A TRANSPORTATION APPROACH TO URBAN DIFFUSION MODELING

by

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Thesis submitted to the Graduate Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

in

Civil Engineering

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August 1976

Blacksburg, Virginia

ACKNOWLEDGEMENTS

Appreciation is expressed to the committee chairman, Dr. N. Thomas Stephens, and members of the committee, Dr. Jamie W. Hurley and Dr. Robert J. Popper for their assistance during this research.

In addition, appreciation is also expressed to the Virginia State Air Pollution Control Board for financial support of this project.

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I. INTRODUCTION

Changes in future urban transportation policies will have an impact on the air quality of the entire urban area. These policies have a direct effect on traffic volume, miles traveled, and vehicle operating characteristics. With the legislation of the National Environmental Policy Act of 1969, it has become necessary to develop a quantitative method of analyzing both the present and future transportation systems' impact on the entire urban area. Furthermore, legislation such as the Clean Air Act has a direct effect on transportation policy implementation. Such Legislation restricts the amount of impact a transportation system may have on the urban environment. The purpose of this study is to create a analytical tool which will combine the transportation planning process with traffic-related pollutant modeling at the mesoscale level.

Urban Diffusion Modeling

There exist a number of analytical models that will permit the assessment of the impact of transportation systems on entire urban areas. The APRAC-1A urban diffusion model computer program, developed by the Stanford Research

Institute, is one of the more advanced mesoscale models for non-reactive pollutants. It uses carbon monoxide (CO) concentration as a measure of the impact of traffic on air quality. In an urban area, 90 to 96 percent of the CO may come from motor vehicles.<14> The inputs to this model are traffic distribution, level of emission, and meteorological data.

While the model as originally developed can be a very useful tool, a number of deficiencies have been discovered in the initial attempts to use it in generalized urban situations. The area of concern is mechanical in nature, involving the actual use of the computer program and procedures. Input procedure details are lacking. The program, with its vast input procedures, has become more of a headache rather than an effective tool to the environmental planner. With this problem in mind, an attempt will be made to reduce the complicated procedures and modeling problems. Basically, the APRAC-1A is the most powerful program of its kind. It is of great importance "to develop it further...rather than turn to less comprehensive alternatives."<8>

Another area where problems occur is the emission model. Test runs show that the emission simulation model in the APRAC-1A did not reflect peak-hour conditions. Also, the model as it exists does not reflect the most currently accepted EPA emissions model input.<19>

As one state official stated, "The APRAC-1A model needs to be revised, with particular attention given to emission factors."<8>

The need for an improvement in the emissions model is great if the model is to be considered reliable. However, one must keep in mind the complexity of many emission factor models. The rate-of-return might not be so great for the amount of computer time and sophistication required.

Transportation Planning

At the present time, the transportation simulation model input is rather crude and lacks sufficient resolution. In addtion the basic input data must be separately calculated and manually inserted. In order to incorporate a computerized transportation planning process into the mesoscale model, a model will have to be selected. This model would have to include as output the traffic data required as input into the mesoscale model. In addition, the input to the mesoscale model (APRAC-1A) would have to be direct. The data should ideally not be handled by the user between the two programming steps.

To meet these criteria, a traffic assignment model has been examined and incorporated into the model. The traffic assignment procedure is usually the final step in the transportation process. It is the procedure that takes "area-to-area trip movements" and loads them on the transportation network. The output from this type of model is the type of input APRAC-1A requires.

The combination of these two processes provides a very powerful and useful analytical tool. The applications of the tool are many. Each transportation policy may be compared with an alternitive policy with respect to environmental air quality impacts. Such policies include exculsive bus lanes, addition of extra lanes on a freeway, and the construction of a new roadway. This Transportation Air-Pollution Analysis Procedure (TAPAP) will be able to serve as a guide in selecting between different transportation policy alternatives. TAPAP is a major step forward in the this interdisciplinary field.

Objectives of the Study

In merging the traffic planning procedure with air quality mesoscale modeling, many obstacles have to be overcome, especially the coordination of the transportation field with the air pollution field. The primary goal of this study is to develop a sophisticated analytical tool that will accurately measure the impacts of different transportation policies on urban air quality in terms of CO.

The following list provides a set of specific objectives that are accomplished during this study:

1. Select a traffic assignment computer program model
2. Make modifications in the APRAC-1A computer program to facilitate input/output (I/O) procedures, and modify the emission rate submodel creating the computer program APRAC-Emission Model (APRAC-EM)
3. Merge the APRAC-EM diffusion model with the traffic assignment model programs to create the TAPAP computer program
4. Perform a case study using the city of Richmond, Virginia to illustrate the above modification and the versatility of the TAPAP computer program

In addition to these objectives, a review of all the current ideas and state-of-the-art techniques was performed.

II. STATE-OF-THE-ART IN MESOSCALE MODELING

Since the traffic-related air pollution model is a vital step in the TAPAP, the most current model needs to be selected. This chapter presents some of the so called "state of the art" diffusion models investigated. The capabilities and deficiencies of each diffusion model investigated are dicussed. Especially pertinent is the work done in mesoscale modeling.

After reviewing the state-of-the-art in mesoscale diffusion modeling, the reasons and basis for the selection of the APRAC-1A computer program model should be clear. The meteorological data required by APRAC-1A will be discussed along with user's experience with the program to point out problems associated with APRAC-1A. These problems will be addressed in order to perfect the TAPAP program.

Traffic-Related Diffusion Models

Most models in the field are concerned with diffusion modeling at the microscale. This modeling is used primarily for determining the air quality impact on the immediate vicinity surrounding a highway. The computer program model "HIWAY" is a prime example.<21> It estimates the CO diffusion within a 1000 foot area on each side of a highway.

It is usually employed for measuring a freeway's impacts on the environment. One problem exists: emission rates for CO are lower around freeways due to increased route speeds.<2> The California Department of Public Works, Division of Highways has developed a few mathematical diffusion models.<3> However, these models are not computer programs and mainly address the microscale.

At the mesoscale, FHWA's special area (SAPOLLUT) is a computer program of major importance in the determination of transportation-related pollutants.<15> The program estimates the amount of highway-related pollutants (CO, hydrocarbons, and nitrogen oxides) emitted by daily traffic volumes on a city's street system. The program contains a table of emissions factors, deterioration factors, speed adjustment factors, and hydrocarbon evaporative emission factors. The input to SAPOLLUT is the FHWA's historical record, which contains operation information describing an urban traffic network. (It is thoroughly discussed in chapter III.) Using the traffic operating characteristics and volumes, SAPOLLUT computes emission estimates by link, zone, and grid.

The major shortcoming of SALPOLLUT is in the area of CO concentrations. No concentrations are calculated, only total "burden" or CO emissions totals by area are produced. Another one of the shortcomings of this program is the great amount of computer time it requires.<15> Its resolution of carbon monoxide information was found inadequate in urban areas.<17> The APRAC-1A computer program methodology had to be employed to resolve this problem. With its grid analysis, the program was found adequate in finding critical areas around the urban area.

The APRAC-1A urban diffusion model is probably the only one of its kind in existence. There have been many attempts at modeling on the mesoscale level, but none have come close to modeling pollutant concentrations created by auto emissions on such a sophisticated scale. The APRAC-1A is, therefore, the only state-of-the-art model in use today that has all the major inputs required for traffic-related mesoscale modeling.<16> These are:

1. meteorological data
2. emission rates
3. traffic data

Walter F. Dabberdt of Stanford Research Institute explains the three objectives in mesoscale modeling as "(1) prediction of the absolute pollutant concentration attributable to a specific emission source, (2) prediction of relative changes in pollutant concentrations from changes in emission rates or meteorological conditions, and (3) combination of the first and second objectives."<7> The APRAC-1A computer model is the only existing computer model which meets objective two on the mesoscale.level.

User's Experience

The greatest complaint about the APRAC-1A urban diffusion model comes not from the model itself, but from the input-output (I/O). The APRAC-1A program requires input of both meteorological and traffic data. The problem arises when all these data have to be coded on cards, requiring that information for each section of roadway be coded, one card for each section. In Richmond, Virginia, there are over 3,000 of these roadway sections which would have to be coded. In addition, the meteorological data must be obtained manually and one card punched for each hour of the study. The user must allocate secondary traffic, though frequently the user does not have any expertise in traffic engineering. This is the traffic not found on the coded traffic network used by APRAC-1A. Many states such as Alabama have modified the program input procedures to cut down the manual effort. Alabama has stored its network on magnetic tape.<20> As George W. Ellis of the Alabama Highway Department states, "Additional automation is required to facilitate the use of models, particularly with respect to generating input for the models."<20>

The APRAC-1A emission submodel was found inaccurate in simulating traffic emission rates. The problem results from the process of categorizing speeds for each type of roadway (i.e., freeway, arterial, etc.). Each type of roadway is assigned a running speed for each hour of the day, except the peak hours. This speed is usually 0.85 of the average daily speed. Thus, the speed is not related to actual volumes. The Alabama Highway Department is conducting studies into using actual observed speeds.<8>

Another problem was presented by "cold starts." The CO emission rate is much greater during the "warmup" period for motor vehicles. A study is being conducted on the feasibility of using "work trips" as a criteria for calculating "cold start" emissions in the urban areas.<8> The significance of these "cold starts" as a contributing factor in the total urban CO concentration has not been fully determined. However, preliminary results have shown that "cold starts" do have some effect on the total urban concentration.

Meteorological Data

The meteorological data input to the APRAC-1A computer model consists of hourly surface observations (i.e., temperature, wind direction, and cloud cover). In addition, maximum and minimum temperatures are required. For planning purposes, the "worst case" situation should be used. The case where traffic is the heaviest and weather conditions are poor will determine whether the air quality standards will be met or violated. It might be mentioned that winds make a big difference in the amount of CO estimated at the receptor since CO concentration is inversely proportional to wind speed and wind direction determines CO transport direction. The wind direction in which the total vehicle miles of travel is greatest will generally be the direction with the highest concentrations. For a comparison between two alternatives, the APRAC-1A computer model must have the same input meteorological conditions.

Another meteorological input required by the APRAC-1A computer model is the upper air sounding (radiosonde) data. Pressure and temperature up to the 500-millibar level are needed. The APRAC-1A at present will read in these radiosonde data from Card Deck Format 505 of the National Climatic Center.<16> In 1973 the Alabama Air Pollution Control Commission recommended mixing depth (maximum and minimum depths) be supplied.<8> This would be in lieu of using the radiosonde data. These are seasonal averages determined by Holzworth for morning and afternoon mixing depths.<13> These mixing depths are quite likely just as accurate as the mixing depths calculated using radiosonde data. Most cities do not have soundings taken in their vicinity. In addition, only the 1200 Greenwich Mean Time (GMT) observation is used. This limitation necessitates some type of additional estimation procedure for full utility.

III. TRAFFIC ASSIGNMENT

A basic knowledge of the traffic assignment procedure is essential in understanding the TAPAP developed in this study. This chapter provides insight into the traffic assignment procedure used by transportation planners. It is important that air pollution analysts be familiar with this procedure in order to coordinate the environmental impacts with the transportation planner.

With the above knowledge and understanding of the traffic assignment procedure, the basis and criterion for the selection of the UROAD program is explained. Basic options, techniques, and I/O procedures found in UROAD are presented. Only the I/O required for TAPAP will be mentioned. Reference should be made to the *UTPS User's Manual* for the discussion of programming procedure.

The Transportation Network System

Before discussing the actual traffic assignment process, an explanation of the transportation network system would be helpful. For coding purposes, the actual physical roadways are represented by one-way sections. Each section usually lies between two intersections. An intersection exists where two or more roadway sections meet. These sections of roadway are commonly called "links." The intersection of two or more links is referred to as a "node." The direction of travel may be changed at these nodes. It might be noted that it takes two one-way links running parallel and in opposite directions to treat the case of a two-lane roadway. Each link is assigned a number for easy reference. Further, the rectangular coordinates of each node are recorded with respect to a reference point in the urban area. All major arterials, freeways, and feeder streets are coded for the urban area under study. Of course, money and resources limit resolution of the coding process.

Since each link represents an actual section of roadway in the transportation network system, information describing each section of the physical roadway and its capabilities must be coded. Travel time, average speed, distance, capacity, existing traffic volumes, and facility type are all important pieces of information which define the actual roadway section which the link represents. In addition, information pertaining to the intersection characteristics is very valuable. Such items include the permitted turns, the turning volumes, and maximum turning capacity (i.e., maximum amount of turns per hour).

Because the information needed to describe the network is so vast, the network must be put in a computer storage device. This information is usually formatted in a specific sequence called the historical record (figure 1). The historical record was developed specifically by the FHWA for network data being stored on computer I/O devices.<9> Raw data can be formatted by using the FHWA's BUILDHR program. <9>

The historical record was designed for easy information retrieval. Not all the information is required to describe the network system. However, the more data obtained, the greater the accuracy of the network. The historical record describes the entire transportation network system. It is this network system on which either the projected or the current traffic volumes are loaded.

Trip Matrices

The traffic assignment procedure employs "area to area" movements. It is usually the last step in the "four-step" transportation forecasting process. The steps include:

1. trip generation
2. modal split
3. trip distribution
4. traffic assignment

The first three steps involve complicated procedures in predicting trips to and from different areas in a city. These areas are referred to as traffic assignment zones. The entire urban area is divided into such zones. It is the

**INTERSECTION RECORD DATA FORMAT

*WORD1- BYTE O, LEG PRES. INDICATOR BITS. BYTES 1-3, A-NODE OF INTERSECTION.

*WORD2- BYTES 0-1, B-NODE CONNECTED TO AO. BYTES 2-3, B-NODE CONNECTED TO A1.

*WORD3- BYTES 0-1, B NODE CONNECTED TO A2. 2-3, B-NODE CONNECTED TO A3.

*WORD4- TURN PENALTIES. BYTE FOR 0 LEG 0, BYTE FOR 1 LEG 1, ETC.

*WORD5- BYTES 0-1, ORIGINAL A-NODE. BYTES 2-3, LEFT PORTION OF A-NODE X-COORDINATE.

*WORD6- BYTE O. A-NODE X-COORDINATE, CONTINUED. BYTES 1-3, A-NODE Y-COORDINATE.

** LINK RECORD FORMAT

*WORD1- BYTES 0-1, A-NODE AND LEG. BYTES 2-3, LEFT PORTION OF X-COORDINATE.

*WORD2- BYTE O. B-NODE X-COORDINATE CONTINUED. BYTES 1-3, B-NODE Y-COORDINATE.

*WORD3- BYTES 0-1, B-NODE, LEG, THIS LINK. BYTE 2 COND, COL 79. BYTE 3, COLUMN 80.

*WORD4- BYTE 0, COL 1, BYTES 1-3 CONTAINED COLUMNS 64 ADM CL, FUNC CL, TYPE FAC.

*WORD5- BYTES 0-3, COLS 67-70, SURF TYPE, TYPE AREA, PERDOMINANT LAND USE.

*WORD6- BYTES 0-3 CONTAINE COLUMNS 71-74, GEOGRAPHICAL LINK LOCATION.

*WORD7- BYTES 0-3 CONTAIN COLUMNS 75-78, ROUTE NUMBER.

*WORD8- BYTES 1-3 CONTAIN COUNT, A-TO-B.

*WORD9- BYTES 1-3 CONTAIN COUNT B-TO-A.

*WORD10- BYTES 0-1, HR/ADT, A-TO-B, COLS 29-31. BYTES 2-3, HRLY CAPACITY, A-TO-B.

*WORD11- BYTES 0-1, HR/ADT, B-TO-A, COLS 52-54. BYTES 2-3, HRLY CAPACITY, A-TO-B.

*WORD12- A-TO-B DATA, BYTE 1, COLUMN 40. BYTE 2, PARKING. BYTE 3, STREET WIDTH.

*WORD13- B-TO-A DATA, BYTE 1, COLUMN 63. BYTE 2, PARKING. BYTE 3, STREET WIDTH.

*WORD14- A-TO-B DATA. BYTES 0-1, UNLOADED TRAVELTIME. BYTES 2-3, DISTANCE.

*WORD15- B-TO-A DATA. BYTES 0-1, UNLOADED TRAVELTIME. BYTES 2-3, DISTANCE.

*WORD16- A-TO-B DATA. BYTES 0-1, OBSERVED SPEED. BYTES 2-3, OBSERVED TRAVELTIME. *WORD17- B-TO-A DATA. BYTES 0-1, OBSERVED SPEED. BYTES 2-3, OBSERVED TRAVELTIME.

Figure 1. The Historical Record Format

transportation planner who defines the boundaries of these zones.

From the transportation planning process, the number of trips originating from one zone which are destined for another zone can be estimated. The combinations of all interzonal trips are put into the form of an Origin-Destination (O-D) trip matrix (figure 2). Thus, the number of trips (t) originating in zone i destined for zone j may be found for any O-D zone pairs. The number of trips is usually expressed in Average Daily Traveled Volume (the average number of vehicles traveling between O-D zones in a day). The FHWA has created a "compressed" format of the matrix for specific use with tape and disk I/O devices.<11>

Traffic Assignment Procedure

The traffic assignment procedure loads the O-D trip matrix volumes on the transportation network system. Each traffic zone is incorporated into the network system by use of a zone "centroid." The centroid is contained within a zone's boundaries at a node. All trips coming into or leaving a zone pass through the centroid. Thus, each O-D zone pair is connected by a number of links, or routes, beginning at one zone's centroid and terminating at another zone's centroid.

The fundamental part of this procedure is the

		DESTINATION ZONES						
		1	2	3		j		n
ORIGIN ZONES	1	t_{11}	t_{12}	t_{13}				t_{1n}
	2	t_{21}	t_{22}					t_{2n}
	3	t_{31}	t_{32}					
	i					t_{ij}		t_{in}
	n	t_{n1}				t_{nj}		t_{nn}

Figure 2. O-D Trip Matrix

evaluation of the driver's choice of routes to complete interzonal trips. This route is found by calculating the path of least impedance between zones. This impedance must be quantified for numerical processing; it may be measured by travel time, distance or user cost. For example, consider the case where travel time is used as a measure of impedance. Using an algorithm (i.e., Moore's Algorithm), a "path" is traced from the original zone to the destination zone along a combination of links with the minimum amount of travel time. This path tracing proceeds from an origin zone to all destination zones. Through this procedure, a minimum time path"tree" is built for all zones.

Once the trees have been built, the trip volumes are assigned on the "paths" between O-D zones. Many methods of assignment exist; these are discussed in the UROAD program section. The "all-or-nothing" assignment loads the vehicles on the path of minimum impedance until one of the links reaches capacity. Once capacity has been reached on any link, no further trips are assigned to that path. The procedure is repeated for each path.

The trips are assigned by an iterative process. One portion of the total interzonal trips is assigned to the network at a time. The iterations continue until all trips have been assigned. In some cases, the trips will not all be assigned. This incomplete assignment usually happens when the "all-or-nothing" assignment method is used.

Traffic assignment procedure output is the directional loading of vehicles on each link in the network system. The Annual Daily Traffic (ADT) volumes are usually used to express the number of vehicles on each link during a 24-hour period. This is a brief explanation of the assignment procedure. It is intended to provide a foundation for discussion of the traffic assignment program UROAD.

Traffic Programs

The APRAC-1A program was designed to manually incorporate data generated from transportation planning programs. The traffic data required by APRAC-1A is the output coming from a traffic assignment computer program.

The integration of APRAC-1A with a traffic assignment program provides a planning tool for estimating envrionmental impacts of different transportation alternatives. The APRAC-1A diffusion model is only as accurate as the traffic information it receives. Therefore, an adequate and reliable traffic assignment program must be chosen. Only one program was found to meet this criteria. Most other assignment programs were found to have too many programming steps or not have the required output needed for the diffusion program model.

Traffic Assignment Program

The program UROAD was selected as the traffic assignment model for this step of the programming methodology. UROAD is a traffic assignment computer program which is part of the Urban Mass Transportation Administration's (UMTA) Transportation Planning System (UTPS) package.<8> This package contains a collection of IBM System 360/370 computer programs which are implemented to plan multimodal urban transportation systems. UROAD is currently one of the most versatile traffic assignment programs available. It performs all operations and calculations within one programming step. UROAD outputs all the necessary information required for the traffic input portion of APRAC-1A. Most major cities and planning districts are employing this type of traffic assignment program for loading present and future trip interchanges on a transportation network. Using present or past trip data, UROAD can be calibrated to load traffic to within ten to fifteen percent of the observed values.<8>

In addition to being an excellent traffic assignment program, UROAD has very good documentation. It is also supported by UMTA. A user may get assistance from UMTA by using a toll-free TTY line. The entire programming package is user-oriented, including UROAD.

UROAD

As mentioned previously, UROAD was selected as the traffic assignment program for this step in TAPAP program. The program employs several options and techniques used in the traffic assignment process. The input to this program originates from two sources; the FHWA's standard format trip tables and the historical record both provide direct input to UROAD. The output consists of twelve "reports" and an updated historical record.

UROAD contains an option for speed/capacity (S/C) tables. If this option is chosen, the capacity and speed for each link will be taken from the S/C tables. These values are provided for each of the five facility types, five area types, and the number of lanes (table I).<9> If this option is not chosen, the speed and volume values will be taken directly from the historical record. After the first iteration, updated speeds are obtained from the S/C tables. In all cases, the S/C tables provide traffic volumes for each link. Thus, this program updates link speeds used as for the modified APRAC-1A input.

Before the paths are created, the initial link impedances are calculated. The user determines these impedances or "costs" by employing a linear combination of distance and speed. UROAD implements the following "cost equation":

Table I. UROAD Speed/Capacity Relationships

	FACILITY TYPE				
AREA TYPE	(1) FREEWAY	(2) EXPRESSWAY	(3) 2-WAY ART.	(4) 1-WAY ART.	(5) CENT. CONN.
(1) C.B.D.	1750 48	800 37	600[1] 22	700[1] 22	10000[3] 10
(2) FRINGE	1750 48	1000 44	550[2] 25	550[1] 29	10000[3] 15
(3) RESID.	1750 67	1100 47	550[2] 28	900[1] 32	10000[3] 15
(4) OUTER CBD	1750 58	1000 37	550[2] 22	650[1] 24	10000[3] 15
(5) RURAL	1750 67	1100 47	550[2] 28	1900[1] 32	10000[3] 15

Notes: [1] These values assume a progressive signal system.
[2] These values assume that on-street parking is allowed.
[3] These values are set artificially high to account for the large number of local streets represented by each centroid connector.

COST = (CTIME x T) + (CDIST x D)

where:

T = the link's travel time in hundreths of a minute

D = the link's distance in hundreths of a mile

CTIME = time coefficient (dollars/hour)

CDIST = distance coefficient (dollars/mile)

The planner may assess the different values of time and money used by the driver to choose between routes. At the present time, the program defaults to the values of CTIME = 0.60 and CDIST = 0.0. By comparing results obtained from UROAD using the past and present traffic information, a cost for travel and time can be determined. Thus, the "cost" of travel and the "value of time" for the calibrated results may be used for future link impedance.

The "path finding" algorithms in UROAD trace the paths of least impedance between the origin zone and all destination zones. These algorithms do not allow for turning penalities at the present time. Once the "trees" have been created, they are "skimmed" along the the different paths. This information is then used to determine interzonal trip information.

Assignment Procedures

The techniques used in the "link loading process" are:

1. all-or-nothing assignment
2. all shortest path assignment (multipath)
3. probabilistic multipath assignment
4. a combination of the above assignments

These assignments can be employed with or without capacity restraint. The capacity restraint option in this program causes loading of trips on the links to be reduced as the volumes on the link reach capacity. The all-or-nothing assignment loads trips on the links until the capacity or a given percentage of the capacity is obtained for any link on the shortest path. Once this criteria is reached on one link, no further trips are loaded on the path between the zones. The "all shortest paths" assignment divides the traffic equally among all shortest paths between O/D pairs. The shortest paths are calculated by the program. The probabilistic assignment is a multipath assignment technique in which each "efficient" path between O-D zones recieves a fraction of the trips loaded. This fraction is proportional to:

EXP (-THETA * DI)

where:

THETA = a diversion variable (0.0-10.0)

DI = the total impedance of the given path minus the minimum path impedance<11>

In the above case, an "efficient" path is defined as one which has the property of always becoming more distant from its origin. (Further reference can be made to the UTPS User's Manual.)<11> As THETA approaches the value of zero, the probability of trip assignment to each efficient path becomes equal ("all shortest path"). Such loadings represent the situations where links are parallel to each other. Each will have the same opportunity of being selected by a driver. This situation occurs when downtown expressways and parallel arterials have the same volumes during peak hours. When THETA approaches ten, the minimum impedance path has the greatest probability of being loaded with O-D zonal trips ("all-or-nothing" assignment). This condition represents links with positional importance. An interstate highway which runs parallel to an old state route with many traffic lights would be a case in point. UMTA suggests THETA = 0.1.<11> The type of assignment selected will depend on the degree of sophistication required. Usually, an "all-or-nothing" assignment with capacity restraint will suffice.

The capacity restraint option can be selected. This option adjusts link times according to:

$$T = T_o + 0.15 \times T_o \times (V/C)$$

where:

T = estimated link travel time at volume V

T_o = free-flow link travel time

V = current link volume

C = link capacity (0.75 of the capacity obtained from the S/C tables)

Using this "value for time," the impedances are updated for each assignment. This value is also used in calculating the "congested" link speed after each iteration of the assignment program. The speed is equal to link distance divided by estimated link time (D/T). UROAD has the capability to perform up to ten iterations.

The UROAD program gives twelve "reports" and an updated historical record. Report number twelve is an impact report giving link emissions for geographical areas. This report may have potential for future use in conjunction with APRAC-1A. However, the updated historical record is the only source needed in the APRAC-1A urban diffusion program. The updated historical record supplies speeds, volumes, V/C ratios, and other traffic information required by APRAC-1A.

UROAD is a very powerful and versatile traffic assignment. The traffic assignment techniques and options in UROAD are many. Using present traffic condition information, UROAD was able to assign traffic volumes to links within ten to fifteen percent of the actual observed value.<11> It was designed to make future transportation network assignments employing future O-D trip matrices. Of course, the program is only as good as its input, and these future O-D trip matrices are not absolute in nature. However, UROAD gives the needed traffic assignment versatility required by TAPAP being built in this study.

IV. MODIFICATIONS OF THE APRAC-1A URBAN DIFFUSION MODEL (APRAC-EM)

The following chapter presents the modification made to various segments of the APRAC-1A urban diffusion model to create APRAC-EM. The original APRAC-1A procedure and the modified APRAC-EM procedures are compared. In some cases, this so-called modified procedure resulted in the deletion of an original procedure. All changes made were to more effectively simulate traffic conditions, both future and present. The changes or attempted changes included (1) changes to the various scales of diffusion, (2) modification of the emission-rate submodel, and (3) "cold starts." In addition, other attempted approaches not included in the modifications are discussed. For a more detailed description of the model, reference should be made to the _User's Manual for the APRAC-1A Urban Diffusion Model Computer Program_. <16>

Changes to the Various Scales of Diffusion

The APRAC-1A model calculates the CO concentration on three different scales of magnitude. These scales include:

1. extra-urban diffusion
2. inter-urban diffusion
3. local diffusion (microscale)<14,16>

The extra-urban diffusion submodel deals with CO transport from nearby cities located upwind from the urban area under study. The intra-urban diffusion submodel calculates the transport of CO from the actual link network in the city. The local diffusion model addresses the problem of the "street canyon" effect. This effect involves the CO diffusion rates created by tall buildings. Each submodel is used in the total calculation of CO concentrations at each receptor throughout the urban area.

The extra-urban diffusion model compensates for the CO transported from upwind cities. It is the background pollution which is transported from one urban area to another. The amount is based on the fuel consumption of cities located 32 to 1000 km from the receptor. Using a box-model concept, the extra-urban concentration (Ce) is estimated by:

$$Ce = \frac{(5.15 \times 10^{-11}) \times F}{u \times h}$$

where:

F = the annual fuel consumption within a 22.5 degree sector 32 to 1000 km upwind of the receptor

u = transport winds (1.5 times the maximum airport daily winds)

h = limiting mixing depth

This estimation assumes h will take on the value of the afternoon mixing depth calculated in the intra-urban diffusion model due to the complete mixing caused by long transport distances and time. The concentration is added to the concentrations coming from other urban sources for each receptor in the city. It is calculated only once during a 24-hour period.

Calculation for this extra-urban diffusion submodel presents a complex problem. First, the fuel consumption information is very difficult to obtain. Usually it must come from tax receipts and is unavailable for recent years. Collection of the information involves much time and effort. Second, the submodel cannot be used for future planning since shifts in urban areas cannot readily be predicted. Therefore, the submodel should not be included in relative and comparative analyses, though it may be used in the calculation and calibration of a model for a base year. This would entail adjusting fuel consumptions until the observed and calculated concentrations coincide.

The local diffusion submodel (the so-called "street canyon" model) was found to be of little use in this demonstration study. Because most receptor heights were lower than the street width and the building-height-to-street ratios were less than one, computed values of CO concentrations were higher than the observed values. Of course, this case is only observed for a demonstration city of Richmond, Virginia, but other cities have reported the same problems.<1> Relative results for planning were the same with or without the submodel. For these reasons, the local diffusion submodel was deleted.

At this point, an explanation of the intra-urban submodel operational mode is appropriate, as it will provide a more thorough understanding of the emissions submodels. As mentioned before, the intra-urban diffusion submodel calculates CO concentrations at specified grid points in the city. These concentrations are generated by the vehicles on the traffic links.

Figure 3 illustrates the sector boundaries established to simulate a receptor collection area. Each link is assumed to be a uniform line source of CO. The bisector angle of the 22.5 degree and 11.5 degree sector is always normal to the current wind vector. In figure 3, the wind is coming from the north. The submodel determines the percentage of each link included in each sector. This percentage is multiplied by the total emission emitted by the link to determine the CO concentration contributed by the link to the sector. All CO concentrations contributed

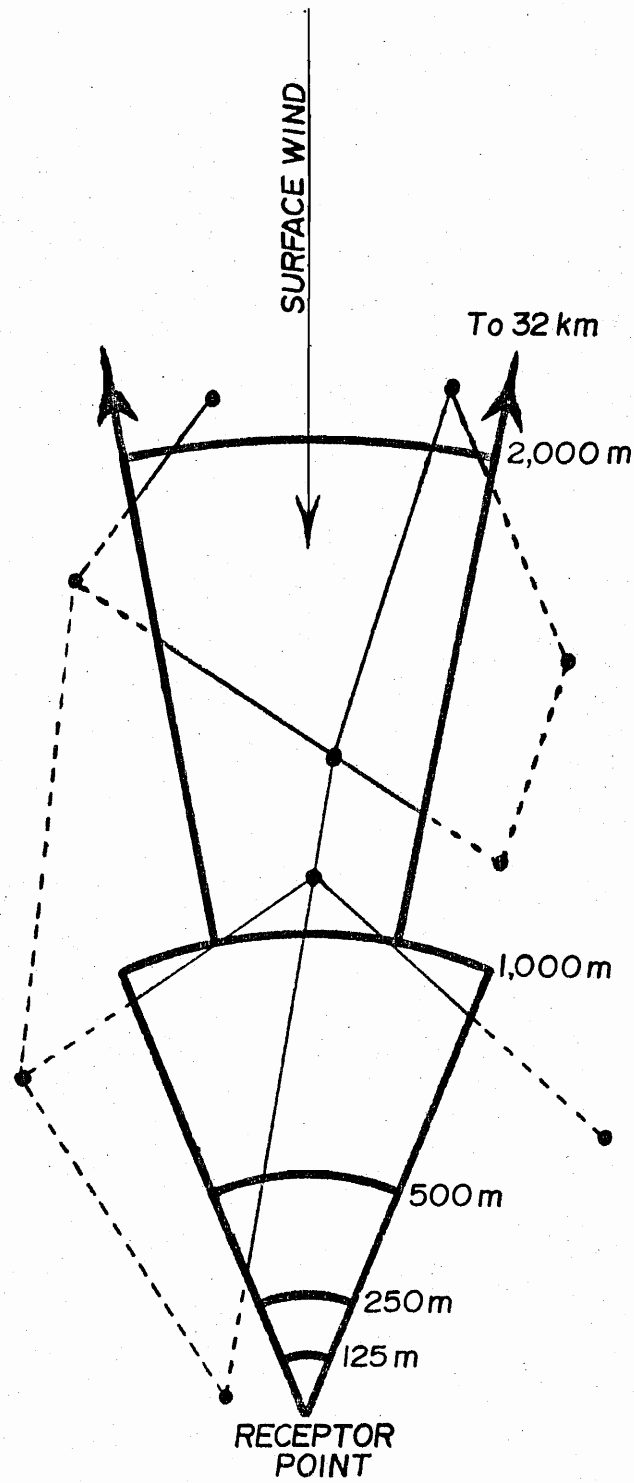

Figure 3. Receptor's Collection Boundaries

by each link are summed up for each sector.

By using the basic Gaussian or box-model, the diffusion of CO is simulated upwind from each sector. It should be noted that the box-model is used when there is a vertical restriction. The diffusion is a function of the stability index, mixing depth, the transport windspeed, and distance from the receptor. Contributions of each segment to the concentration at the receptor point are computed separately and then totaled. This process is repeated for all receptor points throughout the city. CO concentrations are computed every hour using the current airport windspeed and direction.

Emission-Rate Submodel

The original APRAC-1A uses link speeds to calculate the emission factor on each link. The CO emission factor for each link is determined by:

$$e=C/S^B$$

where:

e = emission rate (q - CO/veh - mi)

S = the average speed over the link either peak or off-peak

C,B = constants reflecting the mix of older and newer model vehicles

Each link is assigned an average speed, which is determined by the link's facility type. Thus, a downtown connector and a "beltway" link would have the same speed, as they would both be designated as a freeway. During peak-hour conditions, this will not correctly simulate the greater volumes and slower speed found on the downtown connector. A more accurate measurement of this situation was devised.

Thus, a volume to capacity (V/C) ratio was employed to give a truer representation of peak-hour traffic conditions. The V/C ratio is the ratio of traffic volume on a given roadway section to the capacity of that roadway. In traffic engineering, the speed vs. V/C ratio relates changes in traffic volumes to changes in speeds associated with those volumes. The V/C ratio is given for each link after the final iteration of the traffic assignment program UROAD. To relate the V/C ratio to an emission factor, the following equations were generated from curves found in NCHRP 133 (figure 4):

for two-lane roads:

$$EFAC = 1.81437 + (4.53592 * VOC)$$

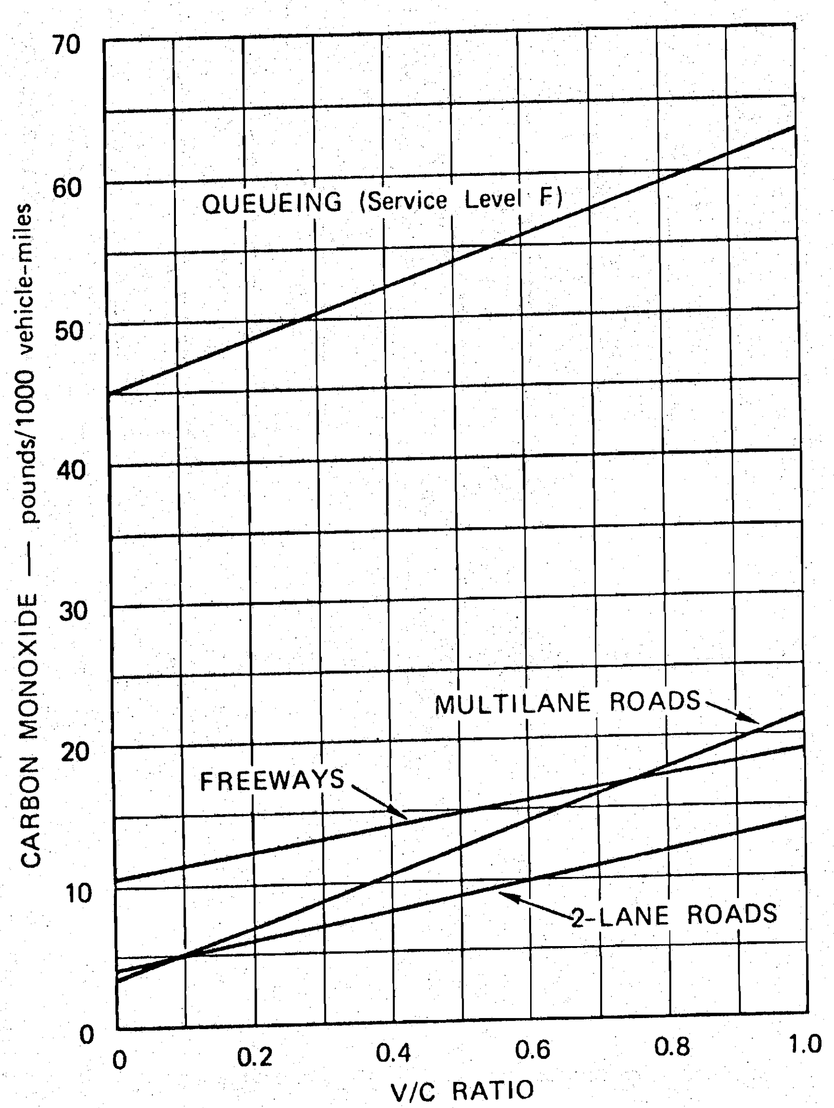

Figure 4. NCHRP: V/C Vs. CO Emission Rate Curves

for multilane roads:

EFAC = 1.58964 + (8.07807 * VOC)

for freeways:

EFAC = 4.74623 + (3.86791 * VOC)

where:

VOC = V/C ratio

EFAC = emission factor in gm/vm

There is a unique equation for each of the four facility types found in the historical record. These equations reflect Level-Of-Services (LOS) from A-E. The LOS is used to give traffic operating characteristics on a section of roadway. LOS A represents free-flow conditions while E represents a non-steady state condition. This is compatible with UROAD which assigns traffic volumes to a link until LOS E is reached. The traffic assignment program UROAD calculates V/C ratios for peak hours. Consequently, these equations are implemented only during peak-hour periods.

For planning purposes, the "base year" emission factors for vehicles were taken from curves found in NCHRP 133.<6> Table 2 gives the factors needed to convert a "reference year" automobile (1968) emissions to average emissions for a given year. These factors take into account the "timetable" set up for future auto emissions standards, the mixture of old and new vehicles, and average "state of repairs" of the automobiles. This allows the program to be used for future comparisons. By deleting these factors, the "worst case" considerations may be calculated assuming that future emission standards are not met. By using these factors, the APRAC-1A diffusion model will have greater potential as a planning tool.

"Cold Starts"

The problems of "cold starts" and secondary emissions were taken into consideration. On the APRAC-1A model prior to these modifications, secondary traffic is assigned to two by two square mile areas as a percentage of the total secondary traffic mileage for the entire urban area. This assignment is made by the user's judgment and is highly subject to error.

An attempt was made to use the intrazonal trips as secondary traffic sources. By calculating the average distance to the zone's centriods from within the zone, an average distance traveled by secondary traffic in that zone

Table II. Emission-rate Factors for Base Year 1968

Motor Vehicle

YEAR	FACTOR
1972	2.30
1973	2.10
1974	1.85
1975	1.60
1976	1.38
1977	1.15
1978	0.95
1979	0.78
1980	0.61
1981	0.50
1982	0.40
1983	0.30
1984	0.20
1985	0.20
1986	0.15
1987	0.10
1988	0.10
1989	0.10
1990	0.10

could be simulated. An average speed (e.g., 25 mph) would be assigned to each zone. The number of intrazonal trips made can be obtained from the trip tables. Using the emission factor equation and the above information, the CO concentration for each zone could be calculated. These zone concentrations may be added to the emissions obtained from the major links. This would allow the APRAC-1A program to update the secondary emission rate automatically.

Using the above intrazonal method, a scheme can be created to allow for "cold starts." For the morning peaks, the emissions from "cold starts" could be calculated by the number of interzonal trips made in the outlying zones. A study could be undertaken to calculate the number of morning, afternoon, and off-peak intrazonal trips that have "cold starts." The concentrations may or may not have any significance.

Many problems were encountered trying to employ the intrazonal trip concept. The geometries of the traffic zones made coding extremely complex. In addition, it was necessary to identify the areas of each zone. Locating zones for the intra-urban diffusion submodel was a very involved process. The required computer time would be prohibitive (45 minutes CPU for 25 zones), as well as the size of the region covered. Thus, the idea was dropped.

MODIFIED APRAC-1A

Except for the changes mentioned above, the remainder of the APRAC-1A urban diffusion model program was left intact. The new computer program evolving from these changes is called APRAC-EM. The modifications to APRAC-1A made by APRAC-EM include (1) the use of V/C ratios during peak-hour conditions, (2) the elimination of the "street model" that calculates the "street canyon effect," and (3) the addition of a factor to compensate for the more stringent emission standards in future years.

The APRAC-EM program is an updated version of the APRAC-1A program. It is designed to give added versatility to the overall analytical procedure TAPAP.

V. DEVELOPMENT AND DESCRIPTION OF THE PROGRAMMING METHODOLOGY (TAPAP)

The following chapter discusses the programming methodology developed to link the traffic assignment program with the urban diffusion model program. The changes in I/O procedures and different programming "steps" are presented. This presentation is an overview of the capabilities and procedures of the TAPAP.

Factors Considered in the Development of the Methodology

Many computer programs are more troublesome than they are effective. This situation can be attributed to the fact that they are not user-oriented. The user becomes entangled and overwhelmed by the input to the program. Because of these problems, the program is discarded. This happens even when the program's results are valid and accurate.

For this reason, the combination of the traffic assignment program UROAD with APRAC-1A was accomplished with simplicity. Ease of operation was the main concern in developing all phases and aspects of the programming methodology. This was true especially where input data was involved. A sincere effort was made to limit the volume of actual data handled by the user to an absolute minimum. This was accomplished without loss of the sophistication or accuracy of any program contained within the methodology. A survey of user complaints was employed in developing the methodology.

Taking these input "problems" under consideration, objectives were formulated to attempt elimination of these major areas of concern. The following objectives were set during the development of the programming methodology:

1. The use of I/O storage devices wherever possible (thereby eliminating data cards)
2. The use of standard format data which already exists (i.e., historical record, standard meteorological tape, etc.)
3. Load modules to replace program decks
4. "Passing" data from program to program without any assistance required by the user
5. Simplicity of operation
6. Clear and comprehensive output

The Program TAPAP

There are four main programs employed in the methodology. The sequence in which they are executed is:

1. UROAD--traffic assignment
2. FORMAT--data preparation
3. WEATHER--input of meteorological data from standard format

4. APRAC--urban diffusion model

The program UROAD has good documentation and is supported by UMTA. The program FORMAT is part of the FHWA's urban planning battery of IBM System 360/370 computer programs. Documentation is lacking and demands a thorough knowledge of the OS JOB CONTROL LANGUAGE. However, it is a very powerful program step in the methodology. A flow chart of the programming steps is shown in figure 4.

Input Data

If all the steps in the programming sequence are to be executed, the following input data is required:

1. historical highway record (link-network)
2. O-D trip matrix
3. surface observations of meteorological conditions
4. upper air soundings (temperature and pressure)
5. coordinates of receptors
6. coordinates of city center, latitude, population
7. hours of peak traffic conditions
8. percentage of total daily traffic volume on the network for each hour
9. the dates to be considered for the analysis period
10. specifications for the type of output desired
11. fuel consumption (optional)

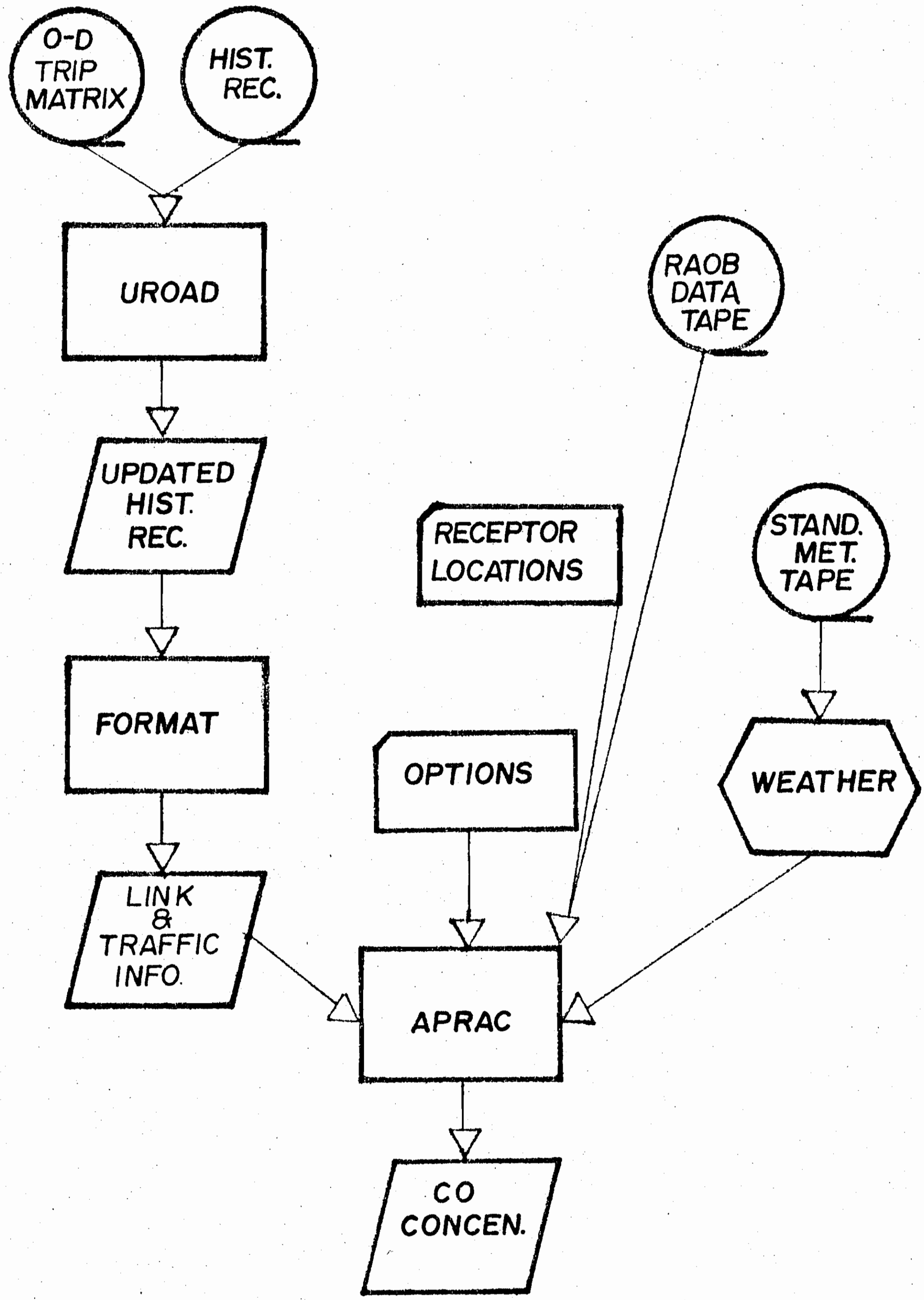

Figure 5. Flow Chart of the Programming Methodology

If the traffic assignment procedure is not performed, an O-D trip matrix is not required. A description of the types of data and the I/O device required for each type will be presented and discussed for each of the program steps. It is important to note the kinds of I/O devices used for data input, storage, and retrieval. The use of disks and tapes will save the user "manual" work and card coding, thereby reducing the probability of human error.

Program UROAD

The program UROAD is the traffic assignment program. This program requires the historical record and O-D trip tables as input. The historical record must contain the coordinates for each node. Some transportation agencies do not code this information in the historical record. The O-D trip matrices must be described in the format specified by the FHWA. They are usually constructed for present and future years. It is of the utmost importance that the type of transportation policies (i.e., exclusive bus lanes) included in the planning process are known. Both inputs are available from transportation agencies in the described format with no modification required.

Using the options found in the UTPS Reference Manual, the traffic is loaded by UROAD onto the highway network described by the historical record. These options would be best determined by a transportation planner and a traffic engineer. After the final loading iteration, UROAD outputs an updated historical record. In addition to the basic information supplied with the original historical record, the updated record contains the calculated direction link volumes and V/C ratios, and the peak-hour speed of the link derived from UROAD's internal speed-capacity tables. This information, along with the node coordinates and facility types, is required as input to APRAC-1A. The information can be stored on disk or tape for later use.

FORMAT

The FORMAT program is presented in the FHWA's urban transportation computer programming manual with little documentation.<9> It was designed specifically to read the historical record input. It also manipulates the input data into the output desired. The program is used to read an historical record and manipulate and condense the data into a format acceptable for use in APRAC-1A and APRAC-EM.

There exist two forms of FORMAT. The first form reads the standard or "old" historical record. This would be the original record used by UROAD. It contains all the input data required by APRAC-EM for a base year. This historical record could be used for analysis of current conditions or the calibration of the APRAC-EM program using base year observations. The second form reads the updated historical record.

The FORMAT program takes the direction link volumes and sums them together for each link. The directional V/C ratios are averaged for each link. The rest of the data for each link is put into the format required by both APRAC-1A and APRAC-EM. This information is stored on disk or tape for future use by APRAC-EM. FORMAT provides an interface between UROAD and the APRAC-EM urban diffusion model.

WEATHER

The program WEATHER reads a standard format tape containing meteorological surface observations (e.g., wind speed and direction, temperature, cloud cover) for a given year. The required data used by APRAC-1A and APRAC-EM is read and put into the proper format. In addition, this program must be supplied with an option to read the RAOB (radiosonde) data from the standard tape supplied by the National Climatic Center.<9> These meteorological data are stored on tape or disk I/O device for later retrieval by APRAC-1A and APRAC-EM.

This program may be overridden. In the case where the surface observations are to remain constant for each year, the user can supply cards with the information. The RAOB does not have to be read during this step. Instead, the seasonal averages may be read in. With the present program configuration, there must be one data card for each day of the year when using seasonal averages.

This program is not capable of locating the maximum and minimum temperature. However, these temperature readings were easily stored on a tape I/O device. Thus, the program WEATHER provides a convenient way of processing the meteorological information required by APRAC-1A and APRAC-EM.

APRAC-EM

The APRAC-EM urban diffusion model uses the traffic and meteorological data provided by UROAD and WEATHER to calculate the CO concentrations at selected points throughout the urban area. An effort was originally made to keep the program APRAC-1A in its original form. However, the amount of data cards and manipulation by the user was greatly reduced for more efficient operation. The program emission model was modified (see chapter IV). The type N cards (link data) were eliminated since this data is supplied by FORMAT. For the city of Richmond (population 249,000), over 3,000 cards were eliminated.

The meteorological data is read in from tape or disk I/O devices. It is no longer necessary to punch out meteorological information for each day of the study. The user simply needs to specify the beginning and terminal dates of the study period. The program will automatically retrieve the information from the appropriate I/O device. Of course, this process can be overridden if the user chooses to do so. The same format card may be employed if this process is overridden.

The following card types are required in order to execute the programming methodology using the APRAC-1A diffusion computer program: <14>

1. Card A (type of run and output)
2. Card B (coordinates of the receptors)
3. Card C (population, latitude, and center of city)
4. Card D (gasoline consumption rate as a function of 16 angular sectors)
5. Card F (peak or off-peak period)
6. Card G (fraction of the 24-hour traffic volumes on Road Types 1 and 2)
7. Card H (hourly fraction of the 24-hour traffic volumes on Road Type 3)
8. Card J (hourly fraction of the 24-hour Saturday traffic volumes on all road types)
9. Card K (hourly fraction of the Sunday and holiday 24-hour traffic volumes for all road types)
10. Card L (starting and ending date of the analysis period)

11. Card M (dates of holidays in analysis period)
12. Card Q (secondary traffic distribution)

All card types pertaining to link data traffic volumes and meteorological data have been deleted in APRAC-EM.

Reference should be made to APRAC-1A User's Manual for a complete explanation of each card type. The number of cards is small when compared to the amount required for the original APRAC-1A. For a 14-day period using Richmond, Virginia, for example, the number of cards was cut from 4,000 to eight.

The different "run types" incorporated into the APRAC-1A urban diffusion model computer program were left intact. The synoptic, climatological, and grid point run types give the versatility needed by users. Again, reference should be made to the APRAC-1A user's manual for a complete explanation of these run types outputs. The outputs and functions are:

1. climatological--makes hourly calculations of up to ten receptors around the urban area (major calculations, i.e., mixing depths, are made once and stored)
2. synoptic--same as climatological run type, except major calculations are executed every hour
3. grid--the concentrations are computed for one hour (up to 625 receptors may be coded)

The climatological run type should be used when more than a 50-hour time period is being investigated. It is more efficient than the synoptic model and should be used for transportation facility planning. The grid point model can be used to give a horizontal perspective of the CO concentrations throughout the entire urban area. This perspective would be provided for only one hour of the day.

Capabilities of TAPAP

The capabilities of the TAPAP program are extensive. The user can either go through the entire programming sequence or enter after execution of the traffic assignment program UROAD. This latter case would occur frequently in the "real world" situation. The transportation agency would calculate the link loadings and build an updated historical record for each of the different transportation policies. The air pollution agency could take these loaded networks and feed them into FORMAT, thus bypassing UROAD.

All program steps are executed as load modules requiring no cards. This also makes for a much more efficient use of computer time. Table 3 gives an overview of the programming methodology.

Table III. Overview of the Programming Methodology

I. U.T.P.S (UROAD)

Purpose:

A) Reads the in O-D trip matrix and historical record

B) Assigns trips to a transportation network

Note: U.T.P.S. documentation and program writeup gives a complete disccusion on UROAD.<20>

II. FORMAT

Purpose:

A) Reads an updated historical record originating from the program UROAD

B) Manipulates the historical record data into into the input format required by the APRAC-1A computer program

Note: A complete explanation of the program is contained in FHWA's IBM transportation programs writeups.<9>

III. WEATHER

Purpose:

A) Reads in surface observations from a standard formatted tape

B) Modifies the meteorological data to meet the required APRAC-1A input format

IV. APRAC

Purpose:

A) Reads in traffic data, meteorological data, and options selected by user

B) Calculates link emission rates

C) Calculates atmospheric conditions such as mixing heights, stability index, etc.

D) Computes the CO concentrations at any point located throughout an urban area

VI. APPLICATIONS AND CASE STUDY

Applications

As mentioned, the programming methodology calculates CO concentrations originating from the traffic network. This methodology provides a powerful tool for transportation planning and air pollution analysis. The TAPAP program employs the APRAC-EM program. In addtion to UROAD both these programs give TAPAP extreme versatility in any type of planning analysis involving transportation air quality impacts. Just a few of the many program applications are presented. However, the number of different applications that can be performed using TAPAP is great.

As for the application of the programming methodology for planning purposes, the options and applications are almost unlimited in nature. By knowing different growth patterns or transportation policies, the environmental impact may be assessed for the entire city. These impacts include every situation from emission standards for vehicles to an exclusive bus lane. The transportation policy changes will have to be made in the transportation planning process. For example, the modal split procedure and the affected links would have to be changed to include exclusive bus lanes in the programming methodology. Items that involve vehicle emissions (i.e., emission standards) are dealt with in the APRAC-EM program.

The "worst case" meteorological conditions are used as input into the model for planning purposes. These include low windspeeds and limited mixing depths. These "worst case" conditions will have to be determined by the user to meet the air quality standards required for each urban area.

A Case Study: Richmond, Virginia

The new TAPAP and APRAC-EM diffusion model were tested using 1975 base year data for the city of Richmond, Virginia (population 249,000). The historical record for the Richmond transportation system included 3,750 links and over 418 traffic zones. The city during this time period had only two monitor receptors, making any type of calibration or verification of the model virtually impossible. However, an attempt was made to at least obtain some kind of correlation between the calculated and observed results.

Approximately 1,500 links were deleted from the network to save computer time. These links are situated on the "outskirts" of the city. They did not affect the calculations in any manner. This technique should be observed when the receptor's collection radius does not include every link in the study area. The savings in computer verification run time will be significant.

The observed values were fed into the computer along with the calculated results. Plots were made to check the validity of the calculated results. Figure 6 shows a typical comparison of the observed and calculated results for a 96 hour period using the APRAC-EM program. These plots were very useful in the analysis of CO concentrations.

The original APRAC-1A program was applied using base year data with no changes. The results were somewhat disappointing. Figure 7 illustrates a four day period. The APRAC-1A program failed to predict the peaks correctly. A weekend time period was selected to show the differences in the actual and the predicted traffic characteristics. This weekend may not be a typical weekend, since some holiday weekends have completely different traffic characteristics. In addition, traffic planners are usually not concerned with off-peak conditions. Information about these off-peak periods is sketchy if it exists at all. More information is needed in this area. However, the results gained from this information might be small for the work required.

Model calibration was undertaken by using the values of FUEL. FUEL is the amount of fuel that is consumed yearly in a 22.50 degree sector ranging 32 - 1000 km from the receptor. The CO concentrations calculated using FUEL compensate for the extraurban CO transport not generated by the vehicles on the traffic network. By increasing or decreasing the original estimated values, the entire "base"

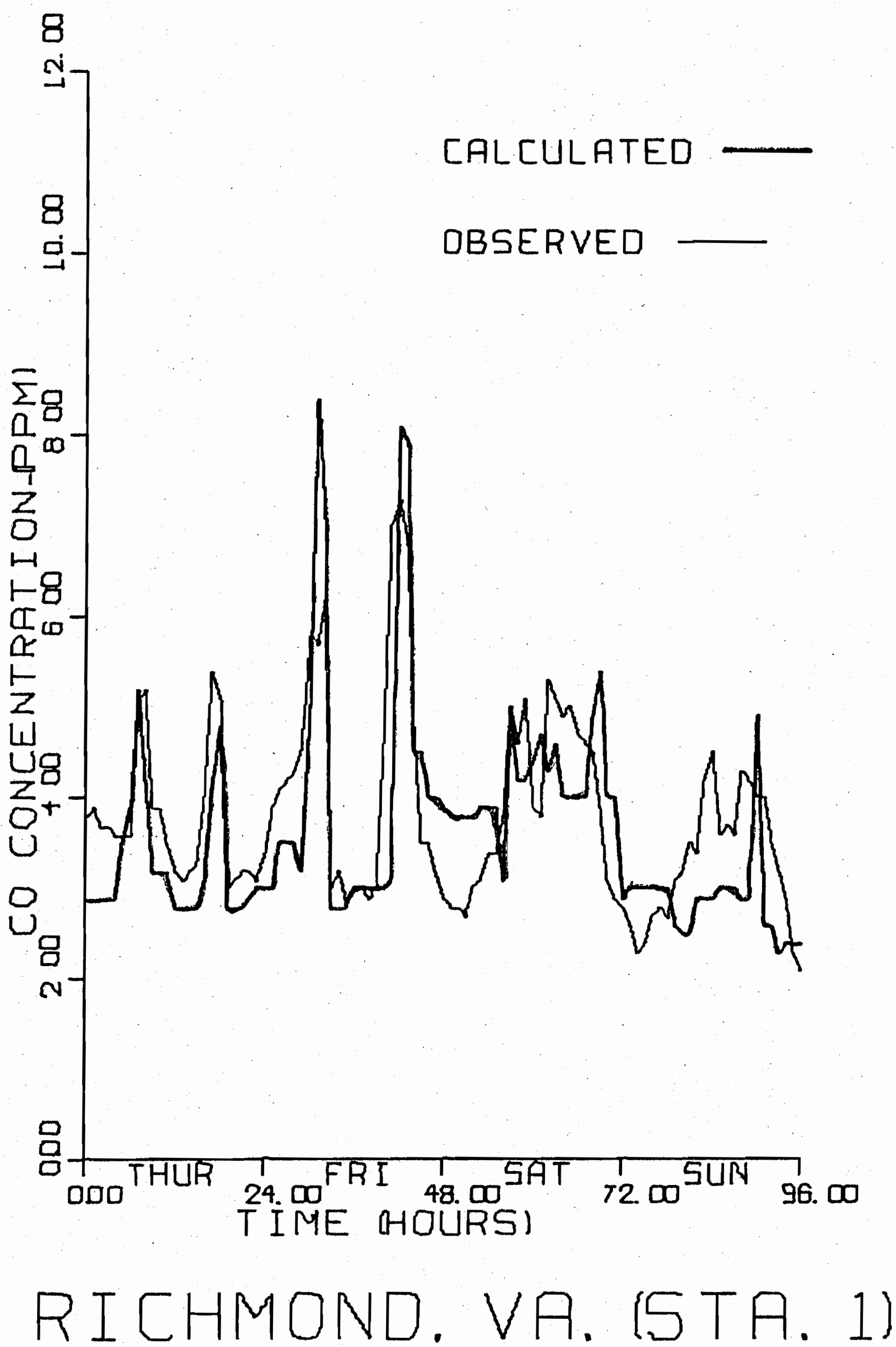

Figure 6. A 96-Hour Comparison of Observed and Calculated Results Using APRAC-EM

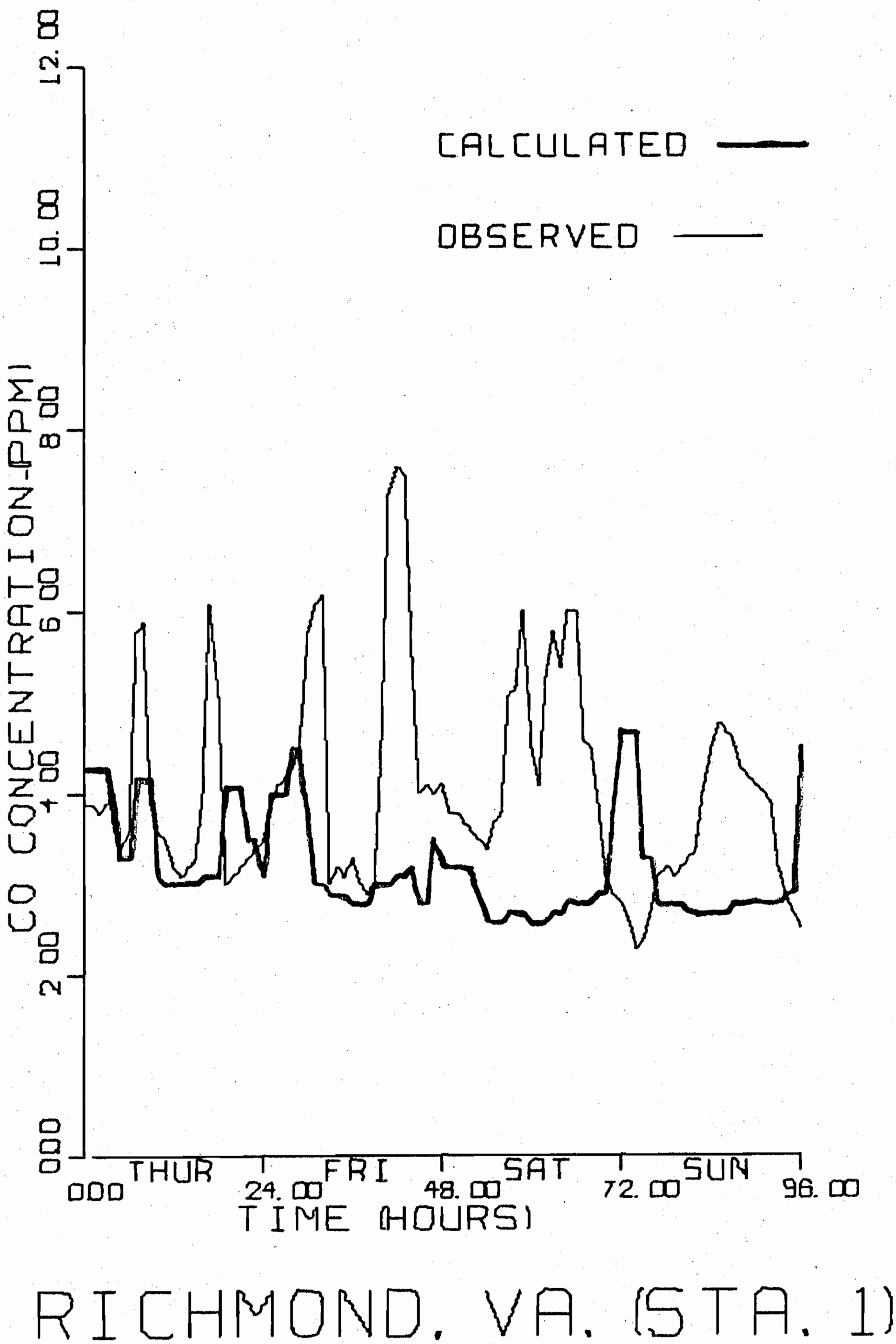

Figure 7. Comparison Between Observed and Calculated CO Concentrations Using the APRAC-1A Emission Rates

CO concentrations may be raised or lowered to coincide with the observed values. The original values were estimated by the user and are questionable. The calibration process employed above seemed to be justified. The results backed up this calibration technique.

In figure 8, the APRAC-EM employing V/C ratio modification was applied. It can be noticed immediately that the peaks were more in line with the observed data. With some of the runs made during different time periods, the V/C ratio modification created moderately high results. These CO concentrations were about 2.5 ppm CO greater than the observed values. As previously stated, more receptors would be needed to give any statistical validity to this comparison. Therefore, the ability of this program to calculate absolute values was not completely verified, though results are encouraging. As figure 9 illustrates, the predicted and observed values may differ greatly. This difference between observed values and calculated results by APRAC-EM is because of the different location of the receptor site and the location where the meteorological data is observed. In most cities the airport where meteorological observations are made is usually miles away from the downtown area. However, the peaks of the calculated results still coincide with the observed CO concentrations.

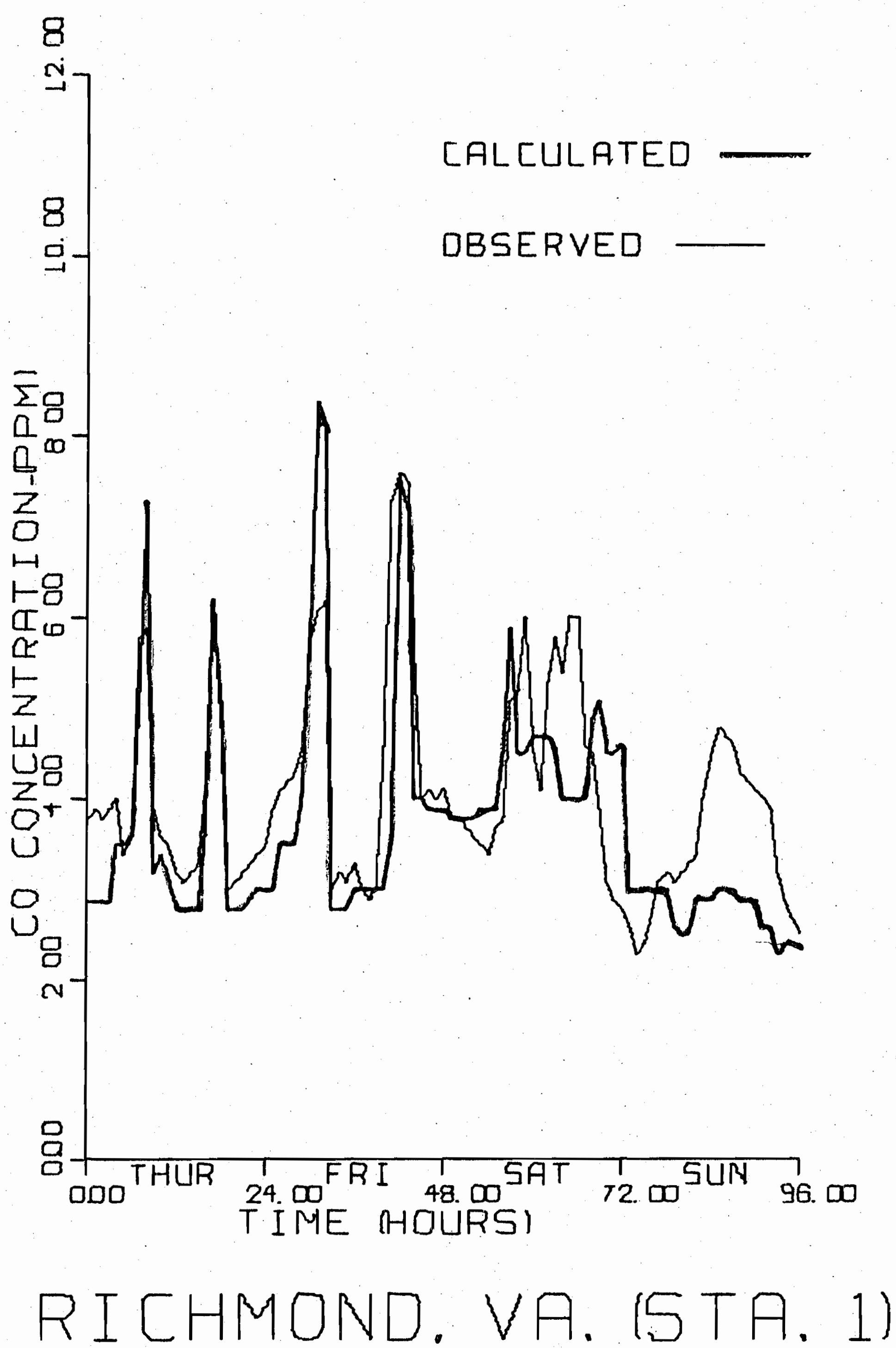

Figure 8. Comparison Between Observed and Calculated CO Concentrations Using APRAC-EM

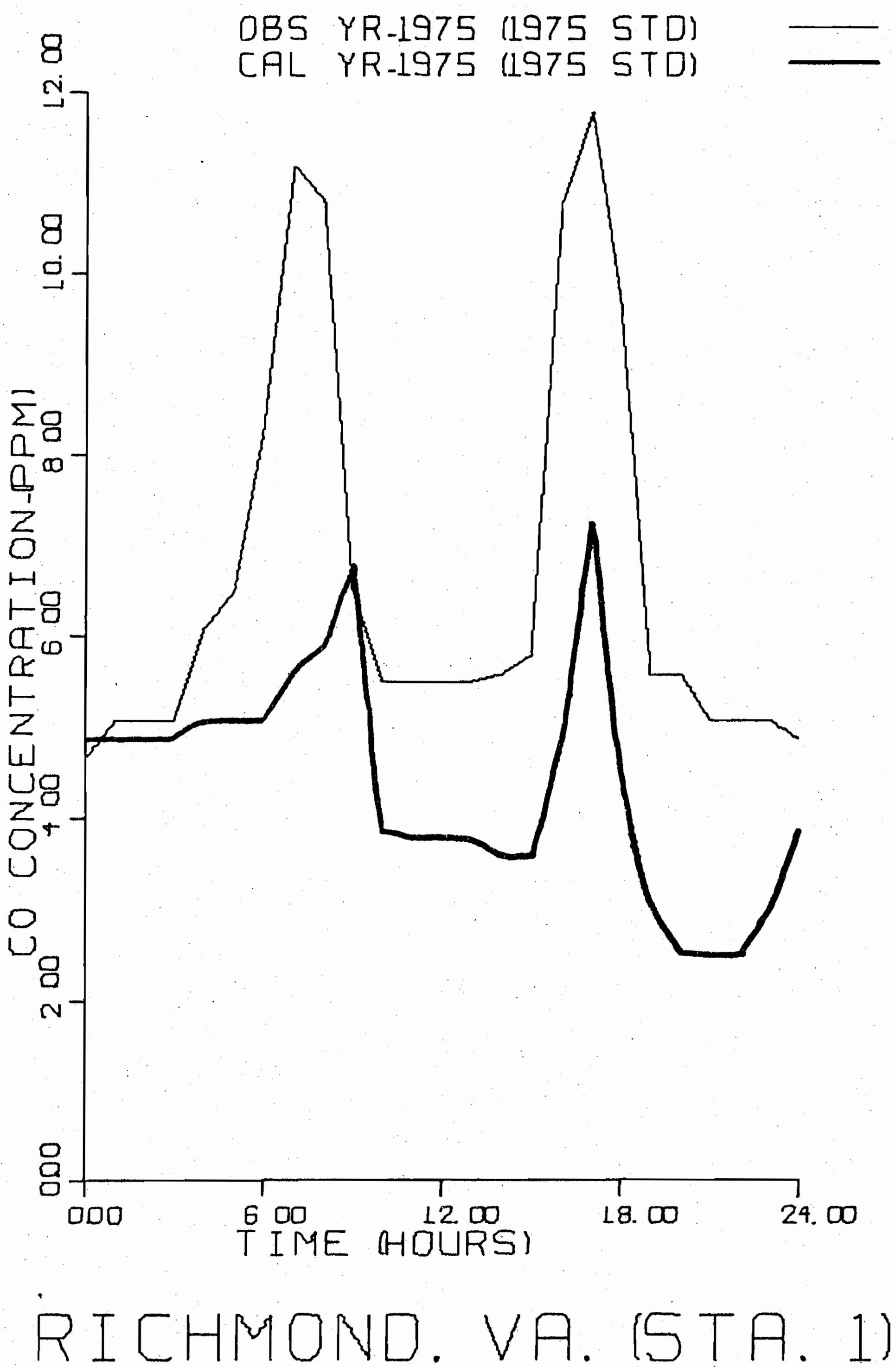

Figure 9. Difference in Observed and Calculated CO Concentrations Using APRAC-EM

To illustrate a planning application of TAPAP,a sample computer run was made using the O-D trip tables for 1975 and 1985. The same receptor site was used as in the first example. The 1985 trip tables provide the trip patterns and needs for the future transportation network. Since there will be no significant changes in the transportation network, the historical record was left unchanged. Figure 10 shows the changes from present (1975) concentrations calculated by the TAPAP program to 1985 calculated CO concentrations. This calculation was made assuming present emission standards for automobiles. The average growth rate for traffic volumes was figured to be approximately three and one-half percent per year. Of course, some traffic zones will have much higher growth rates than others. Because of the versatility of the UROAD traffic assignment program, all of these situations can be included in TAPAP program. Figure 11 shows the predicted values of CO concentrations using the automobile emission standards set for 1985. The average reduction in concentration levels was found to be around 35 percent, even with the increase in traffic volumes. A comparison of present emission standards with future standard predictions indicates a great difference in concentrations (figure 12). The TAPAP vividly illustrates the need for emission standards. This application is a very important factor since EPA auto

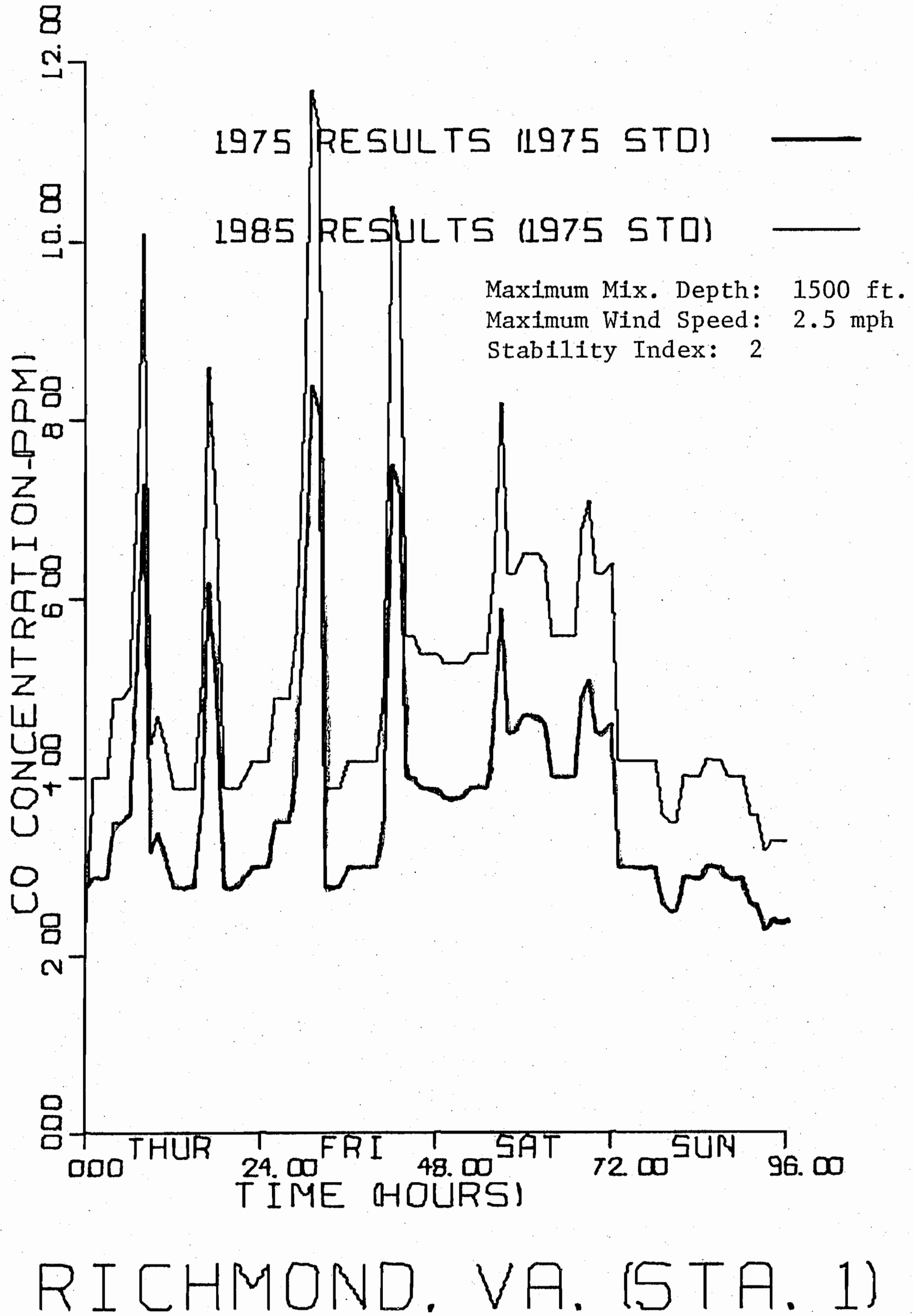

Figure 10. Comparison Between 1975 and 1985 Calculated CO Concentrations Using 1975 Emission Standards With TAPAP

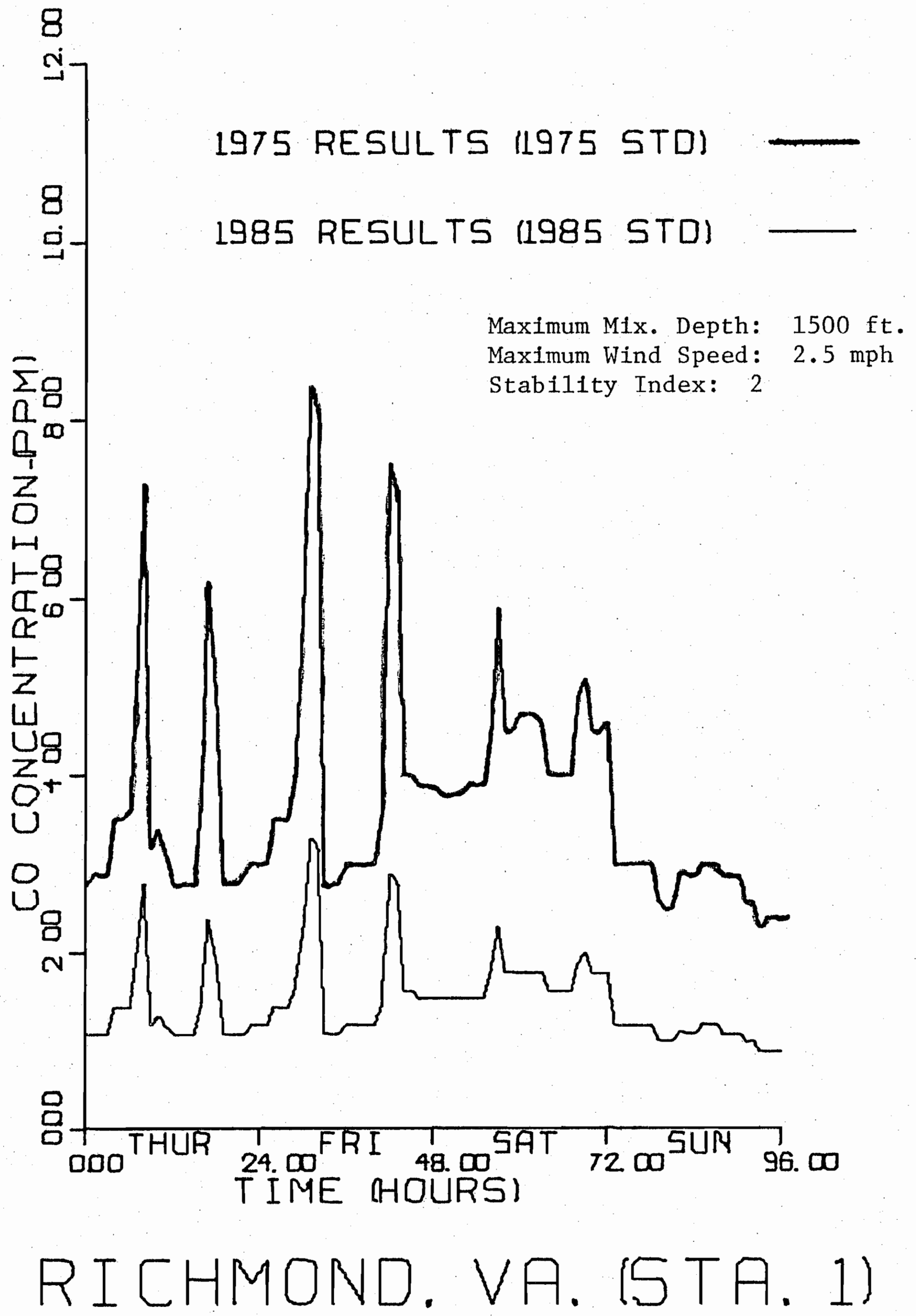

Figure 11. Comparison Between 1975 and 1985 Calculated CO Concentrations Using 1975 and 1985 Emission Standards, Respectively, With TAPAP

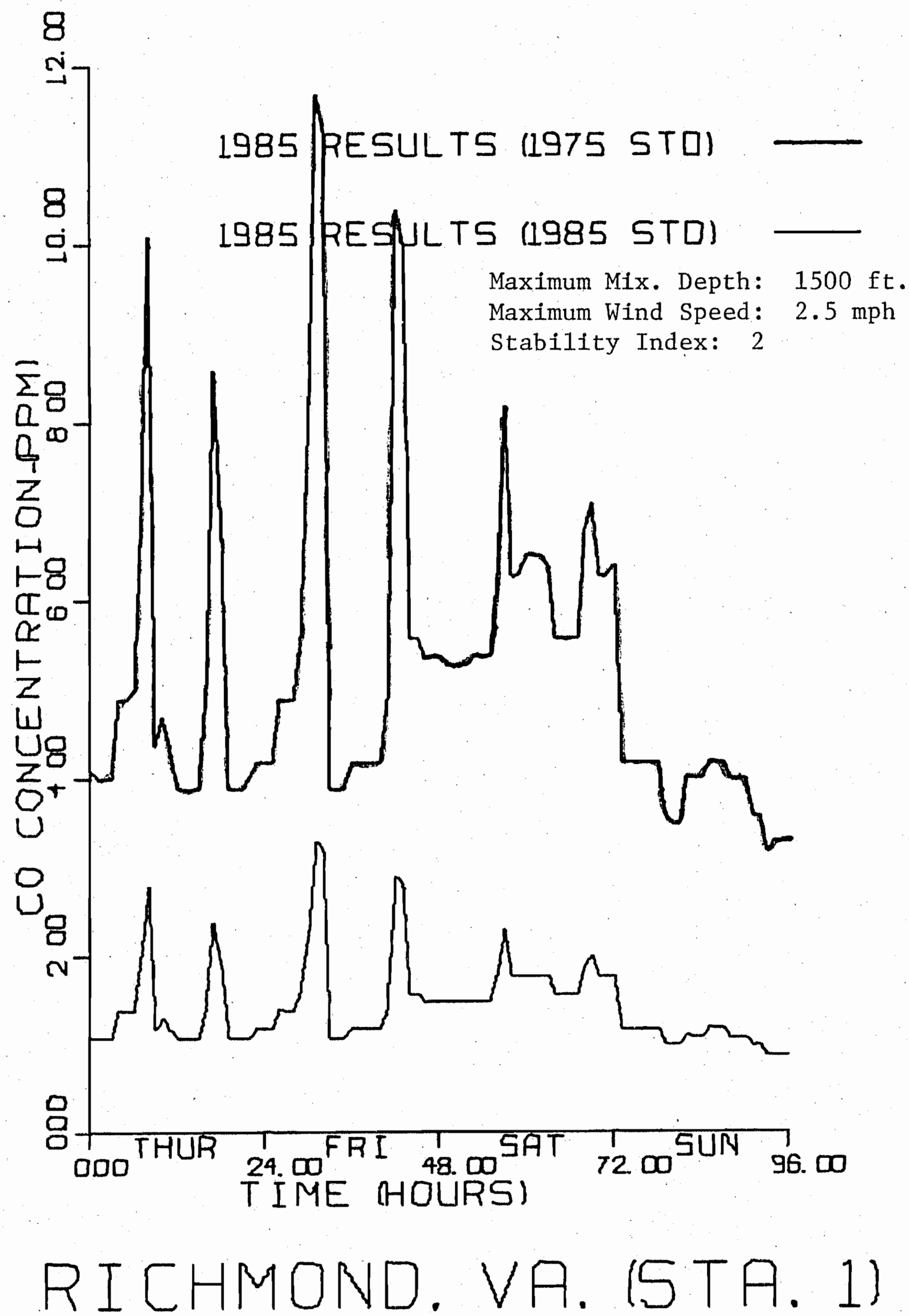

Figure 12. Comparison Between 1985 Predicted Concentrations Using 1985 and 1975 Auto Emission Standards With TAPAP

emission standards will probably be revised in the future.

It might be noted that the Federal air quality standards permit a maximum eight hour level of 9 ppm CO and a maximum one hour level of 35 ppm CO.<3> These values have been determined necessary to protect the public health. Using the "worst case" situation, a rough estimate can be made whether these standards are met.

Experiments using TAPAP were performed with the Richmond-Petersburg turnpike data. Construction of two new lanes is now nearing completion. A receptor was simulated and located at a strategic point along the turnpike. Figure 13 shows the location of the receptor and the boundaries of the primary collection area. The wind direction was choosen such that a four-lane section of the turnpike could be isolated for the analysis. Traffic conditions were calculated with V/C ratios. The four-lane and six-lane CO concentrations were calculated using the TAPAP program (figure 14). The CO concentrations decrease with the six-lane highway due to increased traffic speed and lower V/C ratios. However, as a five percent annual growth rate was applied, using 1975 emission standards, concentrations increased because of slower speeds and greater volumes (figure 15). The 1985 emission standard offset any gain made by these conditions (figure 16).

These are but a few of the applications that can be

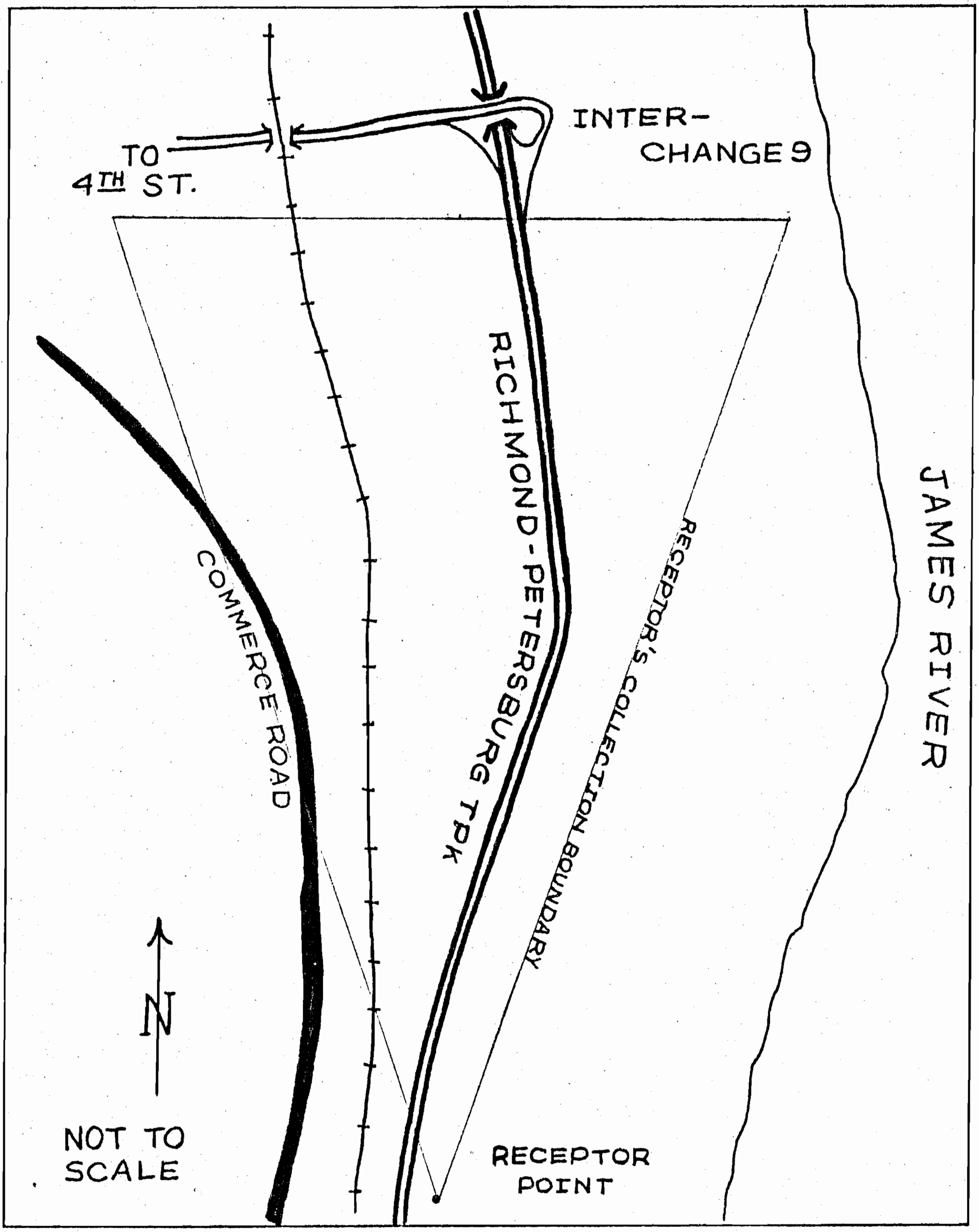

Figure 13. Receptor Location for Turnpike Analysis

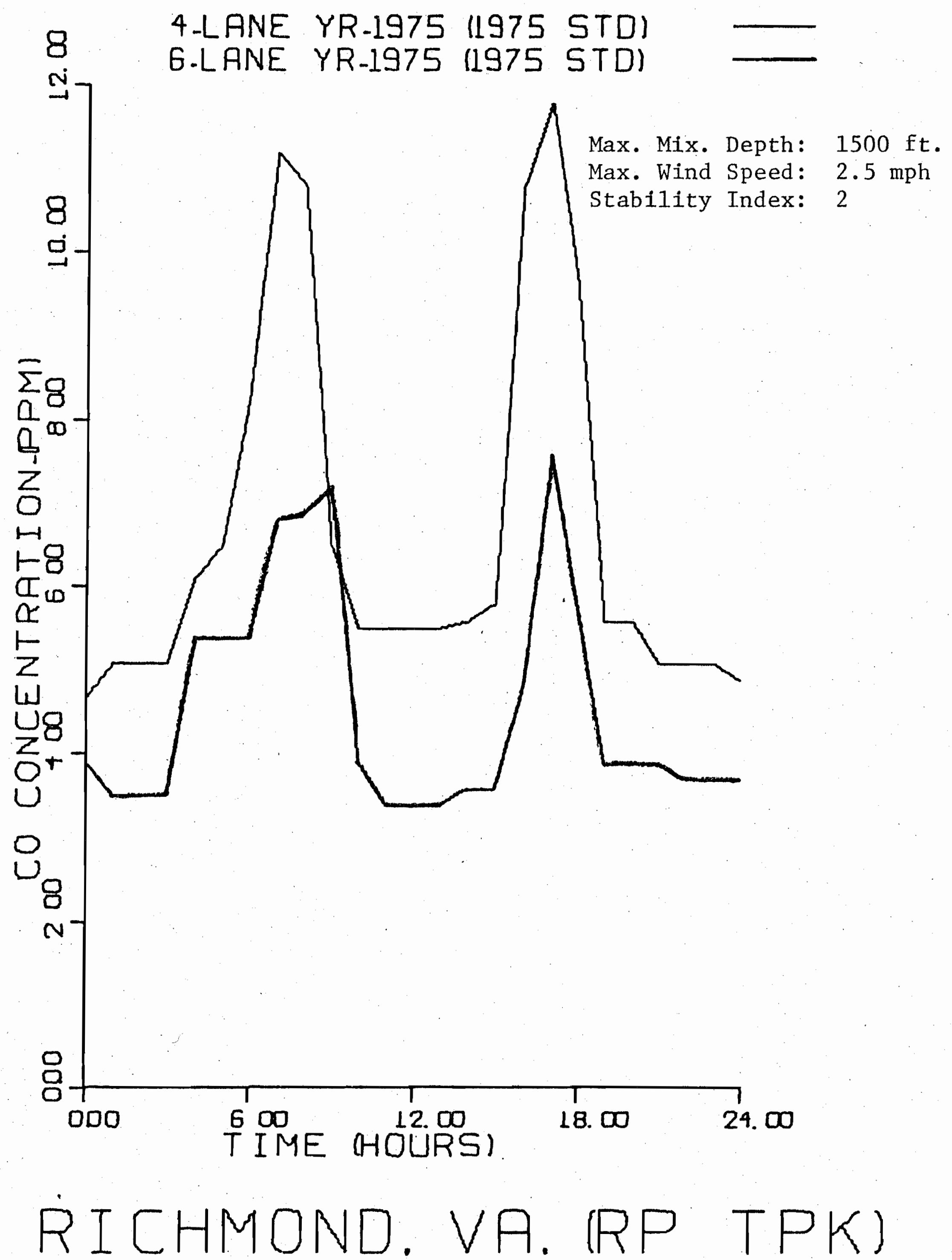

Figure 14. Four-Lane and Six-Lane CO Concentrations Using 1975 Traffic Conditions and Auto Emission Standards Using TAPAP

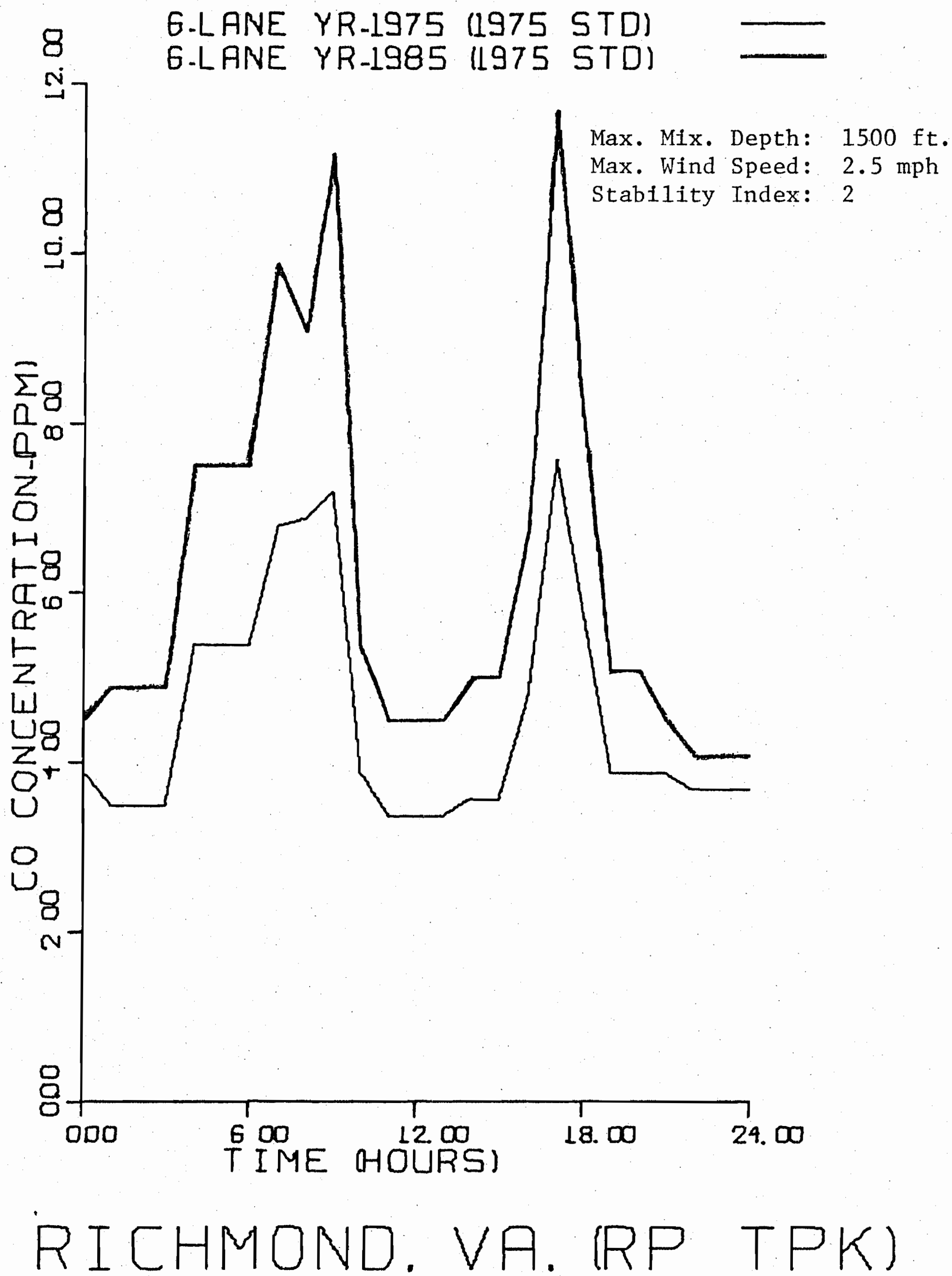

Figure 15. Comparison Between Six-Lane 1975 and 1985 CO Concentrations With 1975 Auto Emission Standards Using TAPAP

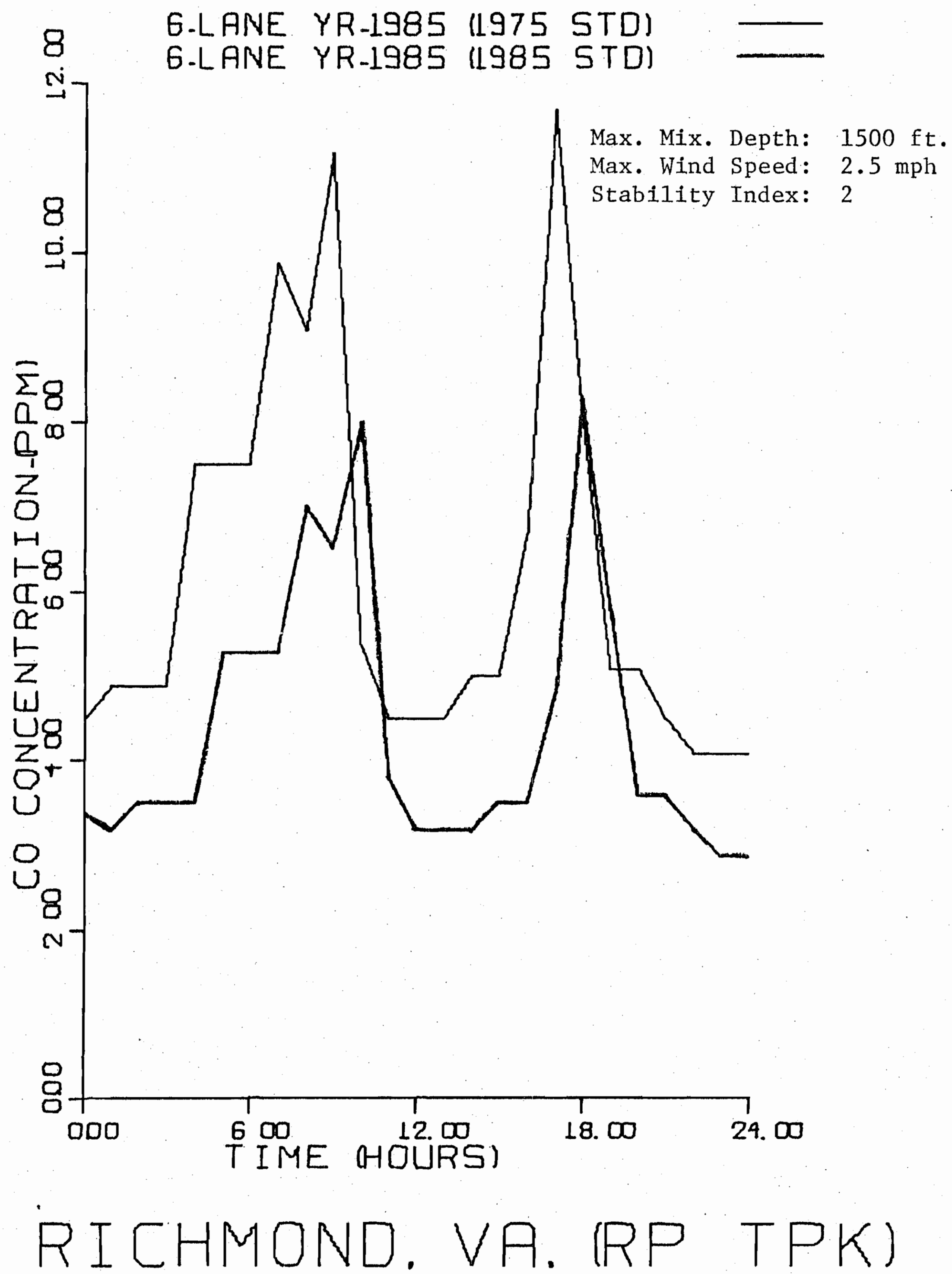

Figure 16. Comparison Between 1985 Six-Lane CO Concentrations With 1985 and 1975 Auto Emission Standards Using TAPAP

made using TAPAP. The applications are limited only by the user's resources. As many as 625 receptor points can be set up using the grid model. With this type of computer run, a "horizontal pattern" of CO concentrations can be made for the entire urban area. Since the TAPAP computer program has a decreased amount of manual I/O manipulation required, the user can spend more time developing different applications rather than allotting time to I/O problems.

VII. DISCUSSION AND CONCLUSION

The TAPAP program was developed to link a transportation assignment computer program with an urban diffusion model computer program. Futher, the vehicle emission-rate model was modified to better simulate traffic conditions (APRAC-EM). The main purpose in developing TAPAP was to provide a tool to analyze the different impacts of transportation policies on the air quality of the urban area.

The card input problem to APRAC-1A was greatly reduced. Both the historical record and standard formatted weather data are used as input to APRAC-EM. They are read into the program from a tape or disk I/O device. The program APRAC-EM contains most of the options and input required by the original APRAC-1A. However, tape and disk I/O devices were used so that the "automatic" I/O procedures could be overridden. The TAPAP can be initiated before or after the traffic assignment program UROAD. This option allows the direct input of updated historical records to the APRAC-EM computer program. These changes in I/O are valuable, as they make the burdensome APRAC program a useable planning tool.

The emission model was modified to more effectively describe congested traffic conditions found during peak hours. Selecting CO vehicle emission as a function of the V/C ratio yeilds greatly improved predictions of CO concentration during the peak hours. The original emission-rate model was not as sensitive in determining emission rates during peak-hour conditions. The values calculated using the original "speed category method" were also found to be significantly lower than observed results.

As far as the planning process is concerned, the TAPAP program can be employed to make comparisons between different transportation alternatives. These comparisons are made using CO concentrations. Many different types of transportation policies can be handled: the transportation policies concerning the traffic network and trip interchanges can be put into effect in the traffic assignment program; vehicle emission standards are implemented and changed in the urban diffusion program.

The TAPAP is a major step forward in assessing the environmental impact of an urban transportation system. With its modified diffusion model (APRAC-EM), the prediction of peak-hour conditions has become more precise. These conditions are of major concern because the highest concentrations occur during the peak-hour. In addition, the model has to be made to compensate for future emission standards. The automation of input data will certainly make the model more useful. The TAPAP program provides a versatile and powerful planning tool for both the transportation and air pollution field.

Future Work

Future work will have to be carried out in three areas. First, more analysis of the TAPAP computer program will have to be performed. The number of receptors should be increased. By increasing the number of receptors, the TAPAP could be given some type of statistical validity. In addition, greater sensitivity analysis should be carried out. This analysis will help in locating the limitations of the TAPAP program.

The second area involves creating a more user-oriented program. Complete documentation of the program sequence is badly needed. Response from users concerning the type of output they require would provide valuable input. User problems and suggestions would be most useful in locating deficiencies of APRAC-1A. These suggestions would be used to guide modifications and changes in the program. The end result would be a more effective user-oriented package.

The traffic and emissions models are the third area of concern. Extensive research will have to be undertaken to simulate the secondary traffic. Factors such as interzonal trips could be used to calculate secondary traffic emissions. The "cold start" condition should also be addressed. Modifications in both the APRAC-EM and UROAD models could yield more reliable results during both peak and non-peak hour periods.

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A TRANSPORTATION APPROACH TO
URBAN DIFFUSION MODELING

by

Harold A. Scott, Jr

(ABSTRACT)

An analytical tool is developed that is capable of predicting both present and future transportation policy impact on urban air quality. The Transportation Air Pollution Analysis Procedure (TAPAP) combines a versatile traffic assignment computer program model with an urban diffusion computer program model. TAPAP assesses the air quality impact of transportation policies such as adding extra lanes to an urban freeway, construction of new roadways, changes in auto emission standards, and exclusive bus lanes. With the stringent air quality standards now being legislated, TAPAP's ability to quantitatively measure a transportation system's present and future impact on air quality is indispensable to urban planning.

The TAPAP program utilizes a modified version (APRAC-EM) of the original APRAC-1A urban diffusion computer program model. APRAC-EM, with its emission model, more

effectively simulates CO concentrations during peak-hour periods when CO concentration levels are the most critical.