SHORT-TERM TRANSPORTATION CONTROL STRATEGIES FOR AIR POLLUTION CONTROL

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Seven short-term transportation control strategies are identified as likely candidates to provide for short-term reductions in carbon monoxide emissions for motor vehicles and attainment of primary standards for carbon monoxide for the 1975 deadline: inspection, maintenance, and retrofit; conversion to gaseous fuels; traffic flow techniques; bypassing through traffic; improvements in public transportation; motor vehicle restraints; and work schedule changes. For each of these candidates, the paper describes the air pollution control potential, the maximum feasible emission reduction, and the institutional feasibility. The findings are based an an EPA-sponsored study of Chicago, Denver, Los Angeles, New York, San Francisco, and Washington, D. C. Emphasis was placed on identifying transportation controls that could be available within a period of 3 years, realistically subject to implementation by state and county governments and institutionally and technically feasible. In addition, three of the control strategies (inspection, maintenance, and retrofit; traffic flow controls; and motor vehicle and public transport improvements) were tested through simulation methods applied to each of the six cities. The paper summarizes the preliminary results of these tests as isopleths of pollution concentration for carbon monoxide, hydrocarbons, and oxide of nitrogen for the 1- and 8-hour periods of maximum VMT for a base year projected to 1977 under both uncontrolled (no transportation control strategy) and controlled conditions.

•IN August 1971, the Institute of Public Administration, Teknokron, Inc., and TRW Systems Group [under contract to the Environmental Protection Agency (EPA)] initiated a six-city study to evaluate the potential of transportation controls for reducing motor vehicle emissions in major metropolitan areas. Section 110 of the Clean Air Amendments of 1970 states (with respect to state air quality implementation plans):

> The Administrator shall approve such plan, or any portion thereof, if he determines ... that it includes ... such other measures as may be necessary to insure attainment and maintenance of such primary or secondary standard, including, but not limited to, land-use and transportation controls. . . .

The purpose of the study was to provide assistance in the preparation of the transportation component of state plans through intensive study of six metropolitan areas (New York City, Washington, D. C., Chicago, Denver, San Francisco, and Los Angeles). The most promising transportation controls were evaluated in detail for their pollution reduction potential and implementation difficulties. These controls included inspection, maintenance, and retrofit; gaseous fuel conversions; traffic flow improvements; increased mass transit use; motor vehicle restraints; and work schedule changes. In evaluating the pollution reduction potential and implementation difficulties of these transportation controls, two efforts were mounted: First, a major examination was undertaken of all potential transportation control candidates; second, selected strategies were tested in each of the six cities. The major focus of this paper will be on the first effort, though some consideration will be given to the preliminary results of the testing of specific strategies.

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STUDY GUIDELINES

Before examining the results of these two efforts, it is essential to spell out the criteria provided to the study by EPA:

1. The project would be concerned essentially with carbon monoxide emissions from motor vehicles although the problems of other motor vehicle emissions (e.g., nitrogen oxides and hydrocarbons) would be kept in mind throughout the study.
2. The project was to focus on attainment by 1975 (later extended to 1977) of primary standards for carbon monoxide although it was expected that recommended transportation controls would also serve to assist in achieving the secondary standards.
3. The measures must be available and must be expected to take effect within the next 3 years. A major alteration in metropolitan land use and urban design, for example, would not meet this criterion because, unless major efforts are already under way (e.g., the Washington, D.C., Metro system), these factors must be considered fixed for at least a decade.
4. The measures must be available locally, i.e., realistically subject to manipulation by state and local governments. A measure that would require basic alterations by automobile makers of the internal-combustion engine, for example, would not be a locally available measure.
5. The measures must be institutionally feasible. For example, measures that are politically unacceptable or administratively unworkable would not meet this criterion.
6. The measures must be technically feasible. For example, a measure that requires retrofit devices that are beyond the state of the art would not be technically feasible.
7. The study focused on light-duty vehicles as defined by EPA, generally stated as commercial vehicles with a rating of up to 6,000 lb or passenger vehicles with capacity of up to 12 passengers.
8. Primary attention was given to automobile air pollution problems arising from travel into, out of, and within the central business district (CBD) during the peak rush hours of workdays.

Within the guidelines, the task of the project (in its first phase) was to identify major transportation control candidates, their potential for pollution reduction, and the difficulties that might be encountered in their implementation. An intensive literature search was undertaken of the existing ideas and experience relevant to transportation controls. As part of this effort (as well as for the second phase), reconnaissance trips were scheduled to each of the selected cities. The purpose of the reconnaissance trips was to obtain information and pertinent documents (e.g., local budgets, transportation plans, and air pollution control statutes) and to interview central city, regional, and state officials having responsibility for both transportation and air pollution control in order to ascertain institutional feasibilities, special economic problems, and specific circumstances in each city with regard to each of the strategies. The interviews and field trip work in each of the cities provided the basic data for both phases of the study as well as the insight for making decisions on potential pollution impacts where data were not available.

From the initial phase of the six-city study emerged an interim report (1) that considered the impact of seven short-term transportation control strategies considered to be the most likely candidates for implementation within the time available to the cities: inspection-maintenance-retrofit, conversion to gaseous fuels, traffic flow techniques, bypassing through traffic, improvements in public transportation, motor vehicle restraints, and work schedule changes. For each strategy, the air pollution control potential was analyzed, the maximum feasible emission reduction was estimated, and its institutional feasibility was explored. The report contains a considerable data base, specific data analyses, and the recording of all relevant experience with each of the controls. The section that follows provides a summary of the findings and conclusions of that report with respect to each transportation control strategy examined.

SHORT-TERM TRANSPORTATION CONTROL STRATEGIES: FINDINGS

Inspection, Maintenance, and Retrofit

Broadly defined, the programs of inspection, maintenance, and retrofit as discussed in the study involved (a) the inspection of in-use vehicles; (b) the identification of high emitters and, hopefully, the provision of some diagnostic information; and (c) some requirement for subsequent corrective action (whether at inspection stations or garages). Conceivably, some corrective actions could be required without inspection. For example, spark plugs or breaker points could be replaced on the basis of their expected life. Corrective action might also be required on the basis of records kept for the federal new car warranty program. Nevertheless, inspection appears to be a necessary prerequisite to corrective action for in-use vehicles on two counts: to determine what corrective action needs to be taken and to reduce possible underservicing or overservicing. For these reasons, it was assumed that inspection should be an integral part of any effective program involving maintenance or retrofit (2).

At the present time, enforcement of federal new car emission standards is the principal public policy to control motor vehicle emissions. Its effectiveness depends on in-use vehicle conformance (i.e., mileage accumulation without a substantial deterioration of exhaust control systems). Under the federal Air Quality Act, authority to regulate emissions from in-use motor vehicles is retained by state and local governments; however, states are required to provide for periodic inspection and testing of in-use vehicles to the extent "necessary and practicable." The same legislation also authorizes federal funding for "effective" inspection, maintenance, and retrofit programs.

Preliminary indications are that regulation of in-use vehicle emissions will be necessary in several large metropolitan areas to meet national ambient air quality standards. But the practicability and effectiveness of inspection, maintenance, and retrofit cannot be precisely established at this time. For example, the time required to physically implement a statewide emission inspection program (whether state owned and operated, state regulated, or operated by the private sector) is probably small (on the order of 6 months to 1 year). This "physical implementation time" would include the time required for constructing facilities, acquiring staff, and training professional personnel and would, of course, depend to some degree on the testing procedure selected. However, the "real implementation time," which includes total elapsed time from consideration of program initiation by the policy-makers until actual program operation, will probably be considerably longer, among other things because of the political problems involved (i.e., resistance to programs on the part of strong rural interests in some state legislatures, opposition from automobile owners associations, and so forth).

Even if such a program could be implemented, estimating the effectiveness of inspection, maintenance, and retrofit over time is impossible at present because of inadequate information (e.g., with respect to deterioration of maintained vehicles between inspections) and inherent uncertainties (e.g., as to post-1975 exhaust control systems). For any area's vehicle population, the potential emission reductions consist of both the initial reduction achieved at the time of maintenance and retrofit and the reduction over time. (Actual on-the-road reductions are significantly less than initial reductions because of the deterioration of emission control equipment efficiency with accumulated mileage—referred to here as reduction "over time.") The potential for initial emission reductions will depend on the accuracy of the test procedure and the level at which emission standards are set (which in turn determines the test rejection rate). Preliminary indications concerning rejection rates seem to indicate that for most states these rates should not exceed 20 to 40 percent so as to prevent a critical overload of commercial repair facilities and to eliminate heavy burdens on the inspection program that occur because of demand for retest (3, 4). The probability of adverse public reaction to high rejection rates should also be a central consideration when inspection programs are developed.

Unfortunately, present knowledge does not permit a determination of the deterioration rates of maintenance and retrofit. Deterioration over time will depend on a number of unknowns, such as the reliability of post-1971 emission control systems (not to mention the uncertainty attached to post-1975 emission control systems, with potentially more sophisticated technology). Deterioration rates for inspection and maintenance are shown in Figure 1. As indicated, an initial emission reduction (from e_3 to e_1) is achieved at the time of inspection and maintenance (t_1). Reductions over time depend on the slope of the deterioration curve. With an early substantial deterioration (curve d), fully half of the initial reduction would be dissipated within 2 months; with linear deterioration (curve d^1), the same initial reduction would return to half its premaintained level within 6 months; with late substantial deterioration (curve d^2), half of the initial reduction would disappear after 9 months. (These deterioration curves and time periods, it should be stressed, are solely for purposes of illustration; further empirical research is required to determine actual deterioration rates over time.)

Different deterioration rates, in turn, require different intervals between inspections. If, for example, initial reductions are dissipated rapidly, frequent inspection would be necessary to maintain vehicles below a given level. With a target emission level at e_2 (Fig. 1), the appropriate interval between inspections would be determined by that point in time at which emissions returned to the target level. Whether the time to t_2 is 2 months ($t_1 - t_2'$) or 6 months ($t_1 - t_2'''$) has an obvious bearing on the costs and feasibility of any exhaust emissions inspection program. Acquiring the additional information needed to make for effective inspection programs will probably take another 6 to 12 months for experimentation in pilot projects. These lead times imply that most federally funded inspection, maintenance, and retrofit programs will probably not be in place until at least 1975.

Without this information, it is nevertheless possible to arrive at a rather broad range of initial emission reductions that can reasonably be expected. On the basis of research performed by TRW, Inc. (5), Northrop Corporation (2), and the state of New Jersey (6), as well as information from EPA officials in the Bureau of Mobile Source Pollution Control, it appears that the most likely initial reduction in aggregate carbon monoxide emissions would be on the order of 10 to 25 percent. (By aggregate we mean the carbon monoxide attributable to light-duty motor vehicles in any given area. To the extent that other motor vehicles or stationary sources contribute importantly to an area's emissions, the reduction possible from inspection and maintenance would be less than estimated here.) However, it appears that values in the upper range (particularly 20 to 25 percent) are decidedly less likely than those in the lower range (particularly 10 percent). It should also be stressed that these values represent a definite upper bound for the air pollution control potential of inspection and maintenance because subsequent deterioration of maintained vehicles (in the interval between inspections) would lessen the effectiveness of this control.

With respect to retrofit, currently available "industry-type" devices appear able to reduce emissions by 20 to 25 percent for precontrolled vehicles. Aggregate emission reductions, therefore, depend on any area's proportion of precontrolled vehicles and their associated vehicle-miles traveled (VMT), bearing in mind that older cars are driven less than newer cars.

If at least 3 years would be required for legislation and the certification and installation of equipment, it appears the earliest date for completion of a retrofit program would be 1975. Based on this assumption (and using vehicle age distribution and VMT by age data), it was possible to calculate the upper bound of possible carbon monoxide reductions for any area. It was concluded that only modest emission reductions are possible especially for the light-duty vehicle population as a whole (1). It was also concluded that retrofit did not warrant further consideration as a control with widespread application. The possibility of new, more effective technology may, of course, alter the situation. Other more sophisticated technology (e.g., catalytic convertors, thermal reactors, and exhaust gas recirculation) is currently being tested and may hold more promise, particularly if it is applicable to controlled vehicles as well.

Gaseous Fuel Systems

Within the next 5 years, only three types of gaseous fuels can be seriously considered as alternatives to gasoline for powering motor vehicles: liquefied petroleum gas

(LPG), compressed natural gas (CNG), and liquefied natural gas (LNG). These fuels are inherently cleaner burning (produce fewer heavy hydrocarbons) than gasoline because of their lower molecular weight and carbon content. In addition, gaseous fuels ignite more rapidly, and the combustion process proceeds more nearly to completion, leaving less unburned fuel in the exhaust stream.

Modification to gaseous fuel requires the installation of a special carburetor, special fuel tanks (pressure tanks for LPG and CNG and cryogenic tanks for LNG), pressure-regulating devices, shutoff valves, and fuel lines. This is generally regarded as "simple" conversion as opposed to more sophisticated (and costly) modifications that may include installation of a special venturi carburetor (to allow for lean air-fuel mixtures at low power levels and enriched mixture at high power operations), refined adjustment of engine variables, exhaust gas recirculation, exhaust air-injection thermal reactor system, and a catalytic convertor. Vehicles modified to this extent, however, would probably have emission levels similar to those required by 1975 and 1976 for gasoline-fueled operations (and therefore would be of little advantage from a pollution control point of view). Consequently, the following discussion is confined to simple conversion. For simple conversion, the cost of modifying an in-use light-duty vehicle to CNG or LPG ranges from $350 to $500, whereas conversion to LNG may cost from $800 to $1,000.

It was the conclusion of the study that the conversion of large numbers of motor vehicles to gaseous fuels would be impractical or unwarranted in most major metropolitan areas for the following reasons:

1. Natural gas is currently in short supply, and no major expansion in capacity is anticipated in the near future. Low supplies of LPG combined with preferential treatment for heating customers have already caused a reduction in conversions and loss of sales.
2. Conversion of large numbers of vehicles and implementation of an adequate fuel distribution system would be extremely expensive.
3. Adequate supplies of conversion equipment are currently not available. Consequently, at least 2 to 3 years would elapse before significant numbers of vehicles could be modified (7).
4. Considerable efforts are currently under way to meet stringent 1975 federal emission standards through modification of conventional gasoline engines. If successful, these efforts would obviate the need for gaseous-fueled vehicles, which would be unable to meet the preceding standards without engine modifications and substantial supplemental equipment.

In some metropolitan areas, however, fuel supplies, distribution systems, and conversion equipment may be adequate for small-scale conversions (e.g., commercial fleets) in highly polluted downtown or densely developed districts. Aside from the possible technical difficulties, the principal institutional problems in implementing small-scale conversions may consist of present safety regulations at both state and local levels that discourage or preclude gaseous fuels for motor vehicle use, the considerable costs and risks for fleet owners and operators of converting to natural gas or LPG, and the limited legal authority of municipalities over large vehicle-fleet owners and operators.

Conversion of gasoline-powered motor vehicles to gaseous fuels should be considered only for large centrally maintained fleets that account for a high proportion of total VMT and operate in severely polluted areas. Medallion taxicabs in the Borough of Manhattan are one such example. Emission reductions achievable through conversion to gaseous fuels are highly variable. However, for pre-1975 motor vehicles, significant reductions in carbon monoxide and hydrocarbon emissions and some reduction in nitrogen oxides emissions can be expected.

New car federal emission standards for 1975 and later are below levels that can be achieved through simple conversion. Consequently, conversion would be an interim measure, assuming 1975 emission standards are achieved. However, diversion of natural gas from power production or space heating to motor vehicle use would be counterproductive from a pollution abatement point of view. Furthermore, as noted previously, implementation problems loom large even for the limited case of converting fleet vehicles. Specific economic and/or regulatory incentives would be required to induce fleet owners to convert to gaseous fuels in view of the capital investments required, the logistics of fuel supply, reduced drivability, new maintenance requirements, and the loss of manufacturers' warranties implicit in conversion.

Traffic Flow Techniques

As used in the study, "traffic flow techniques" refer to those traffic engineering measures that have as their principal objective a reduction in delays, idling periods, and stops and starts that, in turn, would tend to increase average vehicle speeds on the existing street network. In terms of air pollution control potential, simply stated, motor vehicle exhaust emissions are lower in freely flowing traffic than in congested, stop-and-go conditions. However, there is some evidence that NO_x emissions increase with increased vehicle speeds. Consequently, consideration of traffic flow techniques requires careful evaluation of pollutant trade-offs, especially in those areas where nitrogen oxides appear to be the primary problem. Assuming an established relation between emissions and speed, what increases in average vehicle speeds and accompanying carbon monoxide reductions can be anticipated from traffic control and flow improvements? Straightforward as this question may seem, a simple answer is not easily given because of a number of complicating factors.

To begin with, from a pollution viewpoint, the degree of potential improvement depends in large measure on the baseline speeds prior to implementation of traffic flow techniques. For example, increasing average vehicle speeds from 5 to 10 mph is much more important from an air pollution control point of view than increasing average vehicle speeds from 25 to 30 mph. In turn, baseline speeds depend on factors such as the physical characteristics of the urban street network under consideration, the existing traffic volumes and available capacity, anticipated growth, and so forth. All of these factors vary by city.

Second, any accurate evaluation of the impact of traffic flow improvements must take into account network (system) repercussions, i.e., those repercussions that extend beyond the specific facility being improved. Unfortunately, however, most available data as to the impact of potential improvements are for specific facilities and not for entire networks. It may be highly misleading to consider an improvement strictly in terms of the specific facility. For air pollution control purposes, improvements need to be studied in terms of impact on the entire street network. In addition, longer time periods (perhaps several years in some cases) would be needed to allow all secondary and tertiary repercussions and adjustments to be worked out. For example, it is well established that increased travel speeds (and therefore shorter trip times) eventually generate longer trips. Therefore, a consequence of improved traffic flow (without motor vehicle restraints) could well be higher VMT with accompanying greater (though perhaps more dispersed) emissions.

Finally, in the short run of 3 to 5 years, the available street capacity is relatively fixed in most large urban areas and saturated during peak hours. Improvements in either added or existing capacity could result in higher speeds or shorter travel times or both; the latter, in turn, could release latent demand, a result of peak-hour capacity saturation, and generate new trips, until once more congestion acts as a constraint on the use of the automobile. The rapidity with which traffic builds up in response to new or improved facilities will depend on many factors including the existing traffic density on the present street network. However, even where capacity saturation is found, overall traffic volume in most U.S. metropolitan areas (and certainly for the cities of Chicago, Washington, D.C., San Francisco, and Los Angeles) will continue to grow—probably at a rate of about 2 to 4 percent a year. Thus, from a pollution viewpoint, both long-term traffic trends and induced travel tend to limit the air pollution control potential of traffic flow improvements in the medium- and long-term period. In most metropolitan areas, the additional capacity afforded by traffic flow improvements would tend to be "used up" within 2 to 4 years because of the higher volumes that would be attracted.

Impact of Traffic Improvements on Speed

Appraisal of the network impact of traffic flow improvements on speed requires a data base currently not available. To begin with, there is no comparability for existing data, all of which relate to specific traffic flow techniques implemented in specific cities at specific sites. The site-specific nature of traffic flow improvements has already been discussed. Second, even if (judgmentally) comparable experience were examined, the data typically available do not include observations over a period long enough to enable evaluation of major repercussions; only the most immediate impacts are usually measured. Furthermore, traffic flow improvements at one point of the street network frequently result in deterioration in traffic conditions at other points; often these network-wide trade-offs are not considered.

Despite the difficulties of developing network averages of the impact on speed of implementation of various traffic flow techniques, an effort was made in the study to evaluate the evidence and estimate the relative orders of magnitude of speed impacts that might be expected. Recent comprehensive research carried out under sponsorship of the National Cooperative Highway Research Program (8) provided a major source of information. The project provided information based on actually demonstrated methods of improving traffic flow on complex networks of city streets as compared with the usual information available for only spot or arterial improvement. Dozens of traffic engineering improvements were implemented and evaluated in Newark and Louisville. A network analysis was conducted to evaluate various models for use in the analysis of downtown area traffic flows. Work of the NCHRP study represents one of the most comprehensive efforts to evaluate the impact of various traffic engineering techniques and provided the major source for evaluating the magnitude of the impact of major traffic control improvements on speed.

The experiments undertaken in Newark and Louisville were reviewed, and all observations in which there were positive increases in speed were assembled and analyzed. Traffic flow control experiments with negative speed results were not taken into account. It was assumed that any speed losses not offset by substantial gains in dominant traffic streams would not be continued. In addition, our purpose was primarily to show the upper bounds of emission reductions that would be possible with successful traffic control and flow techniques.

Based on these before and after results, it was found that, of the 43 instances in which average travel speeds increased after implementation of traffic flow techniques, approximately two-thirds of the speed improvements fell between the class intervals of 5 to 10 percent at the lower bound and 35 to 40 percent at the upper bound. Our experience in the six cities indicated that, at least for the six cities in the study, the improvement in speed was anticipated to be somewhat in the range of 10 to 15 percent (clearly closer to the lower bounds).

Assuming an increase in average vehicle speed along an urban arterial of 10 to 15 mph, emissions might be reduced by about 20 percent, at best. However, these emission reductions would be short-lived unless accompanied by some form of restraint. At worst, emissions could be significantly greater than if no "improvements" had been implemented at all.

It was concluded that traffic flow techniques, unless accompanied by motor vehicle restraints, could well be counterproductive from an air pollution control point of view. Furthermore, many traffic flow techniques would render public transport (especially bus) less attractive relative to the automobile. Finally, implementation of traffic flow improvements on a network-wide basis would be a costly measure, particularly when weighted against the short-lived effectiveness of these controls.

Bypassing Through Traffic

In large central cities, through traffic can account for about 5 to 20 percent of total traffic volumes, even at peak hours. From an air pollution control viewpoint, bypassing through traffic would shift VMT away from already congested central city roadways and smooth traffic flows by a separation of through and local traffic in the areas affected. Both results would reduce emissions in high pollution areas of the central city, the first by redistributing emissions elsewhere and the second by bringing higher average vehicle speeds, fewer stops and starts, less idling, and emission reductions associated with these improvements.

Several possibilities are available to bypass through traffic, including the use of circumferential routes, inner-city barriers, and directive signs or signals.

An important example of bypassing technique, using inner-city barriers, was implemented in Gothenburg, Sweden, in 1970 (9). The city's CBD was divided into wedge-shaped quadrants. Physical barriers were constructed between these quadrants, thus making traffic through the CBD impossible (except to emergency vehicles such as fire and ambulance and public transit). In effect, each quadrant became a self-contained precinct with only local circulation allowed. All other traffic was required to use a ring road, entering and leaving each quadrant at designated locations (Fig. 2).

The success of the barriers in decreasing through traffic in Gothenburg can be clearly seen. After 8 weeks of operation, traffic on one of the main arterials (Oestra Hamngatan) was decreased by some 70 percent. As Figure 2 shows, traffic has shifted to the peripheral streets. Barriers have not been used in large scale anywhere in the United States as yet, and the size of the experiment in Gothenburg (whose population numbered slightly more than 444,000 in 1971) does not provide adequate evidence that a similar strategy can be easily and quickly transferred to any major United States city. Even the comparatively small Gothenburg experiment entailed a planning period of 7 years. In fact, given the size and extent of vehicle ownership in most major cities in the United States, it is doubtful that a similar experiment could be implemented before at least 2 or 3 years of planning. To the extent that similar measures depend on new construction, they are not likely to be implemented in less than 5 years.

If other measures, such as directive signs or signals, are used and are designed specifically to attract and divert vehicles away from central cities, some emission reduction may occur and more rapid implementation may be possible. It was the best judgment that the reductions that could be achieved in the short term—within 5 years—would not exceed 5 percent for most central cities. More substantial reductions would require motor vehicle restraints to discourage through trips. Given the substantial share of through traffic in some central city areas (a third or more of total traffic is typical in the CBD), this possibility appears to merit more attention that it is now receiving. However, construction of major highway facilities including circumferential routes is not likely to be feasible by 1977. In urban areas where circumferential facilities are already under construction, some bypassing of through traffic might be possible by 1977. But where no plans exist, at least 8 to 10 years would be required. Even with an accelerated effort, it is unlikely that major construction of circumferential facilities could be achieved in less than 5 to 8 years.

Improvement in Public Transportation

In the study, mass transit was considered as conventionally defined (rail and bus systems) as well as including a number of other means of conveyance such as the taxicab, demand-responsive systems, car pools, and people movers. Improvements in public transportation could, conceivably, reduce motor vehicle emissions in the short run by attracting motorists away from their automobiles and in the long run by encouraging high-density development and more efficient land use.

Before proceeding, however, a caveat is in order concerning the role of public transport improvements in the context of air pollution control. Extensive review of recent experience with public transport improvements reveals that these improvements alone hold little promise for attracting motorists out of their automobiles. Modal diversion to public transport, moreover, does not necessarily reduce motor vehicle traffic. Of all public transport improvements in recent years, the Philadelphia-Lindenwold line has often been cited as a great modal diversion success. However, special analysis undertaken as part of this study did not establish that any significant reduction in motor vehicle traffic had occurred. The best judgment is that public transport improvements would be unlikely to reduce the VMT of light-duty vehicles (and hence emissions) by more than 5 percent in any major metropolitan area. Improve-

Figure 1. Hypothetical deterioration rates for inspection and maintenance.

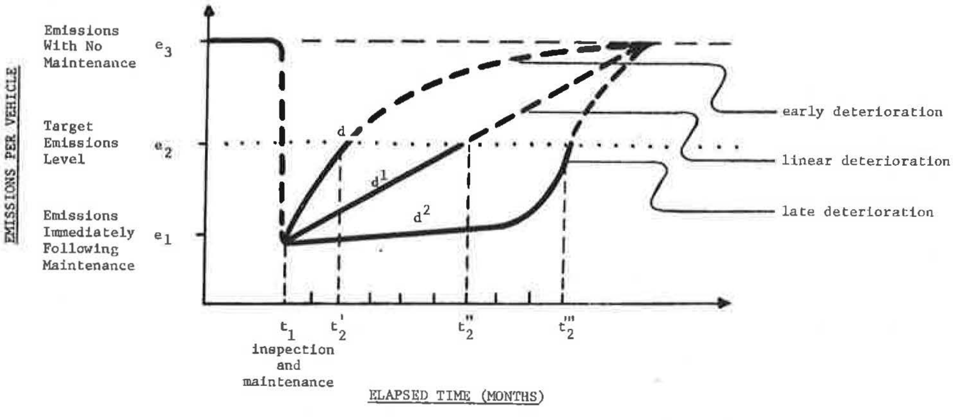
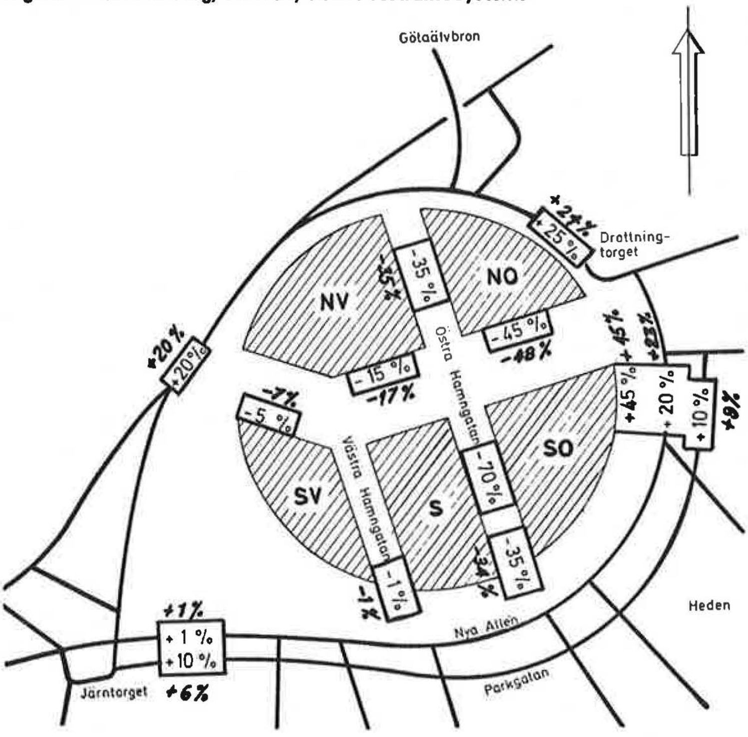


Figure 2. Gothenburg, Sweden, traffic restraint system.



Source: Curt M. Elmberg, "The Gothenburg Traffic Restraint Scheme" (Paris: Organization for Economic Cooperation and Development, May 1971), p. 22.

Note: Hatched areas are quadrants; lines represent major arterials. Numbers refer to percentage change in vehicle volumes along central area routes two weeks and eight weeks (figures in boxes) following introduction of scheme in August 18, 1970.

ments in public transport, therefore, are a necessary but not sufficient condition for reducing motor vehicle emissions. They are necessary because reducing motor vehicle use in high pollution areas will require substantially improved public transport to provide an alternative means of making trips. They are not sufficient, however, because public transport improvements, unaccompanied by motor vehicle restraints, will reduce motor vehicle traffic only modestly, if at all. Indeed, as a result of some improvements, especially rail, emissions may actually increase where they are currently worst, in the downtown and other densely developed areas. Historically, the effect of good transit has been to encourage the economic development of the CBD it serves. When a new transit system is installed, development tends to take place around the downtown stations of that line. Development is especially intense at the node points—where two or more lines cross. Because ground rents are high, the new office buildings also tend to be high. As a result, more people tend to work in the downtown than was previously possible. Although a large number of new workers probably ride the new, convenient transit system to work, some percentage will use motor vehicles. The proportion of new motorists may be small relative to transit users, but their absolute numbers are important, particularly at peak hours.

Capital Costs—Of considerable importance in connection with public transportation is the issue of costs of improvements. Within the time available to complete the study, preparation of detailed estimates of the investment costs required to substantially improve public transportation was not possible. However, preliminary estimates were prepared of potential investments in public transport between 1970 and 1980 to allow identification of the overall orders of magnitude implied. The estimates included a mix of short-lived or off-the-shelf items (buses, transit cars, and so forth) and very long-lived or custom-built items (new rights-of-way, including track and structures for high-capacity rapid transit and commuter rail). Not included were demand-responsive transit systems and generally untested technology. The estimates include substantial unmet demands (at 1971 population levels) that are expected to be fulfilled or initiated before 1980.

The basic approach was to estimate rail transit on the basis of work under way and plans in process and bus transit on the basis of industry replacement cycles, population growth, rate of urbanization, and changes in real per capita income. These estimates do not include the scope of changes (i.e., substantial improvements in public transport services) that apparently are needed to meet national air quality standards by 1975, and in that context they must be considered conservative. Table 1 gives the estimates for the six cities focused on in this study. The estimates indicate that about $13.8 billion will be required for investment if the existing plans plus some moderate improvements (such as people movers) are implemented.

The estimates should be considered within the context of severe financial difficulties facing most transit systems across the United States. Most systems cannot cover operating costs let alone finance improvements. Consequently, federal funding would be required. However, if (as provided for in the Urban Mass Transportation Assistance Act of 1970) the federal government provided two-thirds of the $13.8 billion investment needs estimated previously, more than 90 percent of federal funds obligated for the entire country would be expended on just the six cities of New York, Chicago, Washington, D.C., Los Angeles, San Francisco, and Denver. Clearly, if even modest improvements in public transport are to be made, a much greater federal commitment will be required.

Operating Costs—In addition to capital investment requirements, improved public transportation will generate increased operating costs. Again, estimates for the six cities are not possible at this point in the study. Moreover, the orders of change will of course depend on the specific operating characteristics of each city's transportation system. However, estimates have been prepared for Washington, D.C., for the year 1975. The estimates must be considered as rough orders of magnitude. The following assumptions were made:

1. The Metro (the new rail transit under construction) will not be in operation by 1975, and all bus services will be used;

2. There would be about a 10 percent passenger diversion to bus transit by suburbanites and a somewhat smaller diversion for trip-makers within the District of Columbia;
3. No cost increases would be required for off-peak service—only for increased demands during the peaks;
4. No change in labor practices would be needed;
5. No fare change would be established until 1975 and thereafter a 12 to 15 percent increase would be made; and
6. Only moderately improved services would be forthcoming.

Table 2 gives the results of these estimates.

The data given in Table 2 show that the overall system deficit would be in the order of $15 million in 1975, if no fare increases were provided, and about $5 million with a fare increase of about 15 percent. Thus, the deficit would increase sharply from the 1969 level without any fare changes and would probably decline slightly with a moderate fare increase. However, even a deficit of $15 million annually by 1975 would not represent an insurmountable cost obstacle (in contrast, perhaps, to the capital investment requirements) for expansion of the service needed, especially if parking taxes are imposed to restrain motor vehicle use. Revenues from such a tax would undoubtedly go a long way toward covering such deficits.

Operating Deficit for the United States—In 1970, for the United States as a whole, the total operating deficit for transit operators amounted to about $288 million (a large part of which was accounted for in large cities such as New York, Boston, San Francisco, and Philadelphia where air pollution problems are at their worst). If no improvements are made in existing public transport services, the deficit (conservatively estimated) can be expected to double by 1975 (and is probably more likely to be closer to $600 million). If major improvements were instituted, operating deficits would be even greater, particularly if fares were not increased.

Motor Vehicle Restraints

In the context of the six-cities study, motor vehicle restraints were considered to be those measures that could reduce to some degree motor vehicle use in high air pollution areas. These measures consist of controls over parking or road use or both by administrative action or pricing policy and are summarized in Table 3. Subsequent sections discuss the air pollution control potential of these motor vehicle restraints and their institutional feasibility (10).

For many transportation controls to be effective, motor vehicle restraints will be required. These restraints could consist of parking regulations or imposition of higher parking prices, regulation of road use (pedestrian malls or vehicle-free zones), or road pricing (toll collection or the use of a congestion pass in high pollution areas). None of these measures will be politically popular, and intense opposition can be expected from those whose direct interests are involved (road users, automobile owners' associations, downtown businessmen, parking garage owners, and others).

This suggests that, for motor vehicle restraints to be at all acceptable to the public, and hence workable and effective, the quality and quantity of public transport must be importantly and visibly improved. Improvements should be made in conjunction with any strategy to reduce motor vehicle use.

The most promising restraint, at least for the short term, would be to intensify control over the location, amount, and use of parking space, both on- and off-street. The most desirable method of control appears to be through municipal taxation, particularly where local revenues will be required for improved and expanded public transport. The effectiveness of parking controls, however, will be limited by several factors. First, through traffic and internal circulation will not be affected; indeed it would probably be encouraged if a lower volume of local traffic results from parking controls in some areas. Second, comprehensive parking controls, particularly over already existing space provided by private firms and government agencies, would be difficult to enforce and would probably require new legislation. In many downtown areas, such space constitutes more than half of existing storage capacity.

To the extent that it is practical, road pricing would be a more effective motor vehi-

Table 1. 1980 investment estimate for urban transport (in millions of dollars).

City	Rail Rapid	Suburban Rail	Buses	CBD People-Movers	Total
New York	2,833.1	2,223.2	587.3	250.0	5,893.6
Chicago	1,011.2	240.9	162.3	12.0	1,426.4
Washington, D. C.	2,970.0[a]	—	—[b]	6.0	2,976.0
Los Angeles	2,162.3	—	—[b]	24.0	2,186.3
San Francisco	427.7[c]	—	—[b]	16.0	443.7
Denver	852.6	—	—[b]	4.5	857.1
Total	10,256.9	2,464.1	749.6	312.5	13,783.1

[a]Approximately $200 million is now under contract or in active bidding.
[b]Estimates for buses are not given except for New York and Chicago where bus investment plans were specified separately as part of comprehensive multimodal plans. However, our estimates for bus investment needs for all metropolitan areas of more than 1 million population (excluding New York City, Chicago, Boston, Philadelphia, and Cleveland–all of which include buses as an intergral part of multimodal plans) amount to less than $119 million. Washington, D.C., San Francisco, and Denver represent a relatively small percentage of this total.
[c]Represents 30 percent of the full cost. About 70 percent is complete, and 30 percent is under contract.

Table 2. Bus transit estimated revenues and expenses for Washington, D.C., area.

Year	Revenue (millions of dollars)	Cost (millions of dollars)	Deficit (millions of dollars)	Passengers (millions)	Deficit per Passenger (cents)
1969	50	58	8	150	5
1975 (no fare change)	65	80	15	186	8
1975 (12 to 15 percent fare increase)	75	80	5	186	3

Table 3. Motor vehicle restraints.

Restraint	Description	Experience[a]	Results
Regulating parking	Reduce by administrative action motor vehicle storage capacity, off-street or on-street parking or both in or near high pollution areas.	Some large cities have moved to control the construction of additional parking garages in downtown areas. However, other off-street parking (e.g., spaces in commercial buildings made available to employees) are usually outside of municipal control. On-street parking has been controlled in relatively few areas, except during peak hours.	Would reduce motor vehicle use in high pollution areas and, to some extent, travel to and from them. This reduction, particularly if combined with controls over on-street parking, could also significantly improve traffic flow. However, through and circulating traffic would not be reduced and might even be encouraged.
Pricing parking	Impose parking prices for off-street or on-street parking or both in or near high pollution areas.	Increased off-street parking charges have occurred in virtually all metropolitan areas because demand exceeded supply. However, nominal charges (well below those for off-street parking in the same vicinity), are still in effect for most on-street parking. Moreover, most off-street spaces are still allocated outside the market mechanism (e.g., to employees and residents). Parking meters are still the major method of charging for on-street space.	
Regulating road use	Reduce by administrative action road network used (e.g., through pedestrian malls or vehicle-free zones) in or near high pollution areas.	Some 24 U.S. cities have introduced such schemes (mostly on an experimental basis) in recent years.	Would reduce or eliminate motor use in high pollution areas and, to some extent, travel to and from them. However, would create host of transportation problems (e.g., fringe parking, goods delivery, improved access, and internal circulation) and possible greater congestion and accompanying motor vehicle emissions on immediately adjacent local streets and arterials.
Pricing road use	Impose charges for motor vehicle use of selected portions of urban street networks in or near high pollution areas.	Toll collection facilities in and around Baltimore, Boston, Chicago, Jacksonville, Kansas City, Miami, New York City, and Philadelphia. Other techniques for imposing road pricing are currently available, as summarized in text, but have only been tried in limited applications or not at all.	

[a]Most experience with motor vehicle restraints has been motivated by objectives other than air pollution control (e.g., reducing congestion, minimizing motor vehicle-pedestrian conflicts, enhancing the aesthetic and commercial appeal of central city areas, and, in the case of parking charges and toll collection, raising revenues). However, particularly in some large cities, growing concern about automobile air pollution has given rise to increasing public support for curbing motor vehicle use.

cle restraint for purposes of air pollution control. This potential, as well as other ancillary benefits, argues strongly for further exploration of the concept to determine whether (and how) such a system could be implemented. Some measures (e.g., toll collection or a congestion pass approach) show promise for near-term application although substantial increases in enforcement may be required. The mechanics of imposing these controls, however, are less of a problem than gaining public acceptance to limit"freedom of the roads" in areas of high air pollution. The feasibility of these measures will, of course, vary widely in different metropolitan areas, depending on such factors as geography of the city, size of the central area, availability of public transport, shape of the street network, urgency of the local air pollution problem, and—probably most importantly—the local attitudes toward air pollution control and the degree to which public officials are willing to propose politically unpalatable measures to achieve air pollution control.

If motor vehicle restraints are to be effective, dramatic departures from previous practice would appear necessary (e.g., tripling or quadrupling parking rates for many areas of the city or tolling off major portions of the downtown). Restraints this severe could cause profound social, economic, and land use effects, many of which may be highly undesirable from other standpoints. For example, severe motor vehicle restraints in some areas of the central city would cause employment centers to shift to the suburbs, an undermining of the city property tax base, and particularly adverse economic effects on low-income residents.

An extensive review of the literature was undertaken to identify the potential impact of motor vehicle restraints. This review indicated that there was little evidence available as to the potential pollution reduction impact of restraints. Based on the little evidence later available and our judgment, and assuming parking controls or some other form of road pricing, the range of reductions in VMT reported in the interim report was estimated to be between 5 and 25 percent with 25 percent being the upper limit of any practical action that might be taken within the time frame of the study, 1977.

As the study progressed toward completion, additional evidence developed—some from reconnaissance trips in the six cities and intensive examination of their respective "implementation plans" and some from evidence obtained (and analyzed) too late to be included in the interim report. All these sources confirmed the difficulty of implementing motor vehicle restraints and suggested that the most likely reduction achievable by the period 1975 to 1977 was closer to 5 to 10 percent.

Modal split models examined for Washington, D.C., Baltimore, and Minneapolis substantiated the fact that substantial changes would be required in parking rates (in the case of Washington, D.C., doubling and tripling of rates were implied) before major diversions in motor vehicle use would occur, e.g., in the range of 20 to 25 percent.

Data available for the Bay Area Rapid Transit System (BART) in San Francisco provided estimates of the reductions expected in motor vehicle use for 1975. These estimates indicated that, in four counties of Alameda, Contra Costa, San Francisco, and San Mateo, the number of trips diverted from motor vehicles to BART by 1975 would reduce the VMT per day by 2.1 percent. In specific important line-haul corridors where transit is more competitive, the diversion factors (for example, San Francisco Bay Bridge) were as high as 8.1 percent, but in general the estimates ranged well below 10 percent when all corridors were taken into account.

Reconnaissance of the six cities substantiated the difficulty of implementing motor vehicle restraints. In fact, with only minor exceptions, the trend appeared to be toward considerable political resistance against any kind of motor vehicle restraint. This does not necessarily suggest that restraints may not come into effect or that, in time, they may not be accepted. However, within the framework of attempting to achieve emission standards by 1977, there appears to be considerable opposition to be overcome. For example, in San Francisco where a 25 percent parking tax has been in effect on commercial space, the study was informed that there had been little or no impact on motor vehicle use with the possible exception of some shift to on-street parking. There has been no change in transit ridership, and there is considerable pressure to remove or substantially reduce the parking tax from 25 to 10 percent. There is indication that such a reduction might be successfully implemented.

Again, in San Francisco, the use of car pool experiments suggested that it was going to be very difficult to achieve the limited goals of diversion of 3,000 vehicles per day to car pools, hardly an overwhelming support for motor vehicle restraints.

In New York City, restraint on motor vehicle use has been an important element in the city's policy for dealing with congestion, particularly in view of the long history of congestion. A number of vehicle ban proposals have been suggested; however, in general, they have been politically unacceptable. For example, efforts to develop the Madison Avenue Mall have been generally deterred, and it appears likely that only limited implementation of the mall will occur.

In Los Angeles, the need for regional controls in order to solve the pollution problem (as described in the interim report) indicated that reductions of 20 percent VMT would have to be undertaken throughout the area because reductions in the CBD alone would not be particularly helpful. The uniformity of the distribution of emissions and the difficulty of implementing them in the Los Angeles area (given the multiplicity of governments and the general importance of the automobile in the daily traffic movements) suggest extraordinary difficulty in implementing any kind of major restraint effort.

In Washington, D.C., it was proposed to provide an all-day parking tax of $1 a day to be implemented as part of the effort to reduce VMT. Estimates ranged from 8 to 16 percent reduction in trips; overall reductions were in the range of 4 percent. Major opposition resulted in postponement of the issue to 1973, and it appears very unlikely that even a small tax of a dollar a day (which would not, perhaps, result in more than a 4 to 5 percent reduction) will be passed, if at all, before 1974—too late to be of any significant value for the target year of 1977.

The Chicago plan indicated that no motor vehicle restraints were contemplated. Emphasis was placed on the automobile manufacturers providing the necessary reduction through changes in engine design or the use of control devices and improvements in traffic flow controls or both. Reconnaissance made it quite clear that there was opposition on the part of city government to any policy of motor vehicle restraint that, in any case, the city felt would not be necessary in Chicago if the automobile manufacturers were made to meet the standards set by EPA.

Finally, in Denver one study of the problem indicated that only small reductions may be expected from any kind of motor vehicle restraint program. Although four proposed parking garages were recently defeated by environmentalists, we were informed that actually all that changed was whether the parking facilities would be built under public control or private enterprise. The city administration is strongly in favor of the construction of the garages and would be opposed to any attempts to stop the private sector building the garages (assuming that it would be legally possible to stop such construction). The city is even more opposed to any kind of motor vehicle restraint; the administration has no present plans for motor vehicle controls and does not intend to implement any. We were further advised that the automobile is an important and basic element in the life of residents in the city of Denver, and no one anticipates any major restraints.

The reluctance and resistance to even limited use of motor vehicle restraints in any form was readily apparent in the implementation plans of the six cities. It is only in San Francisco and Los Angeles that any estimates are provided for reductions through motor vehicle restraints. In both cities, a 20 percent reduction is provided; however, these are values estimated by the state, and there is no evidence provided that such reductions could be achieved. Furthermore, there is no plan provided as to how such reductions could be achieved or whether it is realistic. For example, the San Francisco plan notes that, through public transportation, car pooling, and changes in working schedules, it is hoped that emissions will be reduced. It is pointed out, however, that "the level of achievement of these measures cannot be closely estimated. The goal, which is set on the optimistic side, is to reduce traffic by 20 percent" (1). Nothing is indicated as to how this 20 percent would be realized or the basis on which it is estimated. In the Los Angeles plan, the same 20 percent is used, and, in fact, the language used to describe the plan is exactly the same as that used for San Francisco with no further evidence.

For the other cities reviewed, the possibilities were unspecified with the exception of Washington, D.C., where a number of limited parking facility proposals are provided (including a ban on on-street parking, sharp increases in commercial parking lot fees, and other potential control devices). In all cities, there is considerable reluctance to indicate any form of motor vehicle restraint or to specifically identify the way in which reductions would be achieved.

In view of the reconnaissance experience—the review of implementation plans, the findings of the interim report, and other evidence reviewed—the following conclusions emerged:

1. It would appear at the present time that it is not politically feasible to achieve any major program of motor vehicle restraint in any of the six cities under review. Though minor programs could emerge in the way of price increases for parking, no significant impact is likely to have any major effect by 1975 and only slightly more by 1977. This is likely to be true for other large cities as well.
2. The only possibility that might negate this conclusion appears to be if it is conclusively demonstrated that there is a serious health hazard effect associated with emissions. At the present time, that does not seem to be a likely prospect, at least by 1975-77.
3. The conclusion of 5 to 20 percent air pollution reduction indicated in the interim report, though within the realm of possibility, must be considered to represent broad ranges. For the six cities in the study at least, based on an evaluation of opinion in those cities, 20 percent appears to be in the very upper limits of what is realistically feasible and seems to be a very unlikely possibility for any of the six cities.
4. A strategy of motor vehicle restraint will have to be accompanied by very substantial improvements in transit involving fairly substantial sums of investment from the federal government.
5. The most feasible restraint appears to be some form of pricing policy—perhaps increases in parking costs or possibly toll roads or some other forms of road pricing. These appear more feasible because of the somewhat more subtle characteristics of the impact, which might reduce public opposition to the motor vehicle restraint. Major vehicle bans and frontal assaults of a similar nature are likely to encounter fierce opposition.
6. For the range of possibilities, all assumptions about reductions of VMT must be considered optimistic in the light of a target for 1977. For purposes of testing a motor vehicle restraint strategy, the range of reductions in VMT anticipated from motor vehicle restraints in the six cities was optimistic (5 percent), moderately optimistic (10 percent), and very optimistic (15 percent). Thus, after careful consideration of all of the evidence and recognizing that a considerable amount of judgment is involved, it was considered that none of the six cities is likely to achieve even a 15 percent reduction in VMT by 1977.

Work Schedule Changes

Recent experience with work schedule changes in the United States and abroad suggests that these measures are feasible. Two measures for changing work schedules were considered: work staggering and the 4-day workweek. Work staggering involves making small systematic shifts in work hours of employees so that currently underutilized travel times to the CBD are more adequately used. Conceivably, this could result in decreased peak-hour congestion, higher average vehicle speeds, and reduced emissions. The 4-day workweek has the same potential effect. Because the workweek is shortened, each workday will be lengthened and thus "out of phase" with traditional peak hours (at least at one of the peaks).

Of the two measures, the 4-day workweek goes further toward reducing motor vehicle emissions than staggered hours because its effect is twofold, both reducing the total number of commuting trips by 20 percent and shifting workers away from peak-hour travel. If this measure were introduced, and working days were spread over a 6-day period, daily VMT for the journey to work could be reduced by as much as one-third. Assuming 30 percent of motor VMT is accounted for by the journey to work, and 25 percent of the labor force would be on a 4-day workweek by 1977, a maximum reduction of 2.5 percent in daily VMT could be achieved [(0.33) (0.30) (0.25) = 2.5 percent]. All of these assumptions, however, appear highly optimistic. Moreover, increased leisure would undoubtedly result in additional

VMT for recreational and other trips (although these are likely to be at off-peak periods and in relatively less polluted areas).

The profound social and economic implications of a large-scale shift to the 4-day workweek suggest that this measure should be considered from a broader perspective than congestion relief or air pollution control alone. Such an examination of the 4-day workweek, though beyond the scope of this study, was considered a priority area for further research.

OVERALL CONCLUSIONS

Based on the findings discussed in the previous sections, a number of conclusions were reached. Because of the range of judgments involved and the complexity of the subject, it must be recognized that such conclusions are at best tentative. However, they are significant in assessing emission reduction timetables and strategies.

1. In most of the metropolitan areas in the study, overall emission reductions of at least 50 percent from existing levels appear required to meet the national ambient air standards for carbon monoxide for 1975-77. These required reductions are substantially higher in some central city areas (e.g., 80 percent in midtown Manhattan).
2. Measured against this scale, most transportation controls that are capable of being introduced in the next few years offer the potential for only modest reductions (Table 4).
3. Even those controls that are easiest to implement will take several years to develop and put into effect. All controls will entail very substantial implementation costs (although in some cases, such as an increase in parking rates, these costs can be recouped from revenues), will involve complicated impacts, and will generate considerable opposition from motor vehicle users.
4. The legal authority to effect transportation controls for reduction of air pollution cannot be quickly established in most states. With the exception of some traffic flow improvements, there is essentially little or no experience with the use of the transportation controls required to achieve the air quality standards.
5. In the absence of more empirical data and computer simulations, estimates for potential reductions must be considered approximations. One difficulty is that some of the transportation controls (notably motor vehicle restraints) could have additive effects by reducing VMT and, thereby, improving traffic speeds. Even if emission-speed relations were known with confidence, additive effects of motor vehicle restraints would result in substantially greater emission reductions than those estimated in our findings.
6. Some of the transportation controls tend to generate additional new traffic (e.g., improved speeds from traffic flow control) and may be counterproductive to achieving and maintaining the air quality standards.
7. Because of the counterproductive character and limited effectiveness of most of the transport controls and the "additive" effects of motor vehicle restraints, such restraints are not likely to be required in many major metropolitan areas (such as the six under study) to reach and maintain national ambient air standards for carbon monoxide by 1975. In addition, motor vehicle restraints would have to be accompanied by important improvements in public transport if serious social and economic repercussions are to be avoided.
8. Assuming substantially improved public transport, the implementation of some forms of motor vehicle restraints would appear technically feasible within 5 years. However, the basic question these measures raise is the extent to which it is politically possible to deprive people of some of the convenience of their cars in return for cleaner air. Changes in the prevailing travel pattern—commutation by private passenger car—and the provision of public transport cannot be brought about overnight. The automobile is intricately related to almost all aspects of community life; the social and economic consequences of changing these established relations are likely to be profound.
9. In the light of all these factors, it would appear that, when motor vehicle restraints are to be recommended, they should be made part of a comprehensive effort and that they should be considered as more than short-term measures for air pollution control. Motor vehicle restraints may be warranted over a longer term and on other grounds (e.g., reducing noise and relieving congestion) than air pollution control.

TESTING OF THREE STRATEGIES: PRELIMINARY RESULTS

In the second phase of the work, three specific strategies (inspection, maintenance, and retrofit; traffic flow control; and motor vehicle-public transport improvements) were tested for their emission reduction impact using urban transportation demand models that provided (by fine-grained zones) data on VMT and speed. These two key inputs of VMT and speed were transferred to a grid system (of 1 mile or 1 kilometer square), and VMT speed data were converted to vehicle emissions based on available information on speed-emission relation in combination with the Hanna-Gifford diffusion model (11).

The resulting concentrations are shown as isopleths on a map of the metropolitan area (the pollutants considered were carbon monoxide, hydrocarbons, and oxides of nitrogen—with carbon monoxide being of primary interest). Concentrations (and isopleth maps) are calculated for the 1- and 8-hour periods of maximum VMT (therefore emissions) for a base year projected to 1977 under both uncontrolled (no transport control strategy) and controlled conditions for the three transportation control strategies in each of the six cities in the study. Examples of the isopleth maps (for the 1-hour maximum for carbon monoxide) are shown in Figures 3 and 4.

In connection with this approach, it must be noted that, because of variation in the transportation demand nodels used (as among the six cities), the detail data base developed by each city for its transportation model, the number of zones used for the analysis, and the reliability of the original statistical base (e.g., origin-destination study, traffic counts, etc.) for any one city, it is not possible to make comparisons among the cities. The approach does, however, provide a means for evaluating for each city the range of impacts that might be anticipated from the respective control strategies tested.

Because of the voluminous nature of the outputs of this phase of the work, and the fact that the final report is still under review by EPA, a complete summary of findings and conclusions cannot be presented. However, a summary of results for Washington, D.C., is presented as an indication of some of the outputs generated by the model.

The diffusion model and transport data were applied to the Washington, D.C., metropolitan area for four meteorological conditions: summer wind at 5.5 m/sec, winter wind at 6.6 m/sec, nominal (typical) wind at 5.0 m/sec, and worst case wind at 2.5 m/sec. The three transportation conditions were current conditions (as close to conditions as transportation data allow for Washington, D.C., 1968), projected conditions for 1977 (assuming no transportation restrictions beyond internal automotive emission controls), and projected conditions for 1977 (with estimations of the effects of various transportation controls). Figure 5 shows the grid system of Washington, D.C., utilized in the model. Figures 6, 7, and 8 show the worst wind condition for the three strategies tested for carbon monoxide. Specifically, the following strategies are shown in the isopleth maps for the 1- and 8-hour periods of maximum emissions:

1. Strategy 1B, inspection and maintenance—A 10 percent reduction in CO emissions was applied as the most likely impact of this strategy (Fig. 6).
2. Strategy 2, traffic flow control—Average speeds within each of the speed rings in the original data were increased to indicate the impact of this strategy (Fig. 7).
3. Strategy 3, combined strategies—The impact of strategies 1B and 2 were combined with a VMT reduction due to vehicle restraints to produce the most optimistic pattern of emission reductions (Fig. 8).

Table 5 gives the maximum emissions and maximum concentrations predicted for carbon monoxide, hydrocarbons, and nitrogen oxides for each of the applied control strategies and the uncontrolled cases. The maximum concentrations predicted are given for the worst case (defined by a wind speed of 2.5 m/sec).

Carbon Monoxide

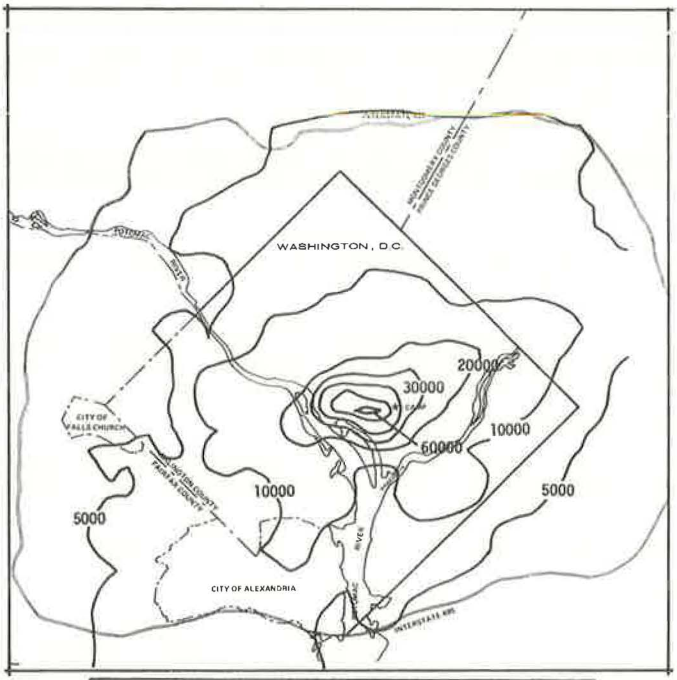
The maximum concentration for all cases occurs near the center of Washington, D.C., in the immediate vicinity of the area of greatest traffic density (Fig. 9). Because there were no major stationary sources of CO in the immediate vicinity of this maximum con-

Table 4. Impact of transportation controls on travel patterns and motor vehicle emissions (carbon monoxide from light-duty vehicles).

Transportation Control Candidates	Impact on Travel Patterns	Impact on Motor Vehicle Emissions
Short Term (2 to 5 years)		
Inspection, maintenance, and retrofit	No changes in modal mix, trip generation, or origin-destination patterns.	Ten to 25 percent. Upper range (particularly 20 to 25 percent) decidedly less likely than lower range (particularly 10 percent).
Gaseous fuel systems	No changes in modal mix, trip generation, or origin-destination patterns.	Less than 15 percent. Appropriate only for large, centrally maintained fleets that account for a relatively high proportion of total VMT (e.g., taxicabs in borough of Manhattan).
Traffic flow techniques	No changes in modal mix. Possible increase in trip generation as a result of improvements in traffic flow. No changes in origin-destination patterns, at least for the short term.	Less than 20 percent. However, emissions appear to decrease for only the year immediately following implementation, after which time emissions may increase above original levels due to growth in traffic volumes. To control traffic volumes, motor vehicle restraints would be required.
Bypassing through traffic	No changes in modal mix. Possible increase in trip generation as a result of improvements in traffic flow. No changes in origin-destination patterns, at least for the short term.	Less than 5 percent. Measures requiring new construction (e.g., circumferential routes) not implementable within 5 years. Modest bypassing may be possible through use of directive signs or signals or both. More substantial bypassing will require motor vehicle restraints.
Medium Term (5 to 10 years)		
Improvements in public transportation	Changes in modal mix by improvements in public transport, no change in trip generation or origin-destination patterns at least in the short term.	Less than 5 percent. Improvements in public transport are a necessary but not sufficient condition for reducing motor vehicle emissions. To have an appreciable effect on emissions public transport, improvements must be combined with motor vehicle restraints. Restraining or restricting motor vehicles, however, would require substantial public transport improvements to provide an alternate means of making trips.
Motor vehicle restraints	Changes in modal mix by improvements in public transport and motor vehicle restraints. Only minor changes in trip generation or origin-destination patterns at least in the short term.	Five to 25 percent. Potential emission reductions depend on the severity of restraints. Several motor vehicle restraints are administratively feasible. However, the mechanics of imposing motor vehicle restraints are much less of a problem than gaining public acceptance to limit "freedom of the road."
Long Term (10 to 20 years)		
Work schedule changes	Changes in modal mix, possible reduction in trip generation (particularly for the journey to work), and changes in origin-destination patterns due to additional recreational trips.	Less than 3 percent. Work trips would be reduced but increased leisure time would probably generate additional recreational trips (although these are likely to be primarily at off-peak periods to and from areas outside the central city).
Land use controls	Change in modal mix, change in origin-destination patterns, and change in trip generation.	Could not be implemented with any appreciable effect on emissions in the short term. Medium- and long-term effects not known.

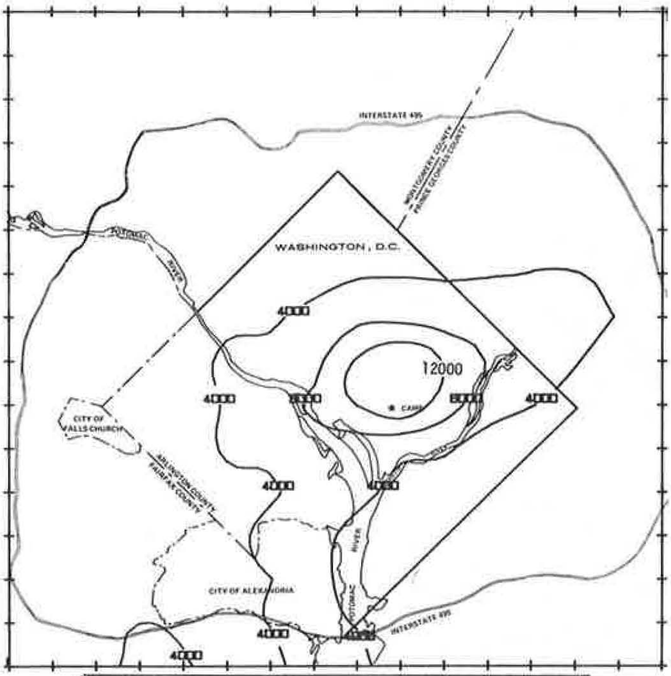
Note: A more complete explanation of the data in this table is given elsewhere (1).

Figure 3. Pollutant concentration, 1968.



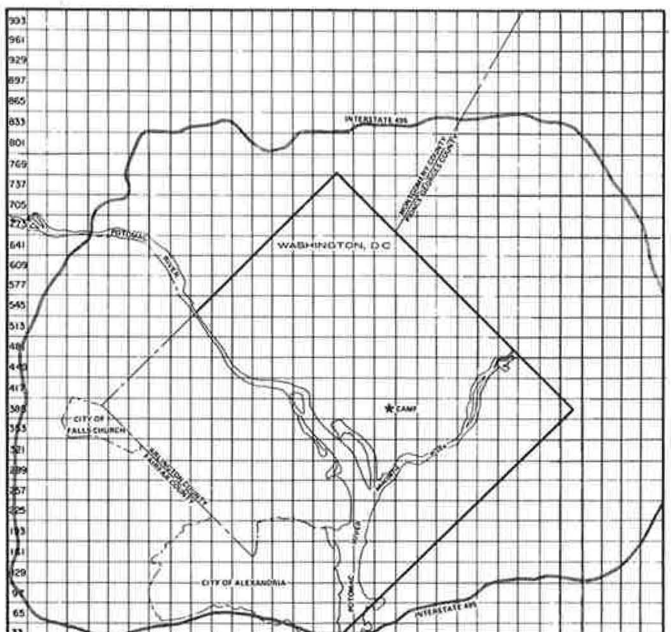
City Washington, D.C. Year 1968 Strategy Uncontrolled
Pollutant CO Case 4 Time Period 1 Hr. Total
Units $mg/m^3 x 10^3$ Federal Standard 40 mg/m^3

Figure 4. Pollutant concentration, 1977.



City Washington,D.C. Year 1977 Strategy Uncontrolled
Pollutant CO Case 4 Time Period 1 Hour Total
Units $mg/m^3 \times 10^3$ Federal Standard $40\ mg/m^3$

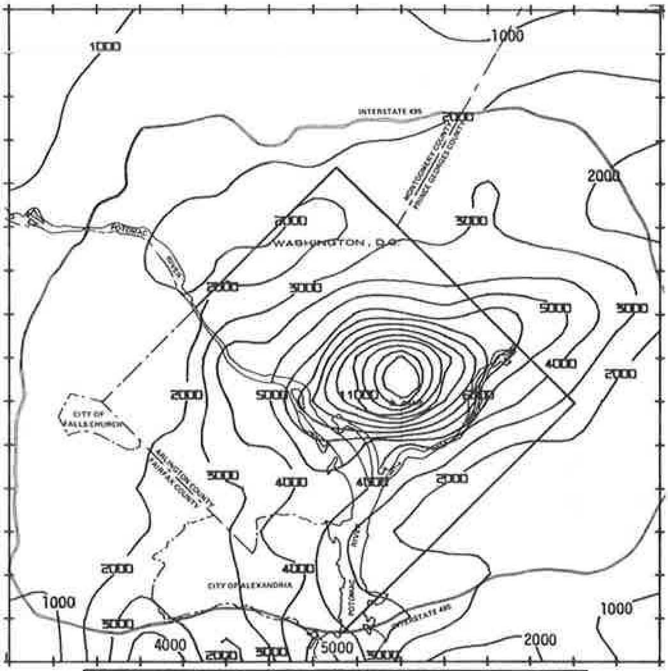
Figure 5. Washington, D.C., grid system.



Total Area = 1024 km^2

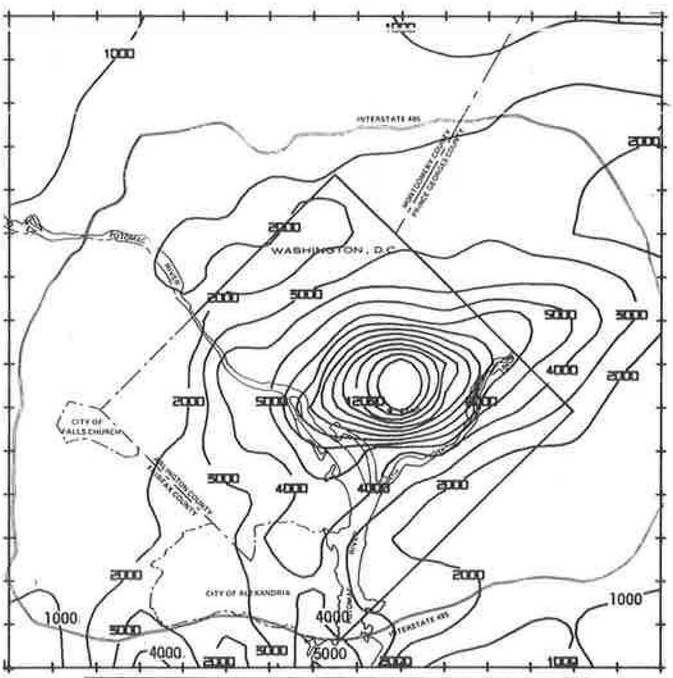
Individual Grid Area = 1 km^2

Figure 6. Strategy 1B.



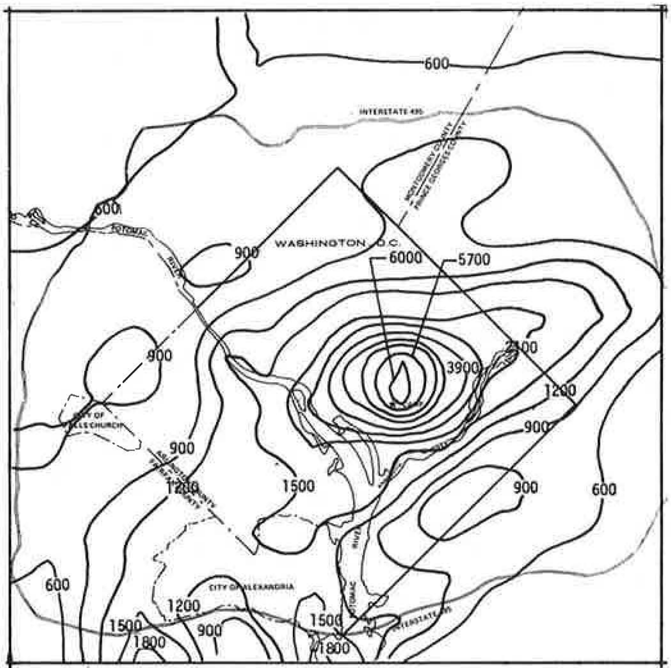
City Washington,D.C. Year 1977 Strategy 1B
Pollutant CO Case 4 Time Period 1 Hour Total
Units mg/m^{3}x10^3 Federal Standard 40 mg/m^3

Figure 7. Strategy 2.



City Washington,D.C. Year 1977 Strategy 2
Pollutant CO Case 4 Time Period 1 Hour Total
Units mg/m^{3}x10^3 Federal Standard 40 mg/m^3

Figure 8. Strategy 3.



City Washington,D.C. Year 1977 Strategy 3
Pollutant CO Case 4 Time Period 1 Hour Total
Units mg/m^{3}x10^3 Federal Standard 40 mg/m^3

Table 5. Maximum emissions and concentrations, Washington, D.C.

	Maximum Emissions (tons/year)		Maximum Concentrations (mg/m^3)	
Pollutant	Total	Mobile	8 Hours	1 Hour
Carbon monoxide				
1968	12,589	12,589	28.4	59.1
1977	4,513	4,513	10.6	22.1
Strategy 1A	3,384	3,384	7.9	16.6
Strategy 1B	4,061	4,061	9.5	19.9
Strategy 1C	4,287	4,287	10.1	21.0
Strategy 2	4,412	4,412	10.3	21.2
Strategy 3	3,687	3,667	8.4	17.2
Hydrocarbons				
1968	2,015	1,773	4.1	8.3
1977	1,862	490	2.9	3.1
Strategy 2	1,859	482	2.8	3.1
Strategy 3	1,854	428	2.8	3.0
Nitrogen oxides				
1968	6,022	439	7.2	7.5
1977	6,005	271	7.2	7.3
Strategy 3	6,001	241	7.2	7.3

centration area (as shown by the difference between the mobile and total emission), the maximum concentrations are a result of mobile source emissions only.

The 1977 predictions show the estimated effect of manufacturers' emission control devices alone on the maximum 8-hour and peak-hour concentrations. It indicates that the 1968 maximum concentrations would be reduced by nearly two-thirds without the application of any further transportation controls.

Strategy 1 illustrates the potential additional reductions in CO emissions by implementing an inspection and maintenance program for the Washington, D.C., region. This strategy would allow a reduction in CO emissions from 5 to 25 percent, with 10 percent (strategy 1B) being the most likely possibility. A 10 percent reduction in CO emissions would bring the 8-hour concentration maximum slightly below the federal standard of 10 mg/m^3.

Strategy 2, the traffic control strategy, would, in effect, increase the traffic speeds in the downtown area. This would, in turn, decrease the emissions and result in a 5 percent decrease in the 8-hour maximum concentration over and above the predicted 1977 concentrations. However, without additional traffic controls, this 5 percent decrease would probably disappear within 1 year because of induced traffic volume increases.

Finally, strategy 3 shows the effect of combining inspection and maintenance (10 percent CO reduction), traffic flow control, and vehicle restraints (10 percent reduction in VMT). The estimate assumes that the full benefit of all strategies would be achieved in 1977. The resulting maximum 8-hour concentration is approximately a 20 percent improvement over the predicted uncontrolled 1977 concentrations and would bring the 8-hour maximum concentration below the federal standard.

Hydrocarbons

The location of the maximum emissions and maximum concentrations for hydrocarbons (Table 5) are shown in Figure 10. It should be noted that peak-hour concentrations are given although federal standards are suggested only for a 3-hour (6 to 9 a.m.) average. Transportation data given did not allow estimation of concentrations for this specific time period; therefore, care must be taken in comparing predicted values with federal standards.

It can be seen by the difference between total and mobile source emissions for hydrocarbons (Table 5) that the maximum concentration values are greatly affected by stationary sources for which no transportation or other controls were considered. For the purpose of analyzing the effect of transportation controls, it may be more appropriate to consider the relative reduction in mobile source emissions rather than the reduction in predicted maximum concentrations. The 1977 uncontrolled mobile emissions are approximately 70 percent less than base-year emissions. Whether this reduction alone would be sufficient to bring actual air quality within the federal guidelines would be dependent on the impact and control of the major stationary sources. The traffic flow control strategy (strategy 2) would have very little effect, by itself, on mobile source emissions; however, by combining traffic flow control with vehicle restraints as given by strategy 3, an additional 12 percent reduction in mobile emissions might be achieved.

Oxides of Nitrogen

Figure 11 shows the location of the areas of predicted maximum concentrations for each transportation control condition for NO_x.

It can be seen from Table 5 that the predicted maximum concentrations are a result of emissions from large stationary sources included in the data base. Maximum concentrations resulting from the maximum mobile source emissions given in the table would be approximately 60 percent less, or about 3.0 mg/m^3 for the 8-hour maximum concentration. As in the case of hydrocarbons, for the purpose of analyzing the effect of transportation controls, it is more appropriate to consider the relative reduction in mobile source emissions rather than the relative reduction in predicted maximum concentrations, which are so grossly affected by stationary source emissions.

Figure 9. Locations of maximum concentration of carbon monoxide for conditions given in Table 5.

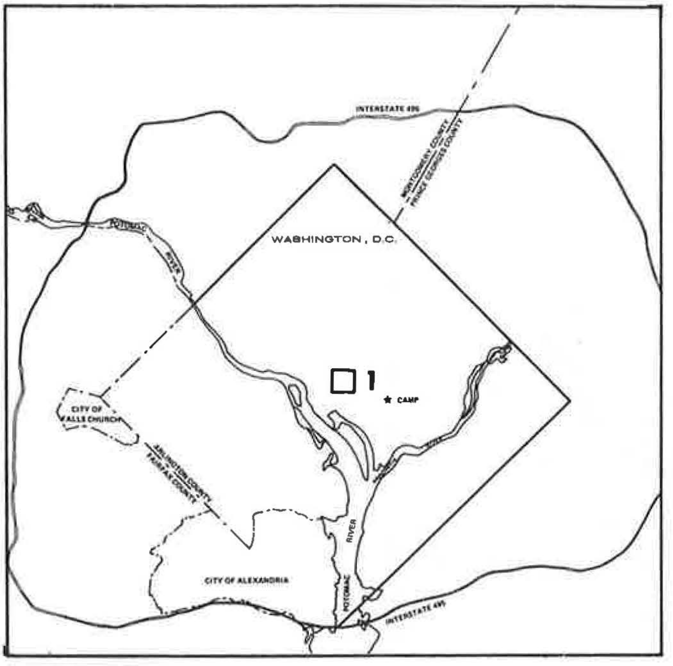


Figure 10. Locations of maximum concentration of hydrocarbons for conditions given in Table 5.

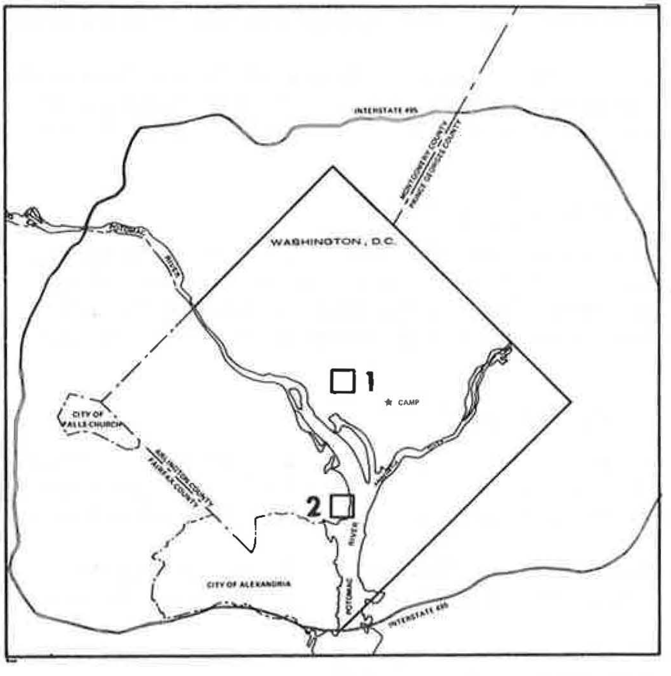
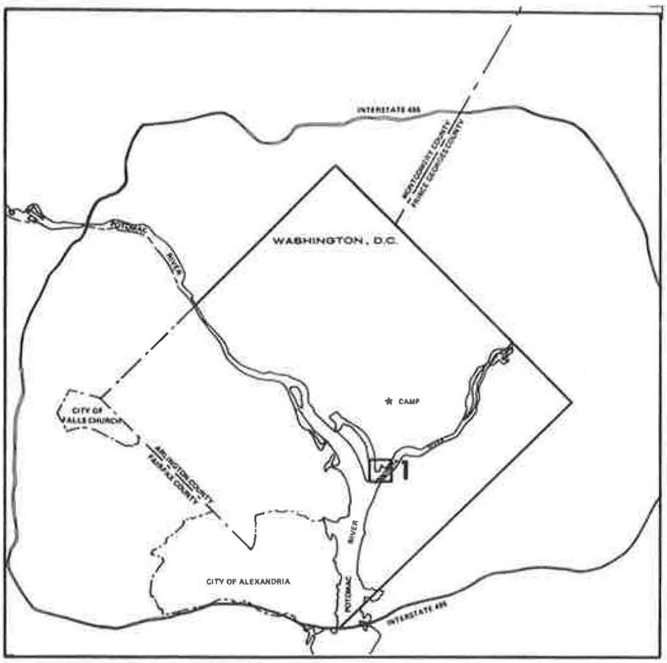


Figure 11. Locations of maximum concentrations of nitrogen oxides for conditions given in Table 5.



The 1977 uncontrolled mobile emissions are, at most, approximately 40 percent less than base-year mobile emissions, largely due to direct automotive emission controls. Whether this reduction alone would be sufficient to bring actual air quality within the federal guidelines would be dependent on the impact and control of the major stationary sources.

Strategy 3 (combined emission and traffic control strategies) is the only transportation control strategy with a direct impact on NO_x emissions. The approximately 10 percent additional reduction in mobile emissions is a result of reduced VMT due to vehicle restraints.

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