft, What Levels:

_____ Use Surface Wind

_____ Wind Rose

_____ Seasonal

_____ Annual

_____ Other, specify:

_____ Wind Speed

_____ Mean, period:

_____ Measured, frequency:

_____ Other, specify:

IV. MODEL INPUT

B. Meterorological Data (continued)

_____ Wind Direction

_____ Mean, period:

_____ Measured, frequency:

_____ Other, specify:

_____ Wind Variability, specify:

_____ Wind Shear, specify:

_____ Other, specify:

_____ Cloud Cover

_____ Surface Paramenters

_____ Temperature

_____ Pressure

_____ Relative Humidity

_____ Dew Point

IV. MODEL INPUT

B. Meteorological Data (continued)

_____ Other, specify:

_____ Aloft, what levels:

_____ Temperature

_____ Pressure Height

_____ Relative Humidity

_____ Other, specify:

_____ Stability Class

_____ How determined:

_____ Number of classes:

_____ Mixing Height

_____ Other, specify:

V. MODEL SOFTWARE

A. Programming Language

_____ FORTRAN IV

_____ PL/1

_____ Other, specify:

B. Lines of Source Code

_____ <1000

_____ 1000 - 1999

_____ 2000 - 3000

_____ >3000

C. Mode of Operation

_____ Batch

_____ Time Share, specify:

_____ Interactive, specify:

_____ Other, specify:

VI. MODEL HARDWARE

A. Computer:

B. Computer Word Size

_____ bits per byte
number

_____ bytes per work
number

C. Program Memory Requirements

_____ < 100K bytes

_____ 100K - 199K bytes

_____ 200K - 300 bytes

_____ > 300K bytes

D. Program Plus Operating Systems Memory Requirements

_____ ≤ 128K bytes

_____ 129K - 256K bytes

_____ 257K - 512 bytes

_____ > 512K bytes

VI. MODEL HARDWARE (continued)

E. Peripheral Equipment Requirements

_____ Card Reader

_____ Card Punch

_____ Line Printer

_____ Disk Drive, how many:

_____ Magnetic Tape Drive, how many:

_____ Drum, how many:

_____ Plotter, how many, specify:

_____ Other, specify:

VII. MODEL OUTPUT

A. Output Format

_____ Receptor Points

_____ Fixed, describe (distances, heights, etc.):

_____ Selectable, describe:

VII. MODEL OUTPUT

A. Output Format (continued)

_____ Fixed Grid Interval, describe:

_____ Variable Grid Interval, describe:

_____ Contour map, describe:

_____ Other, describe:

B. Averaging Interval of Output

_____ Yearly

_____ Seasonally

_____ Monthly

_____ Daily

_____ 8-hourly

_____ Hourly

_____ Other, specify:

VII. MODEL OUTPUT (continued)

C. Output Form

_____ Tabular Data (attach sample, define terms). List output parameters:

_____ Graphical Data (attach sample).

_____ Line printer generated

_____ CRT plotter

_____ Other, specify:

D. Other Information About Output

VIII. MODEL APPLICATIONS

A. Air quality analysis as part of an environmental impact statement:

	Number of Analyses Performed, 1970-present	Locations
Highway		
Airport		
Other, specify:		

Comments:

VIII. MODEL APPLICATIONS (continued)

B. Air quality analysis of proposed or existing transportation system (but not part of an environmental impact statement).

	Number of Analyses Performed, 1970-present	Locations
Highway		
Airport		
Other, specify:		

Comments:

VIII. MODEL APPLICATIONS (continued)

C. Analysis to determine the impact on air quality of:

	Number of Analyses Performed, 1970-present	Locations
(1) Traffic Control Strategies		
(a) Highway		
(b) Airport		
(c) Other, specify:		
(2) Vehicle Pollution Control		
(a) Motor vehicles		
(b) Aircraft		
(c) Other, specify:		

VIII. MODEL APPLICATIONS

C. Analysis to determine the impact on air quality of: (continued)

(3) Other, specify:

Comments:

D. Microscale air quality analysis of a transportation system as part of a regional air quality analysis.

	Number of Analyses Performed, 1970-present	Locations
Highway		
Airport		

VIII. MODEL APPLICATIONS

D. Microscale air quality analysis of a transportation system as part of a regional air quality analysis. (continued)

Other, specify:

Comments:

E. Other type ot analysis, specify:

IX. COMPUTATIONS

In order to provide a rough indication of the operating speed and the cost of running the model, describe a typical problem that has previously been run and supply the information requested.

A. Typical Problem:

B. Computation Specifications for this Problem

CPU time:

Running time:

Cost of run:

Computer:

Personnel (set up, run, interpretation, etc.):

IX. COMPUTATIONS (continued)

C. Other pertinent information on computations

X. MODEL VALIDATION

Has the model been validated with real-world data? If so, indicate the period of time, sample size, geographical area, site geometry, and the results of such validations. Indicate what performance measures were used (e.g., mean absolute error, correlation coefficient, etc.). Attach pertinent publications or name references.

XI. MODEL COMPARISONS

Have the model predictions been compared with those of other dispersion models? If so, describe the results of such comparisons. What comparison measures were used? Attach pertinent publications or name references.

XII. MODEL AVAILABILITY

Is the computer program for this model in the public domain?

_____ Yes

_____ No

A. If yes, check the appropriate option.

The following can be obtained from:

Name:

Address:

_____ A deck of cards, cost: $ _________

_____ A listing, cost: $ _________

_____ A users manual, cost: $ _________

_____ Other, specify item and cost:

_____ The model is available on a time sharing computer system. Give name, address, how to access, cost, etc.:

XII. MODEL AVAILABILITY

Is the computer program for this model in the public domain? (continued)

B. If no, check the appropriate option:

_____ The model is proprietary and can only be accessed via a contract with this company.

_____ The model is under development and is expected to be available to the public in ______________________.
(month) (year)

_____ Other, specify:

Data Code: II ____

DOT/TSC MD-01/31
O.M.B. No. 004-S76008

TRANSPORTATION AIR POLLUTION MODEL AND DATA QUESTIONNAIRE

PART II

TRANSPORTATION AIR POLLUTION DATA

1. Project Name:

2. Sponsor:

3. Starting data of measurements:

4. Completion data of measurements:

5. Site Information (Check all that apply):

____ Single Highway

____ At grade ____ Cut ____ Elevated ____ Fill ____ Other, specify:

____ Multiple Highway

____ At grade ____ Cut ____ Elevated ____ Fill ____ Other, specify:

____ Complex Interchange

____ City street

____ Airport

____ Other, specify:

6. Approximate number of measured data points

Number of

_____ Receptors

_____ Grid points

_____ Vertical levels. What levels:

_____ Measurements per _____ hour _____ day _____ week _____ other:

_____ Total measurements

7. Data Acquired

a. Pollutant

_____ CO

_____ HC

_____ NOx

_____ SOx

_____ Particulates

_____ Aerosols

_____ Photochemical oxidants

_____ Ozone

_____ Lead

_____ Other, specify:

7. Data Acquired (continued)

b. Highway

_____ Average Daily Traffic

_____ Hourly

_____ Other, specify:

Airport

_____ Aircraft

_____ Service Vehicles

_____ Access Vehicles

_____ Other

Other, specify:

8. Data Availability

Are these data currently available?

_____ Yes

_____ No

If not, when will data become available?

Cite name and address where data can be obtained now or in the future:

Comments:

Model Code: I ________

DOT/TSC MD-01/1
O.M.B. No. 004-S76008

S A M P L E

TRANSPORTATION AIR POLLUTION MODEL AND DATA QUESTIONNAIRE

PART I

TRANSPORTATION SOURCE AIR POLLUTION DISPERSION MODEL

I. GENERAL DESCRIPTION OF THE MODEL

A. Model Name:

B. Model Type:

__X__ Gaussian

____ Puff

____ Plume

__X__ Modified, explain:

____ Conservation of Mass (Numerical)

____ Other, explain:

C. Basic Equation (define model parameters):

This concentration due to a single line source at a receptor is given by:

$$C(R) = \int_{0}^{L} Q_s \, P_R(\ell) d\ell$$

Where:

$C(R)$ is the concentration at receptor R
L is the length of the line source
Q_s is the line source strength

$P_R(\ell)$ is the concentration produced at R by a unit strength point source located a distance ℓ from the end of the line source.

To compute the integral, the Model divides the line source into smaller line source segments and computes the sum of the contributions of each segment to the pollutant concentration at the receptor. The line source is divided into progressively greater numbers of smaller line source segments until successive calculated values of pollutant concentration seem to have coverged. The contribution from each small line source segment is calculated by the trapezoidal rule, which approximates the contribution to the integral by a small line source segment as the average of the contributions of point sources located at each end of the segment. Thus, the above equation becomes:

$$C(R) = \frac{Q_s}{N}\left[\frac{P_R(0) + P_R\left(\frac{L}{N}\right)}{2} + \frac{P_R\left(\frac{2L}{N}\right) + P_R\left(\frac{L}{N}\right)}{2} + \cdots\right] + E_N$$

$$= \frac{Q_s}{N}\left[\frac{1}{2} P_R(0) + \sum_{i=1}^{N=1} P_R\left(\frac{iL}{N}\right) + \frac{1}{2} P_R(L)\right] + E_N$$

Where

N is the number of line source segments of length $\frac{L}{N}$ into which the line source has been divided.

E_N is the error term (which decreases as N increases).

Thus, each step in the calculation of the concentration due to the line source is reduced to the calculation of the concentrations at the receptor due to N point sources. N is continually doubled until a covergence criterion is met.

To claculate the concentration at a receptor due to a point source, the Model uses the following equation adapted from the Workbook of Atmospheric Dispersion Estimates, Public Health Service Publication No. 999-AP-26, by D. Bruce Turner:

$$P_R(x,y,z,H) = \frac{1}{2\pi U\sigma_y\sigma_z}$$

$$\exp\left(\frac{-y^2}{2\sigma_y^2}\right)\left[\exp\left(\frac{-(z-H)^2}{2\sigma_z^2}\right) + \exp\left(\frac{-(z+H)^2}{2\sigma_z^2}\right) + \sum_{N=1}^{J} A(N)\right]$$

$$A(N) \triangleq \exp\left(\frac{-(z-H-2NL)^2}{2\sigma_z^2}\right) + \exp\left(\frac{-(z+H-2NL)^2}{2\sigma_z^2}\right)$$

$$+ \exp\left(\frac{-(z-H+2NL)^2}{2\sigma_z^2}\right) + \exp\left(\frac{-(z+H+2NL)^2}{2\sigma_z^2}\right)$$

Where:

P_R is the concentration at receptor R which is located at point (x,y,z) due to a unit point source of pollution located at point (0,0,H). {x is the downwind distance; y is the crosswind distance, z is the vertical distance}.

U is the wind speed.

σ_y a function of x, is the standard deviation of concentration in the crosswind direction.

σ_z a function of x, is the standard deviation of concentration in the vertical direction.

L is the height of the mixing layer.

J is chosen such that N=J is the first value of N such that A(N) is less than a given small constant.

This equation is a form of the standard Gaussian plume model of air pollution dispersion. The first exponential accounts for crosswind dispersion. The first z exponential gives the contribution of pollution directly from the source. The second z exponential gives the contribution of pollution which was reflected from the ground. The A(N) terms account for multiple eddy reflections from both the ground and the stable layer.

I. GENERAL DESCRIPTION OF THE MODEL (continued)

D. Pollutants

_X_ CO, units:

____ HC, units:

____ NOx, units:

____ SOx, units:

____ Particulates, units:

____ Aerosols, units:

____ Photochemical oxidants, units:

____ Ozone, units:

____ Lead, units:

____ Other, list:

E. Other General Information

The program can easily be altered to handle any non-reactive pollutant by the introduction of a scaling factor.

II. IMPLEMENTATION OF THE MODEL

A. Status

Is the model implemented in a working computer program?

__X__ Yes

_____ No

_____ Other, explain:

B. In its existing form can the program be directly used for modeling air pollution from transportation sources?

__X__ Yes

_____ No

_____ Other, explain:

C. Unique Features of the Model

The latest version of the TSC/EPA model has a maximum-seeking feature which automatically locates local maxima of pollutant concentrations associated with a highway complex.

:II. IMPLEMENTATION OF THE MODEL (continued)

D. When was the model last used to calculate air pollution from a transportation source and for what type of project?

The model was last used in 1974 to analyze the air pollution in the years 1980 and 1995 associated with a proposed complex highway interchange in Baltimore, Maryland.

III. TRANSPORTATION SOURCES ACCOMMODATED

Highways

_X_ Single lane

_X_ Multiple lane

_X_ Multiple lane with median strip

_X_ Multiple highways

_X_ Rising/descending road

_X_ At-grade

_X_ Elevated

____ Viaduct

_X_ Depressed

_X_ Curved roads

____ Other, specify:

III. TRANSPORTATION SOURCES ACCOMMODATED (continued)

Airports

____ Gates

____ Taxi Strips

____ Runways

____ Aircraft Mix

____ Aircraft Operating Modes

____ Service Vehicles

____ Access Roads

____ Parking Lots

____ Power Plants

IV. MODEL INPUT

A. Emission

1. Highway

__X__ Traffic Distribution

__X__ Entire Road

__X__ By Lane

__X__ By Direction

____ Other, specify:

IV. MODEL INPUT

A. Emission

1. Highway (continued)

__X__ Traffic Estimates

____ Average Daily Traffic

__X__ Average

__X__ Hourly , if available

__X__ Other, specify:

Peak hours assumed to be 10% of ADT; daytime off peak hours assumed to be 5% of ADT if hourly data not available

__X__ Vehicle Mix

__X__ % Heavy Duty Vehicles

____ % Buses, separately

____ % Trucks, separately

____ Age Distribution

____ Other, specify:

IV. MODEL INPUT

A. Emission Computations

1. Highway (continued)

__X__ Year Being Analyzed

__X__ Traffic Speed

__X__ Entire road

__X__ By lane

__X__ By direction

_____ Other, specify:

__X__ Emission Factors

_____ EPA, national, specify:

_____ State, specify:

__X__ Other, specify: This model has no built-in emission factors. These can be added in a subroutine or input directly. Values from the California Division of Highways Air Quality Manual CA-HWY-MR 657085(2)-72-10, April 1972 have often been used.

IV. MODEL INPUT

A. Emission Computations

1. Highway (continued)

_____ Other Factors, specify:

_____ Emission Equation or Model, specify:

2. Airport

_____ Aircraft Activity

_____ By hour

_____ By day

_____ By month

_____ By year

_____ Other, specify:

_____ Aircraft Classification

_____ By type

_____ None used

_____ Other, specify:

IV. MODEL INPUT

A. Emission Computations

2. Airport (continued)

_____ Aircraft Operational Mode

_____ Start-up

_____ Idle

_____ Shutdown

_____ Taxi

_____ Delay

_____ Aircraft Operational Mode

_____ Landing

_____ Take-off

_____ Approach

_____ Climb-out

_____ Other, specify:

_____ Automobile Traffic Estimates (within airport)

_____ Average Daily Traffic

_____ Average Hourly Traffic

_____ Average per passenger

_____ Other, specify:

IV. MODEL INPUT

A. Emission Computations

2. Airport (continued)

_____ Vehicle Mix (within airport)

_____ % Heavy Duty Vehicles

_____ % Buses, separately

_____ % Trucks, separately

_____ Age Distribution

_____ Other, specify:

_____ Additional Airport Emission Sources

_____ Service & Auxilary Vehicles

_____ Type

_____ Operational mode

_____ Other, specify:

_____ Additional Airport Emission Sources

_____ Heating plant

_____ Fuel type

_____ Rating

_____ Operating cycle

_____ Other, specify:

IV. MODEL INPUT

A. Emission Computations

2. Airport (continued)

_____ Fuel Storage Facility

_____ Nearby Airport Surroundings

_____ Roadways

_____ Other, specify:

_____ Other, specify:

3. Other, specify:

IV. MODEL INPUT (continued)

B. Meteorological Data

_X_ Surface Wind

____ Wind Rose

____ Seasonal

____ Annual

____ Other, specify:

_X_ Wind Speed

_X_ Mean, period: any desired, usually hourly

_X_ Measured, frequency: any, if available

_X_ Other, specify: analyses generally done for worst case of 1 mps

_X_ Wind Direction

_X_ Mean, period: same as wind speed

____ Measured, frequency: same as wind speed

____ Other, specify: analyses generally done for worst case of wind parallel to the roadway.

____ Wind Variability, specify:

IV. MODEL INPUT

B. Meteorological Data (continued)

_____ Other, specify:

_____ Winds Aloft, What Levels:

_____ Use Surface Wind

_____ Wind Rose

_____ Seasonal

_____ Annual

_____ Other, specify:

_____ Wind Speed

_____ Mean, period:

_____ Measured, frequency:

_____ Other, specify:

IV. MODEL INPUT

B. Meterorological Data (continued)

____ Wind Direction

____ Mean, period:

____ Measured, frequency:

____ Other, specify:

____ Wind Variability, specify:

____ Wind Shear, specify:

____ Other, specify:

____ Cloud Cover

____ Surface Paramenters

____ Temperature

____ Pressure

____ Relative Humidity

____ Dew Point

IV. MODEL INPUT

B. Meteorological Data (continued)

_____ Other, specify:

____ Aloft, what levels:

_____ Temperature

_____ Pressure Height

_____ Relative Humidity

_____ Other, specify:

_X_ Stability Class

_X_ How determined: Turner Workbook, 1969, Public Health Service Publ. No. 999-AP-26

_X_ Number of classes: 6

_X_ Mixing Height

_____ Other, specify:

V. MODEL SOFTWARE

A. Programming Language

__X__ FORTRAN IV

_____ PL/1

_____ Other, specify:

B. Lines of Source Code

__X__ <1000

_____ 1000 - 1999

_____ 2000 - 3000

_____ >3000

C. Mode of Operation

__X__ Batch

_____ Time Share, specify:

_____ Interactive, specify:

_____ Other, specify:

VI. MODEL HARDWARE

A. Computer:

B. Computer Word Size

__8__ bits per byte
number

__4__ bytes per work
number

C. Program Memory Requirements

__X__ < 100K bytes

_____ 100K - 199K bytes

_____ 200K - 300 bytes

_____ ≥ 300K bytes

D. Program Plus Operating Systems Memory Requirements

__X__ ≤ 128K bytes

_____ 129K - 256K bytes

_____ 257K - 512 bytes

_____ > 512K bytes

VI. MODEL HARDWARE (continued)

E. Peripheral Equipment Requirements

__X__ Card Reader

____ Card Punch

__X__ Line Printer

__X__ Disk Drive, how many: 2

____ Magnetic Tape Drive, how many:

____ Drum, how many:

__X__ Plotter, how many, specify: 1 CALCOMP. Separate routine exists for plotting predicted vs observed concentrations.

____ Other, specify:

VII. MODEL OUTPUT

A. Output Format

__X__ Receptor Points

____ Fixed, describe (distances, heights, etc.):

__X__ Selectable, describe: Input any desired number of x, y, z receptor coordinates.

VII. MODEL OUTPUT

A. Output Format (continued)

_____ Fixed Grid Interval, describe:

_____ Variable Grid Interval, describe:

_____ Contour map, describe:

_____ Other, describe:

B. Averaging Interval of Output

_____ Yearly

_____ Seasonally

_____ Monthly

_____ Daily

__X__ 8-hourly An average of 1 peak hour and 7 daytime off peak hours.

__X__ Hourly, generally the peak hour

_____ Other, specify:

VII. MODEL OUTPUT (continued)

C. Output Form

__X__ Tabular Data (attach sample, define terms). List output parameters:

__X__ Graphical Data (attach sample).

_____ Line printer generated

__X__ CRT plotter

_____ Other, specify:

D. Other Information About Output

VIII. MODEL APPLICATIONS

A. Air quality analysis as part of an environmental impact statement:

	Number of Analyses Performed, 1970-present	Locations
Highway	1	Baltimore, MD
Airport		
Other, specify:		

Comments:

A complex interchange was analyzed. Model had to be modified to accommodate rising and descending ramps in order to perform analyses of CO concentrations in 1980 and 1995.

VIII. MODEL APPLICATIONS (continued)

B. Air quality analysis of proposed or existing transportation system (but not part of an environmental impact statement).

	Number of Analyses Performed, 1970-present	Locations
Highway	5	Baltimore, MD
Airport		
Other, specify:		

Comments:

Analyses of CO concentrations in 1978 were performed for a complex interchange, urban main streets with and without intersecting streets, an urban highway and a parkway. In order to conduct these studies, the model had to be modified to handle multiple roadways.

VIII. MODEL APPLICATIONS (continued)

C. Analysis to determine the impact on air quality of:

	Number of Analyses Performed, 1970-present	Locations
(1) Traffic Control Strategies		
(a) Highway		
(b) Airport		
(c) Other, specify:		
(2) Vehicle Pollution Control		
(a) Motor vehicles		
(b) Aircraft		
(c) Other, specify:		

VIII. MODEL APPLICATIONS

C. Analysis to determine the impact on air quality of: (continued)

(3) Other, specify:

Comments:

D. Microscale air quality analysis of a transportation system as part of a regional air quality analysis.

	Number of Analyses Performed, 1970-present	Locations
Highway		
Airport		

VIII. MODEL APPLICATIONS

D. Microscale air quality analysis of a transportation system as part of a regional air quality analysis. (continued)

Other, specify:

Comments:

E. Other type of analysis, specify:

IX. COMPUTATIONS

In order to provide a rough indication of the operating speed and the cost of running the model, describe a typical problem that has previously been run and supply the information requested.

A. Typical Problem: The geometric set-up consisted of a four lane highway (2 lanes per direction) with three receptors located on each side. The problem is to compute the CO concentrations at the 3 downwind receptors for 220 cases. (A Case is a complete set of input parameters for a particular hour.)

B. Computation Specifications for this Problem

CPU time: 2300 secs.

Running time: 2400 secs.

Cost of run:

Computer: $470 (Based on $700/hr.)

Personnel (set up, run, interpretation, etc.): $600 (Based on 40 man-hours, $15/hr.)

Model Code: I _____

IX. COMPUTATIONS (continued)

C. Other pertinent information on computations

The cost of running the model for multiple cases (as here) is quite high because the program has not been optimized for this situation. With a simple modification of the computation algorithm, it would be possible to reduce the running time by at least an order of magnitude.

X. MODEL VALIDATION

Has the model been validated with real-world data? If so, indicate the period of time, sample size, geographical area, site geometry, and the results of such validations. Indicate what performance measures were used (e.g., mean absolute error, correlation coefficient, etc.). Attach pertinent publications or name references.

Since air quality data suitable for model validation have not yet been available to the Center, it has not been possible to validate the model. However, the Center has developed the Transportation Air Pollution Studies (TAPS) System, a package of computer programs for storing, manipulating and retrieving air quality data, coupled to routines for analyzing the performance of dispersion models with a wide variety of performance measures. The TAPS System is described in Report No. DOT-TSC-OST-73-24. This System will be used to test the model as soon as suitable air quality data are received.

XI. MODEL COMPARISONS

Have the model predictions been compared with those of other dispersion models? If so, describe the results of such comparisons. What comparison measures were used? Attach pertinent publications or name references.

The TSC/EPA model has been compared with 12 other highway air pollution dispersion models, using the input parameters of a portion of the Airedale data from Washington, D.C. The following distance measures were calculated for the output of all 13 models in pairs: The average absolute difference, the 80th percentile difference and the correlation coefficient. Clusters of model predictions were formed by defining cluster diameters for each of the distance measures and determining which pairs of models had prediction distances less than these diameters for each measure separately and for all measures combined. Five models were found to cluster consistently and these were defined as consensus modelels. The TSC/EPA model was a member of this consensus group.

This work is reported in the forthcoming publication, Highway Air Pollution Modeling: A Preliminary Evaluation of Thirteen Models by Eugene M. Darling, Jr., David S. Prerau, Paul J. Downey and Peter H. Mengert.

XII. MODEL AVAILABILITY

Is the computer program for this model in the public domain?

__X__ Yes

_____ No

A. If yes, check the appropriate option.

The following can be obtained from:

Name: Eugene M. Darling, Jr.

Address: U.S. Department of Transportation
Transportation Systems Center, Code 622
Kendall Square
Cambridge, MA 02142

__X__ A deck of cards, cost: $ __0__

__X__ A listing, cost: $ __0__

__X__ A users manual, cost: $ __0__

__X__ Other, specify item and cost:

At no cost, reports are available describing applications of the model.

_____ The model is available on a time sharing computer system. Give name, address, how to access, cost, etc.:

XII. MODEL AVAILABILITY

Is the computer program for this model in the public domain? (continued)

B. If no, check the appropriate option:

_____ The model is proprietary and can only be accessed via a contract with this company.

_____ The model is under development and is expected to be available to the public in _______________ (month) _______________ (year).

_____ Other, specify: