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ESTIMATING AUTO EMISSIONS OF ALTERNATIVE TRANSPORTATION SYSTEMS

Metropolitan Washington Council of Governments
Washington, D.C.

FINAL REPORT

April 1972

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DEPARTMENT OF TRANSPORTATION

OFFICE OF THE SECRETARY

Assistant Secretary for Environment and Urban Systems
Washington, D. C. 20590

OFFICE OF THE SECRETARY OF TRANSPORTATION

WASHINGTON, D.C. 20590

I am pleased to forward to you a copy of the report Estimating Auto Emissions of Alternative Transportation Systems, which was prepared by the Metropolitan Washington Council of Governments under a contract with my Office. The study was cooperatively guided and reviewed by a technical advisory committee whose membership included representatives from Federal and State planning, highway, health, and environmental control agencies and the Metropolitan Washington Coalition for Clean Air.

The objective of the study was to develop and demonstrate a methodology for estimating the relative magnitudes of automobile pollutants for alternative regional transportation systems.

A major concern of my Office is that transportation planning include objective consideration of economic, social and environmental factors to the same degree as traditional engineering concerns such as user benefits and construction costs. In metropolitan areas, air pollution associated with highway traffic is a problem that looms high among the environmental issues faced by citizens, planning agencies, and official decision makers.

There have been extensive efforts to develop sophisticated models for predicting dispersion of pollutants, and their resultant effects on ambient air quality. Accuracy of many of these methods has not been adequately validated, and their application to comparison of alternative transportation system plans is complicated and time consuming.

The design for this study was developed after consultation with metropolitan planners, air pollution control specialists, public health professionals and highway planners. It does not attempt to deal with the total problem of transportation related air pollution, but does offer a reasonable uncomplicated method whereby a planning agency may predict relative amounts of automobile emissions that may be expected for various combinations of highway and non-highway transportation system choices in a metropolitan area.

This study is one of a series which the Office is sponsoring in the interest of improving the consideration of urban transportation in relation to the environment. I hope it will provide a useful tool for interdisciplinary examination of the relationships between highways, motor vehicle travel, mass transit systems and air pollution.

Sincerely,

John E. Hirten
Acting Assistant Secretary for
Environment and Urban Systems

ESTIMATING AUTO EMISSIONS OF ALTERNATIVE TRANSPORTATION SYSTEMS

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16. Abstract

This report discusses the development and application of a model which can estimate the magnitudes of carbon monoxide, hydrocarbons, and oxides of nitrogen automobile emissions for alternative transportation systems.

The model consists of three distinct phases: (1) an auto vehicle trip origin sub-model, (2) a sub-model which produces forecasts of auto travel characteristics, and (3) an emission level estimator. It produces estimates at the subarea level.

Results of applying the model to the Washington, D.C., Region are discussed. This application studied the effects of both alternative highway and transit systems on 1976 emissions within the Region.

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Abstract

This report discusses the development and application of a model which can estimate the relative magnitudes of carbon monoxide, hydrocarbons, and oxides of nitrogen automobile emissions for alternative regional transportation systems.

The computation of auto emissions is accomplished by means of a computer program which accepts travel and facility data, together with assumed emission rates, and calculates speed and vehicle-miles of travel by type of facility by sub-area; applies the rates (for peak and off-peak travel speeds and volumes) and calculates the amount of emission by sub-area. Emission rates are a function of the speed of travel and the age distribution of vehicles in the year under study. A portion of the program logic is based on a model developed by the Tri-State Transportation Commission for estimating highway facility requirements, modified for the purpose of calculating auto emissions.

In the Washington, D. C. area application, the effect of alternative transit and highway systems were included in the evaluation by allowing the introduction of larger scale transit systems to influence the number of vehicle trip ends through reductions in auto ownership, as well as by influencing the magnitude of vehicle trip generation. Nine future alternative highway and transit system combinations, together with a base year transportation system, were evaluated for their effect on auto emissions by sub-area. The sub-area emissions were aggregated to jurisdictional totals for purposes of comparing the alternatives. The "null" or no improvement alternative was included as one of the alternatives.

Using 1976 emission rates supplied by the U.S. Environmental Protection Agency (E.P.A.) for the Washington, D. C. area, it was found that substantial reductions in carbon monoxide (CO), hydrocarbon (HC), and oxide of nitrogen (NO_x) emissions could occur without any change in either the highway or transit system, despite an estimated increase of over 6,000,000 vehicle-miles of travel daily by 1976. These reductions, caused by better emission controls in newer vehicles, would be: 51% for CO, 62% for HC, and 24% for NO_x, and are based on the assumption that the 1975 automotive emission standards are met and are fully effective.

Additional reductions would be brought about by construction of the full 98-mile rail rapid transit system (METRO) along with its supporting bus feeder system. A substantial reduction is also made by a partial 30-mile rail rapid transit system.

At the regional scale, little or no variation was found in the levels of CO or HC emissions as a result of the alternative highway systems examined. In general, increased travel was offset by the higher speeds of travel made possible by an expanded freeway system. Network analysis is required to study these results in detail, however, since variations within portions of a sub-area can occur. NO_x emissions increased as vehicle-miles of travel increased, and this pollutant increased with the larger highway systems tested.

These findings are based on the emission factors supplied by E.P.A. If these factors are revised as a result of further research, it is quite possible that some of the results obtained would change. Revisions to the emission factors can be readily accommodated by the model developed in this study.

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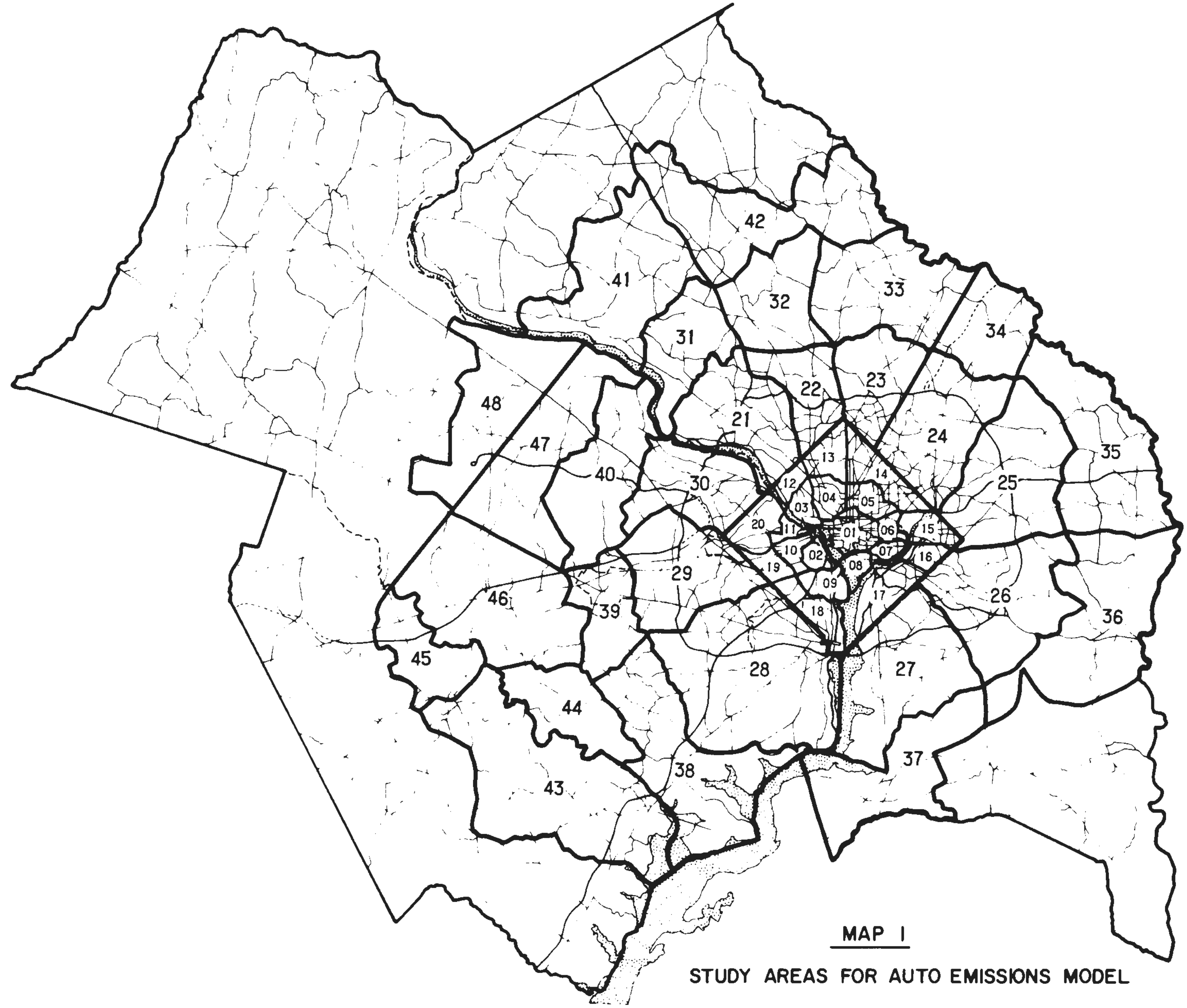


MAP I

STUDY AREAS FOR AUTO EMISSIONS MODEL

Introduction

A major problem exists in transportation planning: how can social and environmental factors, such as air pollution, be given the same objective consideration as that given to traditional engineering concerns such as user benefits and construction costs? This study attempts to develop a methodology by which emissions of carbon monoxide, hydrocarbons, and oxides of nitrogen can be estimated for alternative transportation schemes within the framework of a long-range transportation planning process.

The methodology makes use of vehicle trip forecasts, along with highway network information, to estimate future travel, the speeds at which this travel will occur, and the emission levels produced. The methodology does not require trip distribution and traffic assignment model procedures. It is aimed at providing a regional overview of the relative magnitude of the air pollution problem in an area. The methodology is not intended to provided air quality forecasts as no diffusion models have been used.

The technique is most useful in making comparisons among various regional transportation system alternatives. Since neither the transportation models nor (more importantly) the emission factors obtained from the U.S. Environmental Protection Agency are flawless, absolute pollution volumes estimated for a particular system should be used with caution. When comparing between alternative systems, however, any variations due to input assumptions would become less significant, allowing more confidence to be placed in the results.

For the Washington, D. C. area -- divided into the 48 sub-areas shown in Map 1 -- nine alternative transportation schemes were tested for 1976. The nine alternatives represented all possible combinations of the three highway systems and three transit systems shown on Maps 2A and 2B in Chapter II. The regional distribution of activities, such as employment and population, used in comparing these systems was based on a Metropolitan Washington Council of Governments forecast for 1976. The amount and distribution of this activity was held constant for all tests, as it was beyond the scope of this study to evaluate the effect of alternative land use patterns.

For each system, estimates of average daily and peak-hour emissions of carbon monoxide (CO), hydrocarbons (HC), and oxides of nitrogen (NO_x) were made and compared. Computer programs have been developed to do much of the work and are available. The use of these programs is discussed in the Appendix.

I General Description

METHODOLOGY

The three-stage Auto Emissions Model developed in this study is shown in Figure 1. For each system tested, a trip generation sub-model is used to determine automobile vehicle trip origins, a travel description sub-model is utilized to convert these trips into travel characteristics and, finally, an emission sub-model is used to convert these travel parameters into estimates of pollutant emissions.

Trip Generation Sub-Model

This sub-model makes use of socio-economic data and transit system characteristics to produce estimates of vehicle trip origins by sub-area. These trip origins are divided into home and non-home origins. The relationships used were developed from data obtained in the Home Interview Survey conducted in 1968 by the Metropolitan Washington Council of Governments.

Home-origin trips were related to the number of households and auto ownership in a sub-area, modified by the transit access to employment. Auto ownership was forecast on the basis of the transit service provided and household income levels expected. Non-home-origin trips were a function of the number of households and employment in a sub-area, modified by the transit access to labor force.

An important point to note concerning the vehicle trip origin model utilized is that the supply of transit service modified the number of auto trips generated by sub-area. Vehicle trip origins by sub-area did not vary with the amount of freeway service provided; however, the average trip length was increased with added freeways.[1/] A fuller description of the trip generation sub-model is given in Chapter III.

Travel Description Sub-Model

This sub-model requires vehicle trip origin and highway supply estimates (amount and location of freeways) to develop, on a sub-area basis, vehicle-miles of travel (VMT) and speeds by highway facility type. The model utilized for this work is the Highway Needs Model developed by Frank Koppelman of the Tri-State Transportation Commission,[2/] calibrated for the Washington, D. C. area.

The rationale behind this model is that (through regression analysis) relationships can be developed among certain socio-economic characteristics (such as population density), highway supply, trip origin density, and vehicular travel characteristics. These relationships are assumed to hold for the future.

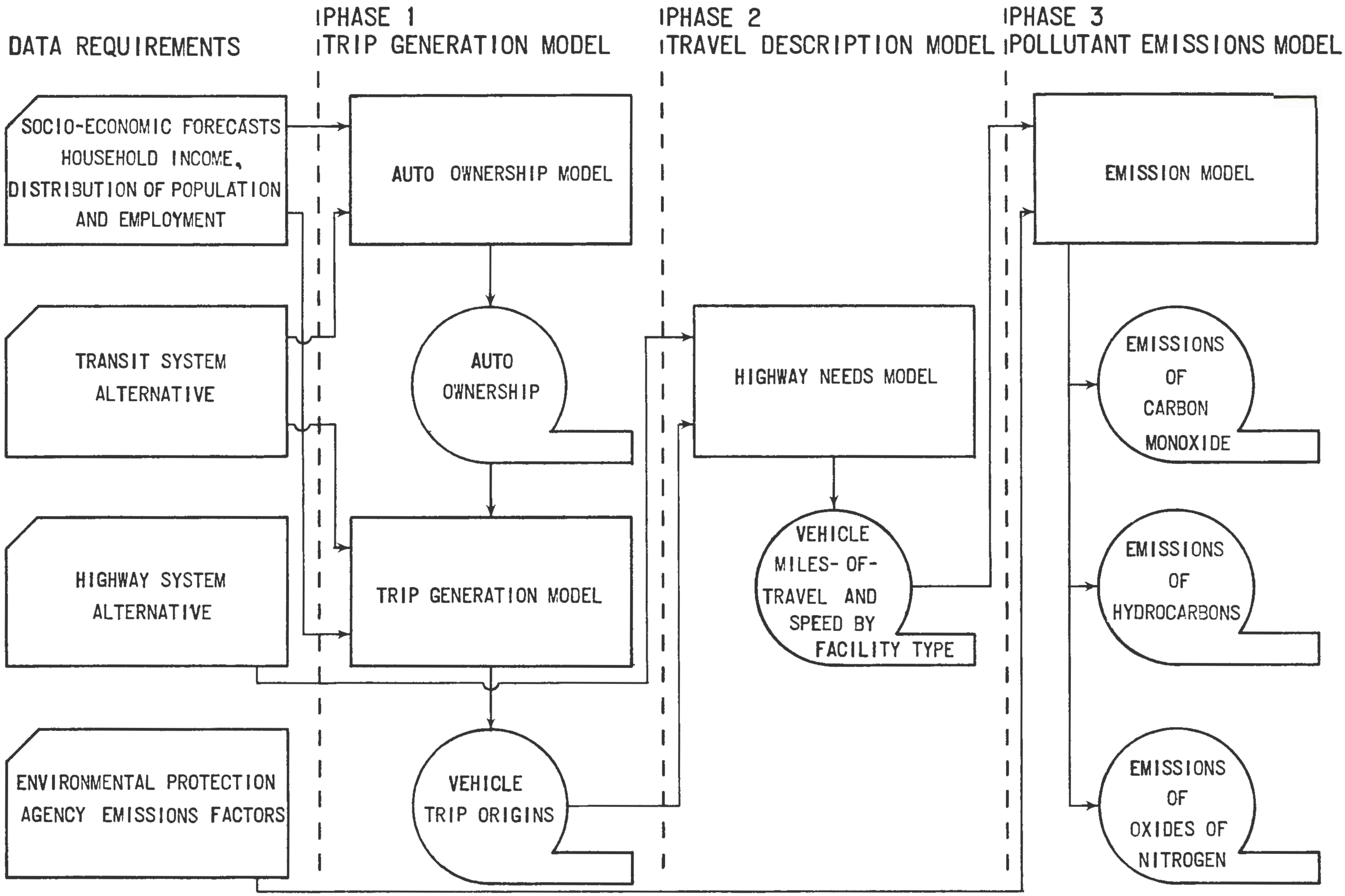
The travel descriptions developed are not link specific; that is, the VMT and speeds determined by the model for expressways, arterials, and local streets are average values for routes within a sub-area. A more extensive description of this model is given in Chapter IV.

1/ Since data availability varies between urban areas, the trip generation sub-model is not an integral part of the Auto Emissions Model. Vehicle trip origins can be developed in any manner found desirable and can be used directly as inputs to the travel description sub-model. The rationale used in the Washington area is presented to indicate how the vehicle trip origin forecasts used in this application were developed.

2/ Koppelman, Frank S., A Model for Highway Needs Evaluation, ITR 4157-2490, Tri-State Transportation Commission, December, 1969.

FIGURE I

FLOW CHART OF AUTO EMISSIONS MODEL



Pollutant Emission Sub-Model

The emission sub-model utilizes average speeds, to determine the CO, HC and NO_x emission rates, in pounds per vehicle mile, for each facility type. This rate is then multiplied by the VMT on each facility type to determine the total pollutants emitted for each of the sub-areas. This process is carried out for both peak-hour and daily conditions.

The emission factors used in this study were supplied by the U.S. Environmental Protection Agency. CO and HC emissions per vehicle-mile of travel decrease with increasing speeds while emissions of nitrogen oxides are assumed to be constant for all speeds. More details on the emissions model and the emission factors used can be found in the following section and in Chapter V.

TECHNICAL ADVISORY COMMITTEE

A Technical Advisory Committee was formed to provide advice on certain technical aspects of the study. The following agencies were represented:

U.S. Environmental Protection Agency

Federal Highway Administration

D.C. Department of Environmental Services

D.C. Department of Highways and Traffic

Maryland Department of Health and Mental Hygiene

Virginia Air Pollution Control Board

Metropolitan Washington Coalition for Clean Air

Department of Health and Environmental Protection, Metropolitan Washington Council of Governments

A major concern of the Committee was reviewing the relationship assumed between auto speed and emission rates. Much discussion centered around the validity of the Environmental Protection Agency emission rates themselves. E.P.A. emission factors are based on non-emission controlled vehicles and on average trip speed.

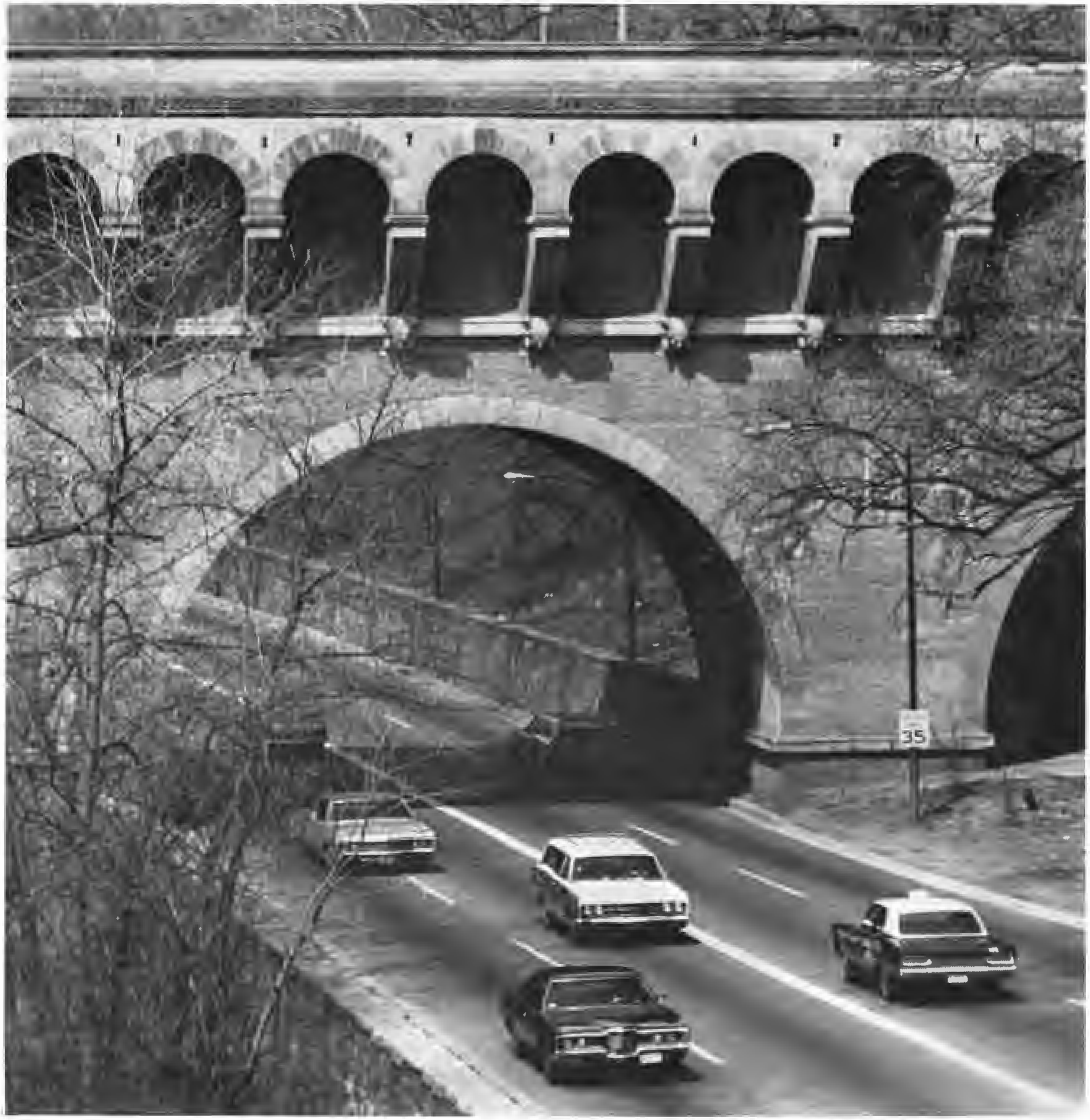
The first consideration caused concern about using the relationships for 1976 where the majority of the auto fleet would have some type of emission control device installed. E.P.A. factors consider that these devices will reduce emissions of CO, HC, and even NO_x in direct proportion to the efficiency of the emission control devices and the degree to which they are incorporated into the car population.

There is little evidence, however, as to how the speed-emission relations have changed with the advent of control devices. That is, even if emissions of CO are reduced for an average route speed of around 19 mph, as indicated by the Federal test cycle, can similar reductions necessarily be expected in the higher speed ranges?

Another related concern is the effect that control devices may have on the oxides of nitrogen emissions. Some Committee members felt that these pollutants, and not the more widely discussed carbon monoxide and hydrocarbons, may quite well be the cause of greatest concern in the future.

The original study design did not include estimating oxides of nitrogen emissions. The Technical Advisory Committee requested that they be included if at all possible. It was agreed that since NO_x emission data were very scarce, an assumption be made that the NO_x emission rate is constant throughout the range of speeds encountered. This assumption is conservative to the extent that all available data, sketchy as they may be, seem to indicate that NO_x emissions increase with speed.

Further discussions centered around the applicability of the E.P.A. emission factors to the study methodology. These factors are based on average overall trip speed; i.e., the total distance covered by an entire trip over all types of roads divided by the time required for it. On the other hand, the travel description model estimates average speed by facility type. There was concern over combining trip specific speed-emission factors with facility specific speeds. At the time the study was initiated, however, there were no data avaible to resolve this inconsistency. The consensus was eventually reached that the E.P.A. factors would be used for this study, but that the reader of the final report would be cautioned to evaluate only the relative differences in the emissions between various strategies and to consider absolute values as tentative at this time.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II Transportation Alternatives

The methodology used in this study can be used to forecast the effects of both transit service and highways on future auto emission levels. For the Washington, D. C. region, nine future systems were tested, consisting of all possible combinations of three highway systems and three transit alternatives. (See Maps 2A and 2B.)

HIGHWAY ALTERNATIVES

The number and extent of freeways was the only variable used to represent the three highway systems. It was assumed that changes in arterial routes were not a major factor in travel patterns in the region. Therefore, arterial and local street supply was held virtually constant in built-up areas between the various 1976 highway alternatives, changing only as the trip end density measures in suburban areas required.

The expressway systems tested were:

(1) Existing 1968 Expressway System This system assumed that, in 1976, no limited-access facilities would be operational that had not been open in 1968.

(2) 1976 "Committed" System This system consisted of the 1968 system with certain additions. It was assumed that I-66 and I-266 in Virginia would be completed into D.C., that the Dulles Access Road would link up with I-66, that I-95 in Maryland would be completed outside I-495, that the East Leg (I-295) would be completed along the Anacostia River, and that the Center Leg (I-95) would be completed within the District of Columbia.

(3) 1976 Full Interstate System This system included those links in the "Committed" Systems plus all Interstate links proposed in the 1968 Interstate Cost Estimates by the three Highway Departments. In Maryland these would include I-95 and I-70S between I-495 and the D.C. line; in the District of Columbia, I-295 and I-70S in the northeast, I-95 and I-66 in the central city, and I-695 in the Mall and Tidal Basin areas were assumed completed. Whether or not these facilities are likely to be built is not a concern of this paper; they are included here to show both their possible effects and the flexibility of the study methodology.

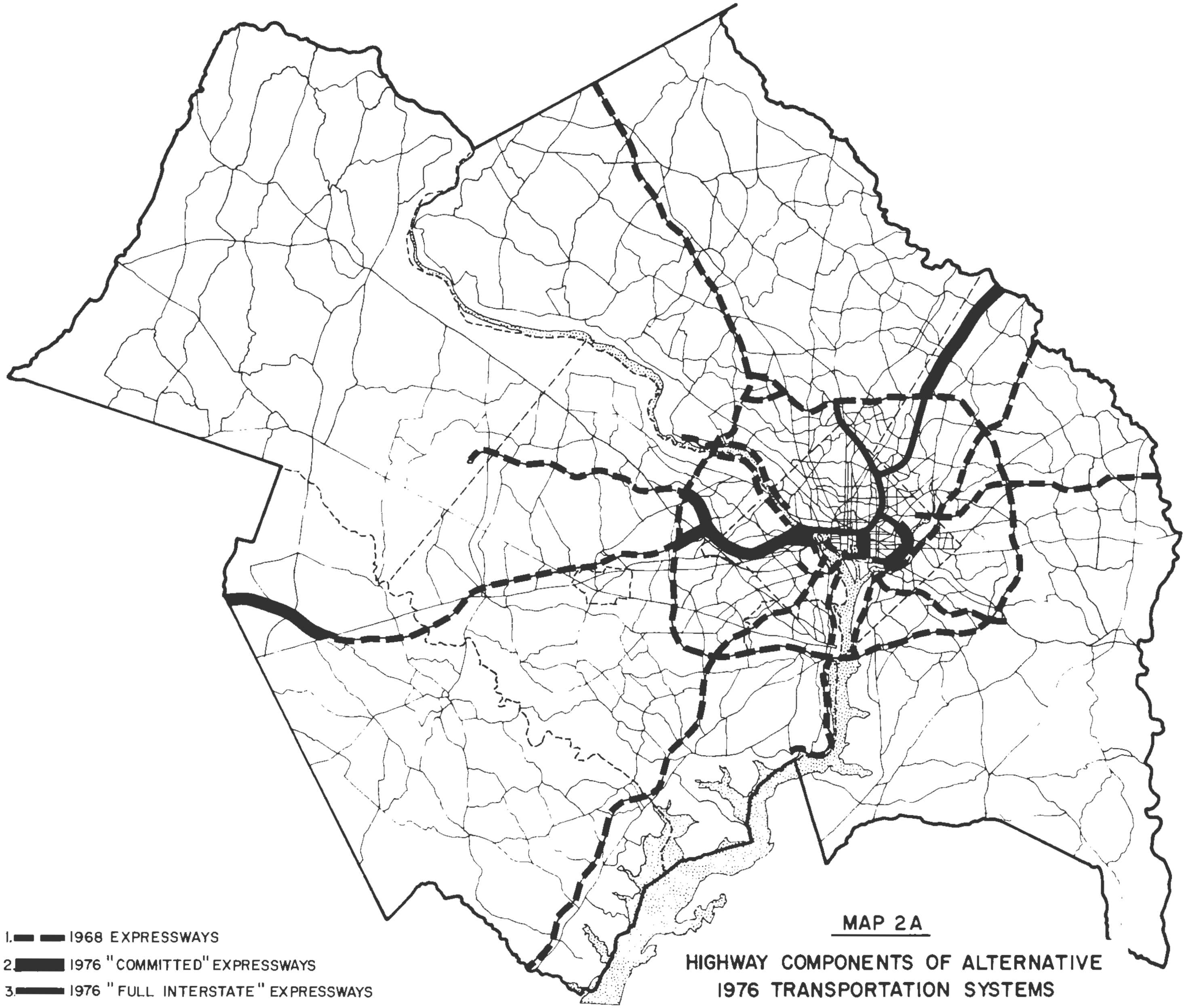
TRANSIT ALTERNATIVES

The transit alternatives consisted of similar extreme cases: no additions to the 1968 system, a reasonable estimate of what would be available in 1976, as well as the full 98-mile adopted rail rapid transit system (METRO).

(1) 1968 Transit This alternative consists of providing, in 1976, bus service identical to that provided in 1968.

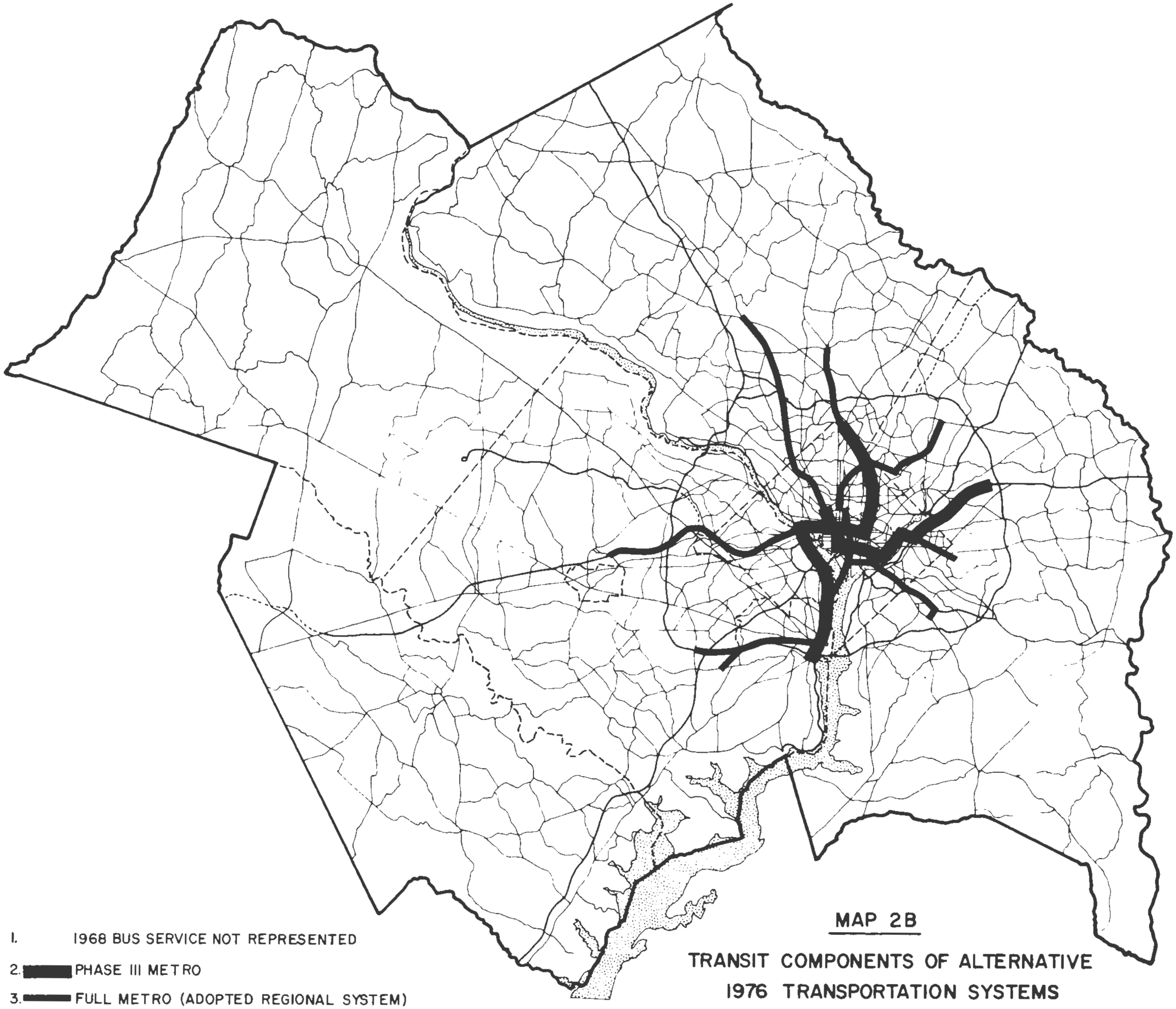
(2) "Phase III" METRO This alternative consisted of the first 30 miles of the METRO rapid transit system currently under construction plus all bus service that would complement and supplement METRO at that stage.

(3) Full METRO This alternative assumed, for testing



MAP 2A

HIGHWAY COMPONENTS OF ALTERNATIVE 1976 TRANSPORTATION SYSTEMS



MAP 2B

TRANSIT COMPONENTS OF ALTERNATIVE 1976 TRANSPORTATION SYSTEMS purposes only, that all 98 miles of the Adopted Regional System would be operational in 1976. The bus service which would exist at the time of this operation was also considered as part of this transit alternative.

These transportation system alternatives, therefore, included some hypothetical cases, since neither the full interstate highway nor the full METRO transit systems could be completed by 1976. It is also unlikely that either the partial highway system or the "Phase III" METRO system will be fully operational by 1976.

III Trip Generation

BACKGROUND INFORMATION

A major advantage of the methodology described herein is that it requires only trip generation estimates in order to forecast travel within the analysis area. Since auto trips make up 9 out of every 10 trips within the region, the trip generation model used reflects vehicle trips by auto only.

The model uses vehicle trip origins as a variable; all vehicle trips are represented in the model by their trip origins-- one-half of total trip ends. For the purposes of forecasting, the model stratifies vehicle trips into two types: home origins (those originating from the home of the auto driver) and non-home origins (all others). These forecasts are based on relations developed through multiple regression analysis techniques using 1968 trip data. A flow chart describing the trip generation model is shown in Figure 2.

NON-HOME TRIP ORIGINS

Non-home trip origins are calculated on a gross basis for each sub-area in the study area. The variables in this submodel are employment, number of households, and the transit accessibility to labor force. Accessibility is measured as the percent of total regional labor force (approximately 1,000,000 in 1968) whose residences are within 45 minutes of the subarea by transit. The transit travel times include total time spent in transit vehicles (buses and/or rail cars), transfer times to switch vehicles, waiting times, and times required to travel to the transit stop.

A graph showing the relation among these variables is shown in Figure 3. This figure indicates the importance of good transit service in reducing the number of vehicle trips.

HOME TRIP ORIGINS

The technique used to determine home-origin vehicle trips is slightly more complex than that for non-home-origin trips. The variables used are income levels and transit accessibility to employment (the number of employment opportunities within 45 minutes of the sub-area by transit). This generation model is based on a rate calculation; the rate argument being the number of autos owned by each household.

An average number of autos per household for each sub-area is forecast using the relations shown in Figure 4. Note the influence of transit service in reducing auto ownership. (See Appendix A for a more complete discussion of auto ownership estimation.) The percentage distribution of 0, 1, 2, and more than 2 car households within an area, as related to the average autos per household level, is shown in Figure 5.

These percentages are multiplied by the total number of households within a sub-area to determine the number of households within each category. The total number of home auto vehicle trip origins is then determined by multiplying the number of households in each auto ownership category by the trip origin rate for homes having that ownership level. This trip origin rate is also affected by the transit service supplied. (See Figure 6.)

SUMMARY OF RESULTS

The extent of the highway system has not been used as a

FIGURE 2
FLOW CHART OF TRIP GENERATION MODEL

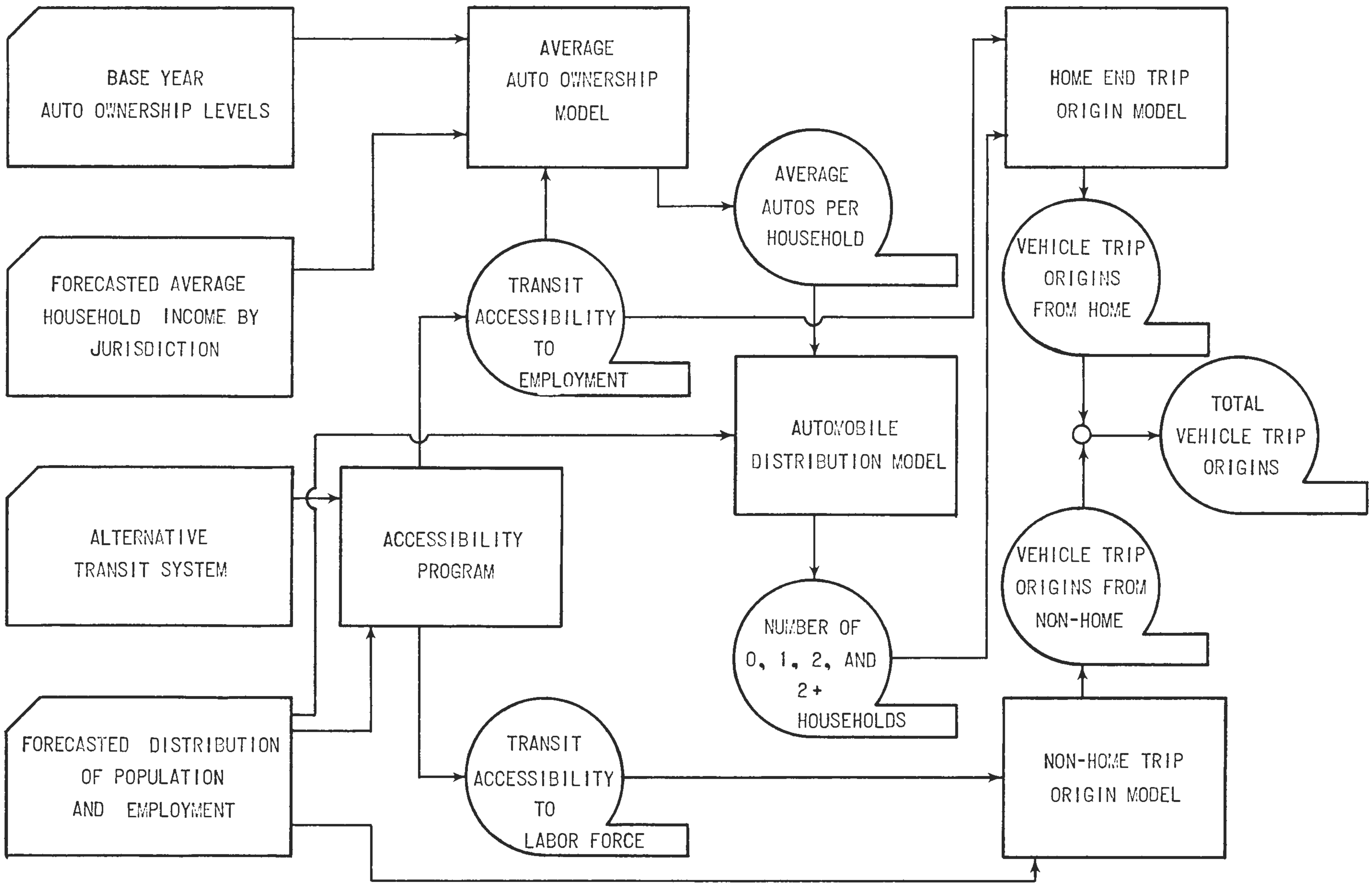
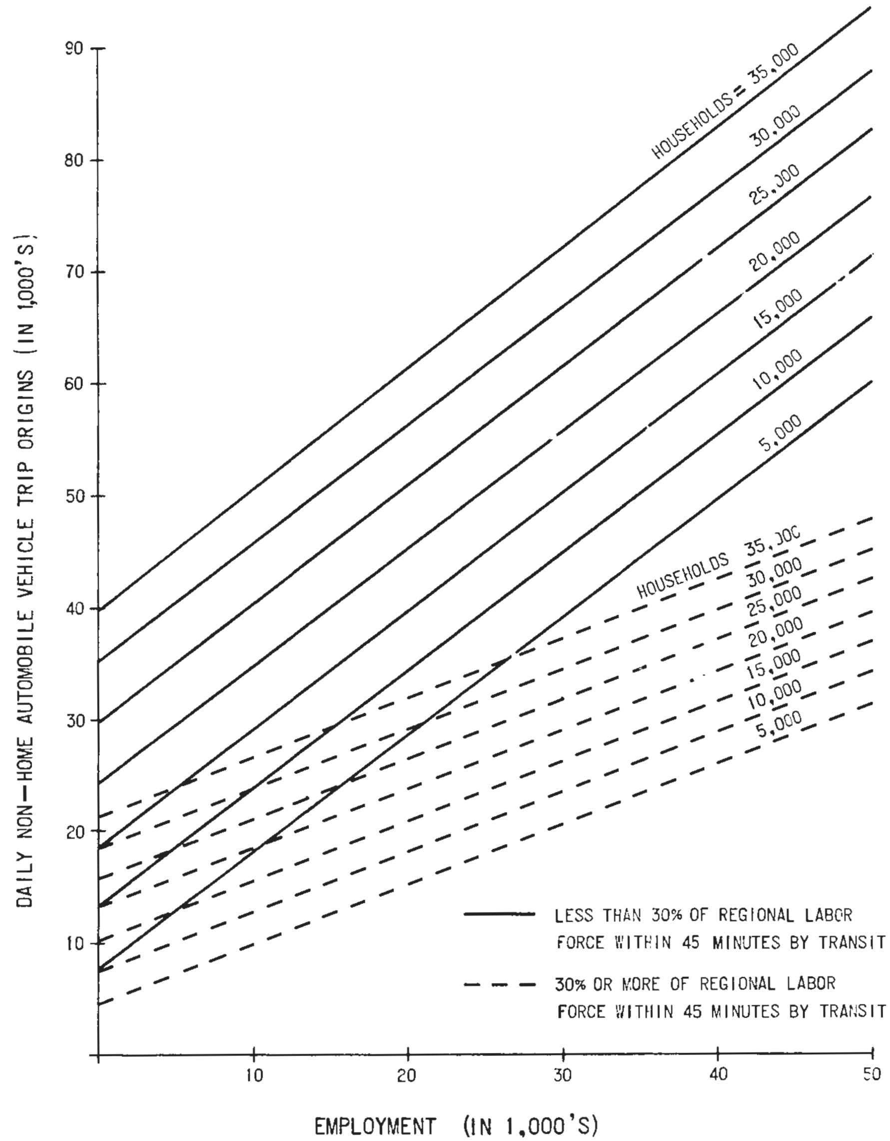


FIGURE 3

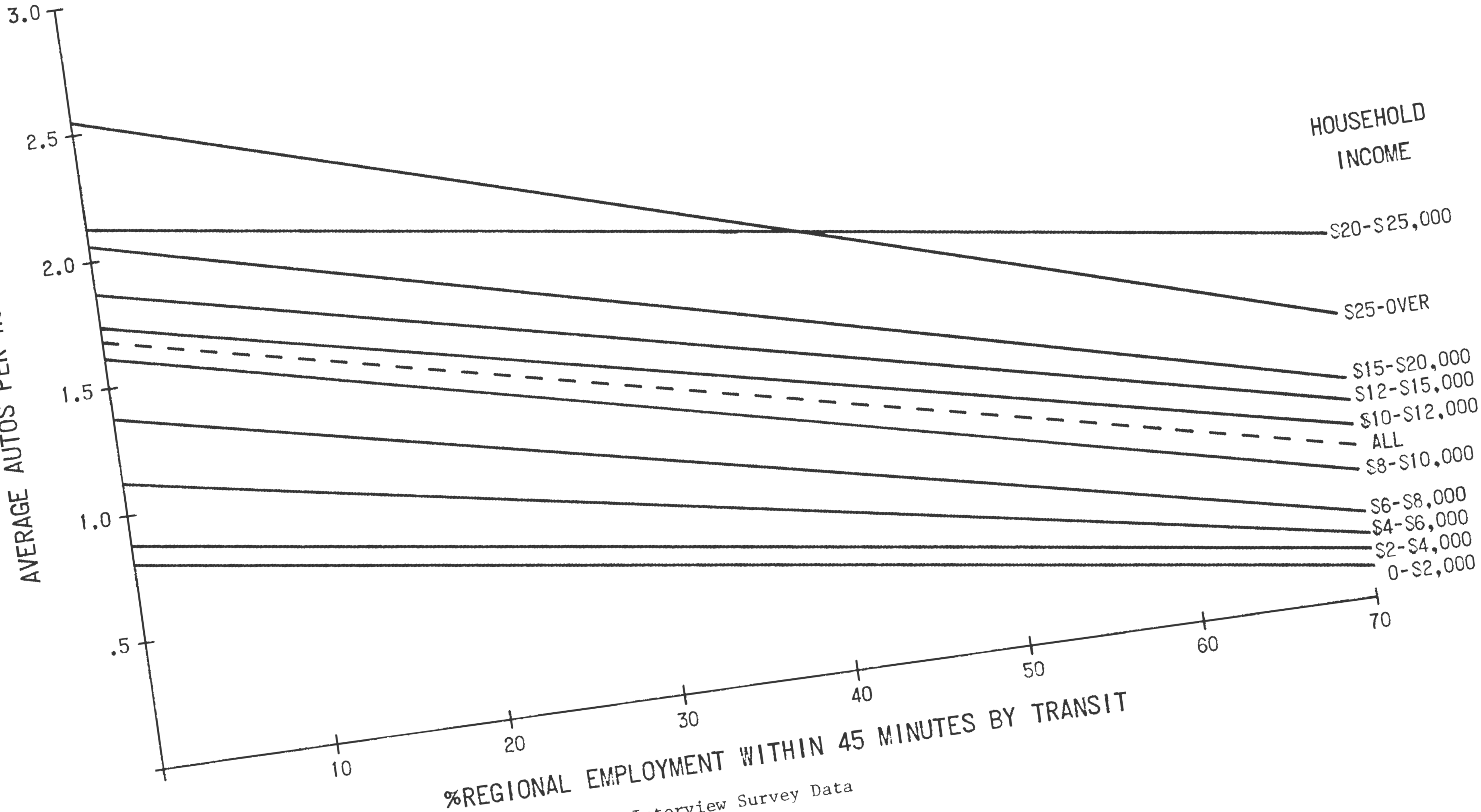
RELATION OF DAILY NON-HOME AUTO TRIP ORIGINS TO HOUSEHOLDS, TOTAL EMPLOYMENT, AND TRANSIT ACCESSIBILITY TO LABOR FORCE



Note: Calibration Based On 1968 MWCOG Home Interview Survey Data
For 134 Internal Analysis Districts

FIGURE 4

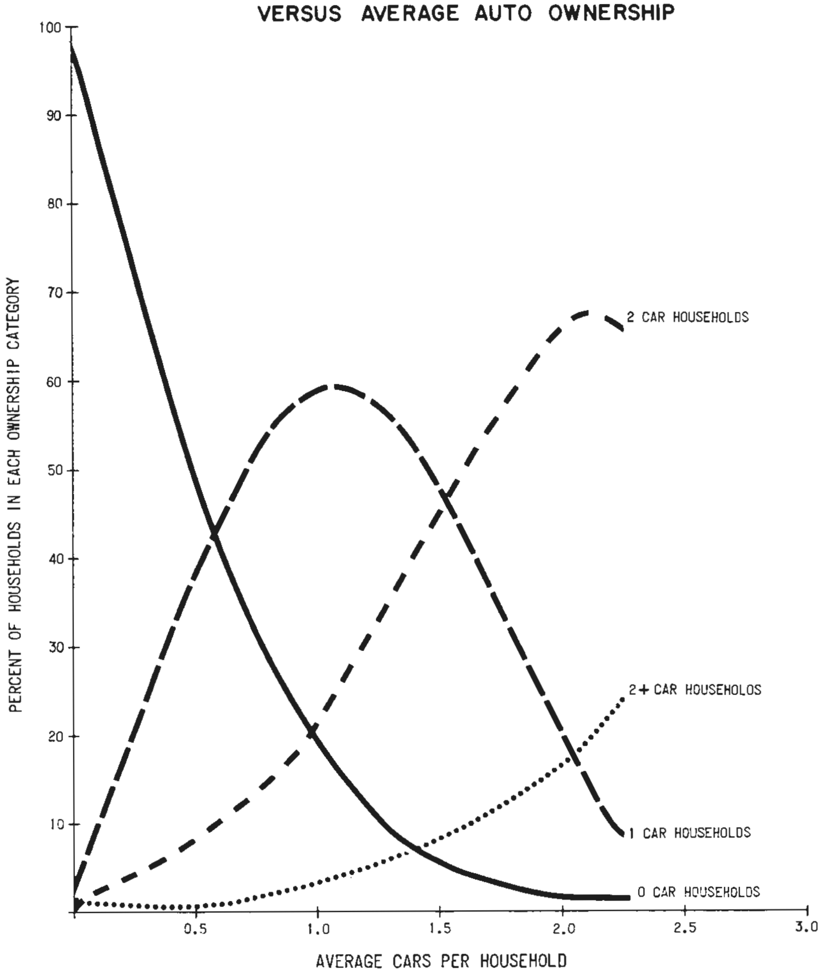
RELATION OF AVERAGE AUTO PER HOUSEHOLD TO INCOME AND TRANSIT ACCESSIBILITY TO EMPLOYMENT



Note: Calibration Based On 1968 MWCOG Home Interview Survey Data
For 134 Internal Analysis Districts

FIGURE 5

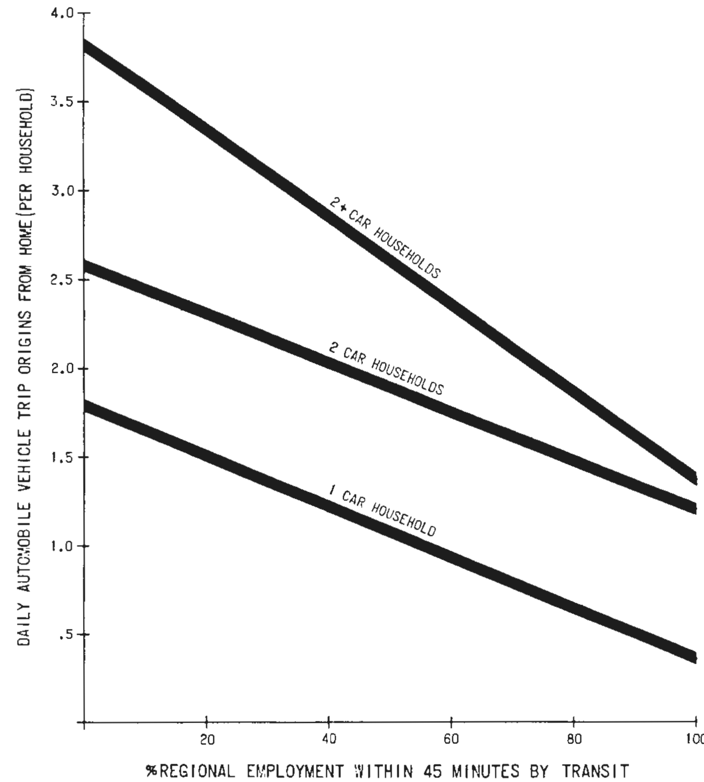
DISTRIBUTION OF 0, 1, 2 AND 2+ AUTO HOUSEHOLDS VERSUS AVERAGE AUTO OWNERSHIP



Note: Calibration Based On 1968 MWCOG Home Interview Survey Data
For 134 Internal Analysis Districts

FIGURE 6

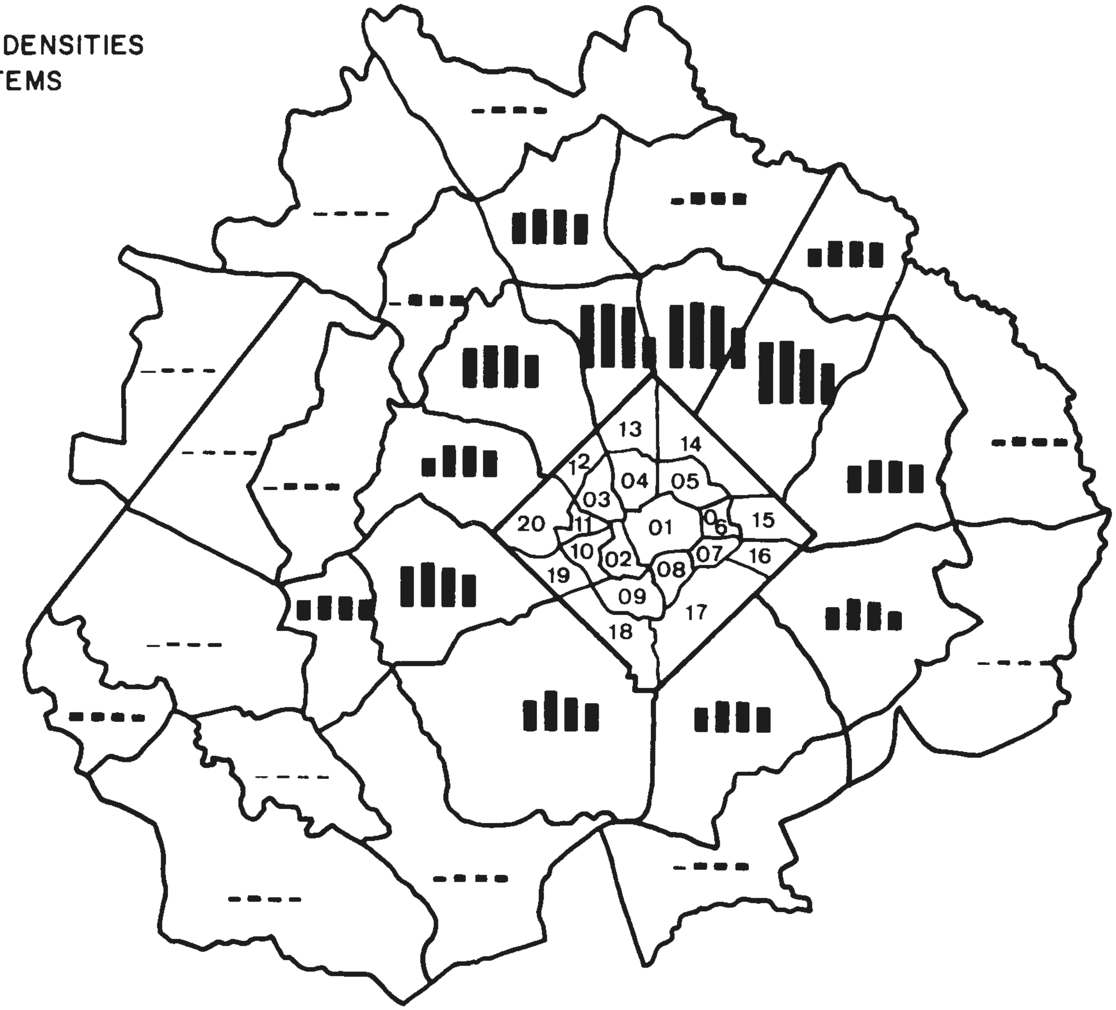
RELATION OF DAILY AUTO TRIP ORIGINS FROM HOME TO TRANSIT ACCESSIBILITY TO EMPLOYMENT AND AUTO OWNERSHIP

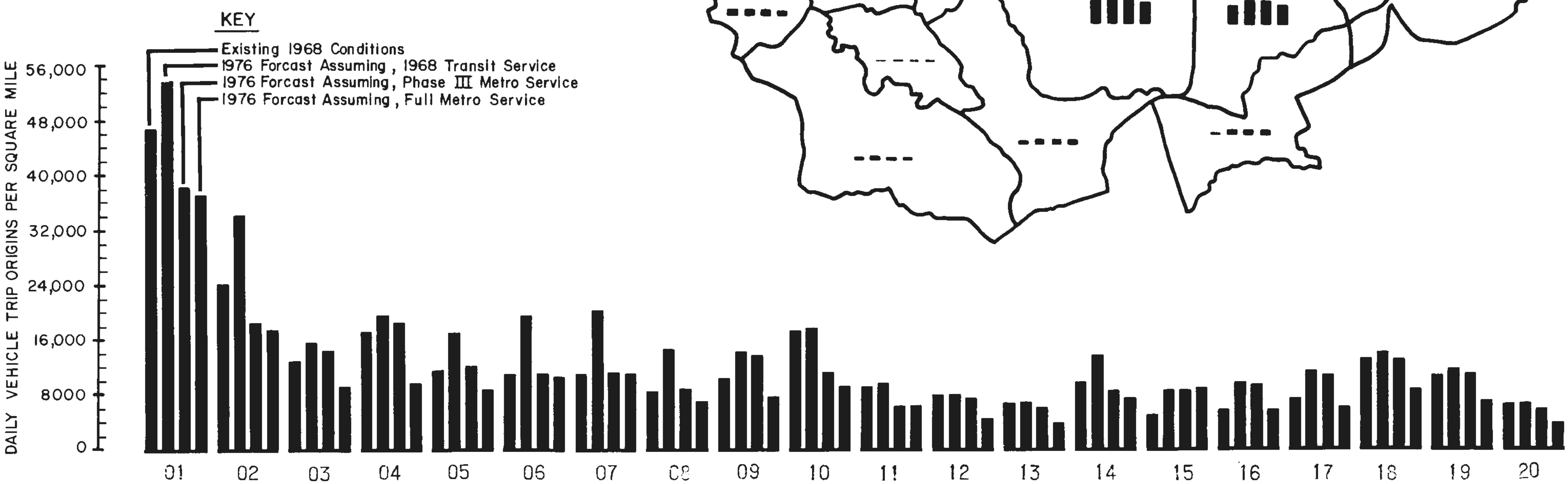


Note: Calibration Based On 1968 MWCOG Home Interview Survey Data
For 134 Internal Analysis Districts

MAP 3

COMPARISON OF AUTO VEHICLE TRIP ORIGIN DENSITIES FOR ALTERNATIVE 1976 TRANSIT SYSTEMS





factor in the vehicle trip generation model. It does affect travel, however, by influencing the length of auto trip. This consideration is covered in Chapter IV.

Thus, the transit component of each alternative transportation system is a major determinant of the number of vehicle trip origins forecast. Table 1 shows jurisdictional totals of home, non-home and total vehicle trip origins for the three 1976 transit systems. Observed 1968 vehicle trip origins are also shown. The forecasts indicate that, if no improvements were made to the base year transit service through 1976, there would be an increase of more than 1,000,000 vehicle trip origins by that date. This increase is cut in half with the addition of the first 30 miles of METRO and supplemental bus services. An actual decrease of over 200,000 vehicle trips is forecast when the full METRO is used as the transit alternative.[3/] It must be emphasized here that full METRO is a purely hypothetical alternative for 1976. The estimated trip origin densities for the 48 sub-areas of the region are shown on Map 3.

3/ A projected 1976 population of 3,069,000 (inside the cordon) is forecast compared to a 1968 figure of 2,553,000. Employment is estimated to reach 1,455,000 versus a 1968 total of 1,062,000.

IV Travel Description

BACKGROUND INFORMATION

The core of the travel description sub-model is the Highway Needs Model developed by Frank Koppelman of the Tri-State Transportation Commission, New York, New York.[4/] Basically, the model provides a means of determining the costs and benefits associated with varying amounts of expressways (freeways) on a sub-area basis with a minimum of forecast data. It bypasses numerous parts of the traditional urban transportation planning process, by eliminating the need to distribute future trips and to assign these trips to networks. The only travel inputs required are vehicle trip origin forecasts by sub-area. (See Figure 7.)

On a subregional basis, a proposed future expressway system is coded into the model. Expressway supply is expressed in foot-miles. The model can then be used to compute the estimated travel developed on the system by type of route--expressway, arterial and local.

The most important relationship used in the model is between vehicle-miles of travel (VMT) density, vehicle trip origin density, and expressway supply. In the Washington, D.C. area, the relationship was found to be the same as that found in the New York region, that is:

$$VMT = 64.3 \times VTO^{0.74} \times e^{(1.6 \times FE/FO)}$$ (See Figure 8)

Where:

VMT = vehicle-miles of travel per square mile

VTO = vehicle trip origins per square mile

FE/FO = proportion of total roadway surface area made up by expressways

The distribution of VMT by facility type (expressways, arterials, or local streets) is related to the distribution of total driving surface among them. Figure 9 shows the impact of expressway supply on VMT distribution.

Since the model is written in FORTAN IV, other relationships are amenable to modification within the source deck. For example, it was found that the expressway speed estimates calculated for the New York region were too high for use in the Washington area; therefore, the source deck was recompiled using a speed equation specifically calibrated for the Washington Region.

The supply of, and the amount of travel on, each type of facility was used to determine estimates of 24-hour speeds. The travel demand was compared to the supply of facilities in each sub-area to determine an average volume per lane by facility type. This figure is then used, along with the vehicle trip origin density and relationships developed from observed speed-volume per lane data, to determine facility speeds on an average daily basis. (See Figure 10.)

Runs of the model produce summary tables which present data for each analysis unit in the study area. One summary table shows estimated system costs, expressway supply per unit of population, and vehicle trip origins. Another table presents, by facility type, data such as speeds, volumes per lane, and lane-miles of facility. A third table outputs vehicle-miles of travel and route miles by facility types and total VMT densities.

4/ Koppelman, F.S., op.cit.

FIGURE 7

FLOW CHART OF HIGHWAY NEEDS MODEL DESCRIPTION RUN

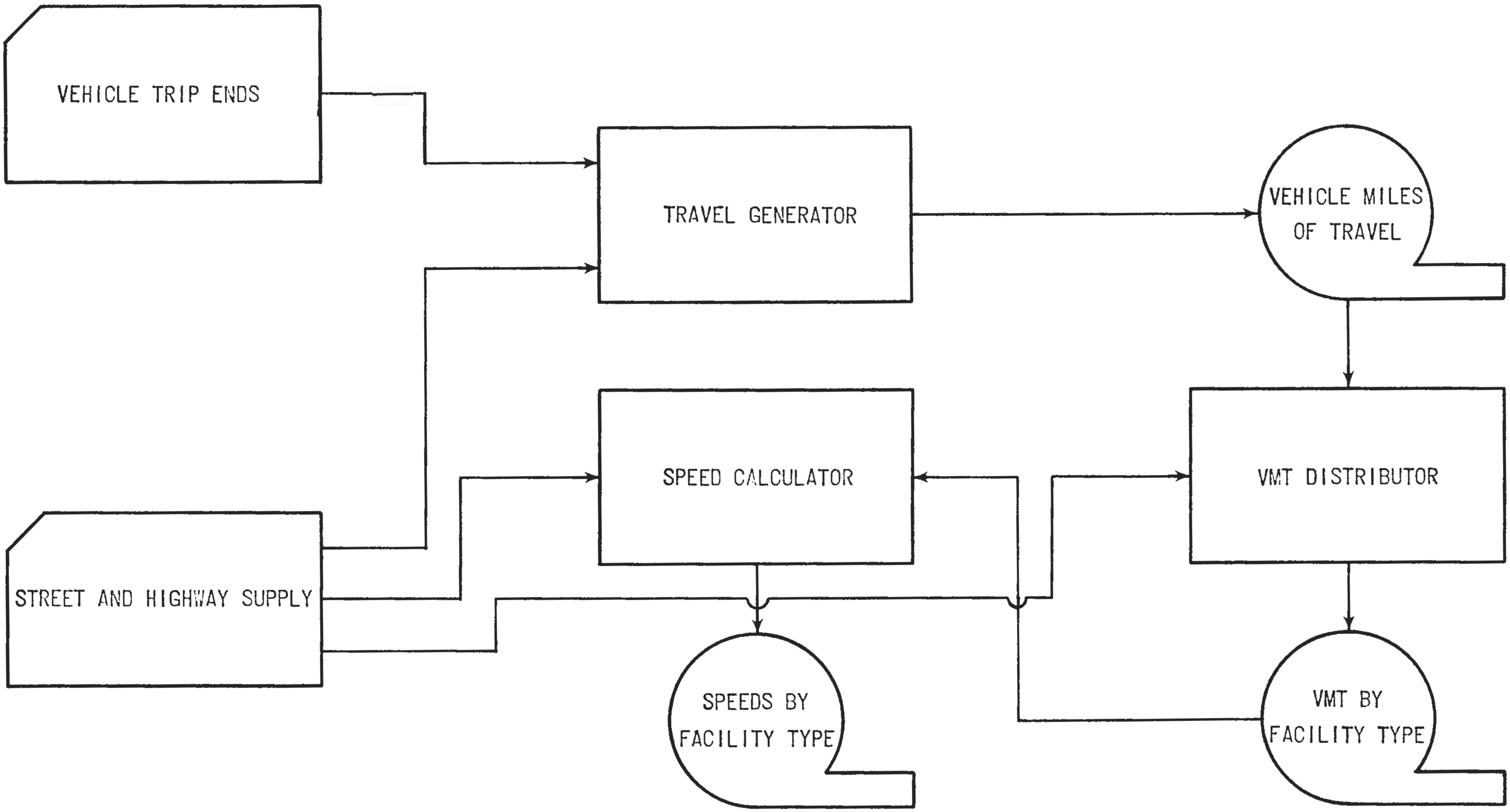
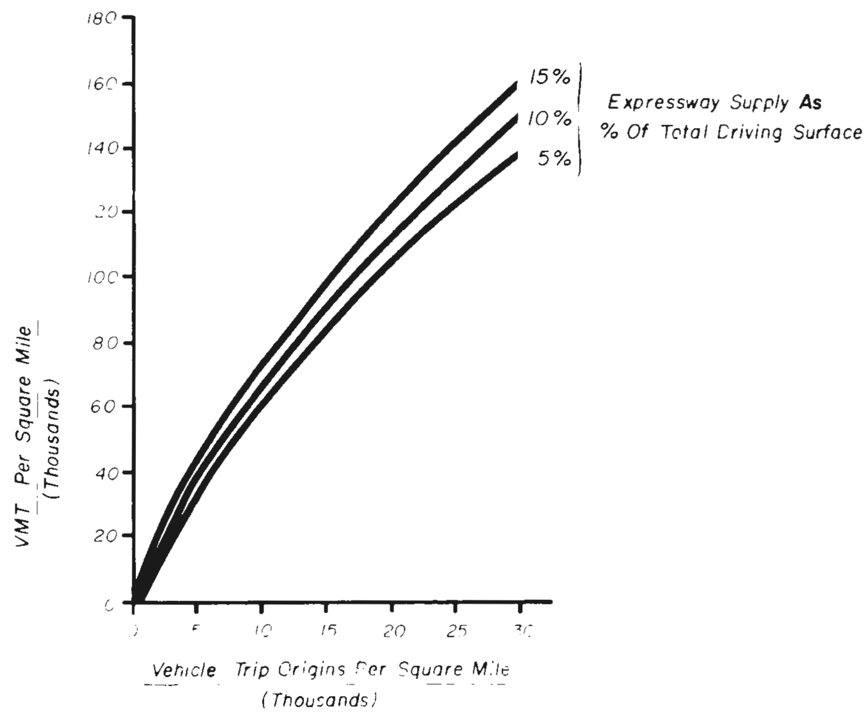


FIGURE 8

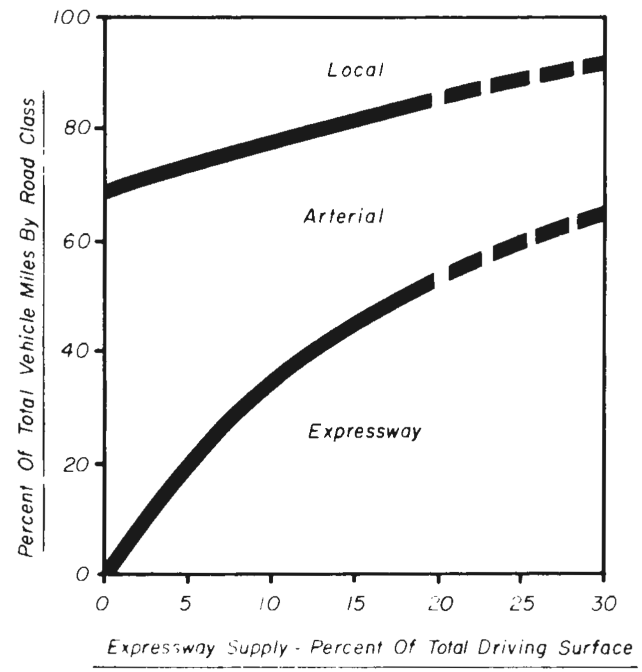
RELATION OF VEHICLE-MILES OF TRAVEL DENSITY TO AUTO TRIP ORIGIN DENSITY AND EXPRESSWAY SUPPLY



Note: Calibration Based On 1968 MWCOG Home Interview Survey And 1968 Traffic Count Data For 134 Internal Analysis Districts

FIGURE 9

RELATION OF VEHICLE-MILES OF TRAVEL (VMT) DISTRIBUTION AMONG FACILITY TYPES TO EXPRESSWAY SUPPLY



Note: Based On 1968 Measuted Conditions In Washington, D.C. Region And On Earlier Work By The Tri-State Transportation Commission, N.Y., N.Y.

1/ Koppelman, F.S. op. cit.

Since peak hour emissions were desired, peak hour speeds were required. To obtain an estimate of peak-hour speeds, the 24 hour VMT was factored to peak hour volumes per lane by facility type, using observed peak-to-daily and directional flow factors. These estimated peak hour volumes allowed a calculation of volume-to-capacity (V/C) ratios for both the peak and the reverse flow for peak-hour conditions. From these V/C ratios, peak-hour and off-peak speeds were calculated for each facility type.

VEHICLE-MILES OF TRAVEL AND SPEED COMPARISONS

A summary of VMT estimates for all transportation systems, by facility and by major jurisdiction, is given in Table 2. Table 3 presents speed data by the same groupings.

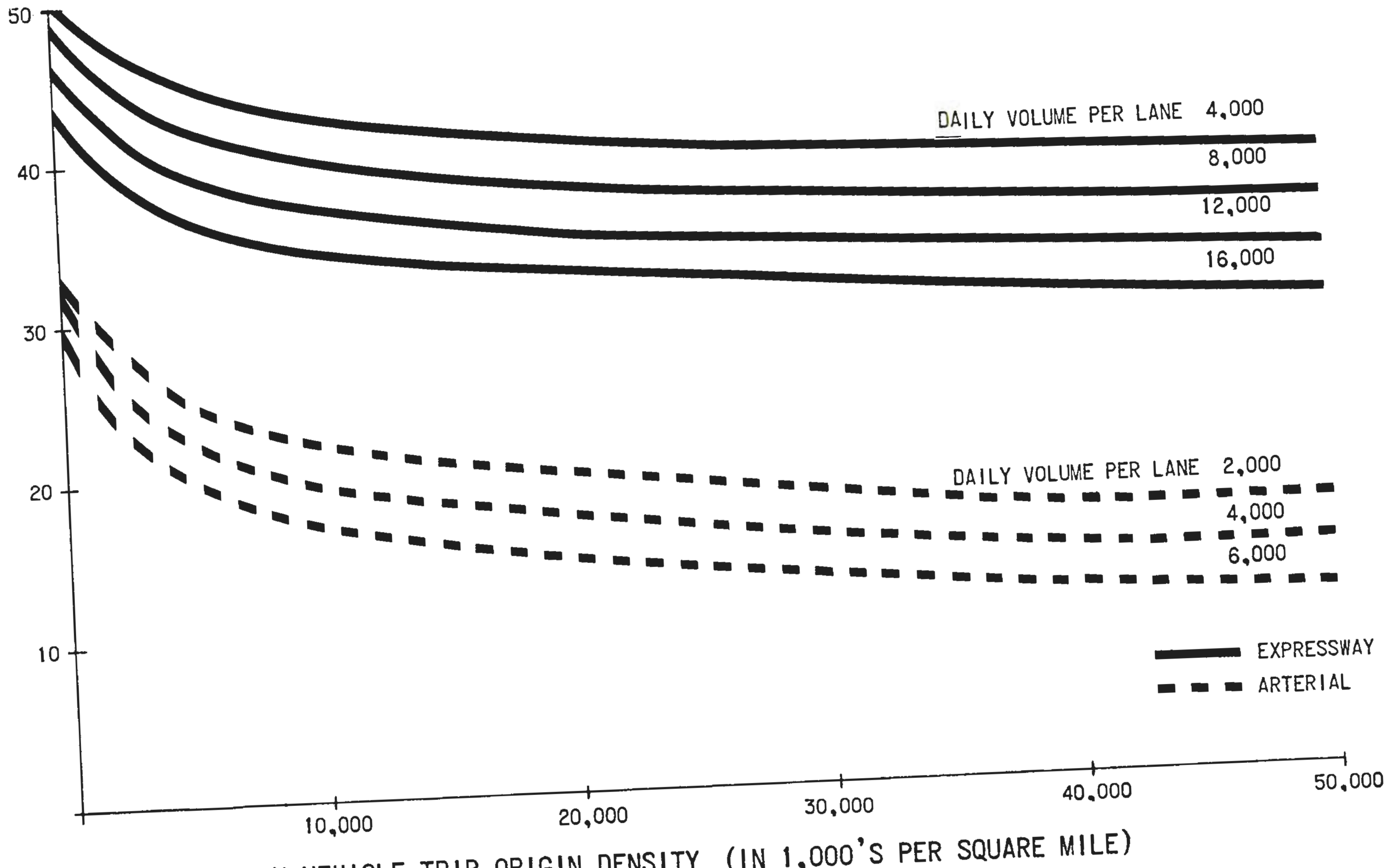
Since the number of vehicle trip ends (and therefore VMT) is a function of transit service, the impact of vastly improved transit service on these travel parameters is considerable. In this study it was assumed that transit service would not only cut down on the number of auto trips made by shifting trips to transit, but would also reduce the amount of auto travel through reductions in auto ownership.

Within the region, the impact of alternative transportation systems on VMT may be considerably greater in one area than in another. Assuming the 1968 highway system as a given for 1976, the Phase III METRO has its greatest effect on VMT within D.C.; building the remaining 68 miles of the rail system, however, has its greatest impact in the suburbs.

In summary, it was found that the METRO rail rapid transit system increases speeds and decreases vehicular travel demands in the region. Additional freeways also increased the speed of travel but increased vehicle-miles of travel as well.

FIGURE 10

RELATION OF AVERAGE DAILY SPEED ON EXPRESSWAY AND ARTERIALS TO TRIP ORIGIN DENSITY AND VOLUME PER LANE



Note: Based On 1968 Measured Conditions In Washington, D.C. Region

V Pollutant Emissions

EMISSION FACTORS BACKGROUND

The VMT and speed estimates produced by the travel description sub-model were then converted to estimates of daily and peak hour emissions of carbon monoxide, hydrocarbons, and oxides of nitrogen. The pollutant emissions sub-model used to accomplish this required emission factors relating automobile speed to the amount of CO, HC, NO_x emitted for each vehicle-mile of travel.

The Technical Advisory Committee eventually decided that the E.P.A. emission factors published in the E.P.A. document, Air Pollutant Emission Factors[5/] were the best available for current use. These factors were modified somewhat by E.P.A. to account for 1976 conditions and the fact that the age distribution of automobiles in the Metropolitan region was different (younger) than the national average.[6/] This resulted in a slightly lower base emission rate for the region, but the proportional changes in rates for speed variations remained identical to that published. The 1968 and 1976 emission rate versus speed curves used are shown in Figure 11.

There are two major concerns with regard to the E.P.A. curves:

1. These curves were developed on the basis of average trip speeds but are being applied on the basis of average facility speed -- that speed on one leg or link of the trip.

2. There is serious question regarding the validity of the speed versus emission rate relations assumed in the E.P.A. curves. The effect of differing speeds on the emission rate assumed in the E.P.A. factors is based on the Rose data developed in the mid 1960's[7/] -- before emission control devices were introduced. Preliminary data from a current five-car study in California[8/] indicates that the impact of control devices might well be to flatten out the CO and HC curves, that is, emission rates may not decrease as rapidly for a given speed increase as they did under the old curves. In addition, whereas the E.P.A. curves indicate that emission rates for NO_x are the same for all speeds, the California test indicates that these emissions might actually rise with an increase in travel speed.

What impact the first of these factors might have on the study is unclear; the probable effect of the second is more clear-cut. If the E.P.A. curves overstate the beneficial aspects of higher speeds on emissions, the decrease in CO and HC emissions forecast for systems which increase speeds by reducing congestion may be overstated.

These doubts concerning the E.P.A. factors have not yet been verified, however, and research is continuing in order to determine more precisely the effect of control devices on the speed versus emission rate curves. In the specific case

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5/ McGraw, M.J. and Duprey, R.L., Compilation of Air Pollutant Emission Factors (Preliminary Document), Environmental Protection Agency, Research Triangle Park, N. C., April, 1971

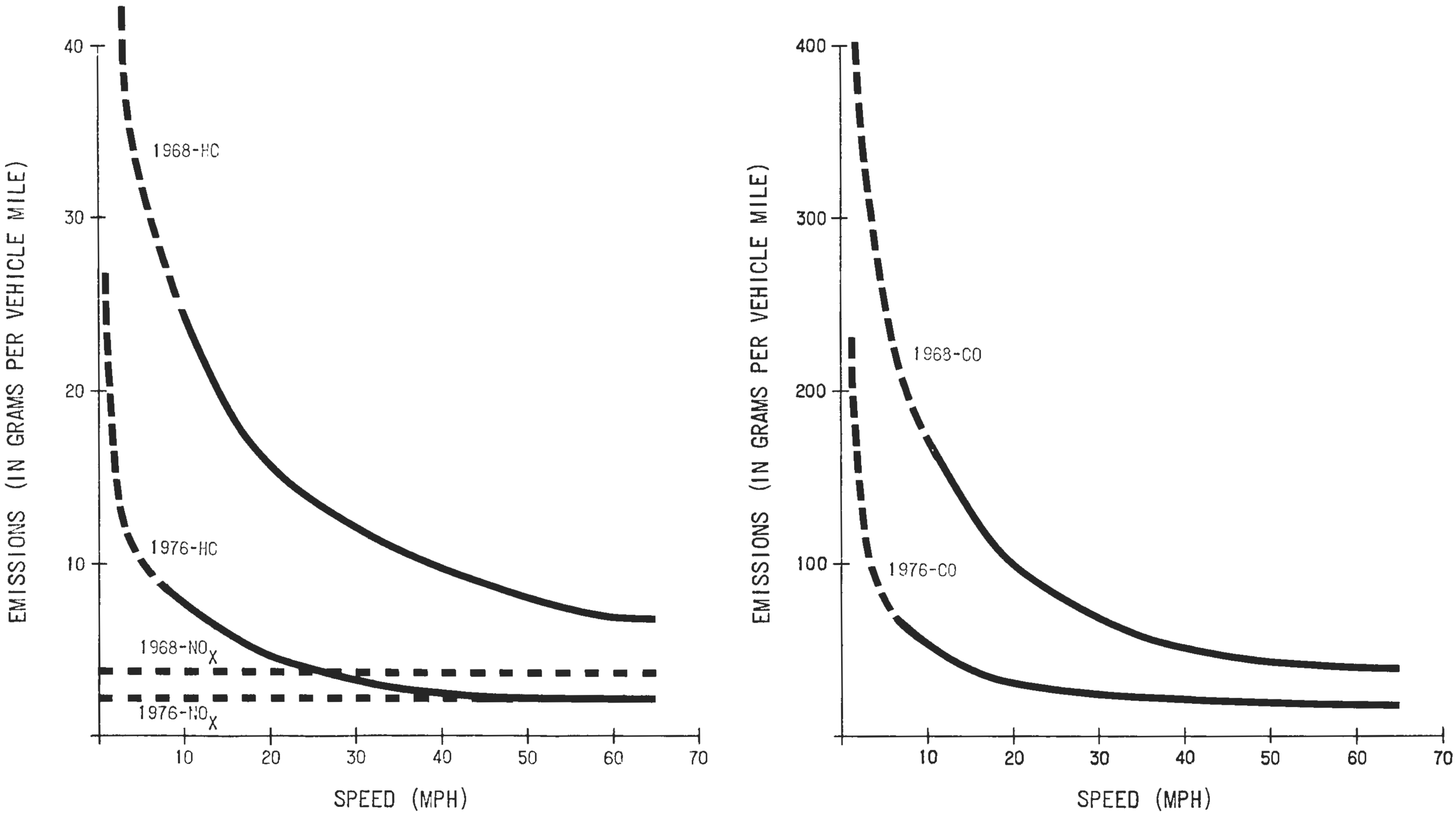
6/ Environmental Protection Agency, Office of Air Programs Memo, "Motor Vehicle Emission Factors for Metropolitan Washington, D. C.," November 4, 1971.

7/ Rose, A. H., Smith, R., McMichael, W. F., and Kruse, R. E., Comparison of Auto Exhaust Emissions from Two Major Cities, paper prepared for presentation at the Air Pollution Control Association Annual Meeting, Houston, Texas, 1964.

8/ California Air Resources Board, Project M-220, March, 1971.

FIGURE II

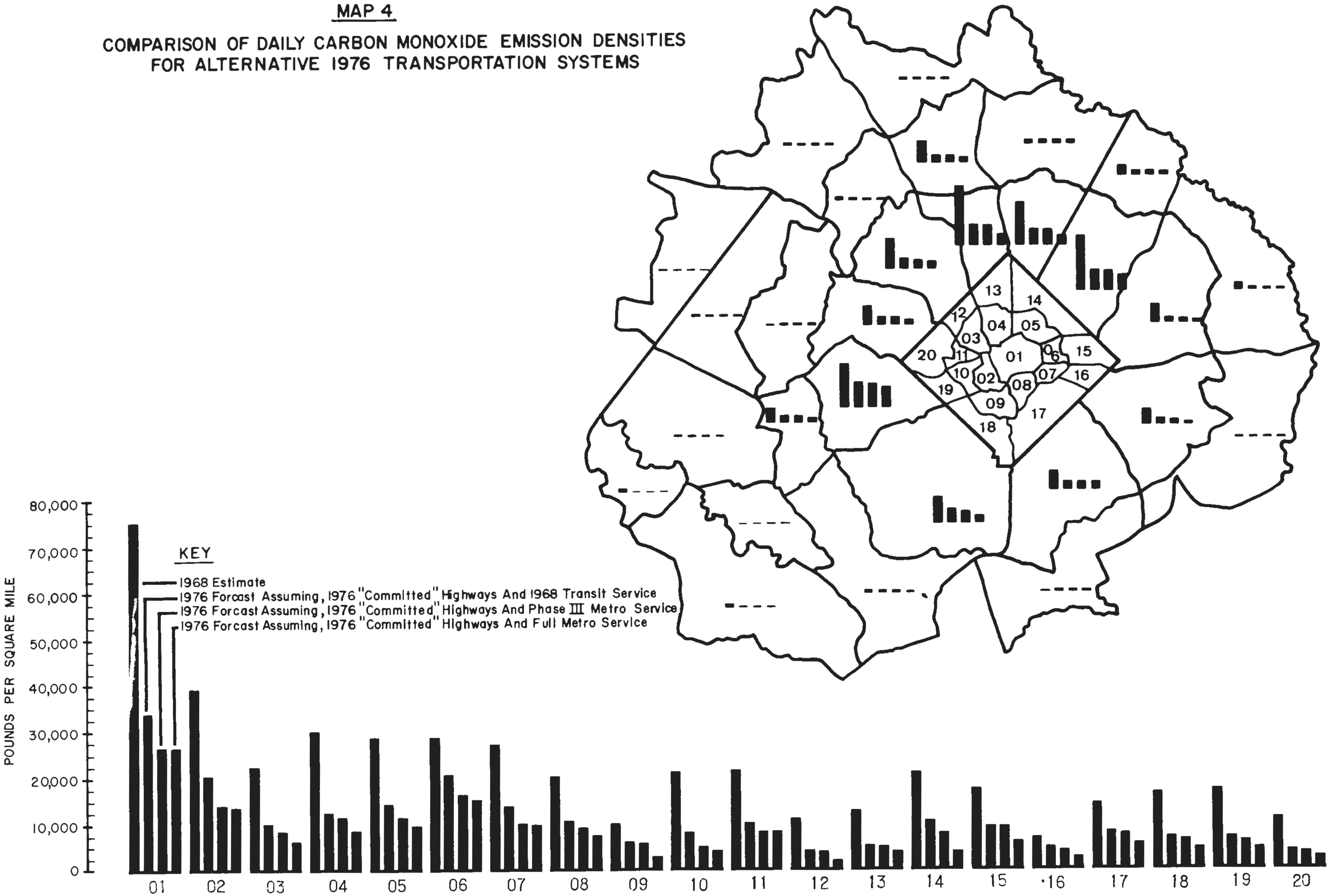
1968 AND 1976 SPEED VERSUS EMISSION RATE CURVES FOR CARBON MONOXIDE (CO), HYDROCARBONS (HC), AND OXIDES OF NITROGEN (NO_x)



Source: (1) McGraw,M.J.,and R.L. Duprey, Compilation Of Air Pollutant Emission Factors (Peliminary Document), Enviromental Protection Agency, April 1,1971.
(2) Enviromental Protection Agency, Office Of Air Programs.
Memo "Motor Vehicle Emission Factors For Metropolitan Washington, D.C.", Dated November 4,1971.

MAP 4

COMPARISON OF DAILY CARBON MONOXIDE EMISSION DENSITIES FOR ALTERNATIVE 1976 TRANSPORTATION SYSTEMS



of the emission model used in this study, revisions to the E.P.A. factors can be easily handled, and results updated as new factors based on continuing research become available.

ACCURACY CHECKS

Before comparing results of the model for various systems and locations throughout the region, it was felt that the model results should be checked against available emission data. The most useful figures against which to compare the model output were the D. C. emission totals published in the District of Columbia Proposed Implementation Plan For the Control of Carbon Monoxide, Nitrogen Dioxide, Hydrocarbons and Oxidants.[9/] Although the jurisdictional emission estimates listed in that document are for 1970, it was felt that the 1968 model estimates would provide a valid basis for making order-of-magnitude comparisons. Table 4 shows a comparison of emissions estimates made by D.C. with those arrived at using the methodology developed in this study.

It is apparent that the carbon monoxide emission estimates are in much greater agreement with the D. C. Implementation Plan estimates than are the hydrocarbon and the oxides of nitrogen estimates. Much of this variation is due to the fact that, while the CO base line calculations done by D. C. used emission factors similar to EPA's, emission rates used for the HC and NO_x calculations were considerably different than the standard EPA rates.[10/] These assumed rates are being studied by EPA at the present time. The difference in HC emissions can be at least partially explained by the introduction of control devices in newer vehicles and the different base years of 1968 and 1970. Discrepancies in the NO_x totals reflect the uncertainty which exists concerning the relation of this type of emission to speed profiles. The fact that this study predicts an NO_x value between the extreme limits of the 1970 D. C. estimates, tends to lend credibility to the estimates of this report and confirm the model's validity for use in comparing alternative systems.

SUBREGIONAL EMISSIONS

Tables 5 through 10 present forecasts of daily and peak hour jurisdictional emissions for all nine 1976 systems, as well as estimates of 1968 emissions. Approximately 40% of all daily CO and HC auto emissions occur in Maryland, with Virginia and the District of Columbia receiving about 30% each. For NO_x, the D. C. figure drops to below 25% and Virginia's increases to around 35%.

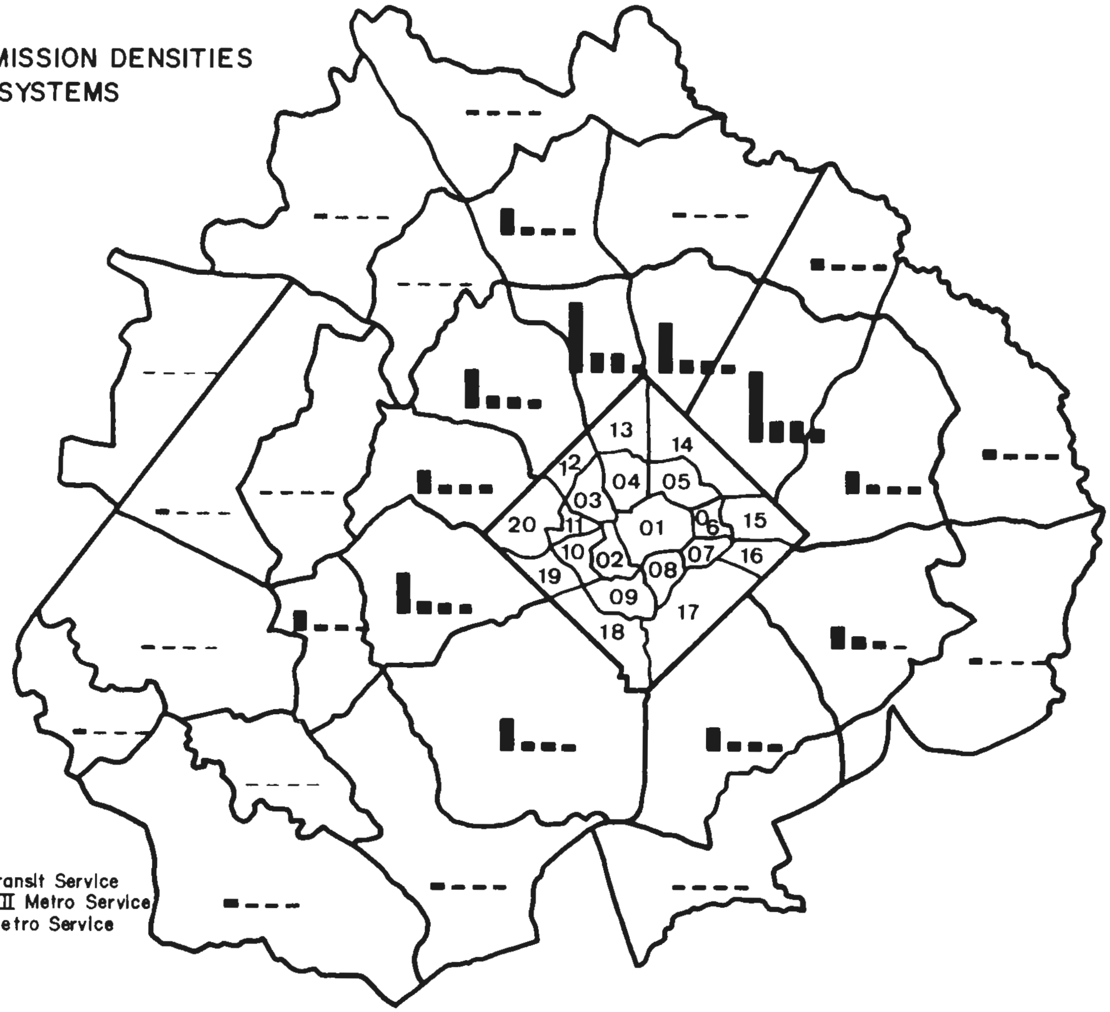
Although the suburban jurisdictions contribute over 70% to regional emissions, the most serious concentrations occur within the District of Columbia. Maps 4, 5, and 6 show emission densities, by sub-area, for 1968 conditions and for three

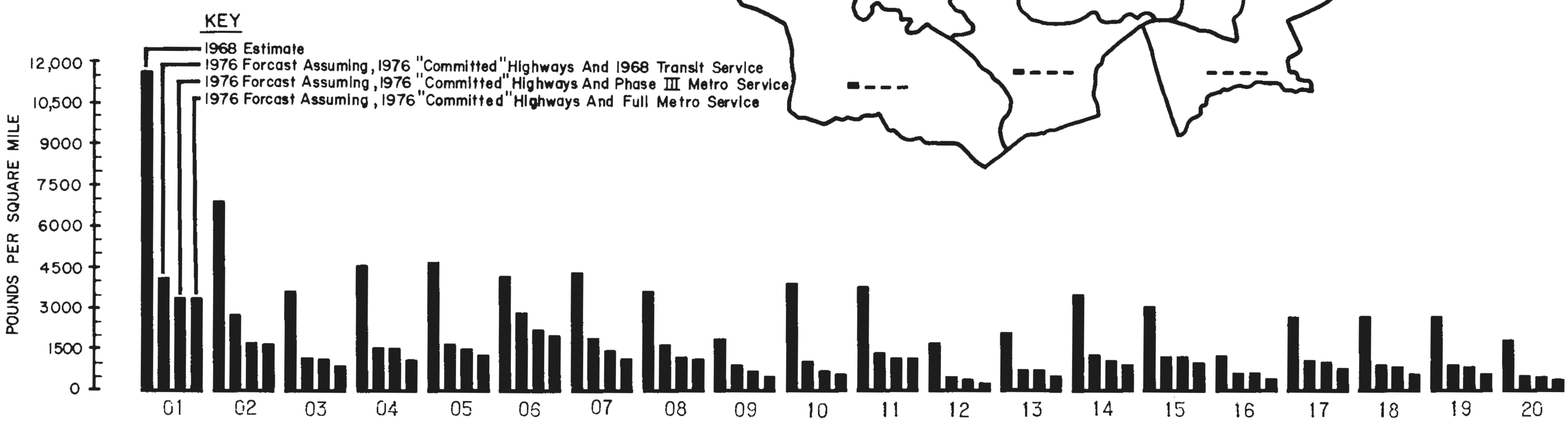
9/ Department of Environmental Services, Government of the District of Columbia, TRW Systems Group, Proposed Implementation Plan For the Control of Carbon Monoxide, Nitrogen Dioxide, Hydrocarbons and Oxidants, October, 1971.

10/ Ibid.

MAP 5

COMPARISON OF DAILY HYDROCARBON EMISSION EMISSION DENSITIES FOR ALTERNATIVE 1976 TRANSPORTATION SYSTEMS





1976 transportation systems.[11/] Using the 1968 base year data as an example, it can be seen that the core area of D. C. (analysis area 1) has CO emission densities double that of the next highest sub-area (the core area of Arlington County.) The emission densities in this area are up to 100 times greater than those experienced at some fringe locations. The magnitude of difference is reduced somewhat for certain 1976 alternatives, but for all system the core is by far the most critical problem area.

The distribution of hydrocarbon densities is similar to that for CO densities. Since HC emission rates do not increase as rapidly as CO rates with decreasing speeds, the core area HC problems do not relate quite as badly to the remainder of the region.

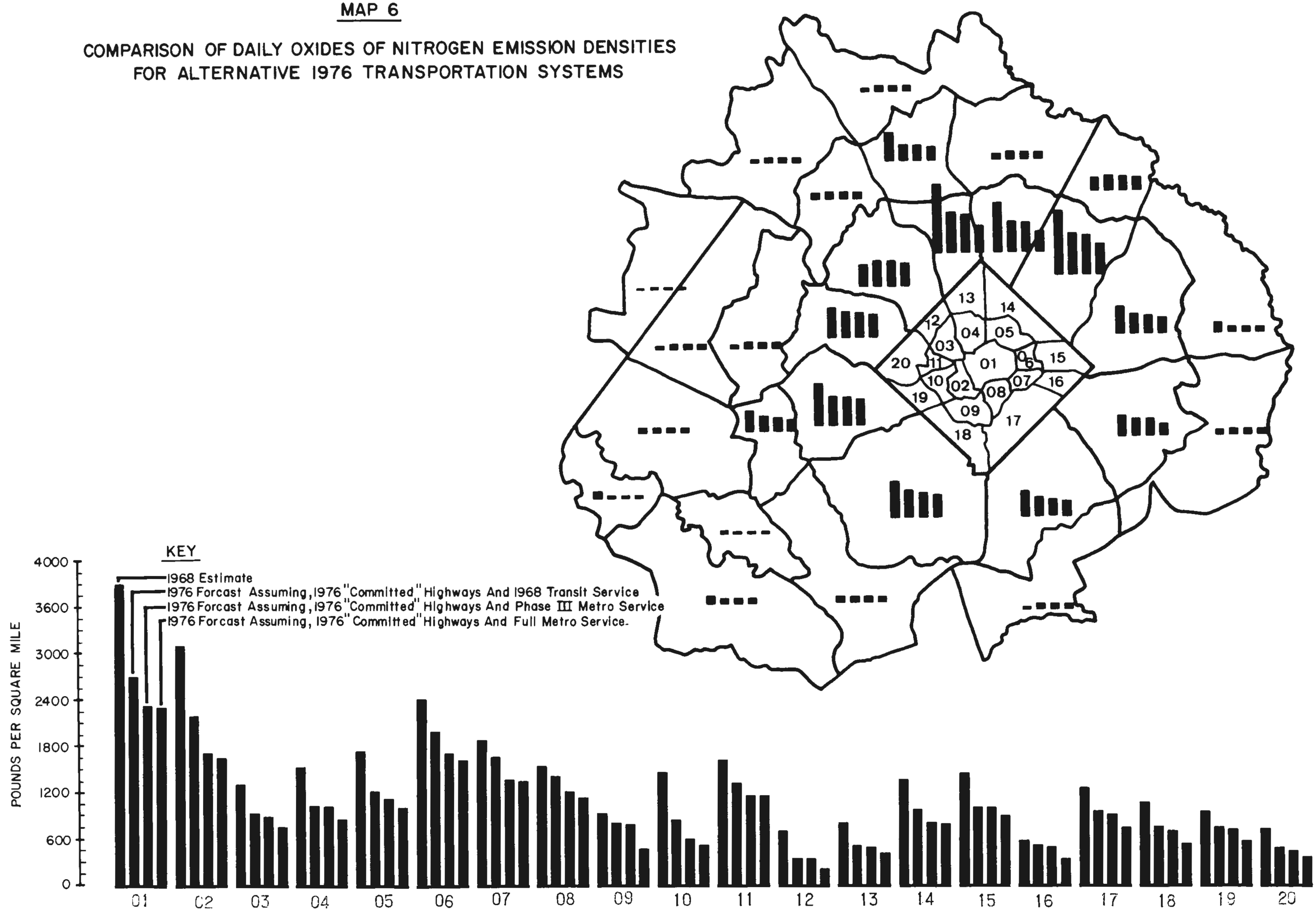
The areal distribution of NO_x densities does not exhibit the same extremes as do CO and HC densities because higher speeds in the outlying areas do not result in lower emission rates. The difference in NO_x emission densities between sub-area 1 and 2, for example, is only on the order of 25%, while the difference in CO emission densities is considerably greater--almost 100%. This points up the importance of speed, as well as the amount of vehicular travel, in determining emission levels.

11/ As can be seen by examining data presented in Tables 5 through 10, the differences in emission levels resulting from varying highway alternatives while holding transit service constant is minor. Since these differences are too small to show up on a map display, Maps 4, 5, and 6 compare 1968 conditions with those expected in 1976 for the three transit alternatives with the highway supply held constant.

The differences noted in this section occur for all future systems to some degree. Specific emission densities within certain areas may be affected more by one system than those in another area but, generally speaking, the points of heavier concentrations for one system remain heavier for all of the alternative transportation systems examined.

MAP 6

COMPARISON OF DAILY OXIDES OF NITROGEN EMISSION DENSITIES FOR ALTERNATIVE 1976 TRANSPORTATION SYSTEMS



VI Comparison Of Alternatives

The emission levels resulting from the nine alternative 1976 systems can be compared with base year (1968) emissions. (See Tables 5 to 10 and Maps 4 to 6.) It is immediately apparent that there will be significant improvements in emission levels regardless of the transportation system assumed, due to improved emission rates. Assuming that 1975 vehicle emission standards are met and are fully effective, the forecasts indicate a decline in daily regional CO emissions of over 51%, a reduction of 62% in regional HC emissions, and a NO_x reduction of 24% below the 1968 levels, even if no improvements were made to the transportation system. The decrease resulting from the introduction of controlled vehicles is, therefore, much greater than that which could be achieved through modifications to the transportation system.

Between jurisdictions, there would be relative differences in the level of improvement resulting from the changes in auto emission rates, with Maryland experiencing the greatest reduction in CO and HC emission levels, and D. C. benefiting most from a reduction in NO_x emissions. These generalizations for average daily conditions are also valid for peak-hour conditions with peak-hour improvement percentages very close to those estimated for the 24-hour period.

In comparing between alternative transportation systems, the transit alternatives studied are also effective in reducing emission levels in the region. In the case of every pollutant, and for every highway system, the difference between the 1968 transit (bus) system and the full METRO alternative is on the order of a one-fifth additional reduction in emission levels, while the difference between the highway configurations studied never exceeded five percent while holding transit service constant.

The additional transit service has its greatest effect on emission levels in the District of Columbia and the downtown central business district or "core" area. The suburban jurisdictions also experience a significant drop in emission levels (on the order of 15 to 20%) as a result of the rail rapid transit system and the associated feeder bus system.

The effect of the limited range of highway alternatives studied is much less pronounced than the effects of control devices or of varying the transit service. There is little noticeable difference in emission levels resulting from the highway alternatives examined. Although the provision of additional freeways in an urban area increases vehicle-miles of travel, such facilities also remove travel from arterial streets and increase travel speed on these routes.

A major goal of this study was to determine to what extent the increase in vehicular travel was counter-balanced by lower emission rates resulting from higher speeds. While there is little discernible effect on regional CO and HC emissions created by highway alternatives, the one pollutant which does increase slightly as additional highways are built is oxides of nitrogen. This is to be expected as the emission rate for NO_x does not decrease for higher speeds and, as previously noted, some additional travel is generated by the provision of freeways or expressway facilities.

VII Summary And Conclusions

SUMMARY

A model has been developed which can estimate the relative magnitudes of carbon monoxide, hydrocarbon and oxides of nitrogen auto emissions for alternative regional transportation systems.

Transportation input data requirements for the model have been simplified to the extent that only vehicle trip origins for the year for which emissions are to be calculated are required, along with the alternative transportation systems under consideration. These systems need only be described in terms of foot-miles of freeways by sub-area.

The number of analysis sub-areas within a region which can be considered is limited to about 50 depending on the degree of aggregation desired. In the application of the model to the Washington, D. C. Metropolitan area, 48 sub-areas, plus 11 aggregation units (counties, states, and regions), were used.

The computation of auto emissions for each sub-area is accomplished by a computer program (written in FORTRAN IV). This program accepts trip origin and facility data, together with assumed auto emission rates and calculates the speed, vehicle-miles of travel, and emission levels by type of facility and by sub-area. Emission rates are a function of the speed of travel and the age distribution of vehicles in the year under study. The program logic is based partly on an existing model developed for estimating highway facility requirements,[12/] specifically modified for the purpose of calculating auto emissions.

In the Washington, D. C. area application, the effect of alternative transit as well as highway systems were included in the evaluation by allowing the introduction of larger scale transit systems to influence the number of vehicle trip origins within a sub-area through reductions in auto ownership, as well as by influencing the magnitude of vehicle trip generation.

Nine future alternative highway and transit system combinations, together with a base year transportation system, were evaluated for their effect on auto emissions by sub-area. The "null" or no improvement alternative was included as one of the nine alternatives.

The programs developed permitted rapid testing and evaluation of each alternative transportation plan tested. Once input data had been prepared and coded, the calculations could be made in a matter of minutes using a high-speed computer. The programs were run on a IBM 360 Model 50, but could be used on smaller computer configurations, if sufficient core is available. The transportation system alternatives examined ranged from considering no additions to either the supply of highways or the amount of transit to extensive improvement in both systems. Vehicle trip origins varied for each of the three transit alternatives considered. Based on forecasts of future population and employment, and compared to 3.5 million daily vehicle trip origins in 1968 transportation system, a forecast of 4.5 million trip origins was made for

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12/ Koppelman, F. S., op. cit.

1976 assuming no improvement to the transit system. With a limited 30 mile rapid transit system considered, this total declined to 4.0 million; while the completion of the full 98-mile rail rapid transit system by 1976 (a purely theoretical case) was estimated to reduce this total below the 1968 level to 3.3 million vehicle trip origins per day.

Vehicle-miles of travel varied not only with the supply of transit and number of vehicle trip origins, but also with the amount of expressway (freeway) facilities. Compared to a 1968 figure of just over 28 million vehicle-miles of travel daily, by 1976 this would have ranged between 38.1 and 39.1 million with existing transit; 34.8 and 36.7 million with a partial rapid transit system; and between 31.0 and 32.7 million with the full adopted regional rail rapid system. The higher figure in each range indicates the magnitude of travel assuming the completion of the full interstate highway system, while the lower figure reflects no additional freeways. A figure between these extremes would be indicated with completion of the committed freeway system.

The program also computed average and daily speeds by type of facility and by sub-area. Peak hour and off-peak speeds were also estimated and used in computing auto emissions. The duration of the peak period was estimated by area (based on current data) and the amount of traffic by direction applicable to each speed range computed.

Average daily speed varied by facility type and area. Compared to a 1968 average daily speed of just under 22 MPH, 1976 average daily speeds ranged between 20 and 24 MPH depending upon the alternative considered. Peak hour speeds had somewhat greater variations, as did expressway facilities. Average daily speeds within the District of Columbia averaged just over 17 MPH in 1968, and varied between nearly 20 MPH down to just under 15 MPH in 1976, again depending on the alternative considered.

CONCLUSIONS

A review of the emission calculations for the Metropolitan Washington, D. C. area indicates that substantial reductions in carbon monoxide (CO), hydrocarbon (HC) and oxide of nitrogen (NO_x) emissions will occur even in the face of an estimated future increase of over 6,000,000 vehicle-miles of travel by 1976. The estimated reductions are

51% for CO, 62% for HC, 24% for NO_x,

and are caused by better emission controls in newer vehicles. *To achieve these reductions, the 1975 vehicle emission standards must be met and be fully effective.*

The largest additional reduction due to transportation system alternatives would be brought about by construction of the full 98-mile rail rapid transit system (METRO). A substantial reduction is also made by a partial 30-mile system. The full 98-mile system is not scheduled for completion until 1980.

With transit supply held constant, little or no regional variation was found in the levels of CO or HC emissions as a result of the alternative highway systems examined. In general, the increased travel was offset by the higher speeds of travel made possible by an expanded freeway system.

Network analysis is required to study these results in detail, however, since variations within each area can occur. NO_x emissions increased as the vehicle-miles of travel increased, and the level of this pollutant increased with the larger highway systems studied.

For each alternative, variations within the metropolitan area were computed by sub-area. The level of pollutants in every case was greatest in the central business district area (CBD) with levels of pollutants being approximately three times higher there than for the District of Columbia as a whole. Suburban levels of CO emissions, for example, were only 6% of CBD levels, on the average.

In this case, the study indicated that the potential for reductions in auto emissions due to the construction of a regional rail rapid transit system to be on the order of a one-fifth reduction over levels which would occur without the system.

VIII Evaluation Of Methodology

ASSUMPTIONS AND LIMITATION

Effects of Simplifying the Transportation Network Description

This study was designed to provide planners and officials with a tool which can be used to rapidly evaluate the relative magnitude and location of auto emissions for alternative regional transportation systems. Input requirements and model calibration procedures were simplified and held to a realistic minimum. Traffic volumes were determined from relationships among vehicle trip origin densities, expressway supply, total travel, and the use of different types of facilities. This bypassed the traditional (and expensive) process of determining origins and destinations for all future trips, assigning them to links on a network, and estimating speeds on the basis of separate analysis for each link on a network.

It should be recognized that the resultant estimates of travel by type of facility in each sub-area, therefore, represent average conditions in that sub-area, and cannot reflect the range of operating conditions which are likely to be found in the sub-area.

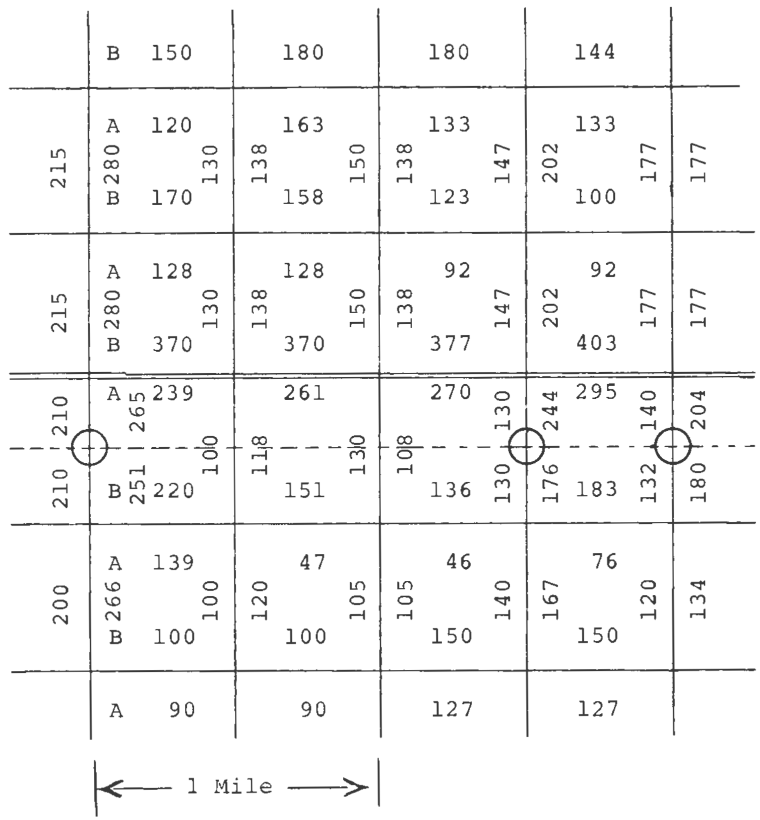
To illustrate, Figure 12 shows before and after arterial street volumes in Chicago due to the opening of the Congress Street Expressway. The total reduction in vehicle-miles of travel on arterial streets in the four square mile area shown was just under eight percent, with 27,600 vehicle-miles of travel daily removed from the arterial street system by the opening of the expressway. This change was not uniform within the area, however, since streets paralled to the new facility had a reduction of nearly 28 percent while streets leading to the facility increased in VMT by over 18 percent. Since speeds can be reduced and emissions increased by increased travel demand, the best way to minimize the effects of freeways on the amount of auto emissions is to give careful consideration to existing problem locations. This should insure that the expressway or freeway facility is located parallel to overloaded arterial streets and that adequate capacity is available on streets leading to interchanges. If this is done, the impact of freeways (assuming satisfactory operating conditions on the freeway itself) can reduce the amount of carbon monoxide and hydrocarbon emissions to levels below that indicated by average conditions. Conversely, the opposite will increase CO and HC emissions above the average. On the other hand, emissions of NO_x will be largely unaffected by the specific design, except insofar as NO_x emissions will increase as total vehicle-miles of travel increases, given the assumption that this emission rate is independent of speed.

Modal Split Assumptions

The relative use of regional transit and auto facilities (modal split) is conditioned by many factors and is usually the subject of elaborate analysis. In the procedure used, the input of vehicle trip ends could be derived from any modal split analysis. For the specific study made, the relative use of transit for trips originating at home was introduced by allowing transit service to influence the level of automobile ownership in a sub-area, and hence indirectly influence the number of

FIGURE 12

EFFECT OF FREEWAY ON TRAFFIC USING ADJACENT STREET SYSTEM----CHICAGO, ILLINOIS



DAILY VEHICLE-MILES OF TRAVEL	LEGEND
ON STREETS PARALLEL TO FREEWAY	__________ Arterials
Before : 195800	------⊕-New Freeway
After : 140300	└─Interchange
ON STREETS PERPENDICULAR TO FREEWAY	Daily Arterial Traffic Volumes (In 100's)
Before : 149500	150 Before Freeway
After : 177400	127 After Freeway

Source: Chicago Area Transportation Study Final Report, Volume 3, Chicago, April, 1962, P. 69

vehicle trip origins. For non-home trip origins, transit accessibility also influenced the magnitude of vehicle trip origins by area. These relationships were calibrated for the Washington, D. C. area using 1968 origin-destination and socio-economic data.[13/] Forecasts of transit use were independently derived using the same transit service variables (transit accessibility to employment and to labor force) which were used to influence auto trip levels. This analysis indicated that the relative use of transit was consistent with the changes in vehicle trip origins for each alternative. That is, the use of transit was greatest when the use of the auto was the lowest and vice-versa. Nevertheless, a more sophisticated analysis would have perhaps first estimated person trips and then split these trips by mode of travel. Such an analysis should be incorporated, when available.

Exclusion of Trucks

This study did not evaluate the emissions caused by trucks. While relatively unimportant as a source of pollution[14/] in the Washington, D. C. area (trucks account for less than one of eight vehicle-miles of travel in the region), they could be important in areas of high truck concentration and in urban areas with a higher proportion of trucks in the traffic stream.

CONSIDERATIONS IN FUTURE APPLICATIONS

Once the assumptions and limitations of the method are understood and accepted, the use of the procedure to rapidly test and evaluate alternative regional transportation plans is a function of input data availability. Vehicle trip origins, by sub-area, are the most essential requirement. These can be obtained from past studies, if available, or can be obtained from population, employment and auto ownership forecasts through trip generation relationships. Calibration of the travel description (Koppelman) model is desirable for each urban area, and will require base-year highway supply and vehicle-miles of travel information by sub-area and by facility type. Vehicle age data should also be available. In those urban areas where trucks constitute a greater portion of the pollution problem than in D. C., it may be necessary to consider their travel and emission characteristics separately.

Any agency with access to the above information is a candidate to apply the procedure as presently described. In reviewing the data requirements, comprehensive transportation planning agencies seem the most likely groups to apply the procedure, since data and forecasts of the type needed should be available to this type of agency.

RESEARCH RECOMMENDATIONS

Based upon the results of the study in the Washington, D. C. area, several areas of potential research are recommended.

First, it is apparent that the largest reduction in auto emissions is due to the auto emission rates assumed which were, in turn, a function of the age distribution of the vehicles in

13/ See Appendix A for a detailed description of the method used.

14/ Estimates made by the Maryland Department of Health place the share of CO, HC and NO_x pollutants due to trucks at 3, 10, and 11 percent, respectively, of the total due to all vehicles.

the metropolitan area. In this study, no differentiation in the assumed age distribution was made by area or time of day. This suggests two possible areas of research; first, to verify the accuracy of the emission rates under actual vehicle operating conditions, and second, to examine the use and trip distribution pattern of vehicles by age.

The E.P.A. factors used in this study do not isolate "cold-start" emissions (those emissions which occur before the vehicle reaches normal operating temperatures) and "hot-soak" losses (those hydrocarbons that escape at the end of a trip after the engine is shut off) from those which occur during "normal" running conditions. They were, in effect, spread out over the entire length of the trip into an average total emission rate (in grams per vehicle-mile) for the entire trip. There is some indication that these "cold-start" and "hot-soak" emissions will take on increased importance as the proportion of vehicles equipped with control devices grows. Perhaps more attention should be given to these specific emissions in future analyses.

Second, the study has clearly indicated that the largest potential for reduction of pollutant emissions (other than through vehicle control devices or age distribution changes) is by improving public (mass) transportation systems. The study made restricted the analysis to an investigation of the effects on auto emissions of a large scale rail rapid transit system. Other strategies, such as interim improvements to the existing transit system or supplemental public transit improvements --e.g., commuter rail (other than METRO) or express busways--were not analyzed. It is suggested that future research applications include these options as well. This may be of particular importance in meeting short-range E.P.A. air quality standards.

In this regard, it is obvious from the analysis made that the critical local problem is centered in the Central Business District area. Since the relatively high level of taxi travel within this area contributes to auto emissions, the effects of lower auto emission rates on this fleet should be analyzed. This can be achieved by equipping such vehicles with the latest control devices, or changing fuel sources for such vehicles.

In addition, the potential for reducing peak hour emission rates to the level of the daily average should be studied by considering the potential for further staggering of working hours in the CBD. The encouragement of car pooling arrangements should also be pursued, perhaps through higher pricing of parking and through providing preferential treatment on facilities (i.e., exclusive lanes) for multi-occupancy vehicles.

Another option which could be analyzed is the potential for applying several of the above measures in combination: i.e., improved bus service, vehicle controls, car pooling, taxi fleet improvements, staggered working hours, etc., in a coordinated attempt to reduce the level of auto emissions in the Central Business District.

Third, the distribution of future population and employment was fixed, owing to the short forecast period (1968-1976) involved. Alternative population and employment forecasts could be analyzed to determine the long-term effect of regional growth and development policies on auto emission levels.

The methodology developed could be utilized and expanded, or supplemented where required, to obtain estimates of the effect of both the long range development policies and the interim strategies.

Finally, while the study achieved the objectives set at the outset, to make the procedure more useful as a policy tool, it is necessary to be able to rapidly convert auto emission output data to air quality measures. It may be possible to convert the study output to such measures for future years by comparing today's air quality variations to the base year output and utilizing simple ratio techniques to estimate future conditions.

References

1. California Air Resources Board, Project M-220, Effect of Speed on Emissions, Los Angeles, California, March 1971.

2. Government of the District of Columbia, Department of Environmental Services and TRW Systems Group, Proposed Implementation Plan For the Control of Carbon Monoxide, Nitrogen Dioxide, Hydrocarbons, and Oxidants, October 1971.

3. Koppelman, Frank S., A Model for Highway Needs Evaluation, ITR 4157-2490, Tri-State Transportation Commission, December 1969. Also published in Highway Research Record 314, pp. 123-134, Highway Research Board, 1970.

4. McGraw, M.J. and Duprey, R.L., Compilation of Air Pollutant Emission Factors (Preliminary Document), U.S. Environmental Protection Agency, Research Triangle Park, N.C., April 1971.

5. Rose, A.H, Smith, R., McMichael, W.F. and Kruse, R.E, Comparison of Auto Exhaust Emissions from Two Major Cities, paper prepared for presentation at the Air Pollution Control Association Annual Meeting, Houston, Texas, 1964.

6. U.S. Environmental Protection Agency, Office of Air Programs Memo, "Motor Vehicle Emission Factors for Metropolitan Washington, D.C.," November 4, 1971.

TABLE 1

AUTO VEHICLE TRIP ORIGINS (IN 1000's) BY JURISDICTION FOR HOME BASED AND NON-HOME BASED TRIPS

JURISDICTION	1968 BASE YEAR CONDITIONS 1/			1976 ACTIVITIES-1968 TRANSIT 2/			1976 ACTIVITIES-PHASE III METRO 2/			1976 ACTIVITIES-FULL METRO 2/		
	HOME	NON-HOME	TOTAL	HOME	NON-HOME	TOTAL	HOME	NON-HOME	TOTAL	HOME	NON-HOME	TOTAL
D. C.	210	516	726	242	897	1,139	184	669	853	116	551	667
MONT. CO.	308	420	728	383	471	854	349	472	821	249	405	654
PR. GEO. CO.	404	473	877	519	553	1,072	446	553	999	353	476	829
MARYLAND	712	893	1,605	902	1,024	1,926	795	1,025	1,820	602	881	1,483
VA. (inside 10 mile sq.)	146	252	398	126	317	443	96	254	350	76	174	250
VA. (outside 10 mile sq.)	330	424	754	481	545	1,026	408	550	958	328	524	852
VIRGINIA	476	676	1,152	607	862	1,469	504	804	1,308	404	698	1,102
REGION	1,398	2,085	3,485	1,751	2,783	4,534	1,483	2,498	3,981	1,122	2,130	3,252

NOTE: See Chapter II for a full description of the three transit schemes examined in this table.

1/ Based on MWCOG 1968 Home Interview Survey data.

2/ Estimated for a preliminary forecast of 1976 activities.

TABLE 2

DAILY AUTOMOBILE VEHICLE-MILE-OF-TRAVEL (IN 1,000's) BY FACILITY TYPE FOR ALTERNATIVE 1976 TRANSPORTATION SYSTEMS

		TRANSPORTATION ALTERNATIVES									
	HIGHWAY COMPONENT	1968 EXISTING EXPRESSWAY SYSTEM				1976 "COMMITTED" EXPRESSWAY			1976 "FULL INTERSTATE"		
JURISDICTION	TRANSIT COMPONENT / FACILITY TYPE	1968 BUS SYSTEM 1/	1968 BUS SERVICE	PHASE III METRO	METRO A.R.S.	1968 BUS SERVICE	PHASE III METRO	METRO A.R.S.	1968 BUS SERVICE	PHASE III METRO	METRO A.R.S.
DISTRICT OF COLUMBIA	EXPRESSWAYS	1,090	1,292	1,163	1,039	1,735	1,569	1,424	2,649	2,366	2,184
	ARTERIALS	4,282	5,658	4,833	4,411	5,231	4,683	4,275	4,912	4,413	4,019
	LOCALS	1,302	1,971	1,648	1,449	1,893	1,662	1,457	1,730	1,520	1,324
	ALL FACILITIES	6,674	8,921	7,644	6,899	8,859	7,914	7,156	9,291	8,299	7,527
MARYLAND	EXPRESSWAYS	3,196	3,658	3,465	3,013	4,249	4,102	3,574	4,714	4,539	3,929
	ARTERIALS	6,552	8,758	8,238	7,201	8,237	7,935	6,942	8,082	7,794	6,837
	LOCALS	2,180	3,772	3,515	3,030	3,798	3,639	3,141	3,720	3,565	3,081
	ALL FACILITIES	11,928	16,188	15,218	13,244	16,284	15,676	13,657	16,516	15,898	13,847
VIRGINIA	EXPRESSWAYS	2,991	3,536	3,270	2,999	4,182	3,918	3,548	4,182	3,918	3,548
	ARTERIALS	4,795	6,626	6,130	5,541	6,240	5,877	5,336	6,240	5,877	5,336
	LOCALS	1,671	2,792	2,559	2,283	2,906	2,718	2,437	2,906	2,718	2,437
	ALL FACILITIES	9,457	12,954	11,959	10,823	13,328	12,513	11,321	13,328	12,513	11,321
REGIONAL TOTALS	EXPRESSWAYS	7,277	8,486	7,898	7,051	10,166	9,589	8,546	11,545	10,823	9,661
	ARTERIALS	15,629	21,042	10,201	17,153	19,708	18,495	16,553	10,234	18,084	16,192
	LOCALS	5,153	8,535	7,722	6,762	8,597	8,019	7,035	8,356	7,803	6,842
	ALL FACILITIES	28,059	38,063	34,821	30,966	38,471	36,103	32,134	39,135	36,710	32,695

NOTE: See Chapter II for a full description of the highway and transit components of the alternative transportation systems.

1/ Figures in this column are base year values based on conditions that existed in 1968. (All other columns show estimates based on a preliminary forecast of 1976 activities.)

TABLE 3

AVERAGE DAILY SPEEDS BY FACILITY TYPE AND JURISDICTION FOR ALTERNATIVE 1976 TRANSPORATION SYSTEMS

JURISDICTION	HIGHWAY COMPONENT / TRANSIT COMPONENT / FACILITY TYPE	1968 EXISTING EXPRESSWAY SYSTEM: 1968 BUS SYSTEM 1/	1968 EXISTING EXPRESSWAY SYSTEM: 1968 BUS SERVICE	1968 EXISTING EXPRESSWAY SYSTEM: PHASE III METRO	1968 EXISTING EXPRESSWAY SYSTEM: METRO A.R.S.	1976 "COMMITTED" EXPRESSWAY: 1968 BUS SERVICE	1976 "COMMITTED" EXPRESSWAY: PHASE III METRO	1976 "COMMITTED" EXPRESSWAY: METRO A.R.S.	1976 "FULL INTERSTATE": 1968 BUS SERVICE	1976 "FULL INTERSTATE": PHASE III METRO	1976 "FULL INTERSTATE": METRO A.R.S.
DISTRICT OF COLUMBIA	EXPRESSWAYS	36.08	33.94	36.14	37.55	35.75	37.54	38.60	36.05	37.87	38.83
	ARTERIALS	18.55	15.93	18.19	19.18	16.57	18.33	19.36	16.89	18.55	19.61
	LOCALS	10.35	9.16	10.14	10.61	9.27	10.16	10.65	9.30	10.16	10.67
	ALL FACILITIES	17.24	14.66	16.60	17.50	15.59	17.17	18.14	16.88	18.44	19.54
MARYLAND	EXPRESSWAYS	41.49	41.90	42.41	43.92	42.85	43.25	44.63	42.71	42.14	44.59
	ARTERIALS	24.61	24.58	25.18	26.77	24.87	25.35	26.92	25.06	25.52	27.03
	LOCALS	13.85	14.39	14.63	15.44	14.38	14.60	15.41	14.43	14.65	15.44
	ALL FACILITIES	23.83	22.94	23.45	24.18	23.44	23.86	25.21	23.91	24.31	25.62
VIRGINIA	EXPRESSWAYS	41.24	40.16	41.68	42.80	41.59	42.62	43.75	41.59	42.62	43.75
	ARTERIALS	24.43	23.86	24.96	26.35	24.16	25.24	26.53	24.16	25.24	26.53
	LOCALS	13.67	14.00	14.55	15.27	13.96	14.53	15.22	13.96	14.53	15.22
	ALL FACILITIES	24.19	22.92	23.92	25.17	23.50	24.45	25.59	23.50	24.45	25.59
REGIONAL TOTALS	EXPRESSWAYS	40.48	39.76	41.06	42.39	40.95	41.95	43.15	40.59	41.69	42.85
	ARTERIALS	22.54	21.27	22.90	24.18	21.77	23.08	24.35	22.07	23.30	24.57
	LOCALS	12.71	12.61	13.35	14.02	12.71	13.37	14.05	12.81	13.45	14.14
	ALL FACILITIES	21.94	20.25	21.64	22.80	21.02	22.15	23.31	21.65	22.72	23.90

NOTE: See Chapter II for a full description of the highway and transit components of the alternative transportation systems.

1/ Figures in this column are base year values based on conditions that existed in 1968. (All other columns show estimates based on a preliminary forecast of 1976 activities.)

TABLE 4

COMPARISON OF AUTO EMISSION MODEL ESTIMATES OF D.C. (IN TONS/YEAR) WITH D.C. DEPARTMENT OF ENVIRONMENTAL SERVICES ESTIMATES

	CO	HC	NO_x
AUTO EMISSION MODEL 1968 ESTIMATE	264,000	43,000	16,400
D.C. 1970 ESTIMATE USING MILEAGE AND MASS EMISSION TECHNIQUE	265,000	25,200	8,500
D.C. 1970 ESTIMATE USING GASOLINE CONSUMPTION TECHNIQUE	265,000	31,800	23,800

1/ D.C. CO estimates reduced 3% to remove truck traffic effects.

2/ D.C. HC estimates reduced 10% to remove truck traffic effects.

3/ D.C. NO_x estimates reduced 11% to remove truck traffic effects.

TABLE 5

ESTIMATED DAILY CARBON MONOXIDE EMISSIONS (IN 1,000 POUNDS) BY JURISDICTION FOR ALTERNATIVE 1976 TRANSPORTATION SYSTEMS

JURISDICTION	HIGHWAY COMPONENT / TRANSIT COMPONENT	1968 EXISTING EXPRESSWAY SYSTEM				1976 "COMMITTED" EXPRESSWAY			1976 "FULL INTERSTATE"		
		1968 BUS SYSTEM 1/	1968 BUS SERVICE	PHASE III METRO	METRO A.R.S.	1968 BUS SERVICE	PHASE III METRO	METRO A.R.S.	1968 BUS SERVICE	PHASE III METRO	METRO A.R.S.
DISTRICT OF COLUMBIA	EMISSIONS	1,598	828	641	555	774	643	556	754	630	546
	% OF 1968	100	52	40	35	48	40	35	47	39	34
MARYLAND	EMISSIONS	2,200	1,053	973	811	1,038	987	822	1,035	984	822
	% OF 1968	100	48	44	37	47	45	37	47	45	37
VIRGINIA	EMISSIONS	1,697	836	750	648	838	766	667	838	766	667
	% OF 1968	100	49	44	38	49	45	39	49	45	39
REGIONAL TOTALS	EMISSIONS	5,495	2,717	2,364	2,014	2,650	2,396	2,045	2,627	2,380	2,035
	% OF 1968	100	49	43	37	48	44	37	48	43	37

NOTE: See Chapter II for a full description of the highway and transit components of the alternative transportation systems.

1/ Figures in this column are base year values based on conditions that existed in 1968. (All other columns show estimates based on a preliminary forecast of 1976 activities.)

TABLE 6

ESTIMATED DAILY HYDROCARBON EMISSIONS (IN 1,000 POUNDS) BY JURISDICTION FOR ALTERNATIVE 1976 TRANSPORTATION SYSTEMS

JURISDICTION	HIGHWAY COMPONENT / TRANSIT COMPONENT	1968 EXISTING EXPRESSWAY SYSTEM				1976 "COMMITTED" EXPRESSWAY			1976 "FULL INTERSTATE"		
		1968 BUS SYSTEM 1/	1968 BUS SERVICE	PHASE III METRO	METRO A.R.S.	1968 BUS SERVICE	PHASE III METRO	METRO A.R.S.	1968 BUS SERVICE	PHASE III METRO	METRO A.R.S.
DISTRICT OF COLUMBIA	EMISSIONS	259	102	81	71	97	82	72	97	82	72
	% OF 1968	100	39	31	27	37	32	28	37	32	28
MARYLAND	EMISSIONS	377	140	130	110	139	112	112	139	133	112
	% OF 1968	100	37	34	29	37	30	30	37	35	30
VIRGINIA	EMISSIONS	295	112	101	88	113	104	91	113	104	91
	% OF 1968	100	38	34	30	38	35	31	38	35	31
REGIONAL TOTALS	EMISSIONS	931	354	312	269	349	318	275	349	319	275
	% OF 1968	100	38	33	29	37	34	30	37	34	30

NOTE: See Chapter II for a full description of the highway and transit components of the alternative transportation systems.

1/ Figures in this column are base year values based on conditions that existed in 1968. (All other columns show estimates based on a preliminary forecast of 1976 activities.)

TABLE 7

ESTIMATED DAILY OXIDES OF NITROGEN EMISSIONS (IN 1,000 POUNDS) BY JURISDICTION FOR ALTERNATIVE 1976 TRANSPORTATION SYSTEMS

		TRANSPORTATION ALTERNATIVES									
	HIGHWAY COMPONENT	1968 EXISTING EXPRESSWAY SYSTEM				1976 "COMMITTED" EXPRESSWAY			1976 "FULL INTERSTATE"		
JURISDICTION	TRANSIT COMPONENT	1968 BUS SYSTEM 1/	1968 BUS SERVICE	PHASE III METRO	METRO A.R.S.	1968 BUS SERVICE	PHASE III METRO	METRO A.R.S.	1968 BUS SERVICE	PHASE III METRO	METRO A.R.S.
DISTRICT OF COLUMBIA	EMISSIONS	99	74	63	57	74	66	59	77	69	63
	% OF 1968	100	75	64	58	75	66	60	78	69	63
MARYLAND	EMISSIONS	177	134	126	110	135	130	113	137	132	115
	% OF 1968	100	76	71	62	76	73	64	77	74	65
VIRGINIA	EMISSIONS	140	108	99	90	111	104	94	111	104	94
	% OF 1968	100	77	71	64	79	74	67	79	74	67
REGIONAL TOTALS	EMISSIONS	416	316	288	257	320	300	266	325	305	272
	% OF 1968	100	76	69	62	76	72	64	78	73	65

NOTE: See Chapter II for a full description of the highway and transit components of the alternative transportation systems.

1/ Figures in this column are base year values based on conditions that existed in 1968. (All other columns show estimates based on a preliminary forecast of 1976 activities.)

TABLE 8

PEAK HOUR EMISSIONS (IN 1,000 POUNDS) OF CARBON MONOXIDE BY JURISDICTION FOR ALTERNATIVE 1976 TRANSPORTATION SYSTEMS

JURISDICTION	HIGHWAY COMPONENT / TRANSIT COMPONENT	1968 EXISTING EXPRESSWAY SYSTEM				1976 "COMMITTED" EXPRESSWAY			1976 "FULL INTERSTATE"		
		1968 BUS SYSTEM 1/	1968 BUS SERVICE	PHASE III METRO	METRO A.R.S.	1968 BUS SERVICE	PHASE III METRO	METRO A.R.S.	1968 BUS SERVICE	PHASE III METRO	METRO A.R.S.
DISTRICT OF COLUMBIA	EMISSIONS	146.3	68.7	55.0	48.3	64.6	54.9	48.1	62.3	53.5	47.0
	% OF 1968	100.0	47.0	37.6	33.0	44.2	37.5	32.9	42.6	36.6	32.1
MARYLAND	EMISSIONS	174.9	82.6	76.7	64.7	80.8	77.2	65.3	80.4	76.7	64.9
	% OF 1968	100.0	47.2	43.9	37.0	46.2	44.1	37.3	46.0	43.9	37.1
VIRGINIA	EMISSIONS	141.4	67.7	60.6	53.2	67.2	61.4	54.2	67.2	61.4	54.2
	% OF 1968	100.0	47.9	42.9	37.6	47.5	43.4	38.3	47.5	43.4	38.3
REGIONAL TOTALS	EMISSIONS	462.6	219.0	192.3	166.2	212.6	193.5	167.6	209.9	191.6	166.1
	% OF 1968	100.0	47.4	41.8	35.9	46.0	41.6	36.2	45.4	41.4	35.9

NOTE: See Chapter II for a full description of the highway and transit components of the alternative transportation systems.

1/ Figures in this column are base year values based on conditions that existed in 1968. (All other columns show estimates based on a preliminary forecast of 1976 activities.)

TABLE 9

PEAK HOUR EMISSIONS (IN 1,000 POUNDS) OF HYDROCARBONS BY JURISDICTION FOR ALTERNATIVE 1976 TRANSPORTATION SYSTEMS

JURISDICTION	HIGHWAY COMPONENT / TRANSIT COMPONENT	1968 EXISTING EXPRESSWAY SYSTEM: 1968 BUS SYSTEM 1/	1968 EXISTING EXPRESSWAY SYSTEM: 1968 BUS SERVICE	1968 EXISTING EXPRESSWAY SYSTEM: PHASE III METRO	1968 EXISTING EXPRESSWAY SYSTEM: METRO A.R.S.	1976 "COMMITTED" EXPRESSWAY: 1968 BUS SERVICE	1976 "COMMITTED" EXPRESSWAY: PHASE III METRO	1976 "COMMITTED" EXPRESSWAY: METRO A.R.S.	1976 "FULL INTERSTATE": 1968 BUS SERVICE	1976 "FULL INTERSTATE": PHASE III METRO	1976 "FULL INTERSTATE": METRO A.R.S.
DISTRICT OF COLUMBIA	EMISSIONS	24.8	9.0	7.3	6.5	8.7	7.5	6.6	8.8	7.6	6.7
	% OF 1968	100.0	36.3	29.4	26.2	35.1	30.2	26.6	35.5	30.6	27.0
MARYLAND	EMISSIONS	31.9	11.6	10.8	9.2	11.5	11.0	9.3	11.5	11.0	9.3
	% OF 1968	100.0	36.4	33.9	28.8	36.1	34.5	29.2	36.1	34.5	29.2
VIRGINIA	EMISSIONS	26.4	9.7	8.7	7.7	9.8	9.0	7.9	9.8	9.0	7.9
	% OF 1968	100.0	36.7	37.1	29.2	37.1	34.1	29.9	37.1	34.1	29.9
REGIONAL TOTALS	EMISSIONS	83.1	30.3	26.8	23.4	30.0	27.5	23.8	30.1	27.6	23.9
	% of 1968	100.0	36.5	32.4	28.0	36.0	33.0	28.6	36.2	33.2	28.9

NOTE: See Chapter II for a full description of the highway and transit components of the alternative transportation system

1/ Figures in this column are base year values based on conditions that existed in 1968. (All other columns show estimates based on a preliminary forecast of 1976 activities.)

TABLE 10

PEAK HOUR EMISSIONS (IN 1,000 POUNDS) OF OXIDES OF NITROGEN BY JURISDICTION FOR ALTERNATIVE 1976 TRANSPORTATION SYSTEMS

JURISDIC-TION	HIGHWAY COMPONENT / TRANSIT COMPONENT	1968 EXISTING EXPRESSWAY SYSTEM: 1968 BUS SYSTEM 1/	1968 EXISTING EXPRESSWAY SYSTEM: 1968 BUS SERVICE	1968 EXISTING EXPRESSWAY SYSTEM: PHASE III METRO	1968 EXISTING EXPRESSWAY SYSTEM: METRO A.R.S.	1976 "COMMITTED" EXPRESSWAY: 1968 BUS SERVICE	1976 "COMMITTED" EXPRESSWAY: PHASE III METRO	1976 "COMMITTED" EXPRESSWAY: METRO A.R.S.	1976 "FULL INTERSTATE": 1968 BUS SERVICE	1976 "FULL INTERSTATE": PHASE III METRO	1976 "FULL INTERSTATE": METRO A.R.S.
DISTRICT OF COLUMBIA	EMISSIONS	9.2	6.8	5.9	5.3	6.8	6.1	5.5	7.2	6.5	5.9
	% OF 1968	100.0	73.9	64.1	57.6	73.9	66.3	59.8	78.3	70.7	64.1
MARYLAND	EMISSIONS	15.4	11.5	10.9	9.4	11.6	11.1	9.7	11.8	11.3	9.9
	% OF 1968	100.0	74.7	70.8	61.0	75.3	72.1	63.0	76.6	73.4	64.3
VIRGINIA	EMISSIONS	12.5	9.4	8.7	7.9	9.7	9.1	8.2	9.7	9.1	8.2
	% OF 1968	100.0	75.2	69.6	63.2	77.6	72.8	65.6	77.6	72.8	65.2
REGIONAL TOTALS	EMISSIONS	37.1	27.7	25.5	22.6	28.1	26.3	23.4	28.7	26.9	24.0
	% OF 1968	100.0	74.0	68.5	60.9	75.7	70.9	63.1	77.4	72.5	64.4

NOTE: See Chapter II for a full description of the highway and transit components of the alternative transportation systems.

1/ Figures in this column are base year values based on conditions that existed in 1968. (All other columns show estimates based on a preliminary forecast of 1976 activities.)

Appendix A

Transit Accessibility

As A

Determinant Of Auto Ownership

TRANSIT ACCESSIBILITY AS A DETERMINANT OF AUTOMOBILE OWNERSHIP

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Introduction

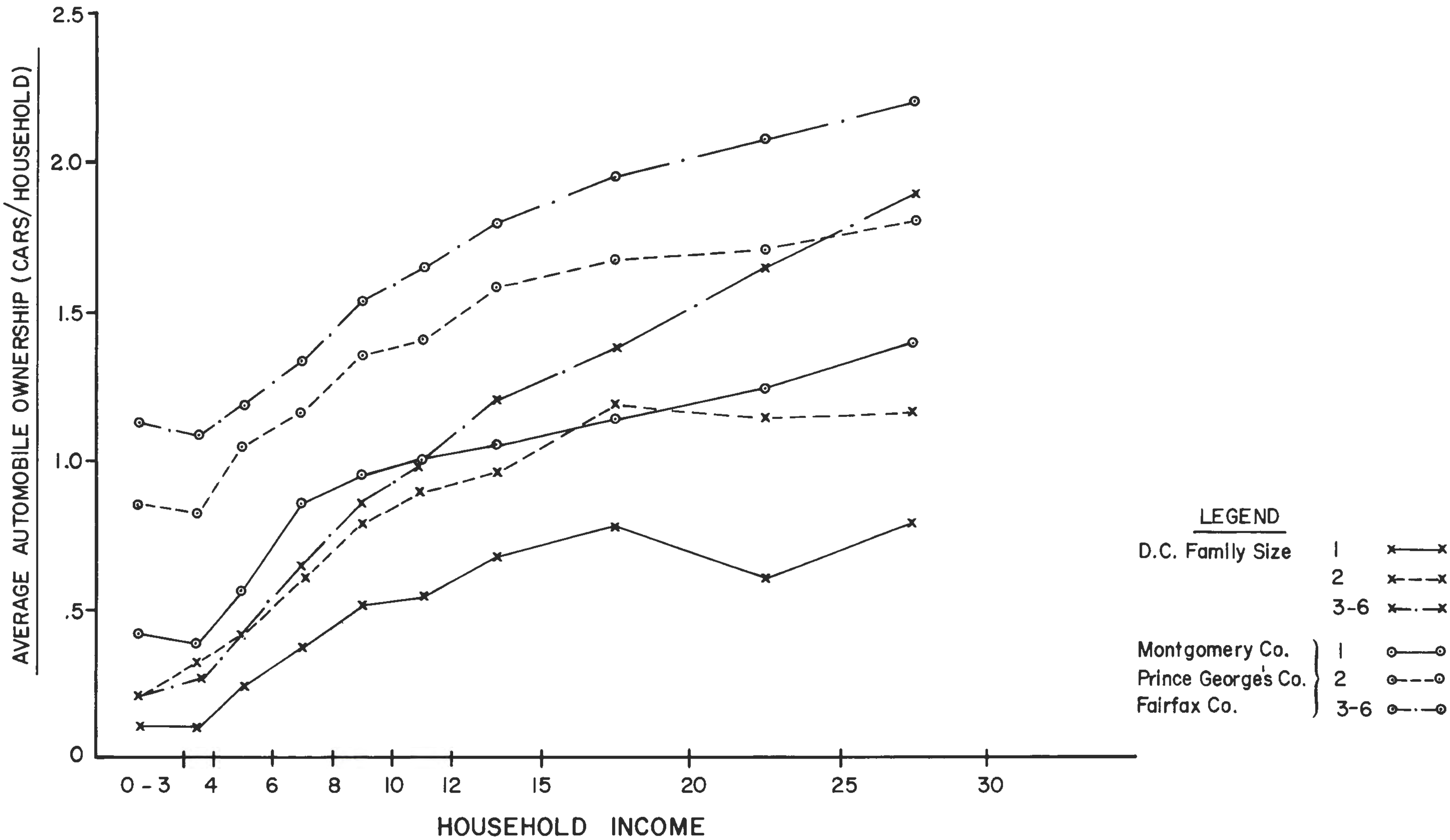
In attempting to define the principal determinants of automobile ownership within the National Capital Region, the two major household characteristics which emerged as the most important were household size and income. When households were cross classified by household income and number of persons in the household, the average number of automobiles owned per household was seen to increase with an increase in either of these variables. The only exceptions are that one and two person households do reach an upper limit of automobile ownership with increasing income. Moreover, when this analysis is broken down by jurisdiction, the pattern is similar but three different levels of automobile ownership emerge for any given income and household size. The lowest levels of automobile ownership, all other things being equal, occur in the District of Columbia. At the jurisdictional scale the next higher level of automobile ownership occurs in the jurisdictions of Arlington County and the City of Alexandria, which are the closest jurisdictions to the District of Columbia. Finally, a different, and higher level of automobile ownership is observed in the jurisdictions of Fairfax, Montgomery, and Prince Georges' Counties. The automobile ownership levels for District of Columbia households of a given size and income are compared with those of comparable households in Montgomery, Prince George's and Fairfax Counties in Figure A-1. It is apparent the average automobile ownership in the suburbs is higher than that of the District of Columbia, even for households of the same size and having the same income. Since both family size and income levels in the suburbs are higher than those of the District of Columbia, all factors point toward higher levels of automobile ownership in the suburbs.

Neighborhood Factors Affecting Automobile Ownership

Many reasons have been suggested for the higher automobile ownership rates in the suburbs. Both income and household size differences have been suggested, but the discussion above shows differences even with these factors held constant. Two other factors which are more related to neighborhood characteristics are density and availability of transit service. The density factor is presumed to affect automobile ownership in two ways. In a positive sense, areas of high residential density tend to attract commercial activity which makes it possible to fulfill many transportation needs by walk trips to stores, banks, barber shops and other commercial activities. An example is the food store located in the basement of an apartment building. At the upper extreme of the density equation is the high density residential area adjacent to a high density employment location. In this case, it may even be possible to make the trip to work on foot, which eliminates the need to own an automobile for

FIGURE A-1

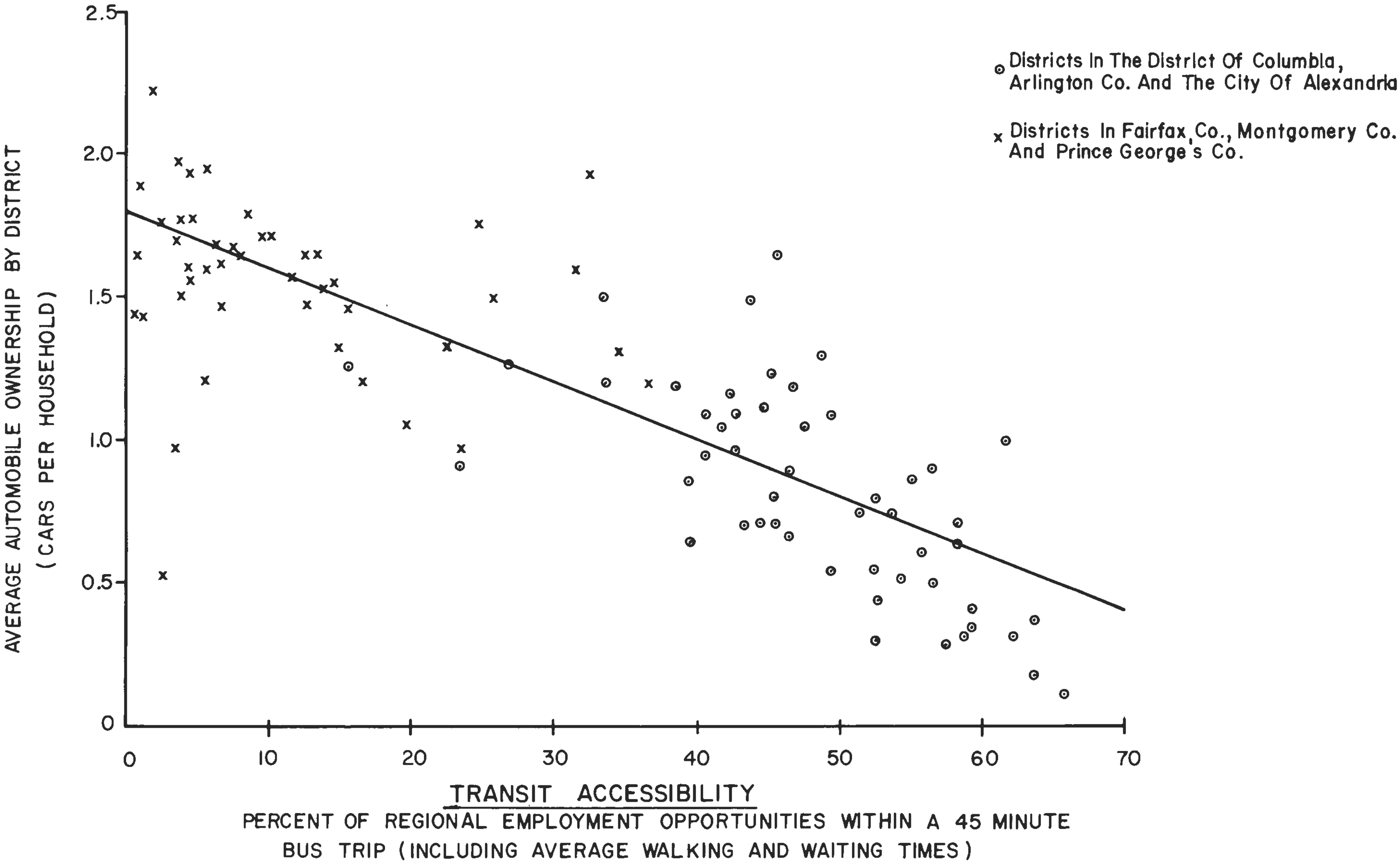
COMPARISON BETWEEN CENTRAL CITY AND SUBURBAN AUTOMOBILE OWNERSHIP RATES



Source: 1968 MWCOG Home Interview Survey

FIGURE A-2

AGGREGATE EFFECTS OF TRANSIT ACCESSIBILITY ON AUTOMOBILE OWNERSHIP WITHIN THE NATIONAL CAPITAL REGION-1968



Source: 1968 MWCOG Home Interview Survey commuting purposes. Density also affects automobile ownership in a negative sense. Increasing residential density makes the cost of owning an automobile greater than in a single family residential neighborhood because of parking, insurance, and vandalism problems.

The factor of transit service operates in a fashion similiar to that of density. Rather than moving activities closer in space, high quality transit service brings activities closer in time. The extreme in this case may be the subway line passing below an apartment and connecting directly to an office building. Although the Washington Area is not yet served by rapid transit, it was felt there is a sufficient range in transit levels of service currently available to test the hypothesis that areas with "better" transit service have lower automobile ownership rates, all other things being equal. The criteria used to determine the measure of goodness of transit service is the percentage of regional employment which can be reached within three-quarters of an hour travel time. Although this measure would seem to ignore the level of highway service provided, it can be justified on logical, if not necessarily theoretical, arguments.[1/] First, since the current transit system involves buses using the highway system, the areas with the greatest highway accessibility also tend to be the ones with the highest transit accessibility. More important, perhaps, is the number of opportunities which an individual really needs. If a worker can reach three out of every four jobs within the region within a forty five minute transit trip, it may not be important that the highway system will deliver the same number of jobs in five or ten minutes less. The current situation is that there are many suburban areas from which workers cannot reach even ten percent of the regional job market within a forty five minute bus ride. It is hypothesized that providing a transit system which can meet this standard will have the effect of encouraging workers to use it, regardless of how good the highway system is. This, in turn, should have an effect on automobile ownership.

Aggregate Effects of Transit Accessibility

Initial attempts at relating automobile ownership to transit accessibility involved a simple linear regression between district averages of these two variables. There are 134 internal transportation districts within the Metropolitan Washington Council of Governments' planning area. Although a significant correlation was determined, it was observed that the districts with the highest accessibility values were those within the central area of the region, and generally had lower average family sizes and lower median incomes than the regional average. On the other hand, the areas with the lowest accessibilities were generally the more affluent suburban areas, with larger households. The results of this first analysis are shown in Figure A-2. Because of this observed correlation between transit accessibility and income, it was apparent that further disaggregation was needed.

1/ Wickstrom, G.V. "Defining Balanced Transportation - A Question of Opportunity," Traffic Quarterly, July, 1971.

Eliminating the Effects of Income

To eliminate the effects of income on automobile ownership, district averages of auto ownership were computed for households within each particular income category. These averages were then regressed against transit accessibility, resulting in ten curves. The curves shown in Figure 4 of the main report resulted in a significant correlation for each income group. The interpretation is that a family having a particular income and living in an area of high accessibility is likely to own fewer cars than a family with the same income who lives in an area with less transit access.

Left unanswered is the effect of density. Although a simple regression between transit accessibility and net residential density does not yield significant results, it may be that the relation is a more complex formula than a straight line. Nevertheless, when the variable of net residential density is added to the equation which relates automobile ownership to transit access, it does not explain any more of the variation in the dependent variable. Furthermore, when net residential density is substituted for transit access in the equation, the correlation is reduced. This would seem to indicate that transit access is a better variable for explaining variations in automobile ownership than residential density.

Interpretation of Findings

Care must be taken in extrapolating these findings to a generalized theory of auto ownership. Transit accessibility operates in several different ways. It is seen to be related to the regional distribution of households of different incomes and family size. This is perhaps the most significant factor in determining the regional distribution of households without cars, with one car or with multiple car ownership. Then, given a household of a particular category, the automobile ownership for this type of household is determined by the transit accessibility in the district of residence. Density is not a significant variable except in its relationship to transit accessibility. Density has historically been a response to the accessibilities provided by different modes. Generally, population densities in Washington are greatest in the areas with the highest transit accessibility, which are also the areas previously served by street cars. The bus has extended the range of the transit market, and the automobile has further extended the range of commuting distance.

It appears, therefore, that the level of transit service provided to an area can have a significant effect on the automobile ownership of residents, all other things being equal. However, provision of this service in advance of development can be extremely difficult, since the initial ridership may not be economically justified. However, if eliminating the need for a second car may be considered as a benefit, it may be easier to justify provision of transit service in advance of residential development.

Recommendations for Longitudinal Analysis

The findings of this analysis indicate that the level of transit service provided to employment can have a significant effect on the level of automobile ownership within a community. Given a current transit network, it should be possible to test this hypothesis using 1970 census data for any urban area participating in the Department of Transportation special tabulation of Journey-To-Work statistics. The true value of these findings, however, is not in defining a base year condition but rather in their implications for future policy. Presumably, improving transit service from certain areas to employment sites or providing transit service ahead of development could reduce the level of automobile ownership within these areas below that which would have been expected without an improvement in transit. If this is the case then the benefits of improved transit lie not only in reducing peak hour highway congestion and downtown parking needs, but also in eliminating the need for a family to own a second, or even third car. Such an analysis can only be done by improving transit and observing the effects on automobile ownership. Two obvious cases for such monitoring are Washington, D. C. and San Francisco, which are both building large scale rapid transit systems. It is recommended that the effects of these and other new transit systems on automobile ownership be carefully checked through a case study which compares before and after conditions.

Appendix B

Program Documentation

DOCUMENTATION OF HIGHWAY NEEDS MODEL

(Travel Description Sub-model)

Use of the highway needs model is described in documentation available from the Tri-State Transportation Commission. The program itself had to be modified slightly, but the documentation is basically the same with the following changes:

1. An eighth parameter control card, which is placed after the ITROL5 card (see following Tri-State Transportation Commission documentation) has been added. This card allows a labelling heading for each run of the model. This heading is in 20A4 format.
2. The program now punches certain critical output needed for input into the pollutant emissions sub-model onto cards, producing one such record for each sub-area and for each aggregation level -- counties, states, and region. The format of each card record is as follows:

Field Names and Descriptions	Format
NS--state identification number	I1
NC--county identification number	I2
NA--sub-area identification number (Note: NA=999 for county summary, NC=99,NA=999 for state summary and NS=9,NC=99,NA=999 for regional summary.)	I3
WY(1)-WY(2)--eight-column county, state, or region name field.	2A4
VMTE--vehicle-miles of travel on expressways	F10.0
ALME--lane-miles of expressways	F7.1
SPE--average 24-hour speeds on expressways	F5.2
VMTA--vehicle-miles of travel on arterials	F10.0
ALMA--lane-miles of arterials	F7.1
SPA--average 24-hour speeds on arterials	F5.2
VMTL--vehicle-miles of travel on locals	F10.0
ALML--lane-miles of locals	F7.1
SPL--average 24-hour speeds on locals	F5.2

Documentation of the Highway Needs Model, as supplied by the Tri-State Transportation Commission, follows on pages 61 thru 68.

CONNECTICUT

NEW JERSEY

NEW YORK

TRI-STATE TRANSPORTATION COMMISSION

100 CHURCH STREET NEW YORK, N.Y. 10007 ● TELEPHONE 433-4200 AREA CODE 212

The enclosed program documentation is preliminary. The authors welcome any comment from users of these instruction sheets concerning their clarity or usefulness. The authors will try to provide assistance in overcoming any difficulties which may be encountered in utilizing these instruction sheets. Please contact either Mr. Frank S. Koppelman or Mr. Ira J. Shelkowitz at the above agency.

For a description of the Highway Needs Model one is referred to the following paper:

Koppelman, Frank S., A Model for Highway Needs Evaluation, Tri-State Transportation Commission, presented at the 49th Annual Meeting of the Highway Research Board, Jan. 1970.

FSK:LJS:rw

HOW TO USE THE HIGHWAY NEEDS MODEL PROGRAM (AHNM 4000)

These instruction sheets are intended to aid the outside user in setting up the input data needed to run the Highway Needs Model Program and in interpreting the program output. They do not explain the theory behind highway need determination nor its implementation within this computer program.

General Information:-

The program is written in BASIC FORTRAN IV language for the IBM 360/30 computer. A compiled, relocatable deck is enclosed for use. Information on program control cards is contained below. IBM system control cards for running on the computer must be supplied by the user.

The computer program provides four levels of data aggregation: the analysis area (at which level all analysis is performed), with accumulations of data to county, state and region levels. Other units of data aggregation may be substituted for these provided that each lower-level unit is a subset of only one higher-level unit, e.g. a planning district may be used instead of an analysis area but each planning district must lie within only one county. All input data must be available at the analysis area level.

Two types of runs may be performed with this program: description and optimization. In a description run a quantified description of the planned future expressway supply is input to the program and capital costs, user costs, and all travel statistics are then calculated. In an optimization run only the future densities are specified; the program determines the future expressway supply which provides maximum benefit (as specified in the user-determined objective function) and computes all costs and travel statistics.

Input Tape:-

The following data must be available on tape as input to the Highway Needs Model Program:

For each analysis area or basic data aggregation level:

1) Identifying state, county and analysis area numbers
2) Area in square miles
3) Known population density, vehicle trip end density, and vehicle miles of travel density
4) Projected population density and vehicle trip end density for the years 1985 and 1990
5) Known existing foot-miles/square mile of expressway, arterial, and local roads
6) Known existing route-miles/square mile of expressway and arterial roads
7) (optional) Planned foot-miles/square mile and route-miles/square mile of expressway and arterial roads for the years 1985 and 1990 (TO BE USED IN DESCRIPTION RUNS ONLY)

For each higher level:

1) Identifying county and state, or state only numbers, according to the convention that:
   for county summary: NA=99
   for state summary: NC=99, NA=99
   for region summary: NS=9, NC=99, NA=99
2) All other data fields are left blank on the input tape for these levels

The above information shall be written on the input tape as records according to the record layout format specified in Tables 1 and 2. The records shall be written in the sequence shown in the following logic flow diagram, Figure 1.

FIGURE 1

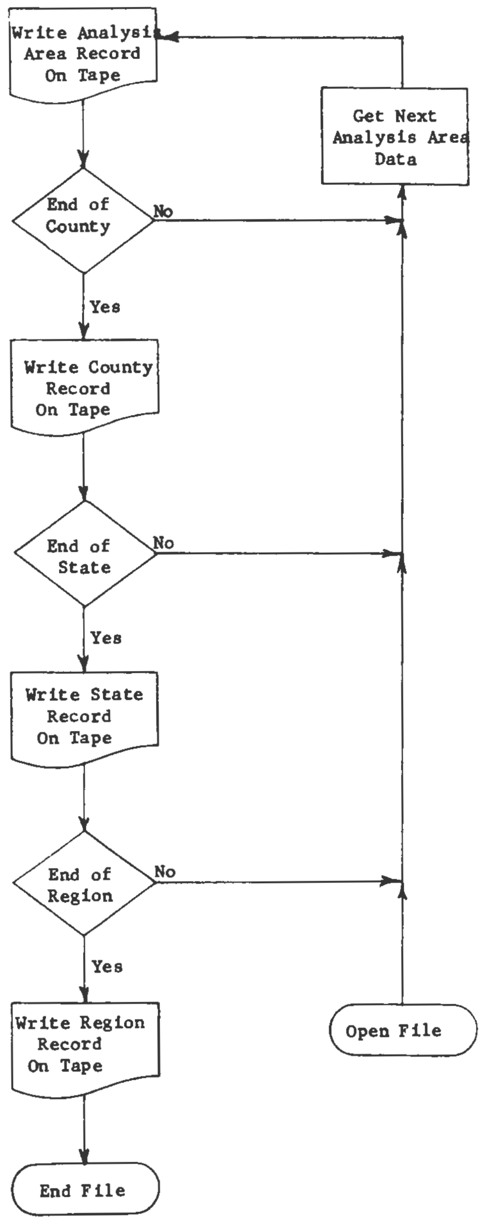

Write Analysis Area Record On Tape
Get Next Analysis Area Data
End of County
No
Yes
Write County Record On Tape
End of State
No
Yes
Write State Record On Tape
End of Region
No
Yes
Write Region Record On Tape
Open File
End File

TABLE 1

Unit Record Layout

1-2	NS
3-4	NC
5-6	NA
7-8	
9-16	W
17-21	AREA
22-28	VTE85
29-35	VTE63
36-42	
43-48	FE63
49-54	FA63
55-60	FL63
61-66	FO63
67-71	FEIP
72-76	ELEIP
77-82	ELE63
83-84	ELA63 (cont'd pos. 83-88)

TABLE 1
(cont'd)

85-88	(cont'd pos. 83-88)
89-97	VMT63
98-104	P
105-111	P63
112-116	FE90
117-121	ELE90
122-128	P90
129-135	VTE90
136-168	

TABLE II

INPUT TAPE:-

Length of each record = 135; (Tri-State tape has 116 records = viz.

  83 analysis areas
+ 28 counties
+ 4 states
+ 1 region
 116

FIELD NAME	DESCRIPTION	FORMAT
NS	Number of State	I2
NC	Number of County	I2
NA	Number of Analysis Area	I2
		2X
W	Name of Region, State, or County	2A4 (literal data-optional)
AREA	Area in Square Miles	F5.1
VTE85	Vehicle Trip End Density-1985 Projection	F7.0
VTE63	Vehicle Trip End Density-1963*	F7.0
		7X
FE63	Known Foot-Miles/Square Mile-Expressway	F6.2
FA63	Known Foot-Miles/Square Mile-Arterial	F6.0
FL63	Known Foot-Miles/Square Mile-Local	F6.0
FO63	Known Foot-Miles/Square Mile-Total	F6.0
FEIP	Planned (1985) Foot-Miles/Square Mile-Expressway	F5.1
ELEIP	Planned (1985) Route-Miles/Square Mile-Expressway	F5.3
ELE63	Known Route-Miles/Square Mile-Expressway	F6.2
ELA63	Known Route-Miles/Square Mile-Arterial	F6.2
VMT63	Known Vehicle Miles of Travel/Square Mile	F9.0
P	Projected Population Density-1985	F7.0
P63	Known Existing Population	F7.0
FE90	Planned (1990) Foot-Miles/Square Mile-Expressway	F5.1
ELE90	Planned (1990) Route-Miles/Square Mile-Expressway	F5.2
P90	Projected Population Density-1990	F7.0
VTE90	Projected Vehicle Trip End Density-1990	F7.0

* or any past year for which data exist

PARAMETER CONTROL CARDS:-

A "run" of the Highway Needs Model Program may consist of any number of cycles. Each cycle involves the unique specification of parameter controls and the execution of the program. Not all parameter control cards need be included for each cycle. The different parameter control cards, and when to use them, are listed below. Card numbers and names are for sequencing and identification purposes only - they do not appear on the punched cards. Numerical values for the different parameters should be specified by the user.

CARD #	CARD NAME	DESCRIPTION	FORMAT
1	KPO	Printout Summation Control (choose one, where) 1 = print all summaries - analysis area, county, state, region 2 = print county, state and region 3 = print state and region only	6X,I1
2	ITROL 1-5	Parameter Change Control (each ITROL must be given a value of one, two, or three, where) First Cycle: all ITROL are set equal to 2 Intermediate Cycles: any ITROL=1 means retention of parameters from previous cycle and it is not necessary to include that ITROL parameter card again; any ITROL=2 means change according to the corresponding parameter card which will follow in the set of input cards To End: ITROL1=3, all other ITROL=1	16X,5I2
3	ITROL 1	Parameter Card Specifies: Kode 1 = year of description or optimization run. This may take on the following values: 1963; 1970; 1985; 1990. and Kode 2 = indicates the base year expressway supply to be used. This may take on the following values: 1 (1963 supply); 2 (1970 supply). and Kode 3 = future planned expressway supply for description runs; or an optimization run. This may take on the following values: 1 (1963); 2 (1970); 3 (1985); 5 (1990); 9 (optimization run).	32X,I4,24X,I1,18X,I1

CARD #	CARD NAME	DESCRIPTION	FORMAT
4	ITROL 2	Parameter Card Specifies TCPH = time cost per hour (dollars) ANCOST = capital recovery factor ($X10^6$) M = interest rate DC1 = construction cost factor - inflation factor	5X,F5.2,15X,F5.2,4X,I2,8X,F5.3
5	ITROL 3	Parameter Card Specifies WW1 = average cost per accident-expressway (dollars/accident) WW2 = average cost per accident-arterial (dollars/accident) WW3 = household relocation cost (dollars/relocated household) WW4 = vehicle operating cost factor (1.0±)	12X,F4.0,14X,F4.0,11X,F5.0,11X,F3.2
6	ITROL 4	Parameter Card Specifies ADJ1 = speed adjustment factor-expressway, 1.0± (for sensitivity analysis) ADJ2 = speed adjustment factor-arterial, 1.0± (for sensitivity analysis) ADJ3 = speed adjustment factor-local, 1.0± (for sensitivity analysis) ADJ4 = accident adjustment factor-expressway, 1.0± (for sensitivty analysis) ADJ5 = accident adjustment factor-arterial and local, 1.0± (for sensitivity analysis) ADJ6 = maintenance cost/mile of expressway (dollars)	20X,5F5.2,F10.0
7	ITROL 5	VMT Equation Numerical Constants such that Equation is: VMT=VVV1+VVV2*VTE**VVV3*2.71828**(VVV4*FE/FO)	30X,4F7.2

First cycle thus contains seven cards.
Each intermediate cycle contains cards #1 and 2 plus any additional cards called for by card #2.
To end the run, cards #1 and #2 are needed only.

A pictorial representation of the cards needed for a sample 2 cycle run is shown below, in Figure 2.

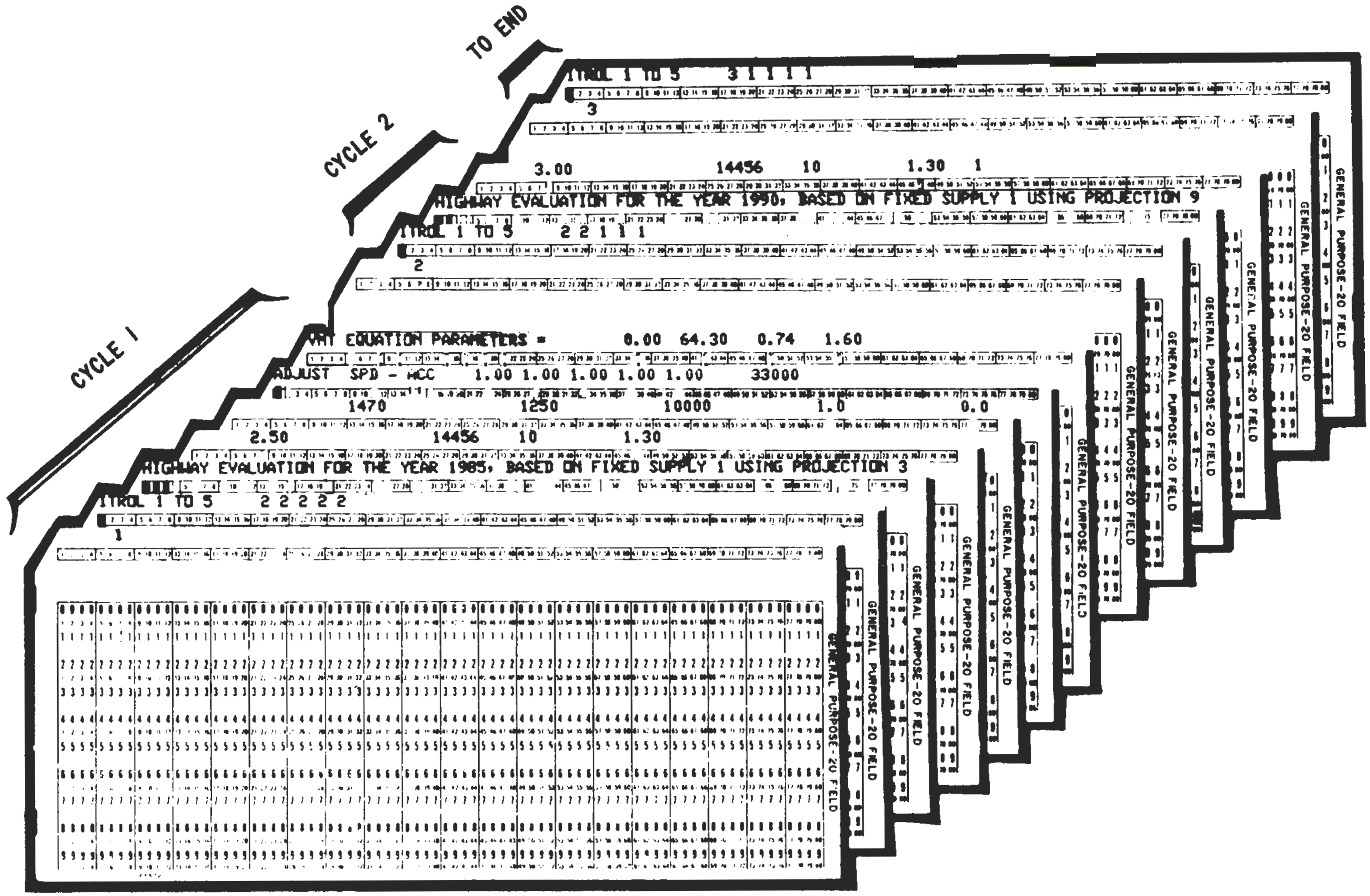


FIGURE 2

SAMPLE 2 CYCLE RUN

OUTPUT:-

The output from a particular run is printed in two parts. The first part consists of initial tables printed in the same sequence as the input tape. The second part consists of a series of three summary tables, also printed in the same sequence. A sample inital table printout is presented below.

```
3  10  29

AVERAGE SPACING            TIME COST      394661.                              DAILY ACCID.      24.   FATAL.        [illegible]
EXPRESSWAY     1.54        ACCID COST      30646.                              ACCID. RATE      855.   FATAL.RATE         9.26
ARTERIAL       0.65        OPER. COST     104947.

                                                    PERCENT TOTAL VMT
                           TOTAL DAY COST 533258.     EXPRESSWAY 55.4    TRAVEL HOURS     123332.
                           DAY CAP. COST   84168.     ARTERIAL   29.8    AVG TRIP LENGTH     6.72
                           ADJ. DAY COST  617426.     LOCAL      14.9

TIME COST  2.50    INTEREST    10 PERCENT
1990

ESTIMATED HOUSEHOLD RELOCATIONS     2900.0
```

In the above sample printout, NS=3, NC=10 and NA=29. Adjusted daily cost is the sum of total daily cost and daily capital cost. Accident rate and fatality rate are per 100 million VMT. For county, state, and region output, the area will also be printed.

The three summary tables contain the following information:

SUMMARY TABLE I:-

State, County, and Analysis Area Identifying Numbers

Vehicle Trip Ends

Expressway Lane and Route Miles and Expressway plus Arterial Route Miles per 10,000 population

Expressway, Arterial, and Total Capital Cost

Expressway Cost per Additional Vehicle Mile

SUMMARY TABLE II:-

State, County and Analysis Area Identifying Numbers

Expressway, Arterial, Local and Total: Volume per Lane, Total Lane Miles, Additional Lane Miles, and Average Speed

SUMMARY TABLE III:-

State, County, and Analysis Area Identifying Numbers

Vehicle Trip End Density and Population Density

Expressway, Arterial, Local, and Total: Vehicle Miles of Travel (Total and Density), Total Route Miles, Additional Route Miles

DOCUMENTATION OF THE POLLUTANT EMISSIONS SUB-MODEL

A. INPUT REQUIREMENTS

The input cards for running the Pollutant Emissions Sub-Model consist of both parameter cards and data cards arranged in the following order:

1. Parameter Cards

One set of parameter cards is required for each run of the model. Although the first 55 cards are required for each run, the length of this parameter deck will vary with the number of sub-areas into which the region has been divided.

Card No(s).	Field Name(s)	Format
1	CO(25), HC(25), NO(25) (CO(25), HC(25), and NO(25), are the emission rates -- in grams per vehicle mile -- of carbon monoxide, hydrocarbons, and nitrogen oxides assumed for 25 miles an hour.)	3(5X,F5.2)
2-5	COADF (I), I=1,70	3(20F4.2/),10F4.2
6-9	HCADF (I), I=1,70	3(20F4.2/),10F4.2
10-13	NOADF (I), I=1,70 (COADF (I), HCADF (I), NOADFF (I) are the ratio of the three pollutant emission rates at I miles per hour to the rates at 25 miles per hour.)	3(20F4.2/),10F4.2
14-54	VOVRC(I), SAR 35(I), SAR 30(I), SAR25(I), SEXP50(I), SEXP60(I), I=1,41 (VOVRC is the volume over capacity (V/C) ratio in .025 increments, from 0.0 to 1.000. SAR35, SAR30, and SAR25, are the average overall speeds attained for each V/C level on arterials having "free-flow" (Level of Service=A	41(F5.3,5F5.1/)
	speeds of 35, 30 and 25 miles per hour. SEXP50 and SEXP60 are the average speeds attained for each V/C ratio on expressways having free-flow speeds of 50 and 60 m.p.h., respectively. (Note: The V/C parameter cards supplied with the source data are based on the Highway Capacity Manual and should remain intact as they are.)	41(F5.3,5F5.1/)
55	NODKS, NOA, Kl, K2, K3, K4 (NODKS is the number of alternatives being tested -- a separate data deck is required for each alternative. NOA is the number of areas for which input cards are supplied -- this number (which cannot exceed 60) equals the number of sub-areas plus the number of counties and states plus 1 for the regional total. Kl, K2, K3, and K4, control the printing of each of the four output tables described in the Output Options section. If KN=1, Table N is printed; if KN=2, Table N is not printed.)	2(8x,12),4(4x,Il)
56-(55+NOA)	NS(I),NC(I),NA(I),AREA(I), CAE(I),DEE(I),CAA(I),DEA(I), CAL(I),DEL(I),PKDR(I), CAPEXP(I), CAPART(I),I=1,NOA (NS(I)=state identification number, NC(I)=county identification number, NA(I)=sub-area identification number, Area (I)=area in square miles. Note: These first four bits of information is all that is required for those areas which represent county, state or region aggregations. The following nine variable fields can be left blank on these cards, but must be filled for each sub-area card	NOA(Il,I2,I3,lX F7.2,lX,6F5.3, F4.2,2F4.l, 2F5.0/)

Card No(s).	Field Name(s)	Format
56-(55+NOA) (CONT.)	(NA≠999). CAE(I), CAA(I), CAL(I)= K factor (peak-hour two-directional flow divided by 24-hour two-directional flow) factor for expressways, arterials, and locals, respectively, within sub-area NA. DEE(I), DEA(I), DEL(I)=D factor (peak-hour, peak-direction flow divided by peak-hour two-directional flow) for expressways, arterials, and locals, respectively. PKDR(I)=duration of conditions which can be approximated by peak-hour characteristics. This time period should include both a.m. and p.m. conditions and is, in general, <u>less</u> than daily "peak-period." CAPEXP(I) and CAPART(I) are the peak-hour capacities (level of service=E), in vehicles per lane per hour, in peak conditions for expressways and arterials.)	

In the Washington, D. C., region, NOA=59; 48 sub-areas + 7 "counties" (including D.C.) + "states" (including D.C.) + 1 (for region)=59.

These sub-area specific parameter cards must be in the same order as those in each data card deck -- the description of which follows. That is, the cards for all sub-areas within a county must be placed in order sequential order followed by the county aggregation card (NA=999); a state aggregation card (NC=99,NA=999) should follow the county groupings for that state with the regional aggregation card (NS=9, NC=99, NA=999) being the last card in the deck.

2. Data Cards

Following these parameter cards are the input data decks one for each alternative tested. Each data deck is preceded by one card whose 80 column field must be used for run identification. Since these input data cards are simply the punched output described at the beginning of the Highway Needs Model documentation, the descriptions are not repeated here.

OUTPUT OPTIONS

The pollutant emissions model gives the user the option of printing out any of four tables:

Table B-1. This table lists total CO,HC, and NOx emissions, in pounds, for every analysis area -- for all basic subareas and all levels of aggregation. These emissions are stratified by time of day (peak-hour and twenty-four hour totals) and by facility type (expressways, arterials, locals, and totals). In order to suppress the printing of Table B-1, K1 (see parameter card descriptions) must be set equal to 2.

Table B-2. This table lists emission densities for CO,HC, and NOx, in pounds per square mile. The format of this table is identical to that of Table 1 with data stratified in the same manner. The figures in this table are simply the emissions listed in Table 1 divided by the land area of each analysis area. K2 should equal 2 to suppress the printing of this table.

Table B-3. This table lists vehicle-miles of travel and overall travel speeds by facility type and time of day. Peak-hour conditions are broken down into peak direction and reverse direction flows. Speeds are given for average off-peak conditions and 24-hour vehicle-miles of travel are given. This table lists data only at the basic subarea level; no figures are given for aggregation levels. Set K3=3 to suppress the listing of this table.

Table B-4. This table list vehicle-minutes of travel by facility type and time of day -- peak-hour peak directional, peak-hour reverse directional, off-peak non-directional. These figures are given for all levels of analysis. This table was designed for use as a transportation planning tool but could be useful as one measurement of motorist exposure. In almost all cases, though, this table would be extraneous, and K4 could be set equal to 2 in the parameter cards so that the printing of it will be suppressed.

Samples of these four tables are shown on the following page.

TABLE B-1

AUTOMOTIVE EMISSIONS OF CARBON MONOXIDE, HYDROCARBONS, AND OXIDES OF NITROGEN

IMAGINARY SYSTEM RUN TO ILLUSTRATE OUTPUT OF THE POLLUTANT EMISSIONS MODEL

ANALYSIS AREA	FAC. TYPE	EMISSIONS OF MAJOR POLLUTANTS (IN POUNDS) CARBON MONOXIDE PK-HR	CARBON MONOXIDE DAILY	HYDROCARBONS PK-HR	HYDROCARBONS DAILY	OXIDES OF NITROGEN PK-HR	OXIDES OF NITROGEN DAILY
121 1	EXP.	1383.	16247.	280.	2528.	267.	2727.
EMISSIONS	ART.	15342.	188249.	1862.	22251.	1274.	14155.
	LOC.	5732.	77077.	647.	8747.	285.	4070.
	TOTAL	22458.	281573.	2789.	33525.	1826.	20952.
121 3	EXP.	0.	0.	0.	0.	0.	0.
EMISSIONS	ART.	2473.	25274.	312.	3150.	254.	2492.
	LOC.	1129.	15005.	129.	1730.	66.	936.
	TOTAL	3602.	40279.	441.	4879.	320.	3428.
121999 COUNTY A	EXP.	1383.	16247.	280.	2528.	267.	2727.
EMISSIONS	ART.	17816.	213523.	2174.	25400.	1528.	16647.
	LOC.	6861.	92082.	776.	10476.	350.	5006.
	TOTAL	26060.	321852.	3230.	38404.	2146.	24380.
122 2	EXP.	2302.	27152.	493.	4515.	606.	6183.
EMISSIONS	ART.	4397.	50878.	585.	6697.	555.	6162.
	LOC.	2509.	33027.	293.	3895.	176.	2509.
	TOTAL	9208.	111056.	1371.	15107.	1336.	14855.
122999 COUNTY B	EXP.	2302.	27152.	493.	4515.	606.	6183.
EMISSIONS	ART.	4397.	50878.	585.	6697.	555.	6162.
	LOC.	2509.	33027.	293.	3895.	176.	2509.
	TOTAL	9208.	111056.	1371.	15107.	1336.	14855.
199999 STATE 1	EXP.	3685.	43399.	773.	7042.	873.	8911.
EMISSIONS	ART.	22212.	264401.	2759.	32098.	2083.	22810.
	LOC.	9371.	125109.	1069.	14371.	526.	7515.
	TOTAL	35268.	432908.	4601.	53511.	3482.	39235.
999999 REGION	EXP.	3685.	43399.	773.	7042.	873.	8911.
EMISSIONS	ART.	22212.	264401.	2759.	32098.	2083.	22810.
	LOC.	9371.	125109.	1069.	14371.	526.	7515.
	TOTAL	35268.	432908.	4601.	53511.	3482.	39235.

TABLE B-2

EMISSION DENSITIES (IN POUNDS PER SQUARE MILE) OF MAJOR AUTOMOTIVE POLLUTANTS

IMAGINARY SYSTEM RUN TO ILLUSTRATE OUTPUT OF THE POLLUTANT EMISSIONS MODEL

ANALYSIS AREA	FAC. TYPE	EMISSION DENSITIES OF MAJOR POLLUTANTS (IN LBS/SQ MI) CARBON MONOXIDE PK-HR	CARBON MONOXIDE DAILY	HYDROCARBONS PK-HR	HYDROCARBONS DAILY	OXIDES OF NITROGEN PK-HR	OXIDES OF NITROGEN DAILY
121 1	EXP.	183.	2152.	37.	335.	35.	361.
EMISSION	ART.	2032.	24934.	247.	2947.	169.	1875.
DENSITIES	LOC.	759.	10209.	86.	1159.	38.	539.
	TOTAL	2975.	37294.	369.	4440.	242.	2775.
121 3	EXP.	0.	0.	0.	0.	0.	0.
EMISSION	ART.	745.	7613.	94.	949.	77.	751.
DENSITIES	LOC.	340.	4520.	39.	521.	20.	282.
	TOTAL	1085.	12132.	133.	1470.	96.	1033.
121999 COUNTY A	EXP.	127.	1495.	26.	233.	25.	251.
EMISSION	ART.	1639.	19643.	200.	2337.	141.	1532.
DENSITIES	LOC.	631.	8471.	71.	964.	32.	461.
	TOTAL	2397.	29609.	297.	3533.	197.	2243.
122 2	EXP.	837.	9873.	179.	1642.	220.	2249.
EMISSION	ART.	1599.	18501.	213.	2435.	202.	2241.
DENSITIES	LOC.	912.	12010.	106.	1416.	64.	912.
	TOTAL	3348.	40384.	498.	5493.	486.	5402.
122999 COUNTY B	EXP.	837.	9873.	179.	1642.	220.	2249.
EMISSION	ART.	1599.	18501.	213.	2435.	202.	2241.
DENSITIES	LOC.	912.	12010.	106.	1416.	64.	912.
	TOTAL	3348.	40384.	498.	5493.	486.	5402.
199999 STATE 1	EXP.	271.	3186.	57.	517.	64.	654.
EMISSION	ART.	1631.	19413.	203.	2357.	153.	1675.
DENSITIES	LOC.	688.	9186.	79.	1055.	39.	552.
	TOTAL	2589.	31785.	338.	3929.	256.	2881.
999999 REGION	EXP.	271.	3186.	57.	517.	64.	654.
EMISSION	ART.	1631.	19413.	203.	2357.	153.	1675.
DENSITIES	LOC.	688.	9186.	79.	1055.	39.	552.
	TOTAL	2589.	31785.	338.	3929.	256.	2881.

TABLE B-3

THE FOLLOWING TABLE INDICATES SPEEDS AND VEHICLE-MILES-OF-TRAVEL CALCULATED FOR PEAK HOUR CONDITIONS (BOTH PEAK DIRECTION AND REVERSE DIRECTION) AND FOR BASE DAY (OFF-PEAK HOURS) CONDITIONS

IMAGINARY SYSTEM RUN TO ILLUSTRATE OUTPUT OF THE POLLUTANT EMISSIONS MODEL

ANALYSIS AREA	FACILITY TYPE	PEAK-HOUR, VMT	PK-DIR. SPEED	PEAK-HOUR, VMT	REV-DIR SPEED	BASE DAY (OFF-PK) 24-HR VMT	OFF-PK SPD
121 1	EXPRSWYS.	20341.	22.36	11844.	26.81	328425.	31.11
	ARTERIALS	101255.	13.79	52162.	14.34	1704637.	12.23
	LOCALS	18525.	5.45	15780.	6.09	490074.	6.62
121 3	EXPRSWYS.	0.	33.56	0.	33.56	0.	33.56
	ARTERIALS	20786.	18.18	9827.	19.03	300126.	16.62
	LOCALS	4420.	8.25	3473.	9.22	112746.	10.04
122 2	EXPRSWYS.	46120.	32.71	26855.	39.12	744640.	43.70
	ARTERIALS	44081.	22.76	22709.	23.72	742109.	22.28
	LOCALS	11420.	10.79	9728.	12.06	302115.	13.12
REGION	EXPRSWYS.	66461.		38699.		1073065.	
TOTAL	ARTERIALS	166123.		84697.		2746872.	
VMT	LOCALS	34364.		28981.		904935.	
	TOTAL	266948.		152377.		4724872.	

TABLE B-4

THE FOLLOWING TABLE SHOWS VEHICLE-MINUTES OF TRAVEL, BY FACILITY TYPE, FOR FOUR DAILY CONDITIONS--(1) PEAK DIRECTION FLOW IN THE PEAK HOUR, (2) REVERSE FLOW IN THE PEAK HOUR, (3) DAILY TWO-DIRECTIONAL OFF-PEAK FLOW, AND (4) A 24-HOUR 2-WAY TOTAL (INCLUDING PEAK PERIOD FLOW DERIVED BY FACTORING UP PEAK HOUR FLOW).

IMAGINARY SYSTEM RUN TO ILLUSTRATE OUTPUT OF THE POLLUTANT EMISSIONS MODEL

		VEHICLE-MINUTES OF TRAVEL BY TIME OF DAY			
ANALYSIS AREA	FACILITY TYPE	PEAK HOUR, PEAK-DIR.	PEAK HOUR, REV.-DIR.	OFF-PEAK, TWO-DIRECTION	24-HOUR FLOW, TWO-DIRECTION
121 1	EXPRSWYS.	54576.	26507.	447204.	690452.
	ARTERIALS	440439.	218204.	6102911.	8078840.
	LOCALS	203999.	155485.	3508820.	4587269.
	TOTALS	699014.	400196.	10058935.	13356562.
121 3	EXPRSWYS.	0.	0.	0.	0.
	ARTERIALS	68596.	30988.	751863.	1050615.
	LOCALS	32129.	22587.	532531.	696680.
	TOTALS	100726.	53575.	1284393.	1747294.
121999	EXPRSWYS.	54576.	26507.	447204.	690452.
COUNTY A	ARTERIALS	509035.	249192.	6854773.	9129455.
	LOCALS	236128.	178072.	4041350.	5283948.
	TOTALS	799739.	453771.	11343328.	15103856.
122 2	EXPRSWYS.	84597.	41185.	721755.	1099099.
	ARTERIALS	116182.	57452.	1458936.	1979838.
	LOCALS	63473.	48378.	1091758.	1427313.
	TOTALS	264252.	147015.	3272449.	4506251.
122999	EXPRSWYS.	84597.	41185.	721755.	1099099.
COUNTY B	ARTERIALS	116182.	57452.	1458936.	1979838.
	LOCALS	63473.	48378.	1091758.	1427313.
	TOTALS	264252.	147015.	3272449.	4506251.
199999	EXPRSWYS.	139173.	67691.	1168959.	1789550.
STATE 1	ARTERIALS	625217.	306645.	8313709.	11109293.
	LOCALS	299601.	226450.	5133108.	6711261.
	TOTALS	1063991.	600786.	14615777.	19610096.
999999	EXPRSWYS.	139173.	67691.	1168959.	1789550.
REGION	ARTERIALS	625217.	306645.	8313709.	11109293.
	LOCALS	299601.	226450.	5133108.	6711261.
	TOTALS	1063991.	600786.	14615777.	19610096.