A GUIDE FOR REDUCING AUTOMOTIVE AIR POLLUTION

Prepared for the

OFFICE OF AIR PROGRAMS

ENVIRONMENTAL PROTECTION AGENCY

November 1971

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By

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PREFACE

This Guide is designed to aid transportation professionals and state air pollution control agencies in selecting transportation controls suggested in the regulations promulgated pursuant to the Clean Air Act of 1970[1]. Actions considered here emphasize the reduction of traffic volume and congestion, and can be implemented within five years. The impact of the suggested actions is not fully understood. Research is now underway on many aspects of the relationship of auto traffic to air pollution. As results become known, the list of suggested actions almost certainly will need revision.

Three other studies that will expand understanding in this area are funded by the Environmental Protection Agency (EPA) and will complement this Guide. One study discusses the legal, institutional, and administrative problems of implementing traffic controls in selected cities. Another covers the longer range air quality implications of transportation and land use planning strategies. In addition, EPA is preparing information on the effectiveness of motor vehicle inspection programs and of emission control devices for in-use vehicles.

The Guide outlines the laws and regulations that require assessment of the air pollution impact of transportation. It then discusses techniques for improving traffic flow, for reducing the concentration of pollution and for reducing auto traffic. The appendixes provide basic information on air pollution.

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CHAPTER 1

MANDATES FOR COPING WITH AIR POLLUTION

THE NEED FOR TRAFFIC CONTROLS

Increasing public opinion and legislation indicate that serious efforts to reduce the amount of air pollution caused by transportation are necessary. Although such reduction will be highly dependent on controlling emissions at their source, urban planning, transportation planning, and traffic engineering can significantly improve air quality. Such measures should complement a source control strategy for most effective emission reduction.

Measures that can be used include the improvement of traffic flow, the dispersal of motor vehicle traffic in time and space, the reduction of the overall amount of vehicular travel, and greater use of vehicles with low emission characteristics. The implementation of these measures requires coordination at all levels of government. Most of the traffic engineering measures suggested in this Guide would be under the control of a traffic engineer, who should work with appropriate air pollution control agencies. Transportation planning measures typically involve city, county, and regional agencies as well as state and Federal authorities.

FEDERAL LEGISLATION

A. National Environmental Policy Act of 1969

This act establishes a broad national policy directed toward improving the relationship between man and his environment, and creates the Council on Environmental Quality (CEQ). Section 102(2)(C) of the act is designed to ensure that the environmental effects of all major proposed Federal legislation, plans, and programs are properly considered. For any proposed action significantly affecting the environment, a detailed statement must be submitted analyzing the following points:

"(i) the environmental impact of the proposed action,

(ii) any adverse environmental effects which cannot be avoided should the proposal be implemented,

(iii) alternatives to the proposed action,

(iv) the relationship between local short-term uses of man's environment and the maintenance of long-term productivity, and

(v) any irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be implemented."

The Office of Management and Budget has established[2] a framework for communicating environmental information among Federal, state, and local agencies. This framework, originally intended to implement requirements for coordination set forth in other Federal legislation, was amended February 9, 1971, to include the coordination of environmental impact analyses. In this framework, selected state, regional, and local planning agencies are designated as "clearinghouses" to be notified by any state or local agency intending to submit an application for Federal financial assistance. The clearinghouse, in turn, notifies all potentially interested persons and groups within its jurisdiction of the planned project. The state or local agency requesting Federal aid may then obtain comments from these persons and groups on the environmental impact of its project; and these comments are included in the request to the Federal agency. If, after reviewing the comments, the Federal agency determines there will be a significant impact on the environment, it must submit an impact statement to CEQ. The impact statement, reflecting all the comments received through the clearinghouse process, becomes part of the public record.

B. 1970 Clean Air Act

This act calls for the establishment of primary (relating to health) and secondary (relating to welfare) ambient air quality standards by the Administrator of the EPA. The Administrator is also required to set standards of performance for new stationary sources of pollution and for motor vehicles. The act requires states to prepare plans by January 30, 1972 for achieving and maintaining the air quality standards within 3 years. The act authorizes the Administrator to act if the states do not, and gives him powers of enforcement.

The Senate Committee on Public Works, in hearings on the National Air Quality Standards Act of 1970 (subsequently replaced by the Clean Air Act Amendments of 1970) reported:[3]

> "Transportation policies must be developed or improved to assure that the impact of pollution from existing moving sources is reduced to the minimum compatible with the needs of each region. Construction of urban highways and freeways may be required to take second place to rapid and mass transit and other public transportation systems. Central city use of motor vehicles may have to be restricted."

C. Regulations Promulgated Pursuant to Clean Air Act

The EPA set out requirements by which the states should prepare, adopt, and submit implementation plans for air quality standard achievement.[1] The requirements define a "control strategy" by which a combination of measures are designated to achieve the aggregate reduction of emission necessary to achieve and maintain a national standard. The measures might include:

1. Emission limitations.
2. Federal or state emission charges or taxes, or other economic incentives or disincentives.
3. Closing or relocation of residential, commercial, or industrial facilities.
4. Changes in schedules or methods of operating commercial or industrial facilities or transportation systems. These would include any short-term changes made in accordance with standby plans.

5. Periodic inspection and testing of motor vehicle emission control systems.
6. Emission control measures applicable to in-use motor vehicles, including mandatory maintenance, installation of control devices, and conversion to gaseous fuels.
7. Measures to reduce motor vehicle traffic, such as commuter taxes, fuel rationing, parking restrictions or staggered working hours.
8. Expanded use of mass transportation through measures such as increased frequency, convenience, or capacity, or by providing special bus lanes on streets and highways.
9. Any other land use or transportation control measures.
10. Any other variation of, or alternative to, the above measures.

D. 1970 Federal-Aid Highway Act

This act requires the Secretary of the Department of Transportation (DOT) to promulgate guidelines by October, 1972 designed to ensure that new highways will be consistent with a state's air quality implementation plan. These guidelines will enable planners to predict and to minimize the air quality impact of a proposed roadway. Highways should be designed, located, and operated so as not to hinder the achievement of air quality standards. The act also allows highway trust funds to be used for construction of preferential bus lanes, bus passenger loading areas, and fringe transportation corridor parking facilities. Detailed information on the act is available from the state representative of the Federal Highway Administration.

E. Urban Mass Transportation Assistance Act of 1970

This act amends the Urban Mass Transportation Act of 1964, placing grant and loan applications under the "A-95" review process.[2] In addition it requires that the applicant afford adequate opportunity for public hearings for all parties interested in the economic, social, and environmental impact; and must hold the hearings unless no one with significant economic, social, and environmental interest has requested such hearings. If hearings are held, the Secretary of DOT is required to ascertain that they were adequate and that all harmful environmental impacts have been minimized. Detailed information on the act is available from the Administrator, Urban Mass Transportation Administration, Washington, D. C., 20590.

STATE LEGISLATION

Most state laws that relate to the measures described in this Guide concern inspection systems and the reduction of emissions from individual motor vehicles. Arizona, California, Colorado, Delaware, Florida, Kansas, Louisiana, New Jersey, New Mexico, New York, North Carolina, Texas, and Vermont require annual inspection and approval of motor vehicle emission control systems. Nine additional states have the legal authority necessary to conduct inspections. Twenty-two states require that control equipment required by Federal law be maintained and not removed, but only half of these are among those states which actually inspect annually.

New Jersey is now preparing to require all cars registered in the state to be tested annually for carbon monoxide and hydrocarbon emissions. Cars violating the standards will be barred from the roads after 2 weeks of grace in which to make required repairs. New Jersey's Department of Environmental Protection estimates that in the first year of operation, the inspection system will reduce carbon monoxide emissions by 20 percent and hydrocarbon emissions by 32 percent.

When inspection systems are included as part of a state's implementation plan, EPA will review the pollution-reduction effectiveness of such systems.

CHAPTER 2

SUMMARY AND CONCLUSIONS

The major points to be summarized from this Guide are:

1. Air pollution caused by automotive emissions is a serious problem.
2. Corrective action must be taken.
3. Much improvement can be achieved through traffic operation and transportation planning measures.

These measures, which supplement the efforts of government and industry to reduce automotive emissions at the source, encompass the following means of reducing harmful exposure to air pollutants:

1. Smoothing the flow of traffic.
2. Reducing concentrations of traffic, both geographically and by time of day.
3. Reducing the total amount of travel.

The Guide lists and discusses a number of techniques. All have been previously used, or at least proposed in the context of improving the capacity and quality of urban transportation systems. Not all of the techniques will apply to every city, but some should. Their aggregate impact will increase the likelihood of improving air quality standards.

Table 2.1 lists the techniques with which this Guide is concerned. While it is impossible to place a precise measure of effectiveness on each technique, there is sufficient knowledge to assign an approximate value. This, shown on the table as "Probable Effectiveness," uses a scale of 1 (least effective) through 5 (most effective). The effectiveness of most techniques in reducing air pollution varies from one city to another for such reasons as the extent to which the technique is already in use, the adequacy of the area's transportation system, or the micro-climate of the area. The difficulty of implementing specific techniques depends on such factors as:

1. The existence of necessary legislation.
2. The willingness of state legislatures to pass new legislation.
3. The ability of the appropriate government agencies to administer transportation controls within the existing institutional framework.
4. The existence of alternative transportation modes.
5. The costs of implementation.
6. The strong support of the public.

Although some measures must be applied on a state or even national scale, some techniques may be most appropriately applied during severe pollution episodes.

TABLE 2.1

TECHNIQUES FOR IMPROVING TRAFFIC FLOW, FOR REDUCING POLLUTION CONCENTRATION, AND FOR REDUCING AUTO TRAFFIC

Techniques for Improving Traffic Flow	Probable Effectiveness[a]
A. Freeways	
1. Reverse-lane operations	3
2. Driver advisory displays	1
3. Ramp control	2
4. Interchange design	2
B. Arterials	
1. Alinement	1
2. Widening intersections	3
3. Parking restrictions	2
4. Signal progression	2
5. Reversible lanes	3
6. Reversible one-way streets	3
7. Helicopter reports	2
C. Downtown Distribution	
1. Traffic responsive control	5
2. One-way street operations	3
3. Loading regulations	3
4. Pedestrian control	1
5. Traffic Operations Program to Increase Capacity and Safety (TOPICS)	5
Techniques for Reducing Pollution Concentration	
A. Staggered Work Hours	3
B. Roadway Concentrations	2
C. Cross-sections	2
D. Elevated, At-grade, Depressed Roadways	2
Techniques for Reducing Auto Traffic	
A. Transit Operations	
1. Bus lanes on city streets	1
2. Bus lanes on freeways	1
3. One-way streets with two-way buses	1
4. Park-ride, kiss-ride	3
5. Service improvements and cost reductions	2
B. Regulation	
1. Parking bans	4
2. Auto-free zones	4
3. Gasoline rationing	5
4. Idling restrictions	2
5. Four-day, forty-hour week	2
C. Pricing Policy	
1. Parking policy	2
2. Road-user tax	5
3. Gasoline tax	5
4. Car pool incentives	2
D. Planned Unit Development	2

[a] Based on traffic volume affected, pollution reduction, population exposure, and any adverse pollution impact (e.g., more or longer trips likely to be induced, or likely to cause traffic congestion). Higher numbers indicate greater levels of effectiveness.

CHAPTER 3

AIR POLLUTION REDUCTION THROUGH TRAFFIC CONTROL

An understanding of the basic relationships between air pollution and transportation operating variables will indicate how traffic control can be used to reduce pollutants. In this chapter, these relationships are set forth, the implications are evaluated, and techniques are suggested for the effective control of traffic.

BASIC RELATIONSHIPS

In simplified terms, the emission of the principal pollutants related to urban vehicles -- carbon monoxide and hydrocarbons -- increases as average speed decreases, and decreases as average speed increases. There is some evidence that the reverse is true for oxides of nitrogen (i.e., that NO_x emissions increase slightly as traffic speeds increase), but this relationship has not yet been satisfactorily quantified. Table 3.1, based on a 1967 British report,[4] indicates a relationship between vehicle operation and the level of pollutant emissions. These emissions are from uncontrolled autos; it should be expected that today's emission rates from controlled vehicles are lower.

Table 3.1. TYPICAL LEVELS OF CONCENTRATION OF POLLUTANTS IN EXHAUST GASES

Pollutant	Idling	Accelerating	Cruising	Decelerating
Carbon monoxide, % by volume	7.0	3.0	4.0	3.0
Hydrocarbons, ppm	820	700	500	4,400
Oxides of nitrogen, ppm	30	1,050	650	20

The same report considered the relative rates at which successive sections of a length of roadway are polluted by carbon monoxide. The case chosen for study was that of three cars stopping at traffic signals, idling, accelerating to 30 mph, running at that speed, decelerating for a stop at a traffic light 800 feet away, and repeating the cycle. The result is illustrated in Figure 3.1 which shows the highly localized peak just before the traffic lights due to idling levels of carbon monoxide from stationary vehicles. The

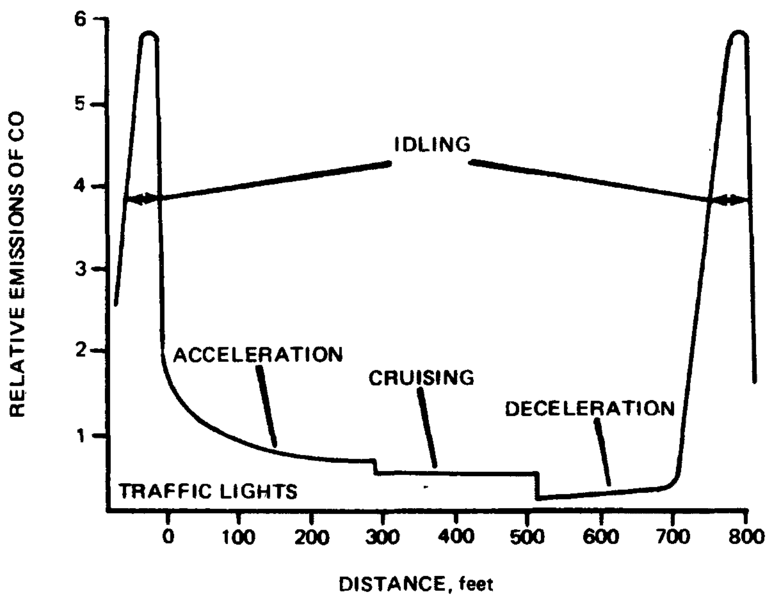


Figure 3.1. Relative emission of carbon monoxide during operating cycle between stops.[4]

subsequent acceleration of the vehicles results in an immediate reduction in local carbon monoxide pollution because, although the rate at which exhaust gas is emitted is higher than when the engine is idling, the time the vehicle spends in each successive unit of roadway diminishes as the vehicle gathers speed. When the car attains a uniform speed of 30 mph, there is a reduction in power requirement and pollution; a further reduction in carbon monoxide emission occurs when the vehicle begins to decelerate because the throttle is still further closed.

The relative emissions of carbon monoxide while idling are more than six times the cruising rate; however, exhaust concentrations of carbon monoxide while idling are less than twice concentration while cruising. This is merely a reflection of the fact that when idling, a much longer time period is spent per unit of roadway.

Another study[5, 6] indicates a direct correlation between increased average vehicle speeds and decreased emissions of carbon monoxide and hydrocarbons. See Table 3.2 and Figure 3.2.

Table 3.2. EMISSION FACTORS[a] FOR GASOLINE POWERED MOTOR VEHICLES

Emissions	1960	1965	1970	1972	1974	1975
Carbon Monoxide	120	120	95	85	75	60
Hydrocarbons						
Evaporation	2.7	2.7	2.7	2.3	1.8	1.4
Crankcase	4.1	2.7	0.9	0.45	0.22	0.22
Exhausts	16	16	12	9.5	7.2	6
Nitrogen Oxides (NO_2)	8	8.5	9	9	7.5	7

[a] Grams per vehicle mile at 25 mph.

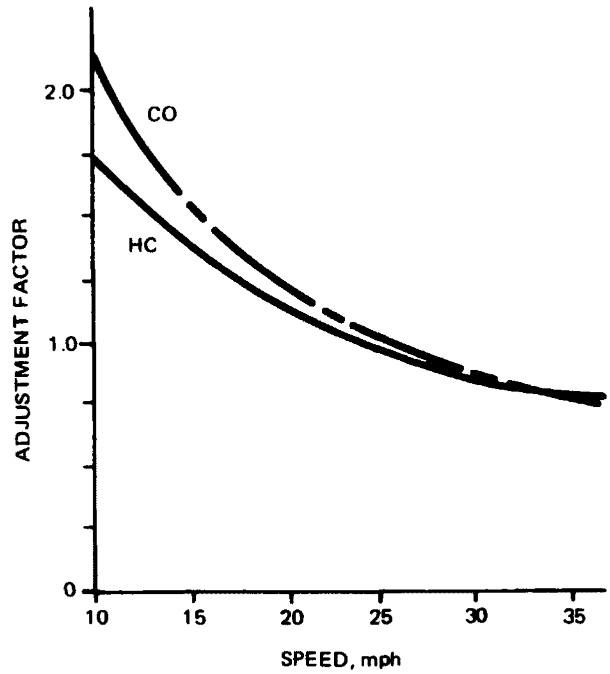


Figure 3.2. Speed adjustment factors for carbon monoxide and hydrocarbons.[5,6]

The emission and speed adjustment factors of Figure 3.2 are for passenger cars, light-duty trucks, and gasoline-powered heavy-duty vehicles, in proportion to their use. Allowance is made for deterioration and scrapping of vehicles as they age, and their replacement by new vehicles. The emission factors of Table 3.2 are for urban driving conditions with an average speed of 25 mph, beginning from a cold start. To determine carbon monoxide and hydrocarbon emission factors for average speeds other than 25 mph, use Figure 3.2. For example, Table 3.2 shows that the emission factor for hydrocarbon exhaust emissions in 1970 was 12 (at 25 mph). To determine the same factor at an average speed of

10 mph, refer to Figure 3.2, which shows a hydrocarbon adjustment factor of 1.79 (approximately) for that speed. Multiplying the emission factor of 12 by the 1.79 adjustment factor gives 21.4 as the emission factor at 10 mph.

CAUTION

The reader is cautioned that Figure 3.2 is based on average speed, not on constant or cruise speed where acceleration and deceleration are not involved. Increasing cruise speed much above 30 mph may increase carbon monoxide and hydrocarbon emissions per vehicle mile. Thus, the traffic engineering recommendations contained in this Guide should not be construed as recommendations for additional urban freeways.

If the objective is to minimize the concentration of carbon monoxide and hydrocarbons, any measure would be beneficial which would smooth the flow of traffic by reducing rapid acceleration and deceleration of vehicles. Some techniques for accomplishing this are described below. The reader should clearly understand, however, that easing congestion may have ancillary effects that would tend to undermime the goal of cleaner air. The relationship between increased travel speed and increased trip length has been well established.[7] Furthermore, a reduction in congestion may tend to induce more people to drive. If steps are not taken to reduce auto travel, the net result of improved traffic flow might be more, longer, and more dispersed trips with greater amounts of pollutants spread over a wider area. Thus, it is strongly recommended that other measures set forth below be used concomitantly with improved traffic flow techniques to reduce the overall number and length of automobile trips in urban areas.

A. Freeways

Freeways have been the subject of numerous operational studies and experiments. As a result, the techniques for improving traffic flow on freeways are relatively well developed.

1. Reverse Lane Operations -- Under this type of operation, one or more lanes are designated for movement in one direction during part of the day and in the opposite direction during another part of the day.

Current examples of the use of this technique include Arlington (Virginia), Detroit, Cleveland, Los Angeles, Boston, and Chicago. To illustrate the effect of reverse-lane operations, assume that Figure 3.3 represents the relationship between average speed and volume per lane for a freeway operating under ideal conditions.

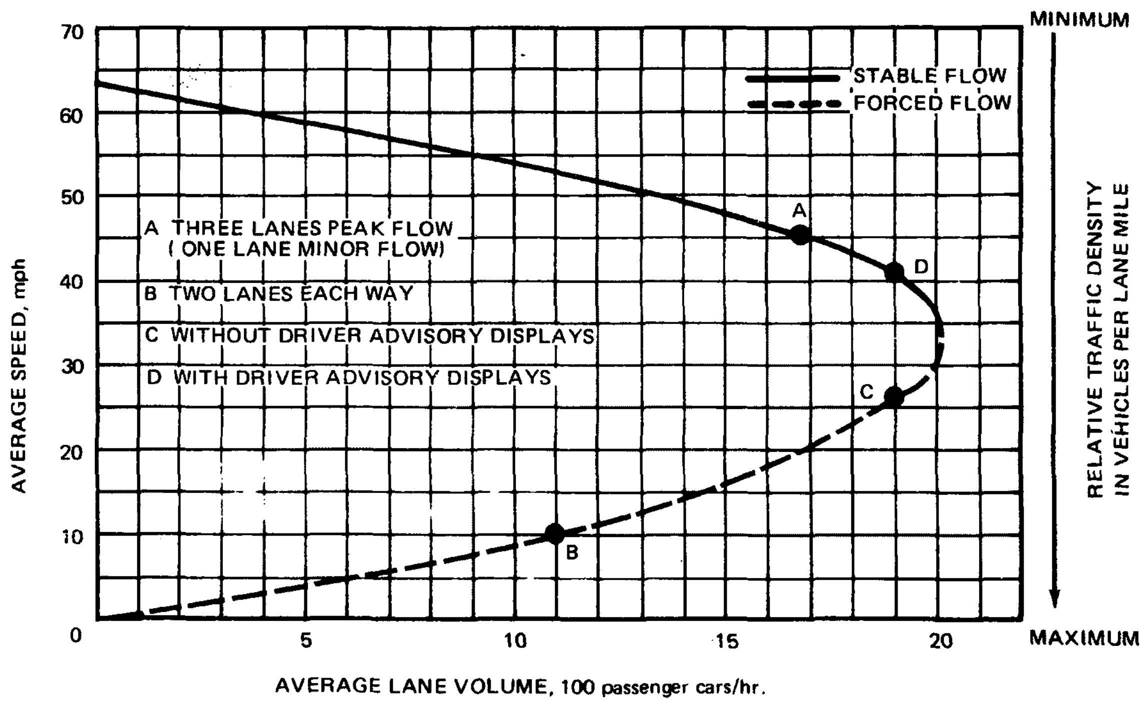


Figure 3.3. Typical speed/volume curve under ideal uninterrupted flow conditions on freeways and expressways.[8]

In Figure 3.3 speed is not a function of volume; speed and volume are both functions of vehicle density. Movement along the curve from the upper left to the lower left represents constantly increasing vehicle density on the freeway. The upper portion of the curve shows the relationship between volume and speed up to a critical vehicle density. Beyond this point, a further increase in density causes the speed to decrease rapidly, with a simultaneous decrease in the average lane volume or rate of flow.

Assuming that in one direction there is a demand for 5,000 trips per hour during the peak period on a four-lane (two lanes each way) freeway, the capacity of the facility will be exceeded and it may well be operating at point B -- 10 miles per hour with extremely forced flow and long queues of vehicles. If, however, it is feasible to allow the facility to operate with three lanes in the peak direction and one lane in the minor flow direction, operation could be at point A -- 1,667 vehicles per hour per lane, 45 miles per hour, with relatively smooth flow.

This increased average speed in the major direction of flow could mean substantial reductions in carbon monoxide and hydrocarbon emissions during the peak period, even if free flow was no longer achieved in the reverse direction.

2. Driver Advisory Displays -- When an expressway is closely paralleled by one or more arterial streets which serve as alternative routes, the use of driver advisory displays can improve the level of traffic flow. The objective is relatively simple -- to advise motorists of the traffic conditions on a freeway, thereby encouraging the use of alternative routes when the freeway is congested. The technique has been used in conjunction with ramp control measures on Chicago's Eisenhower Expressway.

To be operational, driver advisory displays must be placed well in advance of the arterial which serves as an alternative to the expressway. Each sign shows traffic conditions by means of color-coded arrows which are automatically controlled from continuous expressway and ramp traffic measurements.

It is difficult to predict the consequences of driver advisory displays since their only use to date has been in conjunction with ramp metering. It is reasonable to assume that motorists will not be diverted from the freeway unless it is congested. Even though driver advisory displays probably will not divert sufficient traffic to permit the average peak-hour speed to approach the design speed of the freeway, the displays could mean the difference between operating at point C or point D in Figure 3.3. Although both points represent the same lane volume, D is in the stable part of the curve at 42 miles per hour, while C is in the forced flow region at 26 miles per hour. Emissions of carbon monoxide and hydrocarbons would therefore be significantly reduced at point D.

For such an approach to improve the ambient air quality, the arterial alternative to the freeway must have sufficient excess capacity to carry diverted traffic at a high level of service; i.e., with little congestion.

3. Ramp Control -- To improve the operating conditions on congested freeways, ramp control (frequently called ramp metering) is a technique that is increasing in usage. Ramp control measures are presently utilized in several locations, including Chicago's Eisenhower Expressway, the John Lodge Freeway in Detroit, the Gulf Freeway in Houston, and the Harbor Freeway in Los Angeles. The technique consists of monitoring freeway traffic volumes and, by some form of traffic control (e.g., a signal) regulating the number of vehicles that can enter the freeway via its ramp system. When freeway volumes approach practical capacity, the number of vehicles permitted to use entry ramps is limited. The technique has been effective. From the point of view of reducing air pollution, it should be noted that resultant traffic delays at ramps raise emissions there; but, for the freeway as a whole, the amount of congestion and resultant pollution are lowered. One advantage over the previous method described is that ramp control is enforceable and not merely advisory.

A study of the Eisenhower Expressway and the adjacent street system failed to disclose any deterioration of surface street traffic operations attributable to the ramp controls except at the entrance-ramp/arterial-street terminals where queues interfered with traffic movements.

Apparently the variety of trip origins and destinations permitted several alternative routes to absorb diverted traffic. In addition, it is suspected that many diverted expressway trips are short in length, thereby allowing the freeway to perform at a higher level for longer trips.

Similar findings were reported for the Harbor Freeway in Los Angeles, where the effect of the added load on streets was too small to measure.

4. Interchange Design -- In most urban areas, the critical determinants of the level of service on freeways are the characteristics of interchanges and weaving sections, because the capacity of a freeway lane is much less when merging or weaving occurs than it is under uninterrupted flow conditions. Certainly, the air quality impact should be a consideration of the highway engineer when deciding on the design of new facilities, especially at interchanges.

B. Arterials

Arterials are the backbone of most urban street systems. Although these systems are commonly obsolete for modern traffic demands, much can be done to improve their effectiveness.

1. Alinement -- Due to the increased emission rate when vehicles accelerate or decelerate, the best highway design from an air quality standpoint is one in which the motorist can travel at a constant speed. Horizontal alinement should be free from small radius curves, which would necessitate braking and accelerating again.

The vertical grade can have a very significant impact on the rate of emissions. To maintain a constant speed, a vehicle is effectively accelerating on an upgrade and decelerating on a downgrade. In the interests of air quality, vertical grades should be as small as possible, consistent with good drainage and design practice.

2. Widening Intersections -- The width of the approach to an intersection has proved to have the most bearing on its capacity. Figure 3.4 illustrates the width/capacity relationship for an urban intersection used for two-way operation with no parking permitted.

> Example:
> Consider the case of an urban arterial with two 12-foot lanes in each direction (a 24-foot approach width) at an intersection with an approach volume of 2,200 vehicles per hour of green time. As illustrated in Figure 3.4, the approach would be operating at a load factor of 1.0--very unstable, inducing considerable vehicle delay. (Load factor is defined as the number of fully utilized green intervals divided by the total number of green intervals for the same period.) If an additional lane were added in each direction (a 36-foot approach width) operation could be at a load factor of 0.0--free flowing, with almost no intersection delay.

Thus, widening the approaches to intersections, which can be achieved by minor construction, can greatly improve arterial street operations. The favorable effect on air pollution is indicated in Table 3.3. Widening of course is not always possible, particularly in intensively developed urban areas.

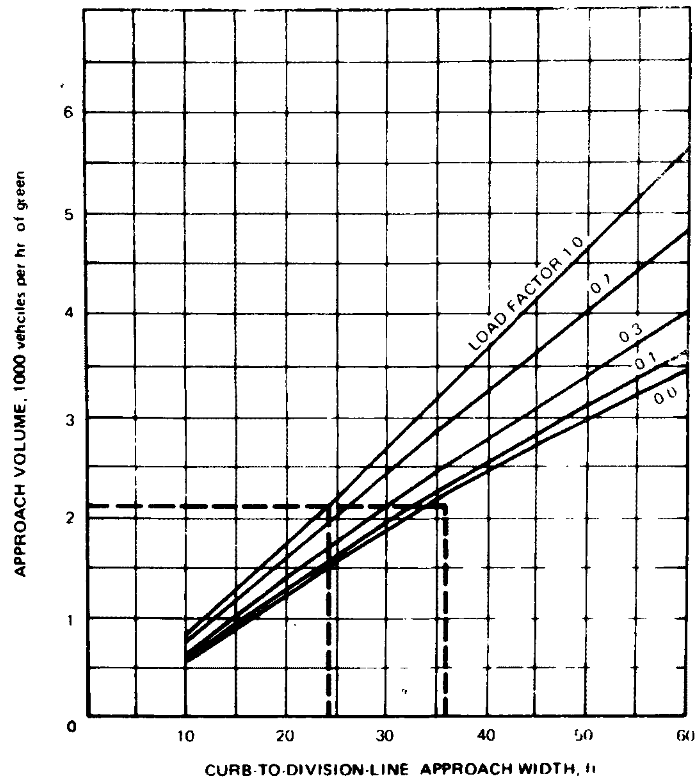


Figure 3.4. Urban intersection approach service volume for two-way streets with no parking.[8]

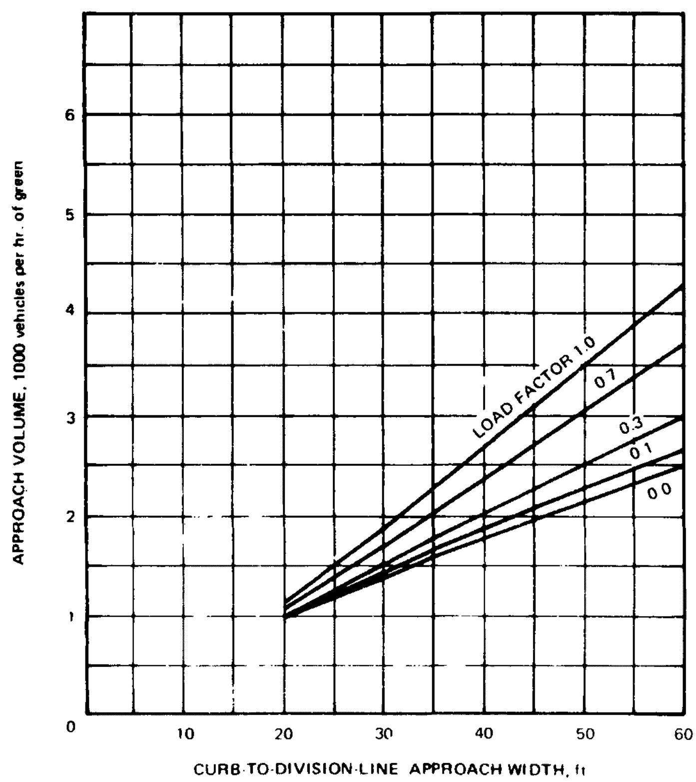


Figure 3.5. Urban intersection approach service volume for two-way streets with parking.[8]

Table 3.3. EMISSIONS VERSUS LOAD FACTOR

Load Factor[8]	Overall Travel Speed, mph	CO Emissions,[a] gm/vehicle mile[5]	HC Emissions,[a] gm/vehicle mile[5]
0.0	30	76.5	11.0
0.1	25	85.0	12.0
0.3	20	102.0	13.5
0.7	15	136.0	17.2
1.0	10	178.5	22.1

[a] 1972 vehicle mix.

3. Parking Restrictions -- Parking conditions at an intersection approach have a pronounced effect on intersection capacity. Because motorists fear sudden maneuvers or opening doors of parked cars, the width of roadway influenced by a parked vehicle is much greater than its physical width. Figure 3.5 illustrates the approach service volumes for two-way streets with parking.

When compared with Figure 3.4, for the case with no parking, the impact of parking on intersection performance is quite apparent.

Example:
Assume that an urban arterial consists of three 10-foot lanes in each direction (a 30-foot approach width), with parking in the curbside lane. An approach volume of 2,000 vehicles per hour of green would overload the intersection approach, causing it to operate in the forced-flow region, with a load factor of approximately 1.0 (see Figure 3.5). If, as a remedial measure,

parking is prohibited, a 30-foot approach width can handle 2,000 vehicles per hour of green time at a load factor of 0.1 -- providing a high level of service and minimal delays (see Figure 3.4).

In addition to increasing the capacity of intersection approaches, parking prohibition contributes to smooth traffic flow with less interference along the route. In many cases local opposition may make parking prohibitions politically unfeasible; e.g., local merchants may oppose discontinuation of parking. A useful compromise is to prohibit parking only during peak flow periods.

4. Signal Progression -- Signals along an arterial can be coordinated to provide progressive movement if the timing of one signal relative to the next is arranged to permit continuous movement of vehicles through the system.

A progressive operation can best be achieved if:

1. There are relatively few turning movements.
2. The demand per cycle can be held slightly under the capacity per cycle.
3. Midblock frictional elements are largely absent.

Figure 3.6 compares typical and progressive arterial operations. Figure 3.6 is similar to Figure 3.3, the speed-volume curve presented in the section on freeways. Typically, the installation of a progressive signal system might increase average overall speeds from 20 to 30 miles per hour with concomitant reductions of carbon monoxide and hydrocarbon emissions.

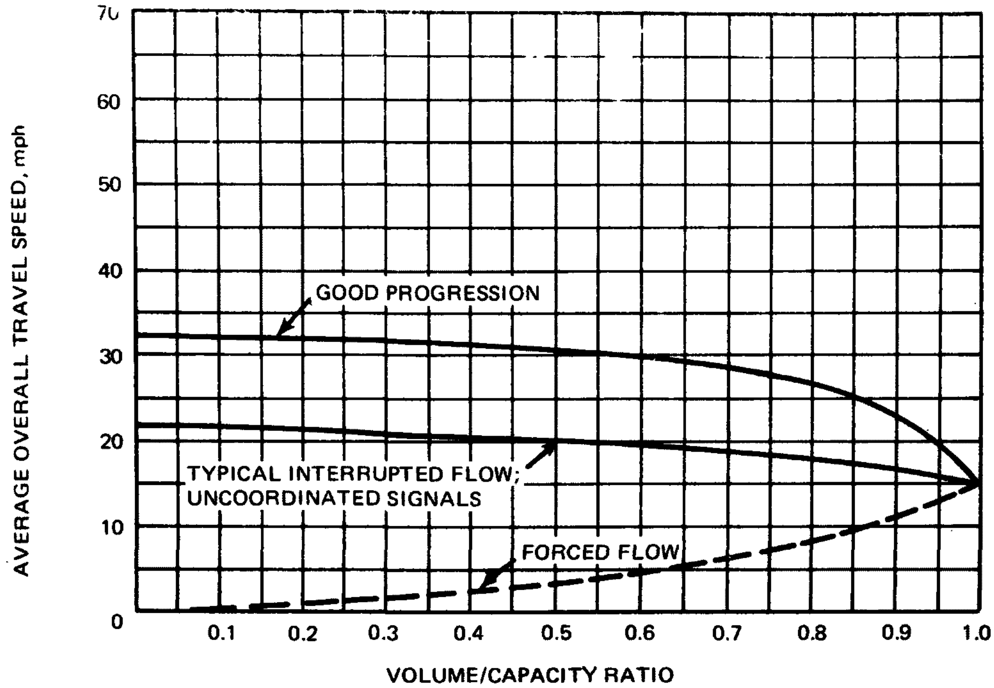


Figure 3.6. Typical relationships between volume/capacity ratio and average overall travel speed, in one direction of travel on urban and suburban arterial streets.[8]

5. Reversible Lanes -- The reversible-lane concept, previously mentioned as a freeway technique, applies equally to arterial street operations. The major advantage of reversible lanes is obvious -- additional capacity is provided in the major flow direction, allowing for a smoother flow of traffic.

6. Reversible One-Way Streets -- An extension of the reversible lane concept is to reverse the direction of flow of the entire street, in accordance with directional peaking characteristics. To warrant reversing the direction of flow of an entire street, flow in one direction should exceed 80 percent of the total flow. In addition, adjacent streets must be capable of carrying the minor flow traffic.

7. Helicopter Reports -- Radio traffic report helicopters are becoming a common sight over many large cities. A helicopter observer relays current traffic conditions to radio listeners and advises them of the best routes to take on a particular day. This technique has considerable potential; it is responsive to the day-to-day peculiarities of travel demands and traffic events. Its success depends on the ability of the observer to advise the motorists properly, as well as the extent to which motorists listen to the reports.

8. Miscellaneous -- There are numerous other arterial operating improvements that will both facilitate traffic flow and reduce air pollution. Improvements such as channelization, lane and other pavement markings, and traffic signs can greatly upgrade traffic flow and in some measure reduce emissions.

C. Downtown Distribution

The downtown street system is probably the most complex component of the urban area road system. From a functional viewpoint, the nature of the downtown street system is largely circulatory -- designed to service adjacent land uses -- with the level of service to through traffic of secondary concern. Traffic flow is interrupted frequently by pedestrian movements, vehicle turning conflicts, traffic signals, and a high number of stop-start transit vehicles in the traffic stream. A major portion of vehicle time is spent idling, accelerating, and decelerating; the result is a relatively high level of air pollutant emissions. Any operational techniques that can improve the stop-start nature of downtown traffic flows can significantly reduce air pollution levels in central cities. Due to the high daytime population densities, reduction in downtown air pollution levels can benefit a relatively large percentage of the population.

1. <u>Traffic Responsive Control</u> -- Considerable attention has been focused in recent years on computerized traffic control systems. North American cities with computerized traffic control systems currently in operation include Toronto, Ontario; San Jose, California; Charleston, South Carolina; and Wichita Falls, Texas.

Several system designs are available, but certain basic features are common to all. Traffic flow is measured by a series of sampling detectors throughout the system network. On the basis of data received from the sampling detectors, the computer selects, from a number of programs, the optimal timing for the system.

Control over traffic signal hardware can be either directly from the computer or through local controllers which are directed by the computer. Traffic flow information is being received and signal timing revised continually to meet the varying demands in a near optimal manner.

The Wichita Falls system reduced vehicle stops by 16.3 percent, average vehicle delays by 31.1 percent, and accidents by 8.5 percent. Peak-hour average speeds on many downtown approach and exit streets increased from 20 to over 30 miles per hour. The San Jose system yielded similar results.

2. <u>One-Way Street Operations</u> -- One-way operation of a given street is generally more efficient than two-way operation, in terms of total vehicles per hour. The major advantages of one-way street operation are reduced turning conflicts at intersections, reduced pedestrian/vehicle conflicts, and ease of installing a progressive signal system. Major disadvantages of one-way streets are longer trips for some vehicles, motorist confusion, less desirable transit service, and the requirement for many additional traffic control devices.

It is difficult to generalize about the effectiveness of one-way streets in reducing air pollution. Although they definitely increase average network speed, this effect is at least partially offset by the overall increase in vehicle miles caused by the necessity for many trips to take a path other than the shortest. To evaluate the possible effect of a one-way system on air pollution, a traffic assignment must be prepared to determine if the increase in speed or the increase in vehicle mileage is the dominating factor. Undoubtedly, there are many cases in which one-way street systems can effectively reduce air pollution.

3. Loading Regulations -- In many downtown areas, the loading and unloading of trucks and other commercial vehicles is a major impediment to smooth traffic operations. The long-range solution to the conflict between loading/unloading and street traffic is for new buildings to include off-street loading facilities, as is now required in many cities. However, many existing buildings must handle their deliveries and shipments from the street. Even when off-street facilities are used, problems exist in moving trucks out of (or into) the traffic stream.

An effective measure to alleviate the immediate problem is restricting loading and unloading time periods. The easiest time restriction to enforce, and the one of most value to reducing traffic congestion, is to prohibit loading/unloading during morning and evening peak traffic hours. Since the largest demand for loading space is from 10:00 a.m. to 4:00 p.m., peak hour restrictions are a reasonable measure.

Another measure that can minimize the conflicts between street traffic and loading/unloading vehicles is the use of a street classification system, designating certain streets (segregated as much as possible from the arterial street system) as service streets.

While it is impossible to relate loading/unloading conditions to traffic flow by any simple formula, it is possible to generalize that the quality of traffic flow is benefited by minimizing conflicts between street traffic and service vehicles. Inasmuch as exhaust emissions relate directly to quality of traffic flow, it is certain that minimizing these conflicts is a positive step in reducing air pollution.

4. Pedestrian Control -- In downtown areas, where pedestrian flows are large, special controls may be used to minimize pedestrian/vehicle conflict. Streets with extremely high pedestrian utilization can be closed to vehicular traffic, either permanently or during a portion of the day. In so doing, it may be necessary to provide additional capacity elsewhere in the street system. Plans of this type are becoming popular in many large cities.

At some locations it may be desirable to use barriers to control pedestrian movement, channelizing and concentrating pedestrian crossings at specific points. A barrier can be a permanent fence or posts with connecting chains located near the edge of the sidewalk. Signs directing pedestrians to the proper crossing locations should be mounted on or near the barrier.

5. Traffic Operations Program to Increase Capacity and Safety (TOPICS) -- The U.S. Congress, recognizing that good transportation is vital to a desirable urban environment, directed the Secretary of Transportation to develop a program by which the Federal Government could assist cities in alleviating their backlog of transportation needs. The result was the Traffic Operations Program to Increase Capacity and Safety (TOPICS). The purpose of this program is to obtain maximum efficiency and safety from the existing major street network through a systematic application of traffic engineering techniques. These traffic engineering treatments would not include construction of major new facilities, but rather the application of more sophisticated signal control, parking restrictions, lane widening, turn-lane additions, and other minor redesign and channelization requiring a minimum of new right-of-way. Although air pollution reduction is not an objective of the program, it is an important byproduct of improved traffic flow.

Since TOPICS is not a particular operations policy, but rather a collection of systematic traffic engineering techniques, many of the actions already identified under freeway, arterial, and downtown operations can be implemented as part of an areawide TOPICS program. Since Federal funds have been available in the program only since January 1969, it is impossible to assess the impact of TOPICS on an urban area. However, the results of a similar program in the British County Borough of Gateshead produced the benefits summarized in Table 3.4.

Table 3.4. BENEFITS OF TRAFFIC MANAGEMENT SCHEME, GATESHEAD[9]

Item	1965 Before	1968 After	Change, %
Traffic Volume entering cordon	78,325	82,080	+ 5
Total vehicle hours within cordon	9,250	7,166	-23
Vehicle miles traveled within cordon	109,900	123,700	+13
Average speed per vehicle within cordon	11.9	16.3	+37
Pedestrian accidents	37	30	-19
Vehicle accidents	27	21	-22

In spite of a higher number of vehicles and an even larger increase in vehicle miles within the cordon, average vehicle speeds increased from 11.9 to 16.3 miles per hour and total vehicle hours were reduced. Thus the reduced emissions per mile would more than offset the increased mileage.

The benefits to be gained by TOPICS in reducing air pollution emissions are very significant. Thus TOPICS should figure importantly in the resource allocation strategy of each city.

TECHNIQUES FOR REDUCING POLLUTION CONCENTRATION

The utilization and design of highways can be effective in reducing the air pollution concentrations in the ambient air. If peak-hour traffic concentrations were reduced by distributing traffic over a larger area and over a longer period of time, the air space available to disperse pollutants would be greater. Also, good design can improve the operational characteristics of the transportation system and thus minimize the concentration of air pollution to which people, plants and structures are exposed.

A. Staggered Work Hours

A possible means of reducing peak period traffic volumes and congestion is to spread the demand for travel over a longer time period, thereby reducing the magnitude of the peak period demand. So doing will reduce vehicle-hours in the system, attendant air pollution, and maximum concentration of pollutants. Staggering the morning rush is particularly important because the wind speed early in the day is low and the atmosphere is generally stable -- conditions that inhibit the dispersion of pollutants. Delaying morning travel peaks would result in cleaner air generally because of both these characteristics. Delaying the morning rush hour in Los Angeles by one hour would reduce oxidant concentrations by 24 percent.[10]

Staggered work hours was first used in the United States during World War II, when approximately 60 cities used the idea to alleviate the critical problem of mass transportation capacity shortage. All cases achieved some degree of success; many cities reduced peak period travel demand by as much as 30 percent. All major staggered-hour plans were terminated after the war.

The most publicized plan for staggered work hours in recent years has been in the lower Manhattan area of New York City. In April 1970 about 50, 000 persons employed by 45 firms and government agencies in lower

Manhattan began a program of staggered work hours, shifting from the traditional 9:00 to 5:00 schedule, principally to a new 8:30 to 4:30 schedule. As of April 1971, there were about 60,000 people representing 70 private firms and governmental agencies on the new schedule. Public response to the project, which is being sponsored by the Port of New York Authority and the Downtown-Lower Manhattan Association, has been overwhelmingly favorable.[11]

A significantly changed pattern in peaking characteristics was evidenced as a result of the staggered hours project. Figure 3.7 indicates the effects at the Port Authority's Hudson Terminal for the afternoon peak. Vehicular counts were taken at the Brooklyn Battery Tunnel and the Battery Parking Garage. Little change has been observed as a result of staggered hours, primarily because the number of participants thus far is but a small proportion of total area employment.

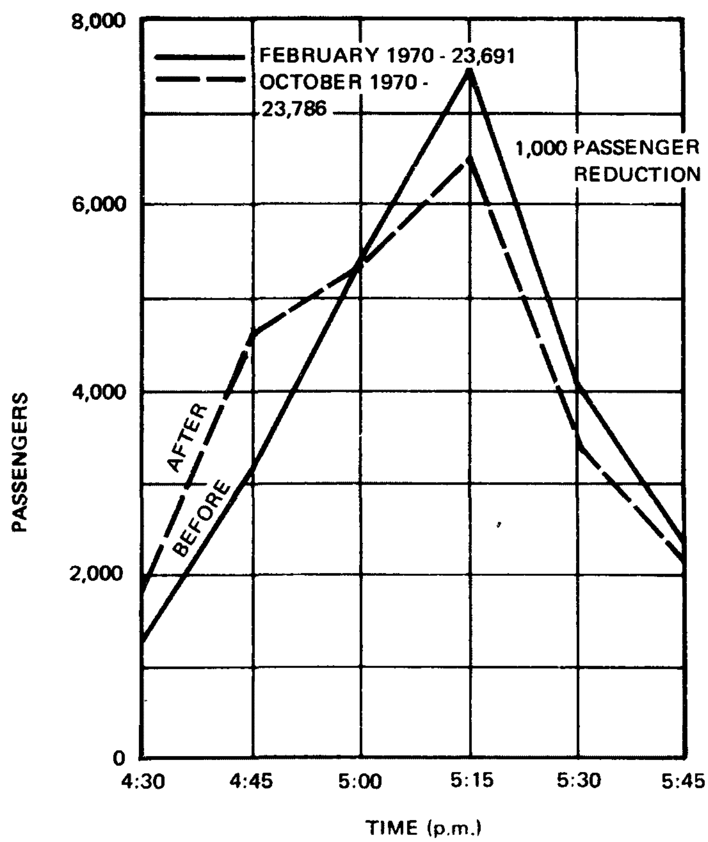


Figure 3.7. Effects of staggered work hours, Hudson Terminal afternoon passenger volumes.[11]

B. Roadway Concentrations

A number of studies have been made of the air pollution distribution pattern (vertically and horizontally) from roadways to understand the effects of highways on pollution in adjacent buildings. Frankfurt-am-Main was the subject of an investigation[12] on the time and space distribution of carbon monoxide emission concentrations.

Figure 3.8 shows the carbon monoxide concentrations on both the leeward and windward sides of a roadway at heights of 3, 16, and 33 meters above the roadway.[12]

Figures 3.9 and 3.10 provide additional information on the decrease of carbon monoxide concentrations with distance vertically and horizontally from a roadway in relation to the pollution level at the roadway.[13] Such information is useful in deciding where to build a structure in relation to the highway so that pollution will not exceed a safe acceptable level. Similarly, the curve showing the decline of pollution with height above the roadway can be useful in determining air-rights construction.

A study[14] was also made of the concentrations of CO resulting from vehicles elevated above ground level on open structure. Each isopleth (line of equal value) in Figure 3.11 shows the recorded concentrations of carbon monoxide emissions in parts per million for vehicles at an elevation of 10 feet. The ambient level was presumed to be zero feet. Emissions are a function of vehicular elevation and horizontal distance from the edge of the roadway in feet. (Elevated roadways on solid fill cross-sections would be expected to exhibit different characteristics.)

C. Cross-Sections

Concentrations of nitrogen oxides, hydrocarbons, and carbon monoxide were measured[15] at various levels above five different types of highways, including an expressway with adjacent structures nearby, an expressway

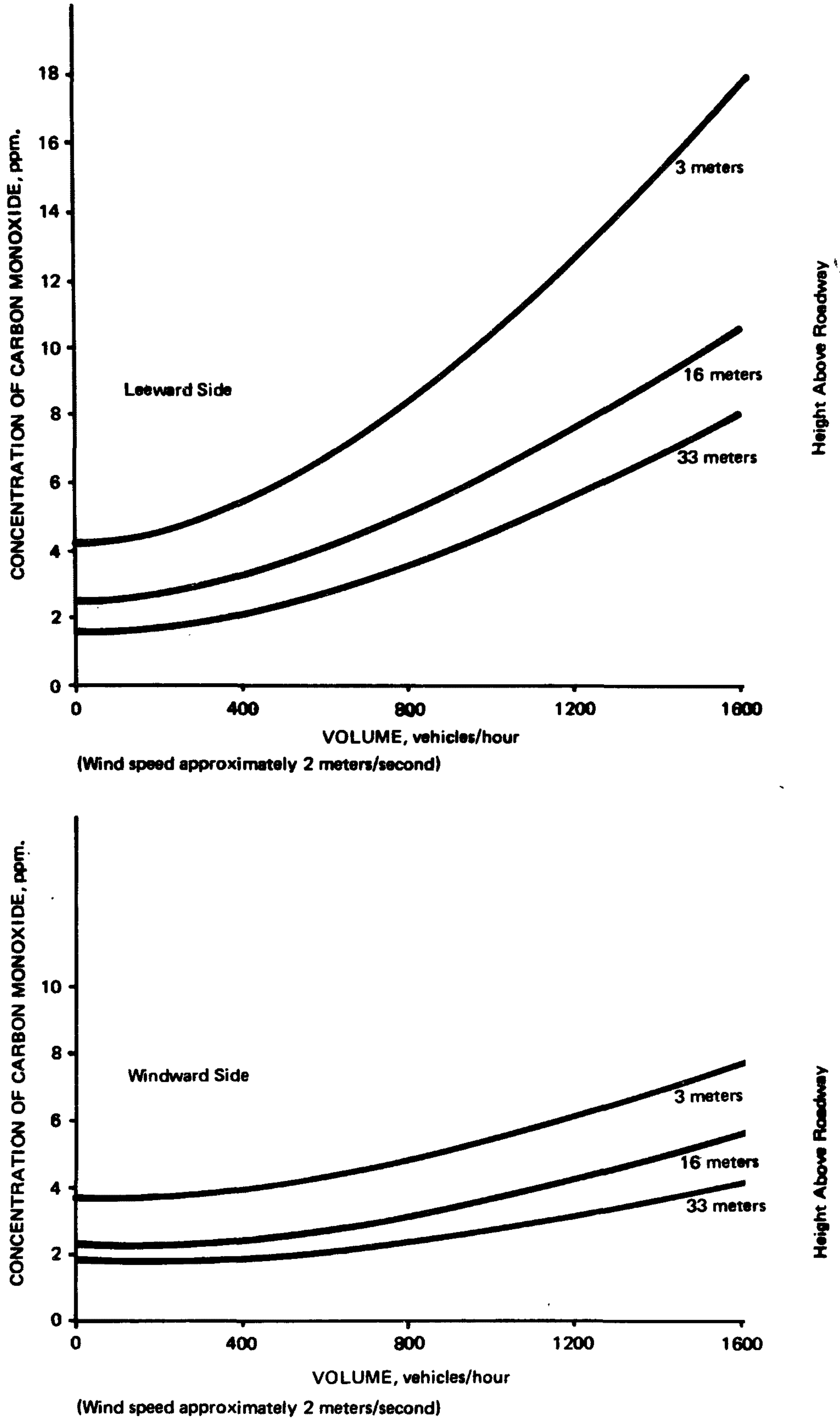


Figure 3.8. Carbon monoxide concentrations depending upon traffic volumes.[12]

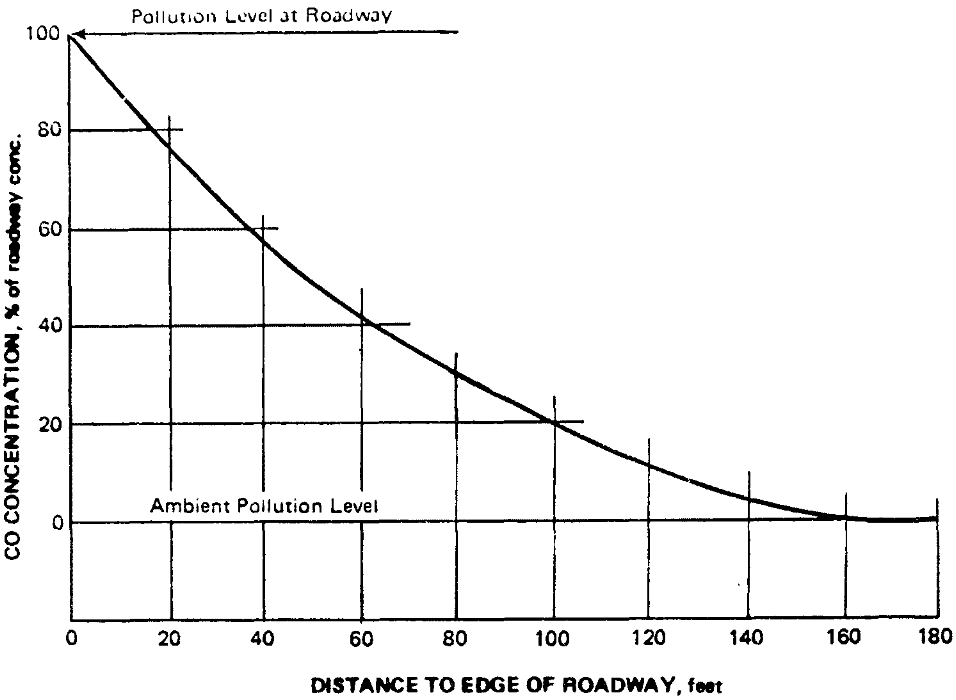


Figure 3.9. Pollution level versus distance to edge of roadway.[13]

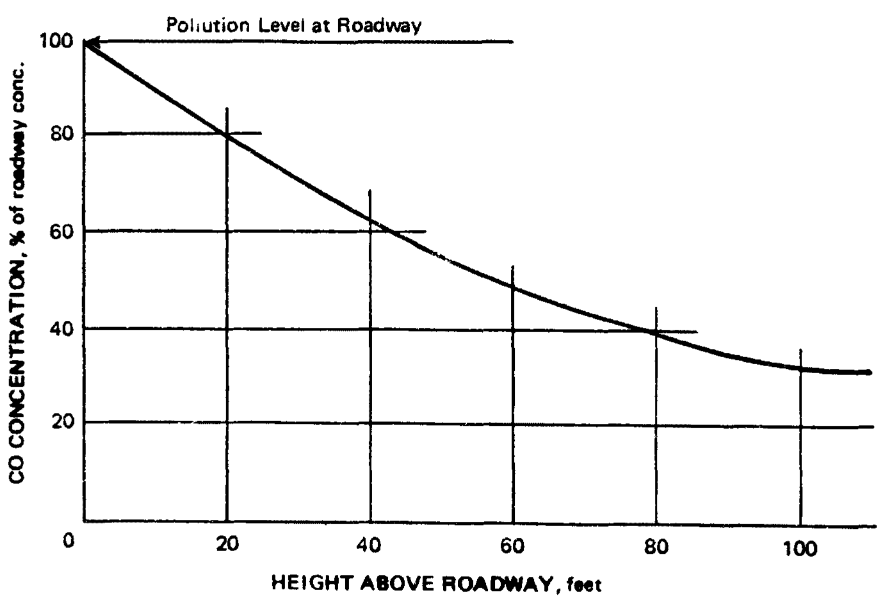
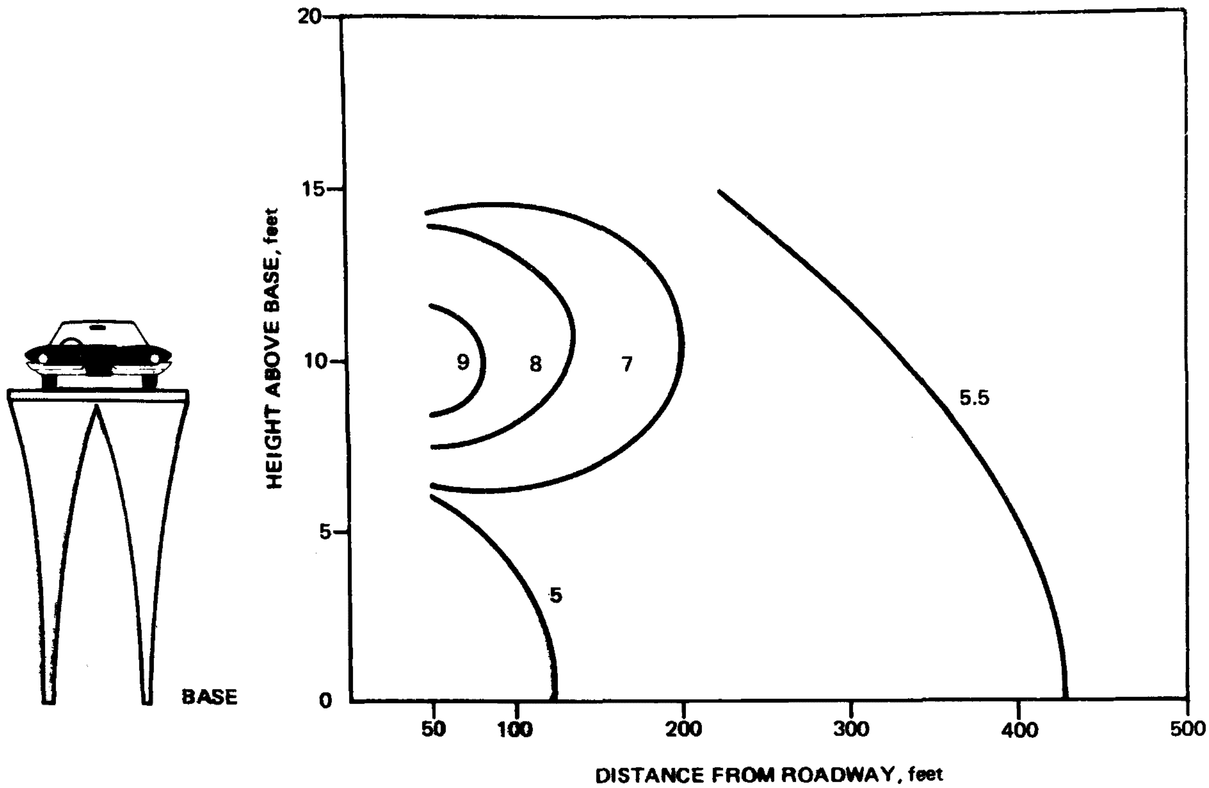


Figure 3.10. Pollution level versus height above roadway.[13]



NOTE: Lines shown on this diagram are isopleths for carbon monoxide concentrations (parts per million as shown).

Figure 3.11. Carbon monoxide concentrations for a highway design.[14]

without these joint development structures, and an expressway boulevard. The average concentration on the four lanes for the expressway without joint development structures was 39 ppm; a similar concentration for a boulevard expressway was 49 ppm, an increase of 26 percent.

Efforts to reduce air pollution by changing highway design may not be aimed as much at reducing total emissions as at reducing concentrations at various significant distances from the roadway. Emissions can be reduced by the design of the highway itself, or by regulating the relationship between the highway and the adjoining land use.

In a study soon to be released, the General Electric Company performed comprehensive air quality monitoring in areas adjacent to highways. The results of this study should substantially improve our knowledge of the basic factors related to air quality and automobile emissions. In addition, the

District of Columbia Department of Highways is sponsoring a project to investigate the concentrations of carbon monoxide adjacent to freeways.

D. Elevated, At-Grade, Depressed Roadways

The decision to design a new highway as an elevated, at-grade or depressed facility can have a major effect on its air pollution impact.

Arguments in favor of depressing highways in urban areas usually point to reduced neighborhood disruption and noise. These arguments may be valid, but depressing a highway affords little opportunity for local wind currents to disperse the emissions. Thus, the motorists traveling on a depressed highway, as well as persons in adjacent areas, may be exposed to unusually high concentrations.

Elevated highways, on the other hand, promote rapid dispersal of pollutants away from the motorist. By virtue of being elevated, they are more exposed to wind currents which transport as well as disperse pollutants. While this pollutant dispersal represents a positive factor for the motorist, the highway design engineer must pay close attention to how it affects adjacent land uses. It may benefit the motorist to have all the pollutants transported away from an elevated highway, but if they are transported directly into an adjacent building the result may be a serious detriment to the occupants. In this regard, the highway designer would do well to consult with local meteorologists to determine the micro-climate of the design corridor. Needless to say, the aesthetic aspects and other environmental impacts of elevated highways have to be considered.

TECHNIQUES FOR REDUCING AUTO TRAFFIC

Any program that focuses exclusively on improving traffic flow to reduce air pollution is likely to be self-defeating. The objective of an effective approach to reducing pollution related to the automobile must be to reduce auto travel. Currently, the best approaches to this objective are:

1. To improve public transportation service.
2. To juxtapose land uses in a manner to minimize the requirements for vehicular travel.
3. To regulate the use of automobiles.

A. Transit Operations

The modal choice decision is influenced by the myriad characteristics of competing modes. Of particular importance are the relative travel time by the best transit and auto routes, the relative cost to the passenger by transit and auto, and the relative service provided by transit and auto.

1. Bus Lanes on City Streets -- A measure that can be taken to improve the attractiveness of transit relative to the auto is to provide reserved transit lanes on city streets. This is rarely easy to do because of the road space thus reserved but usually not used to capacity, and the problems of providing for turning movements and of enforcement. Nevertheless a number of exclusive bus lanes are in existence and show good results. Both speed and reliability of buses benefit from exclusive lanes, particularly if signals are timed to facilitate their movement.

In corridors with high transit volumes, overall traffic flow may be improved, in addition to improving transit service.

2. Bus Lanes on Freeways -- The speed and reliability of transit service can be substantially improved by providing exclusive bus lanes on urban freeways.

There are several operational projects in the early implementation stage. Among these are the Shirley Highway (I-95) project from Northern Virginia to Washington, D. C. Buses on the Shirley Highway use the reversible lanes in the freeway median over a distance of nearly 9 miles in both directions. With the completion of temporary lanes and the addition of 30 new buses in the spring of 1971, express routes were carrying nearly 7,500 passengers on 160 inbound runs during the morning peak by September

1971. Buses save 30 minutes over automobiles for the same portion of the Shirley Highway trip. There is insufficient data to determine the impact of the bus lane on travel in the corridor; however, a 3-year Urban Mass Transportation Administration demonstration and evaluation project is in progress.

Another operation, the Blue Streak Demonstration Project, is being tested in Seattle. This project consists of special buses using the Seattle Freeway reversible roadway in the peak direction over an 8 mile distance and an exclusive on-off ramp in the downtown area. A 475-car parking lot was constructed at the end of the line. Within a month the lot was filled, with many additional vehicles parked illegally. In summary, the public response has been very favorable. Further evaluation of the project is underway at the time of writing this Guide but it will be necessary to expand the park-ride capacity in order to determine the full impact of the high-speed bus service.

3. One-Way Streets with Two-Way Buses -- Bus operators generally are of the opinion that one-way streets have an adverse effect on transit ridership. Riders may have to walk farther and in any case can no longer alight from and board buses on the same street. A one-way street system may also have the effect of lengthening bus routes and travel time. By providing a reverse-direction exclusive lane it is possible to retain two-way bus operation on a one-way street, with potentially higher ridership than would be obtained if buses ran on two one-way streets instead. There has been limited application of this technique, but it would appear to merit trial where appropriate conditions exist.

4. Park-Ride, Kiss-Ride -- Because of the difficulty of providing effective bus service in low density residential areas, one of the most promising transit improvements is the provision of park-ride and kiss-ride facilities in conjunction with express bus or other transit services. A park-ride facility includes a parking lot and express bus stop; a kiss-ride facility is

a lane set aside for autos to discharge or load passengers without impeding traffic flow. Commuters are thus able to travel by car in less congested areas where bus service would involve a long walk or wait (or both), but use transit for the portion of the trip where traffic is more difficult and parking expensive. Seattle's Blue Streak and Cleveland's rapid transit system are examples of the effective use of this technique. Completion of the Blue Streak evaluation will indicate the potential for reduced vehicular traffic and attendant air pollution.

5. Service Improvements and Cost Reductions -- The effect that transit operating policies have on the demand for auto trips is fundamental in any effort to reduce auto travel through transit improvement. One of the most ambitious efforts to identify the relationship between transit and auto demand was a study[16] performed for the U.S. Department of Transportation, using data from the Boston metropolitan area. Based on origin-destination data collected in 1963 and 1964, an econometric model of urban passenger travel demands was developed using constrained multiple regression techniques. The model measured the relationship between the number of trips by purpose and mode and the socio-economic and land use variables that give rise to travel demand. The major quantitative outputs of the study were demand elasticities and cross-elasticities by mode and trip purpose.

Transit demand was found to be relatively inelastic with respect to fare changes (i.e., a 1 percent increase in fare decreased ridership less than 1 percent), indicating that transit usage would not be markedly increased by reducing fares. This finding has been corroborated by numerous studies[17,18] of transit patronage before and after fare increases, although instances of greater than 1.0 elasticity (representing a more than proportionate loss of riders in response to fare increases) have been seen recently.

A second major conclusion was that most of the cross-elasticities are very low or negligible. The low cross-elasticities indicate that it is difficult to reduce the number of auto travelers by improving transit service or lowering fares. The demand for auto trips was found to be more sensitive to reductions in transit travel times than to reductions in fares. It was estimated that the institution of a free transit system in Boston would result in a 4 percent areawide reduction in automotive exhaust emissions.

The model reflected the fact that several elements are included in the effect brought about by a change in service of a travel mode. For example, a transit fare reduction will attract additional trips that consist of trips not previously made at all, and trips diverted from auto. The trips diverted from auto may not be typical auto trips, in terms of such factors as auto occupancy. The reduction in number of auto trips may in part be offset by new auto trips, induced because of road capacity vacated by the diverted trips. All of these elements are influenced by the cost and service aspects of the available modes. There is evidence that the elasticities are non-linear and may also vary from city to city in ways not fully predictable. Thus the findings described here, although generally indicative, do not apply specifically.

In summary, it appears that the modal choice decision is more a factor of the socio-economic characteristics of the traveler than of relative costs and travel time. Nevertheless, changes in service and fares can have useful impact in attracting trips to transit from auto, thereby reducing the amount of auto travel and resultant emissions. There is a greater likelihood of inducing the auto traveler to use transit by improving the level of service (travel time including waiting and walking) than by reducing fares. The greatest diversion is likely to occur by increasing frequency, reliability, and accessibility of service. Consequently, efforts to subsidize transit operations might best be directed toward improving service rather than reducing fares.

B. Regulation

There are several governmental policies that go beyond the normal pricing policy in that they regulate traffic by writ. Although they may be difficult to implement in the political framework of decision making, there can be no doubt about their effectiveness in reducing traffic congestion and air pollution. In any event, they may be useful measures to bear in mind for possible implementation during emergency air episodes.

1. Parking Bans -- One such measure is to prohibit parking in downtown areas -- thereby necessitating a switch to a transit mode on the part of commuters. As in the case of a parking tax, through motorists would be unaffected if not encouraged. A similar proposal, though less severe, is to limit the number of downtown parking spaces to a certain "acceptable" number. The impact of either measure may be in part to redistribute travel to locations where parking is available. If this were to occur, there would be a corresponding redistribution of pollution at some detriment to the new locations.

2. Auto-Free Zones -- Banning vehicles completely in certain parts of a city has been tried in many locales. Tokyo has banned cars from 122 of its busiest streets on Sundays, the busiest shopping day in Japan; air pollution levels were cut in half. New York City took similar action, resulting in as much as a 90-percent reduction in carbon monoxide levels on some autoless streets. Unfortunately, such a ban tends to raise traffic levels, congestion, and attendant pollution levels in adjacent areas. When an auto ban was implemented in a section of Rome, disastrous traffic jams and air pollution were created all around it. A similar ban in Florence, however, had favorable results. A requirement in implementing auto-free zones, therefore, is to plan carefully for traffic movement at the periphery of the zone.

An interesting technique is being tried in Gothenburg, Sweden, where planners found that 30 to 40 percent of downtown traffic was through traffic. The solution was an old planning idea with a new twist. A ring road was constructed around the center city -- an old planning idea. The new twist was to erect barriers dividing downtown into quadrants so that cars could no longer drive through the central business district. On Ostra Hamngatan, a street which still has the most intensive pedestrian exposure in the city, the CO content in the air has been reduced from about 65 to 5 ppm.

3. Gasoline Rationing -- Another method of regulating vehicle travel in urban areas is to ration gasoline. Basically, each vehicle would be alloted a certain amount of gasoline per unit time. It would be up to the vehicle owner to limit his trips to those that he could accomplish within his gasoline allotment.

Although it would be politically difficult to implement, gasoline rationing would be effective in reducing automotive emissions. An advantage of the idea is that it might have less tendency to redistribute trips, a characteristic of localized measures.

4. Idling Restrictions -- Emission characteristics during acceleration, and idling have been discussed. The concentration of carbon monoxide in exhaust gases of an idling vehicle is nearly twice that of a cruising vehicle. Thus, any regulatory measures aimed at restricting vehicle idling times would be a positive step toward cleaner air. While it would be difficult to construct and enforce a useful regulation to limit idling, it is conceivable that a public information program could achieve driver cooperation in shutting off auto engines wherever long delays are anticipated or encountered.

Stockholm, Sweden has initiated a program which prohibits idling or warming of automobile engines in excess of 3 minutes while the vehicle is parked. Drivers are informed of this prohibition by signs and by printed notices placed on the windshield. Violations are punishable by law.

5. Four-Day, Forty-Hour Week -- Although the 4-day, 40-hour work week presently encompasses a very small fraction of the labor force in the United States, it appears to be gaining in popularity at an increasing rate. At the latest count, over 100 firms around the United States had switched to the 4-day week in one form or another. Some have adopted a 36-hour week with 9-hour days.

The possible effect of widespread implementation of the 4/40 concept on traffic volume, congestion, and air pollution is difficult to predict, although indications are favorable. One effect of lengthening the work day would be similar to the staggered work hours concept: peaking of traffic demand would be reduced by an amount dependent on the number of persons changing over to 4/40. In addition, on 1 or more days, the total number of work trips would be significantly reduced. This reduction would have a primary pollutant-reducing effect because of trips no longer made; a secondary effect is that trips made would be at improved traffic flow.

There is little knowledge of the overall effect on trip making patterns that would result from a substantial changeover to 4/40. A new weekly schedule may change the entire trip generating character of an area. In particular, there might be greater overlap between downtown shopping trips and work trips.

The idea generally seems very promising; progressive urban areas might consider promoting 4/40 on the basis of expected improvements in air quality.

C. Pricing Policy

One way to reduce emissions is to impose operating penalties or disincentives, which would place special charges on traffic using congested roads. The underlying theory upon which road pricing schemes are based is rooted in classical micro-economic techniques. The vehicular volume on a particular roadway is interpreted as the point of equilibrium between the demand and supply functions of the given roadway. The demand function represents the number of trips that would be made at a particular price. (To the economist, the term "demand" has no significance unless a price is stated.) The "price" should include not only money cost, but also a measure of travel time (which can be expressed in monetary terms), comfort and convenience, and other pertinent factors. These can all be reduced to a common monetary denominator and included in the "price" of travel.

The supply function, on the other hand, expresses the price per trip as a function of the number of trips made. (Note that this supply function is different from the typical industry supply curve used in the theory of the firm: it is a price/volume curve where the price is the user cost of a trip as perceived by travelers. Thus, as the traffic on a highway increases, travel time increases, operating costs increase, and correspondingly the "price" increases as shown in Figure 3.12.

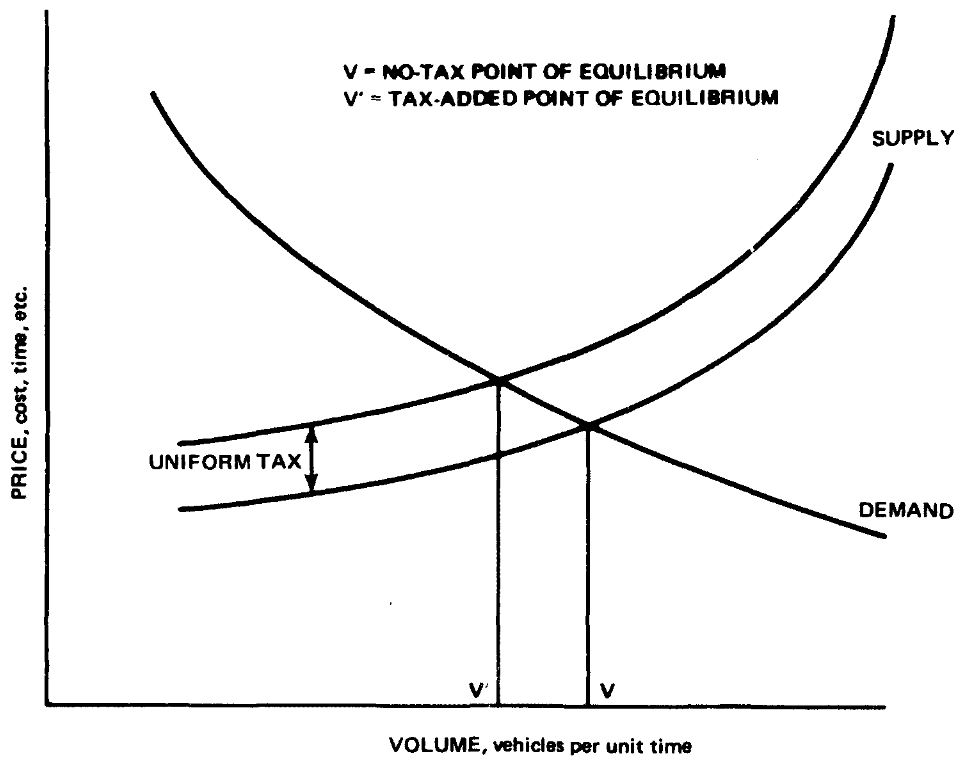


Figure 3.12. Supply-demand relationships.

Imposing a uniform tax effectively creates a new supply function. Actually, a change in price structure redistributes income among consumers and causes a shift in the demand curve. In this instance, any tax that results in reducing the number of current users may induce new users to begin using the roadway. For example, a highway toll may reduce the number of low-income drivers, while the resulting reduction in congestion will cause more high-income drivers to use the facility. But assuming no demand shifts, the new point of equilibrium will be at a volume V'. Thus, the imposition of a uniform tax results in a volume decrease of (V - V'), allowing the facility to operate at a higher level of service in terms of speed.

Although this is an oversimplification of road pricing policy, it is sufficient as a basis for discussing pricing mechanisms as a means of reducing traffic congestion. The various pricing policies discussed below may prove very useful in reducing traffic congestion, although there are problems involved in their implementation.

Road-pricing policies can adversely affect the economic growth of a region. A study of the Hampton Roads area of Virginia indicated that pricing policies on river crossings could have a significant impact on employment in the region. These effects might be offset if uniform restraint measures were used over a wider area.

Measures that discourage auto travel to a downtown area may adversely affect retail activity; but, time-selective parking policies should help to offset such effects. Improvement of mass transit also will be important.

Another major objection to congestion pricing is the claim that it is economically regressive. Most likely to be priced off the roadway are the low-income motorists. Pricing them off the road may also mean pricing them out of a job if no adequate alternative mode of transportation exists. Rebates to those of low income might be an appropriate way to alleviate this problem. Providing good transit service is equally relevant.

These problems are significant but the willingness of the public to grapple with them is growing. The control of parking charges has had some acceptance, and is being seriously considered for the new Metro system in Washington, D. C. Road pricing has been very closely studied in Great Britain, to the extent of devising a "black box" that can be installed in an automobile to record road-user charges. A current study in Venezuela is examining the applicability of road pricing there. Germany taxes engine displacement; Bermuda limits maximum size; and Great Britain heavily taxes automobiles and motor fuels.

1. Parking Policy -- One way to implement a pricing policy is to regulate parking charges in congested areas. Parking charges could be maintained uniformly higher than the market rate, thereby reducing the number of trips made throughout the day. Alternatively, parking charges could be regulated under a variable charge strategy according to time of day or location. For example, high all-day parking rates would discourage commuting by automobile.

In Canberra, Australia, a theoretical simulation study showed that increased parking costs would reduce vehicular travel by increasing car occupancy and transit usage.[19] This reduction in travel would reduce the air pollution generated by vehicles. Figure 3.13 shows that adding a $1.00 parking cost would reduce air pollution in Canberra by approximately 30 and 40 percent in the town centers and central area, respectively.

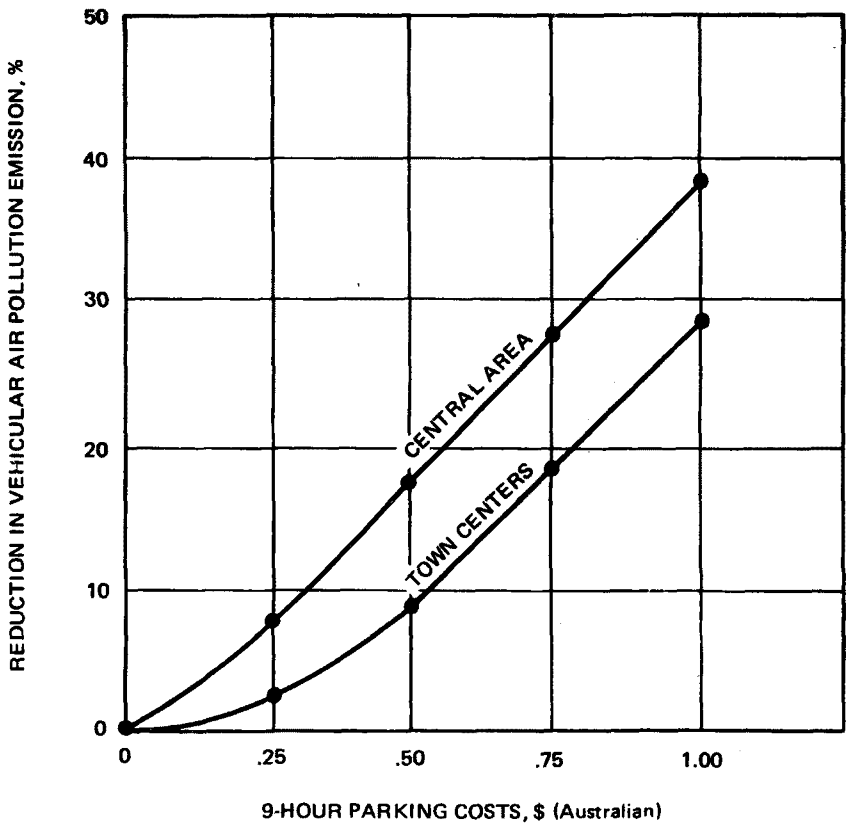


Figure 3.13. Effects of parking costs on vehicular air pollution emissions.

Although some benefits might be realized from taxing parking space in congested areas, any restraint based on parking restrictions alone will affect only those who live and work in the particular area. The restraint will not affect through traffic, which may even increase its use of street capacity vacated by autos no longer parking.

2. Road User Tax -- Another pricing measure that could be used to discourage auto trips is to implement a road-user tax. Charging autos to travel through the dense city center would reduce traffic volume considerably. Such a plan could be implemented by charging a toll for vehicles entering a central cordon area. Other means of collection, such as a daily pass displayed within the vehicle, have been proposed. As a means of implementing a pricing policy, a road user charge has the advantage of being applied to moving vehicles, not merely those that park in the area. Like higher parking charges, however, the measure is selective toward those in a particular area and therefore politically difficult to implement.

3. Gasoline Tax -- Increasing gasoline taxes as a means to discourage auto trips into central areas has been suggested from time to time. Although there is no information to substantiate any conclusion in this area, it does appear that gasoline taxes would affect auto travel. Depending on the amount, the tax could reduce trip making or encourage the use of more economical autos. The British tendency toward small-displacement engines, which taxes motor fuels heavily, is a case in point. The tax would have to be applied over a wide region in order to discourage motorists from going to outlying areas to buy their gasoline. Even more important, the gasoline tax is not a direct out-of-pocket cost which the motorist must bear each time he makes a trip. Therefore, his sensitivity to a gasoline tax would not be as great as his sensitivity to a more direct toll system.

4. Car Pool Incentives -- Typical urban-area auto occupancy for travel to work is 1.2 to 1.3 persons per vehicle. Through car pooling, the same number of employees could be accommodated in far fewer autos. Pricing policy could be used to provide incentives for car pooling. Tolls could be higher for low-occupancy vehicles. In particular, such a scheme might prove worthwhile for cities where a large percentage of commuter traffic utilizes bridges and tunnels where tolls already exist or could be implemented easily. Note that uniform but higher tolls also would encourage car pooling.

D. Planned Unit Development

The evolution of planned unit development and new towns over the past decade is encouraging to the air pollution abatement agencies. Planned unit development brings various land uses together on a neighborhood level; the "new town" concept does so on a town basis.

Locating residential areas near shopping and employment centers minimizes the need for vehicular travel by locating major trip origins and destinations near to each other.

Although their impact on air quality is long term, planned unit developments should be actively promoted by traffic engineers and air pollution control officials. The Urban Planning Guide will explore this concept in greater detail.

APPENDIX A

INTRODUCTION TO AIR POLLUTION

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INTRODUCTION TO AIR POLLUTION

Recent legislation requires that the transportation professional consider the air pollution impact of his plans. To do so, he must become familiar with air pollution terminology and characteristics. The purpose of this appendix is to provide this information.

TYPES OF POLLUTANTS AND THEIR SOURCES

A. Classification of Pollutants

Air pollutants are commonly classified as either gaseous or particulate. Gaseous pollutants behave much like the air itself; they do not settle out. Particulate pollutants may be either solid or liquid, and their performance in the atmosphere varies according to chemical composition and size: heavier particles settle close to the point of emission; and smaller, less-dense particles travel great distances. Urban aerosols, formed by the grinding or atomization of solids and liquids, are particulate matter ranging in size from approximately 6×10^{-7} to 1 micron; they include mist, smoke, dust, fumes, and spray.

Air pollutants also can be categorized as either primary or secondary. A primary pollutant is emitted directly into the atmosphere and initially retains its form as emitted. A secondary pollutant is formed in the atmosphere from reactions that may be chemical, photochemical, or biological.

A third way of classifying pollutants is by chemical composition -- either organic or inorganic. Many of the most common pollutants -- the oxides of carbon, nitrogen, and sulfur -- are inorganic; organic pollutants include hydrocarbons, aldehydes, and ketones.

To classify an air pollutant properly all three classifications should be used; for example, carbon monoxide is a primary, inorganic, gaseous pollutant.

B. Units of Air Pollution Measurement

Air pollutants can be quantified in several ways: on the basis of emissions from sources, according to concentrations in the ambient air, or according to rates of exposure.

The source strength of air pollutants can be quantified in units of mass or weight per unit volume, for example, grams per cubic meter of air or pounds per cubic foot. Emissions may also be stated in terms of weight per unit time, weight per unit weight of product, weight per BTU, weight per unit area for area sources, or mass per unit distance for vehicles.

Concentrations of pollutants in the ambient air are normally reported as mass or weight per unit volume of air, such as micrograms per cubic meter. The unit parts per million (ppm), although used, is being discontinued. Settleable particulate matter sometimes is expressed in terms of tons per square mile per month or the currently recommended grams per square meter per month; and suspended material as micrograms per cubic meter or Coh's (Coefficient of Haze), a unit of measurement of visibility interference.

Also of concern in the expression of concentrations of air pollutants is the quantity and duration of exposure experienced by plants, animals, or humans. Called the dosage or rate of exposure, units indicate both concentration and time involvement, with levels stated in terms of micrograms per cubic meter either per hour, 8-hour period, day, or year. In many cases, the average concentration over a given period of time is of concern; in other cases, the maximum concentration is more important.

When reviewing regulations or statements concerning concentrations of air pollutants, it is important to understand the units used; that is, whether they relate to the ambient air concentrations, to emissions, or to exposure dosages.

C. Classification of Sources

Pollutants emitted to the air in greatest abundance are carbon monoxide (CO), oxides of sulfur (SO_x), oxides of nitrogen (NO_x), hydrocarbons (HC), and particulate matter. Emission inventories of these five pollutants are commonly divided into five source categories: transportation, fuel combustion in stationary sources, industrial processes, solid waste disposal, and miscellaneous. Nationwide emissions by category, presented in Table A. 1, indicate that carbon monoxide is the major pollutant by weight, and that transportation activities are the major carbon monoxide contributor. Emissions of urban origin from stationary combustion and transportation activities, account for greater than 75 percent of the total emissions in these five pollutant categories. The motor vehicle is a major contributor to air pollution. It contributes approximately 92 percent of the total transportation carbon monoxide, about 50 percent of the hydrocarbons, and 40 percent of the nitrogen oxides.[20]

VARIATIONS IN AIR POLLUTION CONCENTRATIONS

Variations in pollutant concentration at or near ground level are a function of both meteorological parameters and emissions, both of which vary in time and space. Both fluctuate from place to place according to daily and annual patterns; the latter also exhibit weekly variations. Thus, pollutant concentrations are a function of location, time of day, day of the week, and season of the year.

Table A.1. ESTIMATED EMISSIONS OF AIR POLLUTANTS BY WEIGHT,[a] NATIONWIDE, 1969[21]

Source	CO	Particulates	SO_x	HC	NO_x
Transportation	111.5	0.8	1.1	19.8	11.2
Fuel combustion in stationary sources	1.8	7.2	24.4	0.9	10.0
Industrial processes	12.0	14.4	7.5	5.5	0.2
Solid waste disposal	7.9	1.4	0.2	2.0	0.4
Miscellaneous	18.2	11.4	0.2	9.2	2.0
Total	151.4	35.2	33.4	37.4	23.8

[a] In millions of tons per year.

A. Variations According to Location

Variations according to location are the natural product of non-uniform distribution of pollution sources; for example, freeway versus center city traffic, and the random movements of air and weather patterns (rain and fog). Figures A.1, A.2, and A.3 illustrate significant variations in pollutant concentrations (in this case, carbon monoxide) as they relate to location in each of three large urban areas across the nation.

The many meteorological observations accumulated over decades permit a fairly reliable estimate of the air pollution potential in various sections of the United States. Regions with a clean sweep of winds within the major storm tracks are least likely to develop high pollution conditions; regions dominated by stagnant air masses and light winds are most likely to experience high pollution conditions.

B. Variations by Time Periods

Space heating and solar radiation are the two major factors influencing seasonal variations in air pollution levels. Secondary pollutants, such as photochemical oxidants, generally are worst in the late summer or autumn when optimal combinations of solar radiation, temperature, and atmospheric stagnations coincide.

Weekly variations in carbon monoxide are a function of the different transportation and activity patterns associated with weekdays, weekends, and holidays. A study[22] revealed a distinct 20 percent decrease in the average carbon monoxide concentrations during the weekend compared to the higher weekday levels. In urban communities, where there are many week-end travelers, the reduction is considerably less.

In general, meteorological conditions at night encourage the accumulation of pollutants; those in the day encourage their rapid dispersion. Diurnal variations in carbon monoxide concentrations are illustrated in Figures A.1, A.2, and A.3; Figure A.4 shows diurnal variation in concentrations of

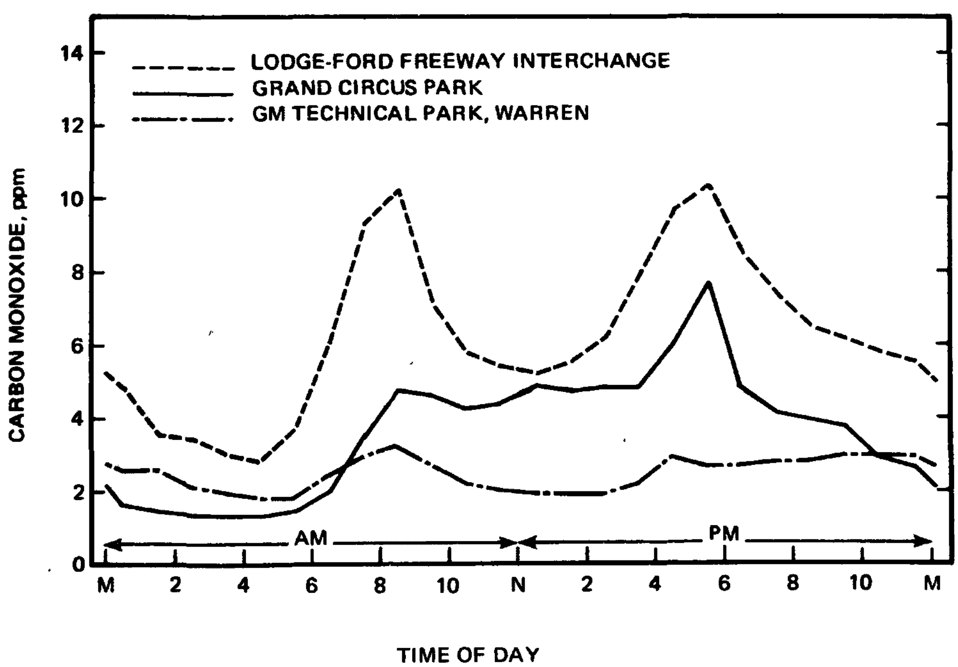

Figure A.1. Hourly carbon monoxide concentrations on weekdays in Detroit area.[22]

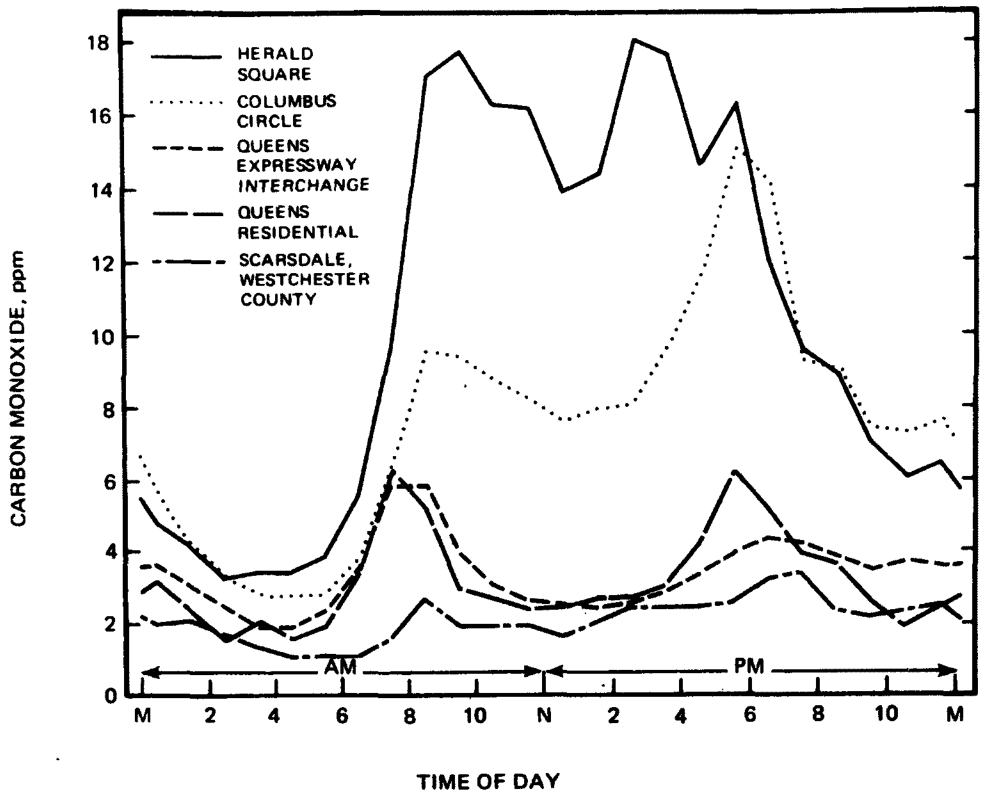

Figure A.2. Hourly carbon monoxide concentrations on weekdays in New York area.[22]

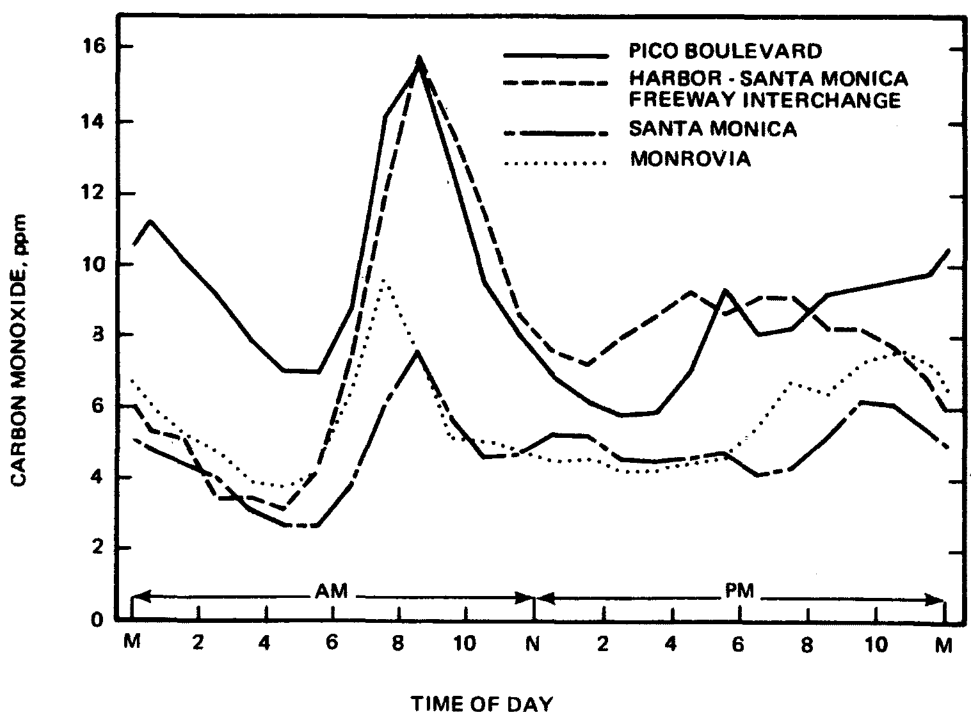

Figure A.3. Hourly carbon monoxide concentrations on weekdays in Los Angeles area.[22]

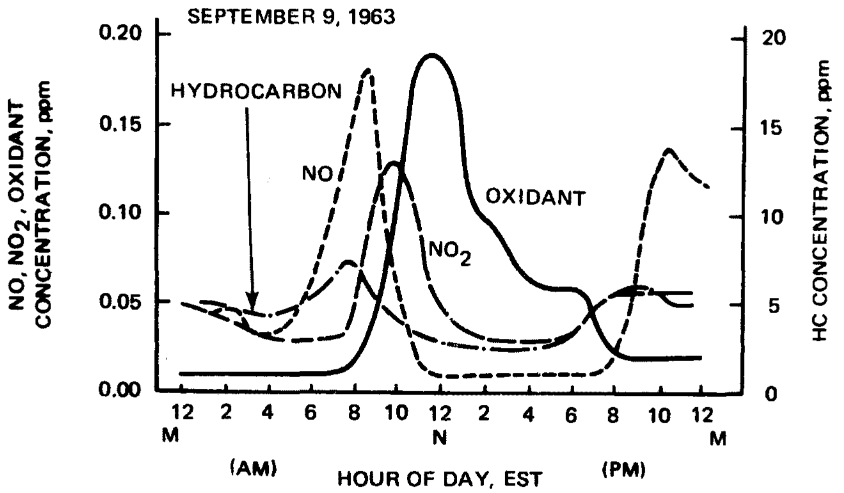

Figure A.4. Concentrations of nitric oxide, nitrogen dioxide, hydrocarbon, and oxidant during a smoggy day in Cincinnati, Ohio.[23]

hydrocarbons, nitrogen oxides, and oxidants. In all of these cases, carbon monoxide, hydrocarbons, and nitrogen oxides exhibit two daily peaks, and considerable work[24] has been directed toward correlating these peaks with traffic flow and meteorological factors. However, only one peak has been observed for photochemical oxidants; it generally occurs in the early afternoon during the favorable reaction conditions of solar radiation and temperature. The delay between the hydrocarbon and nitrogen oxide peaks and the oxidant peak is normal because the oxidants are produced by chemical reactions involving hydrocarbons and nitrogen oxides.

METEOROLOGY

Meteorological and topographical conditions in some areas favor the accumulation of pollutants. Lighter particles and gases as emitted by vehicles diffuse only as rapidly as meteorological conditions permit. During this diffusion, the nature of the pollutants may be changed by natural, physical or chemical processes, such as solar radiation, rain, fog, and interaction with the normal constituents of the atmosphere. Typical examples are the oxidation of nitric oxide to nitrogen dioxide and the photochemical action that forms oxidants.

In a dry atmosphere, the adiabatic lapse rate (rate of temperature decrease with increase in elevation) is $1^{\circ}C$ per 100 meters ($5.4^{\circ}F$ per 1,000 feet). When the actual lapse rate is greater than this theoretical rate, a parcel of air that begins to rise continues to do so and the atmospheric condition is called "unstable." If, however, the actual lapse rate is less than the adiabatic rate, the surface air remains near the surface and the atmospheric condition is called "stable."

An increase of temperature with altitude (an inversion) can occur at any time, but is most common during the night and early morning. An inversion acts as a lid; it separates layers of air and prevents polluted air from rising. If an inversion is accompanied by low winds, a layer of highly polluted air may build up over a broad area.

Three major forces -- wind, heating, and cooling -- cause shifts from stable to unstable conditions and back again. Wind, in addition to horizontal motion, usually has vertical eddies and, since rapid vertical air motions tend to be adiabatic, helps to establish an adiabatic lapse rate. The sun, which heats the surface more than the air, increases the lapse rate and, thus, contributes to instability. Conversely, at night the ground loses more heat by radiation than the air does, tending to make the surface cooler than the air layers above; this cooling contributes to stability. Usually there is a daily cycle from stability to instability and back again.

When the cycle is broken and the atmosphere remains stable for a prolonged period of time, a serious accumulation of pollutants is possible.

High pollution potentials are generally favored by light winds and clear skies which promote the formation of temperature inversions. A buildup of high pollution concentrations in the central core of the cities then occurs as the result of this inversion "lid" coupled with a near-surface air movement toward the center city. This air flow is the result of the heat island effect in which the asphalt and concrete city heats up and acts like a chimney, drawing in cooler air from the surrounding areas.

High pollution potential is defined as a stagnating anticyclonic condition which, coupled with the continued operation of several sources, is conducive to the occurrence of high concentrations of pollution. As defined, the high pollution potential refers to developing meteorological factors only. The National Meteorological Center in Suitland, Maryland prepares daily 36-hour alerts. This information, called Air Stagnation Advisories (ASA), is available through U.S. Weather Bureau Stations. Being an objective system, the method has its shortcomings, the greatest of which is the lack of individual appraisal and forecasting for each city based on its local meteorology, and areal distribution of pollution sources. The local air pollution control office can provide the necessary in-depth knowledge of a specific urban community.

Within the space of a few miles, microclimatic conditions may considerably influence the effects of pollution. A detailed survey of the meteorological terrain is needed to assess variations in local conditions; this is particularly advisable when planning future communities and industrial areas. For example, it used to be a rule of thumb to locate industrial areas downwind of a settlement with respect to the prevailing wind direction. Unfortunately, in many instances the wind at times of stagnation or near-stagnation conditions may be quite different from the most frequent wind. In some cases, the slight draft under those conditions may be entirely opposite to the prevailing wind, thereby causing a more severe pollution condition than would have been anticipated.

SITE CONDITIONS AFFECTING DISPERSION

The city in a general sense may be considered a collection of microclimates. The pattern and profile of the air motion in the total atmosphere over an urban area are modified, sometimes considerably, in each of these microclimates by the spatial arrangement and character of buildings and other structures, by surrounding vegetation, and by roadway configurations. Superimposed on this is the air movement resulting from traffic flow. In addition, the relative influence of each of these factors depends on the magnitude of the background air movement and solar heating conditions. Factors found to be dominant at higher wind speeds may decline in significance at the lower wind speeds which present the greater potential for severe pollution episodes.

A. Urban Heat Island Effect

The combined effects of topography and urbanization decidedly influence the radiation, moisture, and temperature conditions of a city. These in turn modify the wind flow patterns. In an urbanized region, vegetation is replaced by a vast man-made environment resulting in changes in moisture conditions which in turn alter the heat distribution. The air is heated by multiple sources including industries, automobiles, space heating, and solar radiation.

It has been estimated that the automobile is an important artificial heat source in the street canyons of a city. Very heavy traffic in parts of London, for example, add an estimated 8°F to the air temperature. Bach[25] calculated that for the built-up area of Sheffield, England, the annual artificial heat generation is about one-fifth of the direct solar radiation received. The ratio is one-third for Berlin. Particulate matter, a byproduct of most artificial heat generation, is 5 to 25 times greater in the urban area than in the rural area.

Temperatures in the urban heat island have been found to be on the order of 5-8^{o}C greater at night than in the surrounding rural areas. Sidewalks, roads, and concrete buildings have relatively high heat capacities and conductivities. The daytime heat storage is greater than for grass-covered fields or forests. The lack of evaporational cooling from the dry building surfaces increases the stored solar energy. After sunset, the stored daytime heat is released from buildings and pavements resulting in air temperatures and winds in the city higher than those occurring in the surrounding country. Munn[26] notes that the heat storage ability of a city is believed to be the major factor of the heat island formation, he adds that the city is a collection of microclimates each dependent upon the character of a built-up area within the entire city.

The heat island effect is found to be maximum in late summer and early autumn when the skies are clear and winds are light. Figures A.5 and A.6 illustrate the morning and evening air circulation and dispersion models in a city and in the surrounding country under anticyclonic conditions.

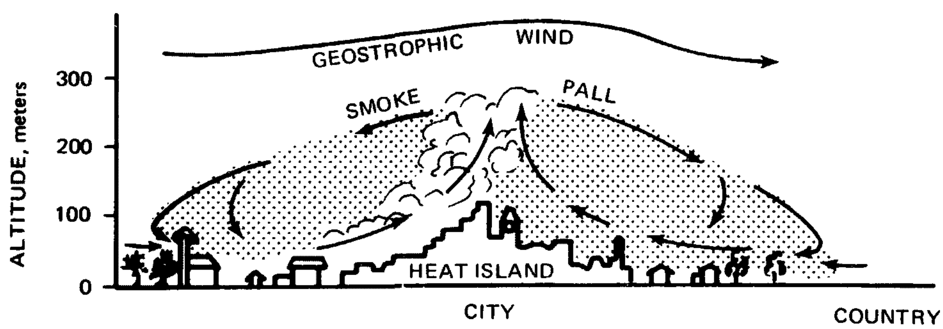

Figure A.5. Urban circulation and dispersion after sunrise.[25]

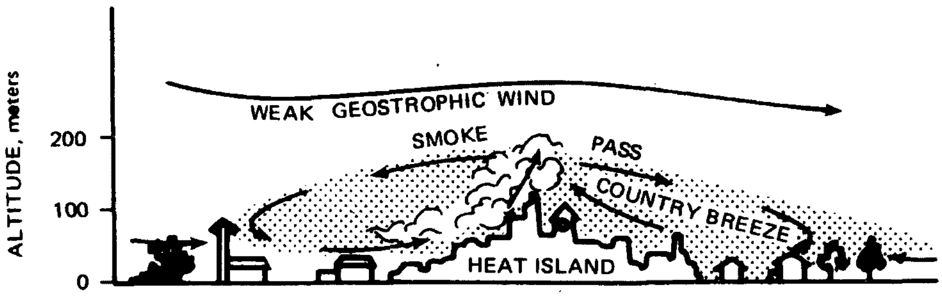

Figure A.6. Urban circulation and dispersion after sunset.[25]

B. <u>Building Configuration</u>

The orientation of a building with respect to the winds produces significant distortions in the local wind pattern. The significance of the flow distortions becomes clear when vehicular emissions exist within an area surrounded by buildings. Air currents can trap pollution, confining it close to the buildings. Pollutants emitted from building roof vents may also become trapped. Hence, roadway vehicular emissions and emissions from roof tops can be conveyed into windows, doorways, and air intake systems.

As background wind speeds decrease, the effect of the vertical temperature profile (lapse rate) increases and becomes a major controlling factor in the atmospheric dispersion of vehicular emissions in the urban street canyon.

During periods of light winds and clear skies, air flow around buildings is, to a great degree, the result of convective updrafts coupled with winds flowing into the center of the urban heat island. The updrafts remove pollutants from the area of the building more effectively than strong horizontal winds if no inversion exists.

The upward dispersion of vehicular emissions is often restricted in the early morning hours by the presence of a stable layer existing from the ground to roof level. The pollutants are trapped in or below this layer. This phenomenon is most pronounced in the walled street canyons of urban centers.

Various building configurations and orientations alter the air flow pattern considerably. Rows of tall buildings lining urban streets modify the microclimate by changing the topography and general aerodynamic boundaries. In these street canyons, the dispersion of the pollutants is determined by the turbulent wake of the traffic, by the differential heating of building tops and streets, and by the general background air movement. Wind speeds at street level may be only 40 percent of the wind speed above the roofs of the buildings.

More open roadway planning with the buildings set back will alleviate this canyon effect. While traffic volume along a roadway section has the most direct relationship to emissions, the higher mid-afternoon wind speeds are the most effective factor in reducing the urban street canyon air pollution concentrations. This effect is gradually lost later in the afternoon as the overall wind speeds start to decrease and traffic volume once again peaks.

C. Roughness Effects

As noted above, the background wind is also modified by the texture and height of surrounding features: buildings, trees, grass, brush, and streets. For example, as wind passes from an orchard to an open field, the wake effect is similar in many ways to that behind a building. Within approximately one-quarter mile the original near-surface wind speed is reestablished. There is an updraft in the air movement as it encounters a rougher surface, such as a row of trees.

Thus, a wide tree-covered green belt along both sides of a major traffic artery provides more rapid dispersion of vehicular emissions. In an urban area, similar transitions can be arranged -- between roadway and green belt, park and buildings, parking lots and streets, and low- and high-rise buildings. The resulting turbulence can lead to more dispersion and dilution.

APPENDIX B

GLOSSARY

APPENDIX B

GLOSSARY

Aerosol	A dispersion of solid or liquid particles of microscopic size in gaseous media. Examples are smoke, fog, and mist.
Air pollution	The presence of unwanted material in the air in sufficient amount and under such circumstances as to interfere significantly with comfort, health, or welfare of persons, or with full use and enjoyment of property.
Ambient air quality	A physical and chemical measure of the concentration of various chemicals in the outside air. The quality is usually determined over a specific time period (for example, 5 minutes, 1 hour, 1 day).
Anticyclone	An area of relatively high atmospheric pressure. In the northern hemisphere, the wind blows spirally outward in a clockwise direction.
Arterial	A major through street, four lanes or more with no (or only limited) access control.
At-grade roadway	Roadway which is at the same level with adjacent land.
BTU	British thermal unit. A measure of heat, Specifically, 1 BTU is the amount of heat required to raise the temperature of 1 pound of water $1^{o}F$ at or near $39.2^{o}F$.
Channelization	Facilitating the flow of traffic by separating or regulating conflicting traffic movements of intersections at grade by use of markings, signs, raised islands, etc.

Coh	Coefficient of haze. A unit of measurement of visibility interference.
Cordon area	An area surrounded by an imaginary line at which surveys are undertaken for traffic analysis.
Cross-elasticity	The change in demand for one mode resulting from a change in the explanatory variables of an alternative mode. (Compare with elasticity.)
Depressed roadway	Roadway which is below adjacent land.
Diurnal	Daily, especially pertaining to actions or events that are completed within 24 hours and that recur every 24 hours.
Downtown distribution system	The local streets in the downtown area that serve adjacent buildings and facilities.
Dust	A term loosely applied to solid particles, predominantly larger than colloidal, capable of temporary suspension in air or other gases.
Elasticity	The percentage change in demand resulting from a 1-percent change in one of the explanatory variables, everything else remaining constant. (Compare with cross-elasticity.)
Elevated roadway	Roadway which is above adjacent land.
Emissions	The total substances discharged into the air from a stack, vent, tail pipe, carburetor, or other source.
Episode	The occurrence of stagnant air masses during which air pollutants accumulate, so that the population is exposed to an elevated concentration of airborne contaminants.
Forced-flow conditions	Roadway traffic flow above the capacity of the roadway, usually bumper-to-bumper stop-and-go traffic.
Gas	One of the three states of aggregation of matter, having neither independent shape nor volume, and tending to expand indefinitely.

Geostrophic wind	Wind that exists in a region approximately 300 to 1000 meters above the surface of the earth and is generally not influenced by surface friction. Its speed constitutes a balance of the forces from the pressure gradient and rotation of the earth.
Inversion	A layer of air in which temperature increases with height.
Major/minor direction	Applies to a roadway at those times when traffic flow in one direction (major) is two (or more) times the flow in the other (minor). Usually occurs during morning and afternoon rush hours.
Microeconomic	The economics over a small section of the total economy, usually referring to only a small number of items.
Midblock frictional elements	Those traffic hinderances causing delays in traffic flow between intersections, such as parked cars, pedestrian crossings, truck loading zones, and driveways.
Mode	Method of transportation such as bus, auto, walking, rapid transit, or taxi.
Month	For reporting analysis of ambient air on a monthly basis, results are calculated to a base of 30 consecutive 24-hour periods.
Peak traffic demand	That traffic flow on an individual street or in an entire area which is the greatest. Usually the peak traffic demand is considered over a short period of time (15-60 minutes) per day.
People movers	Moving walkways, escalators, small automated cars on fixed routes, etc.
Queue	A standing or slow moving line of autos or people.
Right-of-way	The land occupied by a roadway.
Smog	A combination of smoke and fog. Extensive atmospheric contamination by aerosols arising partly through natural processes and partly from human activities. Often used loosely for any air contamination.

Smoke	Small gas-borne particles that are produced by incomplete combustion, consisting predominantly of carbon and other combustible material, and present in sufficient quantity to be detectable independently in the presence of other solids.
Solid-fill cross-section	An elevated section of roadway on earth fill.
Topography	The configuration of a surface, including its relief and the position of its natural and man-made features.
Traffic assignment	A modeling process whereby trips from all origins to all destinations are assigned to specific routes, based on travel time and other factors.
Vapor	The gaseous phase of matter that normally exists in a liquid or solid state.
V/C ratio	The ratio of volume, or number of vehicles, using a roadway to the capacity of that roadway.
Weaving	The crossing of traffic streams moving in the same general direction, accomplished by merging and diverging.
Weaving section	A length of roadway designed to accommodate weaving: at one end, two roadways merge; and at the other, they separate.
Year	For reporting analysis of ambient air on a yearly basis, results are calculated to a base of 12 30-day periods.

APPENDIX C

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APPENDIX C

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