PROVIDING FOR AIR QUALITY AND URBAN MOBILITY

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The process of incorporating air quality considerations in planning, the basic relations between transportation and air pollution, techniques for achieving air quality, and the institutional difficulties of implementing transportation control techniques are discussed in this exploration of ways in which air pollution considerations might be incorporated in the decision-making process. The air quality problem related to transportation is not solely a function of vehicle emissions, and the planner must understand how factors such as direction and speed of wind, time of day, and physical barriers affect the problem. Primary and secondary air quality standards established by federal and state governments are discussed and tabulated. The relation of vehicle technology and the effects of speed, travel mode, and operation mode on the emission of pollutants are set forth. Techniques of air quality control are grouped into programs oriented toward vehicles, traffic flow, and reduction of pollution concentration. There is a need for improvement of communications between DOT and EPA, and obstacles that may arise are noted. The report shows that transportation control techniques may be used to achieve air quality (some of these may infringe on mobility goals and others may not). It is suggested that short-term actions aimed at ameliorating air pollution must aim at fostering communication among responsible agencies. Long-term actions require research and more analytical information.

•RESIDENTS of urban America have a variety of social goals, all of which may be desirable but many of which may be conflicting. One such conflict within the present state of technology and controls is that between urban mobility and an air-pollution-free environment.

Mobility goals require that a transportation technology and system be available to provide safe, rapid, convenient, and economical linkages between different land uses for all segments of our society. In the past these goals have been achieved by using conventional transit systems and the automobile. These transportation decisions have resulted in our present level of mobility. In addition, the resulting transportation technologies and systems have affected the urban and economic structure of our metropolitan areas and have contributed to air and noise pollution, water pollution, and loss of social amenities.

Environmental goals, on the other hand, relate to the air we breathe, the water we drink, and the land on which we live. It is clear that these goals were not addressed seriously in the past. This was due in part to a lack of knowledge about the pollution problem, that is, to a lack of understanding of the effects of transportation decisions on the environment. Today there is sufficient evidence to see how actions to achieve mobility goals may create a pollution problem. Conversely, attempts to achieve environmental standards may create mobility problems for segments of our population and have serious economic effects on business, industry, and even personal income.

The objective of this paper is to explore ways in which air pollution considerations might be incorporated into the decision-making process. This objective may be achieved by incorporating air quality considerations in transportation planning. In this paper, the basic relations between transportation and air pollution will be set forth, and

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techniques for achieving air quality will be described. With this information, the institutional difficulties of implementing transportation control techniques to achieve air quality will be set forth. Finally, conclusions will be set forth on short- and long-term directions that might be taken.

INCORPORATING AIR POLLUTION CONSIDERATIONS IN TRANSPORTATION DECISIONS

Figure 1 shows how air quality considerations can be incorporated into the planning process. As indicated, transportation alternatives produce air pollutant emissions, generally as a line source. These emissions, when combined with current background air pollution levels, spread or diffuse in the atmosphere and result in certain levels of air pollution that either meet or exceed the air quality standards for that area. If the standards are exceeded, the air pollution might then be reduced by modification of the transportation or land use plan and by direct controls on the emission sources.

Because the air quality problem related to transportation is not solely a function of vehicle emissions, the planner must understand how the immediate problem may be aggrevated or relieved by certain factors such as wind speed, wind direction, time of day, physical barriers, and other elements that tend to affect the dispersion of pollutants. If, because of adverse meteorological and site characteristics, pollutants tend to concentrate in a given area, factors other than emissions must also be considered in the introduction of transportation and air quality goals. It then becomes a question of the amount and location of mobility or the quality and location of pollution control. Thus, air quality is a prime consideration of overall urban mobility and must be included in the process described.

Based on provisions of the Clean Air Amendments of 1970, the Environmental Protection Agency (EPA) has formulated emission standards for individual groups of vehicles and air quality standards for a geographic region. The emission standards are, of course, the core of a control program aimed at reducing air pollution. The motor vehicle in 1969 accounted for an estimated 60 percent of the total carbon monoxide (CO) from all sources, about 50 percent of the hydrocarbons (HC), and about 35 percent of the nitrogen oxides (NO_x) (1). The other major gaseous pollutants, oxides of sulfur (SO_x), are developed primarily from power plants, such as those used to power urban electric systems, and other stationary sources. Thus, urban transportation severely affects the urban air environment.

Minimum air quality standards are established by the federal government for certain pollutants. The various states, however, may set more stringent standards if they so desire.

Primary ambient air quality standards were developed to protect the public health, and secondary standards were set to protect the public welfare. National primary and secondary ambient air quality standards are given in Table 1. Each standard specifies an averaging time, frequency, and concentrations. The standards specify that the maximum concentrations are not to be exceeded more than once per year. The responsibility for attaining the ambient air quality standards is with the states and local air quality control agencies.

BASIC RELATIONS AND EFFECTS

Many factors affect the air pollution generated by transportation facilities: emission control and technology, vehicle speed, operation mode, traffic mix, topography, altitude, wind speed, wind direction, and local meteorology. The basic relations needed to estimate air pollution from transportation policies vary by the type of pollutant and the state of the art.

Control Technology and Emission Factors

The basic cause of automobile air pollution is the technology of the vehicle itself. EPA has promulgated certain requirements to reduce vehicle emission levels. A timetable for achieving reduced vehicle emission levels was included in the 1970 Clean Air

Figure 1. Air quality considerations in the planning process (8).

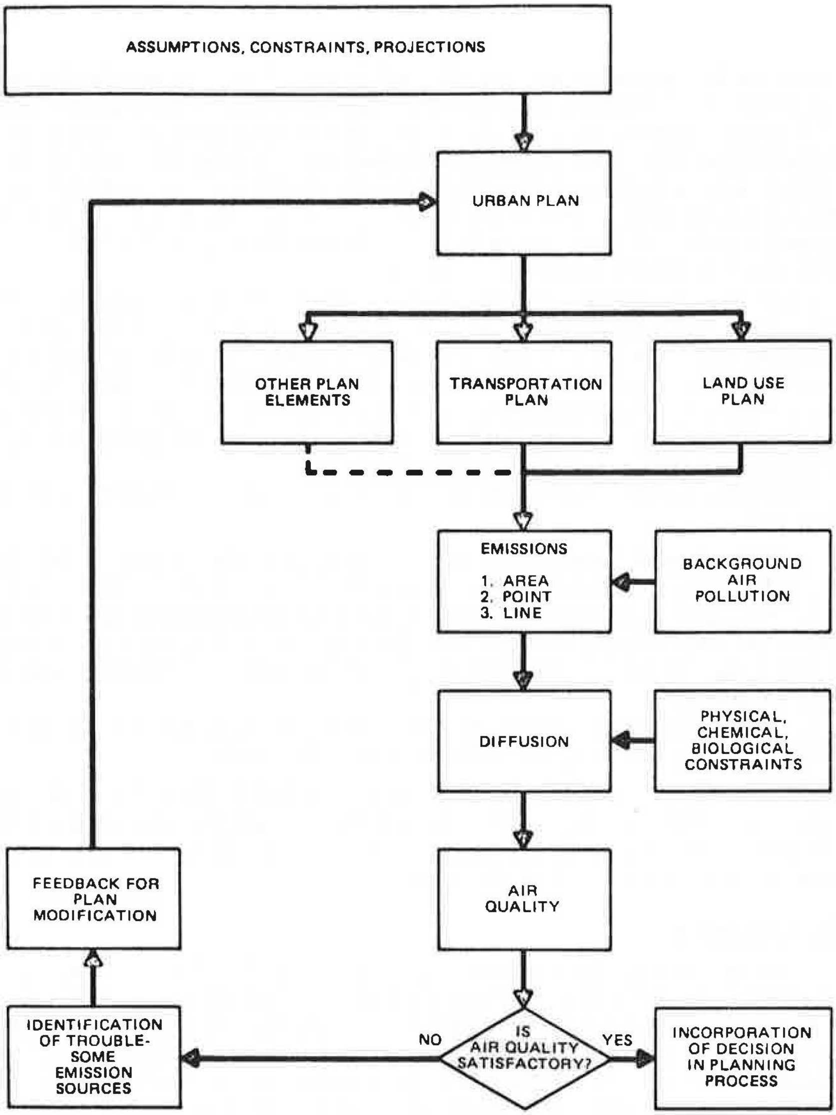


Table 1. Primary and secondary ambient air quality standards (2).

Pollutant	Standard	Averaging Time	Frequency Standard	Concentration µg/m	Concentration ppm
Carbon monoxide	Primary and secondary	1 hour	Annual maximum[a]	40,000	35
		8 hours	Annual maximum	10,000	9
Hydrocarbon (nonmethane)	Primary and secondary	3 hours (6 to 9 a.m.)	Annual maximum	160[b]	0.24[b]
Nitrogen dioxide	Primary and secondary	1 year	Arithmetic mean	100	0.05
Photochemical oxidants	Primary and secondary	1 hour	Annual maximum	160	0.08
Particulate matter	Primary	24 hours	Annual maximum	260	—
		24 hours	Annual geometric mean	75	—
	Secondary	24 hours	Annual maximum	150	—
		24 hours	Annual geometric mean	60[c]	—
Sulfur dioxide	Primary	24 hours	Annual maximum	365	0.14
		1 year	Arithmetic mean	80	0.03
	Secondary	3 hours	Annual maximum	1,300	0.5
		24 hours	Annual maximum	260[d]	0.1[d]
		1 year	Arithmetic mean	60	0.02

[a] Not to be exceeded more than once per year.
[b] As a guide in devising implementation plans for achieving oxidant standards.
[c] As a guide to be used in assessing implementation plans for achieving the annual maximum 24-hour standard.
[d] As a guide to be used in assessing implementation plans for achieving the annual arithmetic mean standard.

Amendments requirements for new motor vehicles. These standards include a reduction of 90 percent (from 1970 levels) in hydrocarbons and carbon monoxide emitted by 1975 vehicles and a reduction in oxides of nitrogen of 90 percent to be achieved by 1976. Table 2 gives the effect of these standards on reducing the rate of emissions of various pollutants from automobiles and light-duty trucks (3). In addition to control technology, vehicle speed, and operation mode, the mix of vehicle types and ages can affect the emission rate and hence air pollution. The factors given in Table 2 represent the vehicle mix for the calendar year shown.

Vehicle mix includes passenger automobiles, light-duty trucks, and gasoline-powered heavy-duty vehicles including buses. Each vehicle class is weighted by number of vehicles by age to account for deterioration of vehicles with age and mileage and by the higher control standards for new vehicles established by federal regulations.

As indicated, the standards imposed on gasoline-powered vehicles and the controls designed to achieve those standards will do much to reduce the pollution level and achieve the ambient air quality standards.

However, many parties speculate that the automotive emission standards may not be achieved:

1. The automobile manufacturers have emphasized strongly that they would not be able to develop the requisite technology in time to meet the 1975-1976 standards.
2. Because a pollution-free engine may not be developed for a reasonable price within the near future, chances are that some kind of mandatory inspection system will be required. However, the technology for measuring emissions quickly and cheaply does not yet exist.
3. The prospects of replacing the internal-combustion engine with unconventional power systems are minimal in the foreseeable future.

These factors reinforce the need to plan transportation facilities and programs to reduce air pollution emissions, concentrations, and human exposure to air pollution. A balanced and comprehensive approach to solving the air pollution problem is the most effective way to achieve the standards.

Effect of Speed

For the emission factors given in Table 2, certain basic relations exist between the emission rate and average network speed. Figures 2 and 3 show the relation between emission rates and speed for highway vehicles for CO and HC by year. This relation represents urban driving conditions and assumes an inherent mode of operation, including a cold start (3). The average speeds are for passenger automobiles and light-duty trucks in proportion to their use. Allowance is made for deterioration and scrapping of vehicles as they age and are replaced by new (controlled) vehicles.

Figures 4 and 5 show the speed-emission relations for rural driving conditions where a hot start is assumed (3). It should be noted that these curves represent the information available to the author in August 1972. More precise information should be made available in the last quarter of 1972. These figures show a negative relation between speed and CO and HC emissions because these emissions are influenced by the air-fuel ratio supplied to the engine. Concentrations tend to decrease as this ratio increases with higher speeds (3).

The speed-emission relation is not so certain for oxides of nitrogen. It appears that there is a positive relation because NO_x formation is influenced by combustion temperature and the amount of oxygen available for interaction with nitrogen, which is not necessarily a concomitant of speed (3).

Figure 6 shows this relation as determined from tests of automobiles for both a steady-state speed and an average speed under actual driving conditions (4). These tests support the conclusion that nitric oxide emissions do tend to increase at higher speeds. Other work has shown similar results (5).

The quandry posed by these relations is the issue of speed being positive in reducing HC and CO but working in an opposite manner in the case of NO_x. There is a need for more adequate data on these basic relations, particularly with regard to NO_x emissions.

Table 2. Emission factors for gasoline-powered motor vehicles (grams per vehicle-mile) (3).

Emission	1960	1965	1970	1971	1972	1973	1974	1975
Carbon monoxide								
Urban	120	120	95	90	85	80	75	60
Rural	70	70	60	55	50	45	40	35
Hydrocarbons								
Evaporation	2.7	2.7	2.7	2.3	2.3	1.8	1.8	1.4
Crankcase[a]	4.1	2.7	0.9	0.45	0.45	0.32	0.22	0.22
Exhausts								
Urban	16	16	12	11	9.5	8.5	7.2	6
Rural	10.5	10.5	8	7	6.5	6.0	5.0	4
Nitrogen dioxide (NO_x as NO_2)	6.6	6.6	6.63	6.47	6.17	5.75	5.55	4.90
Particulates[b]	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.1
Sulfur oxide[c] (SO_2)	0.18							
Aldehydes (HCNO)	0.36							
Organic acids	0.13							

Note: Average urban speed of vehicles is 25 mph; average rural speed is 45 mph.

[a]Crankcase emissions for vehicles after 1962 are negligible. These data are based on pre-1962 vehicles left in the vehicle population.
[b]Urban factor = rural factor.
[c]Based on sulfur content of 0.04 percent and a density of 6.17 lb/gal.

Figure 2. Carbon monoxide emissions (urban).

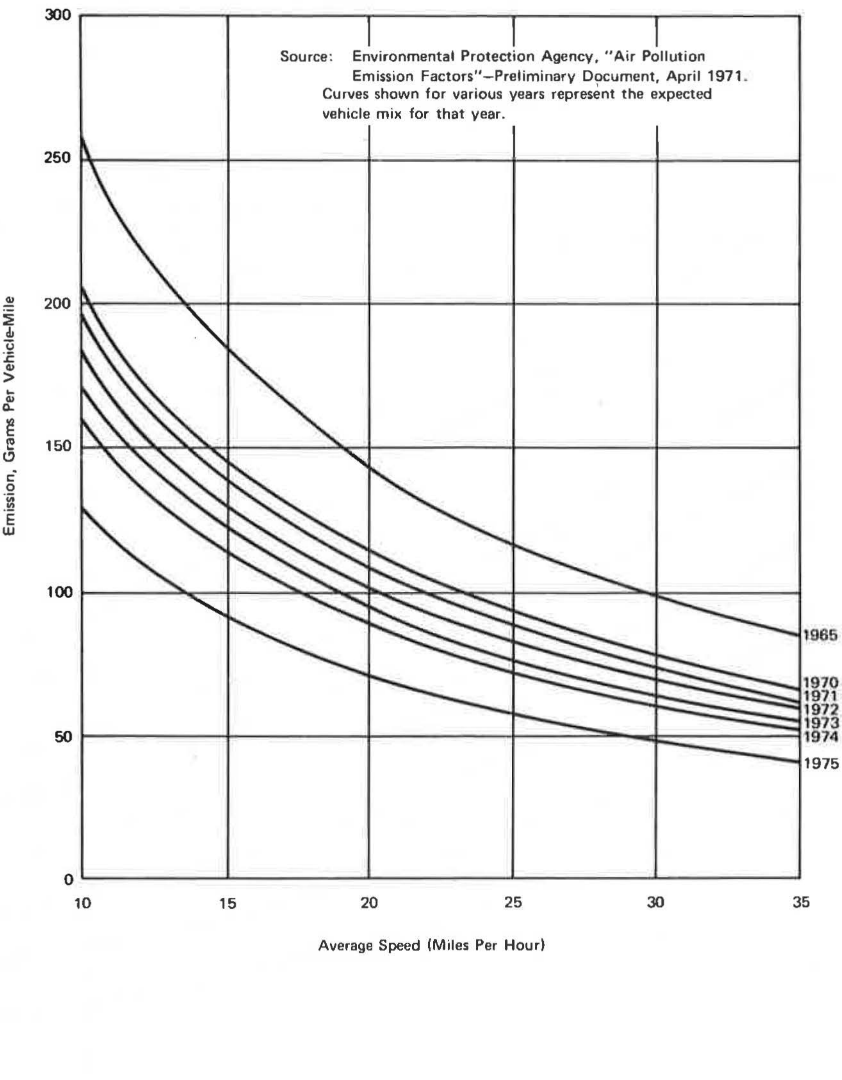


Figure 3. Hydrocarbon emissions (urban).

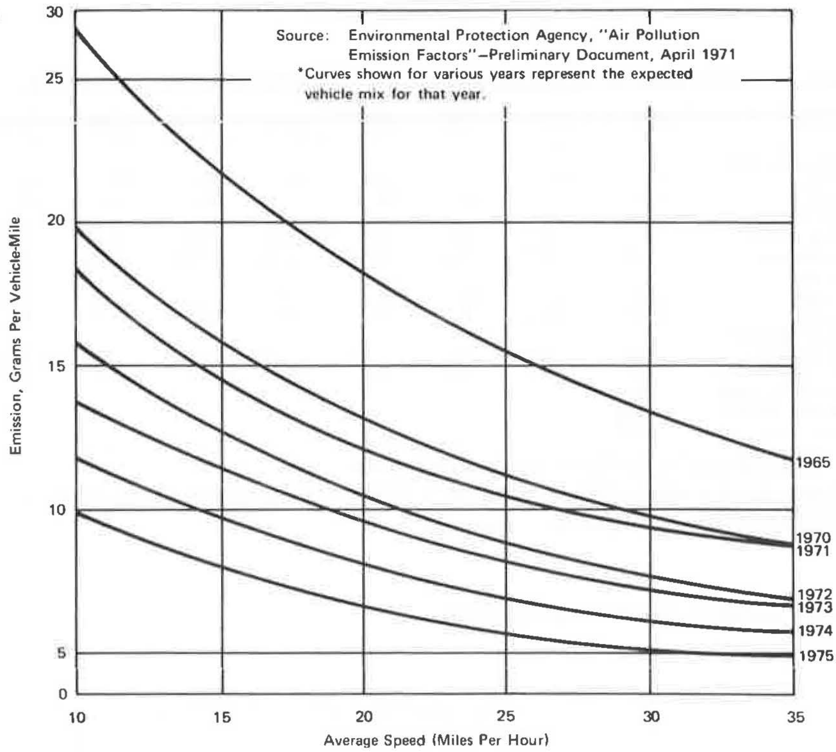


Figure 4. Carbon monoxide emissions (rural).

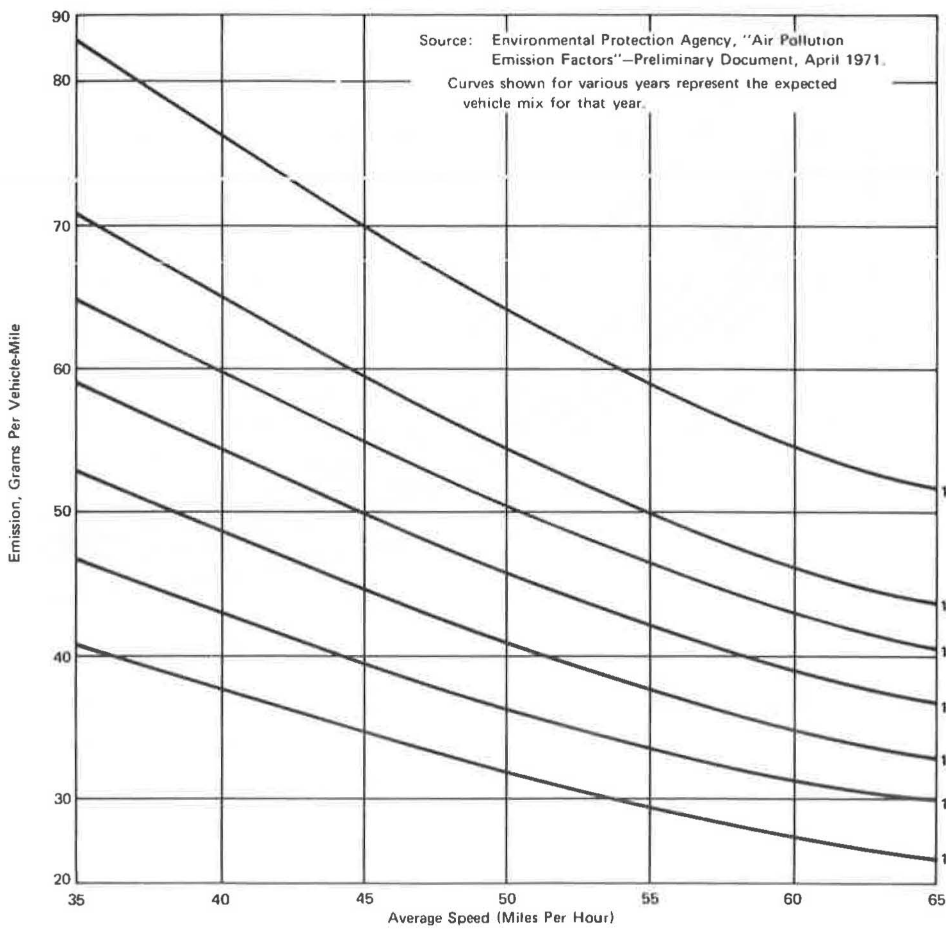


Figure 5. Hydrocarbon emissions (rural).

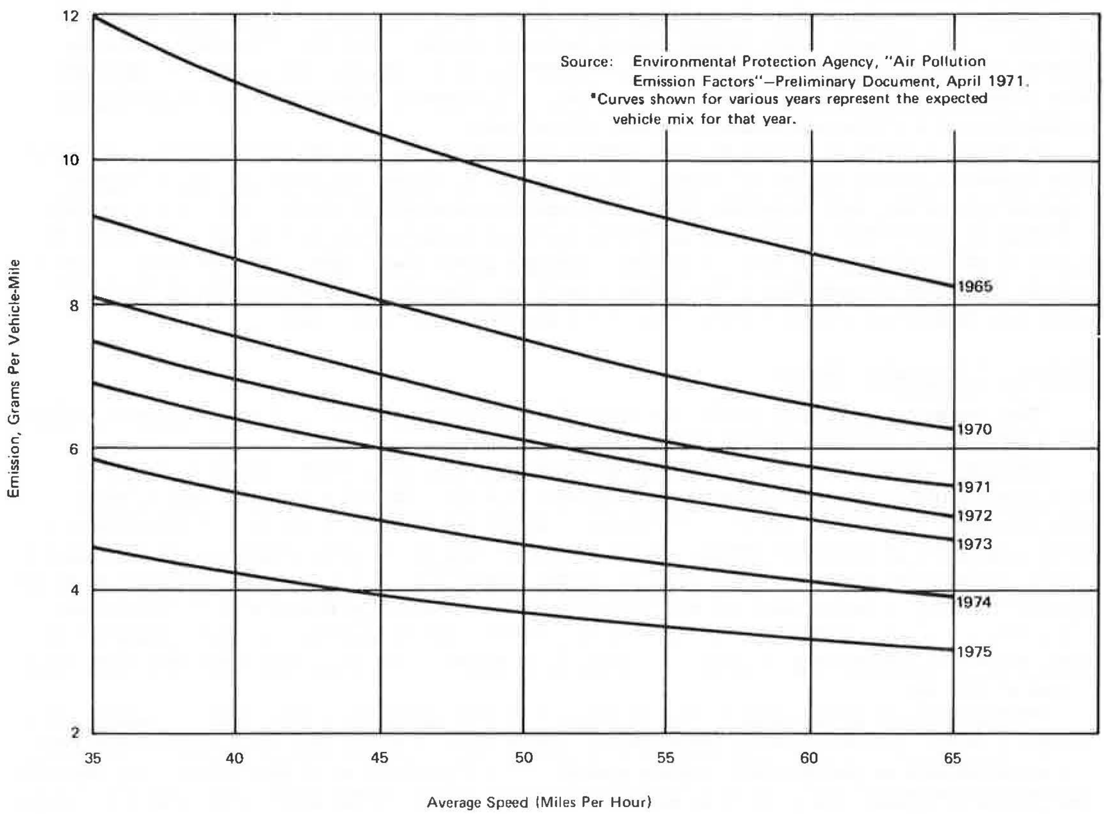
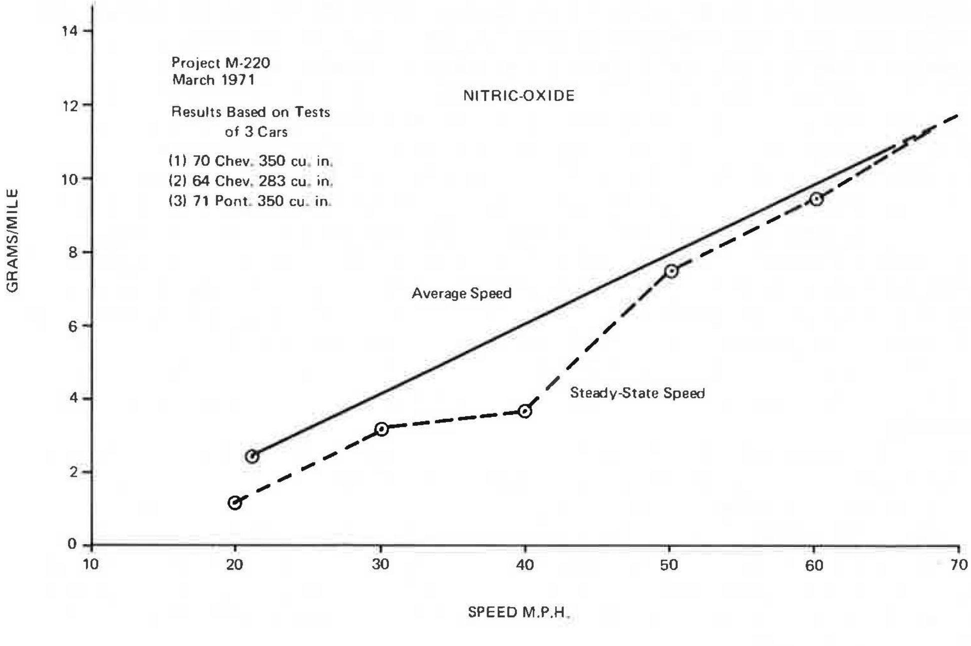


Figure 6. Nitric oxide emissions (4).



Effect of Travel Mode

Table 3 gives the exhaust pollutant emissions in grams per vehicle-mile for automobile (1972 vehicle mix), diesel bus, diesel locomotive, and electric rail. Although these data are based on information currently being revised by EPA, they do indicate the relative differences among travel modes. The speed relation is not available for emission data on modes other than the automobile.

A useful methodology has been devised by Scheel (6) to relate emissions by mode on the basis of person-miles of travel. This study has made assumptions about speed, operating cycles, and emission standards and concludes that the impact on air quality of transit under 1971 conditions is slight and that future impacts will depend on the degree of utilization of the transit mode. Table 4 gives the findings of this study. However, it should be noted that this table should not directly be compared with Table 3 because different emission factors and other assumptions were used.

Effect of Operation Mode

The mode of operation is also an important factor in the amount of automotive pollution generated and the concentration of that pollution.

Figure 7 shows the carbon monoxide emissions related to the operating cycle as measured along a length of roadway in Great Britain. Readings were taken of three automobiles traversing an 800-ft section of road; the motion cycle represents the vehicle stopping at a traffic signal, idling, accelerating to 30 mph, operating at that speed, and decelerating for a stop at the next traffic signal (7). This type of operation is most typical on city streets, causing concentrations of emission pollutants at intersections or other locations where the idle and acceleration phases occur. Another analysis of this effect on emissions is given in Table 5, in which emissions are related to a vehicle-mile of travel.

The effects on emissions of the variations in the operating cycle are, of course, reflected in new vehicle testing procedures and in the emission factors used to calculate concentrations of pollutants in urban areas. The significance of this effect may readily be observed; thus, one goal is to endeavor to reduce the peaking effects caused by stop-and-go operation.

TECHNIQUES FOR ACHIEVING AIR QUALITY

Many techniques can be used to achieve air quality standards or reduce further degradation of the air: programs oriented to vehicles, techniques to reduce traffic, techniques to improve traffic flow, and techniques to reduce pollution concentration.

The federal emission standards for new motor vehicles will reduce automotive pollutants. A large percentage of automobiles on the road in 1975, however, will not be controlled by the standards. State or local governments can develop programs to modify or correct in-use vehicles through inspection and maintenance, retrofit, or gaseous fuel fleet conversion. An inspection and maintenance program aimed at air pollution control devices will work toward ensuring that all devices are performing maximally. Retrofit can also be used for pre-1968 cars. The technology for post-1968 and pre-1974 vehicles, however, needs further testing before it can be effectively used. Conversion of vehicle fleets to other types of gaseous fuels such as liquefied petroleum gas (LPG), compressed natural gas (CNG), and liquefied natural gas (LNG) can also be applied. These programs oriented to source control on the vehicle must be carefully assessed from funding, administrative, and legal viewpoints prior to plan completion and implementation.

Emission controls on the vehicle supplemented by the programs oriented to vehicles identified previously may not be sufficient to meet ambient air quality standards. Therefore, other transportation control strategies need to be considered. Techniques to reduce traffic will reduce vehicle-miles of travel and, hence, vehicular emissions. Reductions in vehicular emissions will improve air quality. Techniques to reduce vehicular traffic can be grouped broadly into four categories: regulation, pricing policy, land use control, and transit operations. References that suggest techniques to reduce traffic are given in Table 6.

Table 3. Exhaust emission factors for various travel modes (grams per vehicle-mile) (3).

Pollutant	Automobile[a]	Diesel Bus[b]	Diesel Locomotive[b]	Electric Rail[c]		
				Coal	Gas	Oil
Carbon monoxide	85.00	20.41	6.35	0.91	Negligible	0.01
Hydrocarbons	9.50	3.36	4.54	0.37	Negligible	1.09
NO_x	6.17	33.57	6.80	37.19	0.05	35.38
SO_x	0.18	2.45	5.90	13.97	0.02	27.21
Particulates	0.30	1.18	2.27	29.30	0.73	3.44

[a]1972 emission factors based on 25 mph and cold-start operation.
[b]Based on fuel consumption estimate of 5 mi/gal.
[c]Expressed as grams per train mile where one train is comprised of four cars, in married pairs, i.e., two power units per train.

Table 4. Relative effects of emissions from different vehicles.

Pollutant	Automobile, 1970	Automobile, 1975	Bus (diesel-arterial)	Gas Turbine	Commuter Train (turbocharged)	Rail Transit
Carbon monoxide	0.24	0.02	0.02	0.003	0.004	0.00
Hydrocarbons	1.56	0.14	0.10	0.012	0.08	0.002
NO_2	3.27	1.63	3.50	0.97	0.58	0.72
SO_2	0.18	0.18	0.52	0.52	0.10	3.40
Total equivalent without particulates[a]	5.25	1.97	4.14	1.50	0.76	4.12
Particulates	0.25	0.25	2.08	2.08	0.33	1.54[b]
Total equivalent[a]	5.50	2.22	6.22	3.58	1.09	5.66

Note: Relative effect = gram per vehicle-mile x relative effect of air quality standards concentration/persons per vehicle.
[a]Measured in grams per vehicle-mile.
[b]Based on 7,250 g/ton of coal, 10 percent fly ash, and 80 percent collection efficiency on control equipment (on person-mile basis).

Figure 7. Relative emissions of carbon monoxide during vehicle operation (9).

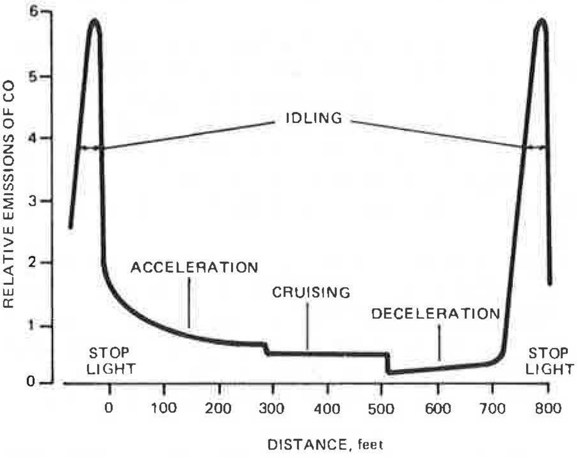


Table 5. Percentage of pollutants emitted per mile for different engine operations.

Engine Operation	Gross Hydrocarbons	Carbon Monoxide	Oxides of Nitrogen
Idle	5.9	7.5	0.03
Cruise	14.1	14.3	21.4
Acceleration	56.2	62.2	78.5
Deceleration	23.7	16.1	0.17

Techniques to improve traffic flow may also be applied to reduce emissions and hence improve air quality by reducing unnecessary idling and stop-start driving conditions. Techniques to reduce concentrations can also be utilized to eliminate "hot spots" of air pollution. Table 7 gives some of the techniques that could be utilized to reduce the concentrations of air pollution. For ease of exposition, these techniques are grouped into freeway operations and design, arterial improvements, traffic distribution, and staggered work hours. Appropriate references have also been indicated.

Application of these techniques to alleviate a mobility or air pollution problem requires that a balance be maintained between the net user benefit-cost (a measure of mobility) and improvement in air quality (reduction in concentration, dosage, or emissions). Figure 8 shows a framework for such a trade-off process using data obtained from a number of metropolitan areas where transportation control strategies have been applied (14). The y-axis indicates a reduction in carbon monoxide emissions. The x-axis indicates net present benefits or costs per person for the agency responsible for implementing the action and for the user. User benefits reflect net user savings in travel time, vehicle operating costs, and accidents.

The techniques to reduce air pollution shown in Figure 8 have been combined to produce maximum emission reduction and net user benefit per person. By application of such a procedure, the user cost and air pollution effectiveness of various techniques to achieve air quality and urban mobility can be assessed. Use of this tool coupled with other devices to assess social, economic, legal, funding, and administrative factors can provide a base for the formulation and evaluation of transportation control strategies aimed at achieving air quality and other societal goals.

HOW TO ACCOMPLISH MOBILITY AND AIR QUALITY GOALS

The previous section suggested transportation actions and techniques that could be applied in some combination toward achieving air quality and urban mobility. Air pollution implementation plans prepared for various Air Quality Control Regions have called for the application of some of these transportation actions and techniques. Programs related to cleaning up the engine through technology may not reduce pollution levels adequately. The problem may become particularly acute for certain metropolitan areas in the short range prior to the development and deployment of pollution-free vehicles in the traffic stream.

Therefore, the problem of the planner may be more related to the "how" than to the "what" of needed short-range transportation strategies. Because time is relatively short (now until 1980), the strategies must be clearly communicated and agreed to by the organizations that plan, build, own, operate, and design transportation. We cannot depend on political innovations to achieve air quality goals by 1980. There is not enough time or money to make such changes in the next 5 to 10 years. Therefore, we need to remove the barriers to clear communications between DOT and EPA and obtain the necessary agreements to achieve the actions.

In many urban areas, the desired transportation actions should be communicated through the transportation planning process to the agency within the metropolitan area that needs to take the action: a highway department, a city traffic engineering department, a parking authority, a toll or turnpike commission, or a federal agency that might own or operate the facility. The action needs to be communicated so that it is clear what needs to be done. The costs for the action, in turn, have to be related to available funds at the disposal of the agency.

Once communication is achieved, then the strategies must be agreed to and implemented by the concerned agency. Such agreements are not always easy. Some obstacles that will emerge are as follows:

1. Insufficient funds on the part of the agency to carry out the action;
2. Insufficient time to develop the plans and details to carry out the action;
3. Insufficient manpower and skills within the agency to do the job;
4. Conflicts between the air quality goals and other goals such as noise pollution, water pollution, and level of traffic service; and
5. Political resistance—business or industrial interests objecting to a regulation if it affects their economic parameters.

Table 6. Techniques to reduce traffic.

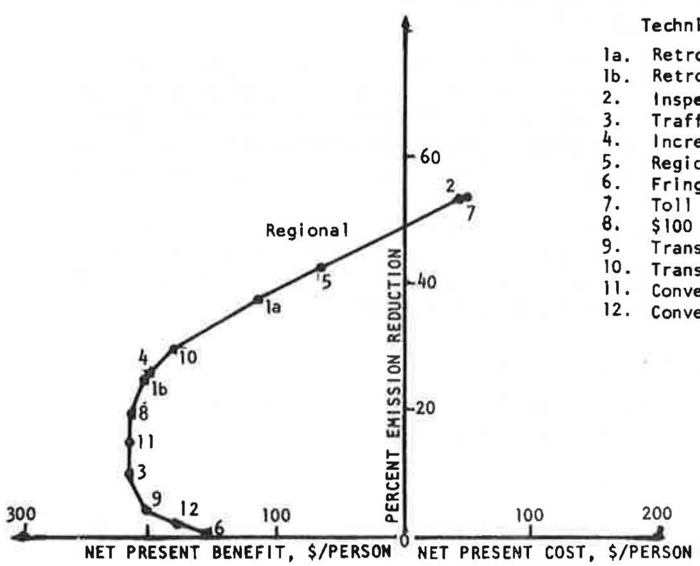
Item	Reference Number	Item	Reference Number
Regulation		Gasoline tax	4, 8, 9, 10
Parking bans	4, 8, 9, 10	Car pool incentives	4, 8, 9, 10
Automobile-free zones	4, 8, 9, 10	Land use control	
Gasoline rationing	4, 8, 9, 10	Control of parking supply	13, 15
Idling restrictions	4, 8, 9, 10	Planned unit development	8, 9, 15
Four-day, 40-hour week	4, 8, 9, 10	Density control	8, 9, 15
Favor priority traffic	4, 10, 12, 13	Transit operations	
Pricing policy		Bus lanes on highways	4, 8, 9, 12
Parking price policy	4, 8, 9, 10, 12, 13	Service improvements and cost reductions	4, 8, 9, 10
Road user tax	4, 8, 9, 10		

Table 7. Techniques for improving traffic flow and reducing concentrations.

Item	Reference Number	Item	Reference Number
Freeway operations and design		Reversible lanes	4, 8, 9, 11
Reverse lane operations	8, 9	Reversible one-way streets	4, 8, 9, 11
Ramp control	8, 9	Cross section design	4, 8, 9, 11
Interchange design	8, 9, 13	Alignment	4, 8, 9, 11
Cross section design	8, 9, 13	Traffic distribution	
Alignment	8, 9, 13	Traffic responsive control	4, 9, 9, 11
Arterial improvements		One-way street operations	4, 8, 9, 11
Widen intersections	4, 8, 9, 11	Loading regulations	4, 8, 9, 11
Parking restrictions	4, 8, 9, 11	Pedestrian control	4, 8, 9, 11
Signal progression	4, 7, 8, 9, 11	Staggered work hours	4, 8, 9

Note: Many of the items listed fall in the Traffic Operations Program to Increase Capacity and Safety.

Figure 8. Average costs and effects for transportation control strategies.



Technique

1a. Retrofit of pre-1975 light duty vehicles
1b. Retrofit of pre-1975 gasoline heavy duty vehicles
2. Inspection and maintenance
3. Traffic flow improvements
4. Increase downtown parking rates
5. Region-wide auto user charge of 50¢ per trip
6. Fringe parking
7. Toll into CBD of 50¢
8. $100 "Bounty" on pre-1968 vehicles
9. Transit service improvements
10. Transit fare reduction
11. Conversion of taxis to LPG
12. Conversion of fleet vehicles to LPG

Source: MVMA-Reference 14

Cities used as bases for calculation of average costs and effects: Baltimore, Boston, Pittsburgh, Seattle, & Spokane

It will take concerted technical and political leadership and effort in the next few years at the federal, state, and local levels to achieve the needed communication and agreements to bring about air pollution reductions through transportation strategies.

CONCLUSIONS

As the cases presented here have shown, transportation control techniques can be applied to achieve air quality. Some of these payoffs can be realized without infringing on mobility goals. Others, however, will require some trade-offs on an individual level, e.g., sacrifice of the private automobile for car pooling or mass transit and restriction of urban travel mobility through traffic restraints or pricing.

The greatest difficulty in the short run (5- to 10-year period) will be in overcoming the obstacles to the agreement and implementation of transportation actions needed to reduce air pollution, particularly those that are a drastic departure from present programs and that require additional funding or legislation. Massive new transportation programs aimed solely at reducing air pollution will probably never overcome the funding, administrative, legal, and political barriers standing in the way.

For short-term transportation actions aimed at ameliorating air pollution there is a need to

1. Foster communication among the responsible agencies and elected officials at the federal, state, and local levels;
2. Provide information on the interrelations of air pollution reduction and transportation actions and provide case studies on cause, effect, and costs;
3. Focus on cost-effective techniques that work toward reducing air pollution caused by transportation sources and minimize infringement on mobility;
4. Apply traffic restraint and control improvements to areas that are highly polluted (these actions will require the most in terms of administrative, legal, and funding effort and should work toward minimizing reductions on urban mobility);
5. Work with, build on, or combine existing transportation institutions rather than attempting to build new institutions focused solely on air pollution; and
6. Have political leadership at the federal, state, and local levels involved in expediting agreements aimed at those transportation strategies that reduce air pollution and can be adequately funded and administered.

For long-term transportation and land use actions aimed at achieving air quality, there is a need to have research and analysis tools that provide information on the air pollution impacts of future transportation and land use policies in the light of a dynamically changing technology and society and to effectively communicate these impacts to decision-makers so that needed policies and institutional changes can be evaluated and implemented.

Given the problems and opportunities, the planner, the air pollution official, and the decision-maker need a process to bring all interests together. The constraints are primarily institutional, political, and economic in nature: The technology to reduce air pollution exists, but wide support will be required to implement it.

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