A PRIMER ON MOTOR VEHICLE AIR POLLUTION

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TABLE OF CONTENTS

	Page No.
SUMMARY	v
INTRODUCTION	1
TYPES OF VEHICULAR POLLUTANTS	3
Carbon Monoxide	3
Hydrocarbons	4
Oxides of Nitrogen	4
Oxides of Sulfur	5
Particulates	5
COMPARISON BETWEEN GASOLINE AND DIESEL ENGINE EMISSIONS	6
EFFECTS OF AIR POLLUTION — GENERAL	7
Effects on Visibility	7
Psychological Effects	7
Effects on Vegetation	7
Effects on Materials	8
Effects on Health of Man and Animals	8
EFFECTS OF INDIVIDUAL POLLUTANTS	9
Carbon Monoxide	9
Hydrocarbons	10
Oxides of Nitrogen	10
Oxides of Sulfur	11
Particulates	12
Lead	13
Photochemical Oxidants	13
ATMOSPHERIC CONCENTRATIONS OF POLLUTANTS	15
Carbon Monoxide	15
Hydrocarbons	16
Oxides of Nitrogen	17
Oxides of Sulfur	18
Particulates	18
Photochemical Oxidants	18

TABLE OF CONTENTS (Continued)

Page No.

AIR QUALITY STANDARDS 19

POSSIBLE SOLUTIONS TO MOTOR VEHICLE POLLUTION 20

Control of Vehicular Emissions 20

Environmental Consideration During Highway Location and Design 21

Emission Reduction Through Improvement of Traffic Flow 23

Emission Reduction Through Traffic Control 24

Utilization of Green Belts 25

REFERENCES 27

APPENDICES

A. Conversion Between Volume and Mass Units of Concentration A-1

B. Glossary B-1

SUMMARY

This primer presents a brief state-of-the art review of motor vehicle air pollution. Its purpose is to aid highway personnel in understanding the nature of this environmental problem on our highways and to present possible solutions for its abatement.

The primer discusses the type of vehicular pollutants (namely, carbon monoxide, hydrocarbons, oxides of nitrogen, oxides of sulfur, and particulates); the differences between gasoline and diesel engine emissions; and the effects of motor vehicle pollutants on health, vegetation, materials, etc. Some measured concentrations of these pollutants in relatively polluted and unpolluted atmospheres are presented, along with the air quality standards set by the Environmental Protection Agency for the purpose of protecting the public from the adverse effects of air pollution. Finally, various possible solutions to motor vehicle air pollution are discussed.

Among the presented solutions, environmental consideration during highway location and design and utilization of green belts are most applicable from the Department's viewpoint. However, further research is needed before these long-range solutions can be effectively used for air pollution abatement on highways.

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INTRODUCTION

Air pollution is not a new phenomenon. Natural forms of air pollution, such as volcanic eruptions, were known and feared by prehistoric man. Man-made pollution probably dates back to the early cave man. Having discovered fire as an invaluable source of heat for keeping warm and cooking food, he undoubtedly was often forced to flee from his cave coughing and choking from the noxious smoke.

As a result of population growth, expansion in industry and technology, and a rising standard of living in the last two decades, air pollution has become one of our most rapidly growing environmental problems.

The motor vehicle, on which almost every American family is highly dependent, is a major source of air pollution. The U. S. Department of Health, Education and Welfare[(1)] recently published a nationwide inventory of air pollutants by type and source (Table 1). This inventory defined the relative contribution of various sources of air pollution as of 1968 and showed that motor vehicles, based on the mass of all pollutants, accounted for 38.9%.

As a builder of roads for the motor vehicles, the Department of Highways has the moral responsibility to do whatever it can to minimize, if not eliminate, air pollution on our highways. We must realize that pollution abatement can be good public relations, and therefore, can and should be a legitimate cost of operation. It is therefore the purpose of this report to aid Department of Highways personnel understand the nature of motor vehicle pollutants and to present possible solutions for their abatement. This report, based on a review of the literature, presents a brief state-of-the-art survey of motor vehicle air pollutions.

Table 1

NATIONWIDE INVENTORY OF MAN-MADE AIR POLLUTION, 1968

Source	Hydrocarbons		Carbon Monoxide		Nitrogen Oxides		Sulfur Oxides		Particulates		Total by Source	
	Weight	Percent	Weight	Percent	Weight	Percent	Weight	Percent	Weight	Percent	Weight	Percent
Transportation												
Motor Vehicles	15.6	48.8	59.2	59.2	7.2	34.9	0.3	0.9	0.8	2.8	83.1	38.9
Gasoline	15.2	47.5	59.0	59.0	6.6	32.0	0.2	0.6	0.5	1.8	81.5	38.0
Diesel	0.4	1.3	0.2	0.2	0.6	2.9	0.1	0.3	0.3	1.0	1.6	0.7
Aircraft	0.3	0.9	2.4	2.4	N	N	N	N	N	N	2.7	1.3
Railroads	0.3	0.9	0.1	0.1	0.4	1.9	0.1	0.3	0.2	0.7	1.1	0.5
Vessels	0.1	0.3	0.3	0.3	0.2	1.0	0.3	0.9	0.1	0.4	1.0	0.5
Motor Fuels (non-highway use of)	0.3	1.0	1.8	1.8	0.3	1.5	0.1	0.3	0.1	0.4	2.6	1.2
Total Transportation	16.6	51.9	63.8	63.8	8.1	39.3	0.8	2.4	1.2	4.3	90.5	42.3
Fuel Combustion in Stationary Sources												
Coal Burning	0.2	0.6	0.8	0.8	4.0	19.4	20.1	60.5	8.2	29.0	33.3	15.5
Fuel Oil	0.1	0.3	0.1	0.1	1.0	4.8	—	—	0.3	1.0	1.5	0.7
Distillate Fuel Oil	—	—	—	—	—	—	0.4	1.2	—	—	0.4	0.2
Residual Fuel Oil	—	—	—	—	—	—	3.9	11.8	—	—	3.9	1.8
Natural Gas	N	N	N	N	4.8**	23.3	N	N	0.2	0.7	5.0	2.3
Wood	0.4	1.3	1.0	1.0	0.2	1.0	N	N	0.2	0.7	1.8	0.8
Total Fuel Combustion	0.7	2.2	1.9	1.9	10.0	48.5	24.4	73.5	8.9	31.4	45.9	21.4
Industrial Processes	4.6	14.4	9.7	9.6	0.2	1.0	7.3	22.0	7.5	26.5	29.3	13.7
Solid Waste Disposal	1.6	5.0	7.8	7.8	0.6	2.9	0.1	0.3	1.1	3.9	11.2	5.2
Miscellaneous												
Forest Fires	2.2	6.9	7.2	7.2	1.2	5.8	N	N	6.7	23.7	17.3	8.3
Structural Fires	0.1	0.3	0.2	0.2	N	N	—	—	0.1	0.4	0.4	0.2
Coal Refuse Burning	0.2	0.6	1.2	1.2	0.2	1.0	0.6	1.8	0.4	1.4	2.6	1.2
Agricultural Burning	1.7	5.3	8.3	8.3	0.3	1.5	—	—	2.4	8.4	12.7	5.9
Organic Solvent Evaporation	3.1	9.7	—	—	—	—	—	—	—	—	3.1	1.4
Gasoline Marketing	1.2	3.7	—	—	—	—	—	—	—	—	1.2	0.6
Total Miscellaneous	8.5	26.5	16.9	16.9	1.7	8.3	0.6	1.8	9.6	33.9	37.3	17.4
Total Pollutants	32.0	100.0	100.1	100.0	20.6	100.0	33.2	100.0	28.3	100.0	214.2	100.0

* Source: U.S. Dept. of HEW publication "Nationwide Inventory of Air Pollutant Emissions, 1968," dated August, 1970.
** Includes Liquid Petroleum Gas & Kerosene
N=Negligible Amount

Note: Weights above are annual figures given in millions of tons.

TYPES OF VEHICULAR POLLUTANTS

Ideally, complete combustion of a hydrocarbon fuel-air mixture should yield only carbon dioxide and water. Combustion in a gasoline engine, however, is not entirely complete. Because of this, the engine exhaust also contains carbon monoxide, unburned hydrocarbons, oxides of nitrogen, and, to a lesser extent, oxides of sulfur and particulates (Figure 1). In addition to these, intermediate combustion products, which include aldehydes, alcohols, esters, ketones, and other acid derivatives, are also formed. They often are found at total concentrations between 0.005 to 0.01 percent, or, 50-100 parts per million (ppm) in the composite of typical exhaust. Since relatively little is known about these trace pollutants, this report will be primarily concerned with the former groups of pollutants.

Hydrocarbons are emitted from the fuel tank and the crankcase, as well as from the tailpipe.

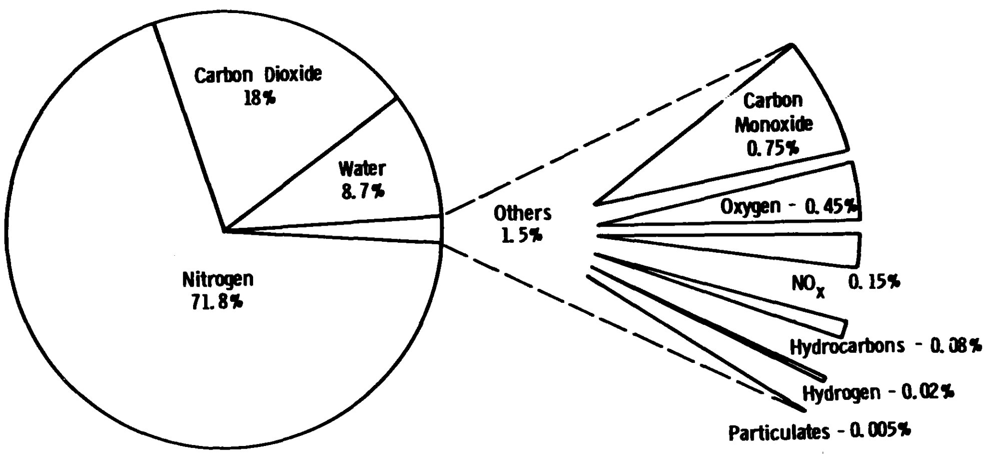

Figure 1. Typical automobile exhaust composition of 1970 vehicle (weight basis).[2]

Carbon Monoxide (CO)

Carbon monoxide is a colorless, odorless, tasteless gas which is toxic at relatively high concentrations. Some natural sources of CO are known, but their ultimate contribution to urban atmospheric concentrations is thought to be relatively small.[3] Carbon monoxide is the most commonly occurring man-made air pollutant.

It is produced by the incomplete combustion of carbonaceous materials used as fuels for vehicles, space heating, and industrial processing, or burned as refuse.

Hydrocarbons (HC)

Hydrocarbons are compounds whose molecules consist of atoms of hydrogen and carbon only. Natural hydrocarbons in the atmosphere arise from biological sources, geothermal areas, coal fields, and natural gas and petroleum fields, and from natural fires.

The hydrocarbons found in motor vehicle exhaust consist of two main types:

(a) Low-molecular weight aliphatics that are highly volatile. This type can be further divided into two groups:

1. Alkanes — these are essentially chemically inert.

2. Olefins — under certain climatic conditions these result in the formation of photochemical smog.

(b) High-molecular weight aliphatics and aromatics that are essentially nonvolatile and are suspended as aerosol, either in fine droplets or attached to soot. These are either settled by gravity, washed out by rain, or remain suspended in the air and may be inhaled into the lungs.

The olefins undergo chemical reactions with highly reactive matters generated by the action of sunlight on other components in the atmosphere, most particularly nitrogen dioxide, and give rise to photochemical smog. The chemistry of these reactions is not fully known, because of the complexity of the hydrocarbon pollutants and partly because of the difficulties of observation and analysis of the involved components at the very low concentration encountered. Some of the recognized constituents in photochemical smog are ozone, aldehydes, and peroxyacyl nitrates, which cause nearly all the detrimental effects of hydrocarbons air pollution.

Oxides of Nitrogen (NOx)

Of the various oxides of nitrogen, the most significant as air pollutants are nitric oxide (NO) and nitrogen dioxide (NO_2). By convention, the term NOx represents the composite atmospheric concentration of NO and NO_2.

In the internal combustion engine, the nitrogen and oxygen in the combustion air are subjected to temperatures in excess of 2,000° F. The result is the formation of NO, a small fraction of which is subsequently converted to NO_2.

Oxides of Sulfur

The oxides of sulfur, sulfur dioxide (SO_2) and sulfur trioxide (SO_3), are common air pollutants which arise mainly from combustion processes. Liquid fossil fuels, like gasoline, contain appreciable quantities of sulfur. Combustion of the fuel in a car engine forms the sulfur oxides in the ratio of 40 to 80 parts of SO_2 to 1 part SO_3.(4)

Particulates

Motor vehicle exhaust contains large amounts of extremely fine particulates (Appendix B) with approximately 70% by count in the size range of 0.02 to 0.06 micron (μ). The particulate matter consists of both inorganic and organic compounds of high molecular weights.(5) The quantity of particulate matter produced in the exhaust varies between 0.02 and 3.2 milligram per gram (mg/gm) of gasoline burned, with an average emission rate of 0.78 mg/gm.

The most significant fractions of the automotive particulate emission are lead compounds (principally a mixture of PbClBr, $NH_4Cl \cdot 2PbClBr$, and $2NH_4CL \cdot PbClBr$) resulting from the use of tetraethyl lead as a fuel additive to provide the antiknock characteristics necessary for present day high compression engines. Approximately 70-80% of the lead burned in the engine is exhausted to the atmosphere.

Motor vehicles also contribute to the emission of asbestos particulates, which result from the wear of brake linings.

COMPARISON BETWEEN GASOLINE AND DIESEL ENGINE EMISSIONS

The two power plants being used in this country for motor vehicles are: (1) the spark-ignited internal-combustion engine (the gasoline engine), and (2) the compression-ignition internal-combustion engine (frequently referred to as the diesel engine).

Unlike gasoline engines, the diesel engines ignite fuel by heat of compression in the presence of relatively large amounts of excess air. Because of this, diesel engines are inherently low in CO and HC emissions, but high in NOx emissions. Since diesel engines do not require lead additives in the fuel (used to prevent knocking, which is not a problem with diesel engines), no lead pollution is discharged to the atmosphere. (6) Emission data gathered under a National Air Pollution Control Administration (NAPCA) contract provided estimates of specific pollutants emitted in gasoline and diesel engine exhausts. [7] A comparison of these data for an average speed of 25 miles per hour in urban areas is shown in Table 2.

Table 2

COMPARISON OF GASOLINE ENGINE AND DIESEL ENGINE EMISSIONS
(in lb. per 1,000 gallons fuel)*

Pollutant	Gasoline Engine	Diesel Engine	Gasoline : Diesel
CO	2,300	60	38.3 : 1.0
HC	200	136	1.5 : 1.0
NO_2	113	222	0.5 : 1.0
Particulate	12	110	0.1 : 1.0

*For an average speed of 25 MPH in urban environments.

As indicated by Table 2, the diesel engine is less of a polluter than the gasoline engine. However, the diesel engine is notorious for the smoke and odor of its exhaust. Diesel smoke results from faulty fuel injection, poor maintenance of the engine, or engine overloading. The offensive odor of diesel exhaust has probably drawn more criticism from the general public than have any other vehicular emissions. Because of the lack of acceptable methods for measuring and evaluating the objectionable combustion odor, it has not been reliably associated with any one or any combinations of fuel and engine design factors. Therefore, the problem of odor is little understood and corrective measures are not available.

EFFECTS OF AIR POLLUTION — GENERAL

Until recently, man and his environment formed a harmonious ecological system characterized by tolerance, adaptation, and interdependence. Today there is a growning concern that man is discharging more than can be handled or tolerated by his own environment.

Air pollution has many known and suspected adverse effects. The major effects may be grouped under five general headings as discussed below.

Effects on Visibility

The most easily observed effect of air pollution is the reduction of visibility produced by the scattering of light from the surfaces of airborne particles. When the air is clear and dry, one can see for miles. As the atmosphere becomes polluted, the range of visibility decreases. A major effect of decreased visibility is the curtailment of transportation.

Psychological Effects

Attitude studies have shown a distinct relationship between peoples' feelings about air pollution and the health effects they claim pollution has on them. Such relationships are possible due to inadequate knowledge of the publicized threat.

A frequent complaint in air pollution is the odor of diesel fumes. People driving behind a diesel-powered vehicle often tend to associate dizziness or nausea with the unpleasant odors and smoke from the exhaust. Factory odors also receive many complaints. Interestingly, residents of a one-industry town rarely complain about pollution, largely because their livelihood is dependent upon the industry that produces the pollution.

Effects on Vegetation

Air pollutants known to damage vegetation include: Ozone, peroxyacetyl nitrate (PAN), nitrogen dioxide, sulfur dioxide, ethylene, hydrogen fluoride, and chlorine. Of these, only the last two are not emitted, directly or indirectly, by motor vehicles. These pollutants destroy plant chlorophyll and disrupt the photosynthesis process by which a plant produces its own food. The damage ranges from relatively minor injury to complete destruction, depending upon the type and condition of plants and the exposure and concentration of pollutants. The visible symptoms of injury to plants attributable to air pollution can be classified in three general categories, not necessarily mutually exclusive: (1) Leaf tissue collapse with necrotic patterns, (2) chlorosis or other color changes in leaves, and (3) growth alterations.

Effects on Materials

A frequent and widespread effect of air pollution is damage to structural metals, surface coatings, fabrics and other materials of commercial value. The destruction is related to many types of pollutants, but is chiefly attributable to acid mists, hydrogen sulfide, and particulate products of combustion and industrial processing. Ozone, a secondary pollutant from vehicular exhausts, also contributes a substantial share. For example, it is known to cause rapid and extensive damage to all kinds of rubber goods and textiles. [9]

Effects on Health of Man and Animals

Man

Because there is no way of knowing what a person breathes in during his lifetime or even during a single day in such a variety of environments as work, home, and recreation, it is extremely difficult to determine the health effects of air pollution. This is especially true in analyzing relationships between pulmonary diseases and air pollution, since the effects of personal air pollution by smoking may be greater than those by community air pollution. While there is not really good evidence that any pulmonary diseases are caused by air pollution, there is good evidence that pollution aggravates them.

Animals

It can be expected that if man is affected by air pollution, animals will also be affected since men and animals have many similar anatomical features.

EFFECTS OF INDIVIDUAL POLLUTANTS

The various effects of individual air pollutants are dealt with in this section. It must be emphasized that health effects of individual pollutants are difficult to assess because of the synergistic effects of various pollutants.

Carbon Monoxide (CO)

Health Effects

The principal toxic properties of CO arise from its reversible combination with hemoglobin which, in living cells, is concerned with the transport of oxygen. The affinity of hemoglobin for CO is more than 200 times greater than that for oxygen. This results in the displacement of oxygen by CO in the blood to form carboxyhemoglobin (COHb). Carbon monoxide therefore reduces the oxygen supply to body tissues and, at high COHb blood content, kills by asphyxiation.

Health effects are therefore related to the percentage of COHb in the blood, which in turn is related not only to the concentration of CO in the air, but also to the time a person is exposed to the polluted air and the degree of activity he is engaged in. In addition to the exposure to exogenous CO, the human body is constantly exposed to a small amount of CO formed endogenously as a by-product in heme catabolism. This by-product results in a normal COHb level in the bloodstream of about 0.5 percent, for nonsmokers. [10]

Some investigators[11] have reported impairment in time-interval discrimination in subjects exposed to 50 ppm CO for 90 minutes. This exposure produces an increase of about 2 percent COHb in the blood. Continuous exposure to 10-15 ppm (Appendix A) CO for 8 or more hours will produce the same increase in blood COHb.

Experimental exposures of human subjects to CO leading to blood COHb levels above 5 percent (a level producible by exposure to about 30 ppm CO for 8 or more hours) have been associated with cardiovascular changes; these changes have been demonstrated to produce an exceptional burden on some patients with heart disease. [12]

Other Effects

There is no evidence to indicate that long-term exposure to carbon monoxide has adverse effects on vegetation or materials up to concentrations of about 100 ppm (0.01%). Ambient CO levels rarely reach 100 ppm even for very short periods of time. In view of this and the foregoing information concerning CO effects, a significant impact on vegetation and materials seems improbable.

It is believed that the long-term global effect of CO is not likely to change the composition of the atmosphere; the increase of CO in the lower atmosphere would amount to only about 0.03 ppm per year. [13]

Hydrocarbons

Health Effects

The present state of knowledge indicates that direct health effects of the gaseous hydrocarbons are unlikely except at such high concentrations that they interfere with oxygen intake, probably on the order of 1,000 ppm or more. However, hydrocarbons are of concern in air pollution, primarily because under certain meteorological conditions they enter into and promote the formation of photochemical smog. [14]

Other Effects

Research on several hydrocarbons proved that of them only ethylene, which is a product of auto exhaust, has adverse effects on vegetation at ambient concentrations.[15,16] The principal effect of ethylene is to inhibit the growth of plants. [17] However, this effect does not characterize ethylene because other pollutants, as well as some diseases and environmental factors, may also inhibit growth.

Oxides of Nitrogen

Health Effects

No evidence shows that nitric oxide (NO) produces any adverse health effect at the ambient atmospheric concentrations thus far measured. The toxic potential of this oxide lies in its tendency to undergo oxidation to nitrogen dioxide (NO_2).

Nitrogen dioxide has been found to cause adverse health effects. An increased incidence of acute respiratory disease was observed in family groups with exposure to NO_2 concentrations between 0.06 and 0.11 ppm over a 6-month period. [18] Greater incidences of acute bronchitis among infants and school children were observed when 24-hour NO_2 concentrations, measured over a 6-month period, were between 0.06 and 0.08 ppm. [18] Experimental exposure of volunteer subjects to 5 ppm NO_2 for 10 minutes has produced a substantial, but transient, increase in both inspiratory and expiratory flow resistance.

Other Effects

It has been found that oxides of nitrogen (NOx) and their corresponding reaction products cause certain textile dyes to fade, cause some textile additives to yellow, deteriorate cotton fabrics, and accelerate corrosion of certain metals. [18]

Recently completed studies suggested that 0.25 ppm or less of NO_2 supplied continuously for 8 months will cause increased leaf drop and reduced yield of navel orange trees. Limited information regarding the effect of NO on photosynthesis indicates that NO would reduce the growth of plants if concentrations of 2.0 to 4.0 ppm persisted continuously. [18]

Under certain meteorological conditions, nitrogen oxides participate in the formation of photochemical smog.

Oxides of Sulfur

Health Effects

Current scientific literature indicates that, for the most part, the effects of the oxides of sulfur on health are related to irritation of the respiratory system. Such injury may be temporary or permanent.[4] Laboratory observations of respiratory irritation suggest that most individuals will show a response to sulfur dioxide at concentrations of 5 ppm and above. At concentrations of 1 to 2 ppm an effect can be detected only in certain sensitive individuals, and on occasion, exposures to 5-10 ppm have caused severe bronchospasm in such persons. [4]

From epidemiologic studies available, it is found that oxides of sulfur in the ambient atmosphere have an effect on the health of the population, and that the degree of effect is related to the extent of pollution, i.e., the concentrations of other pollutants, particularly particulates. Those predominantly affected were individuals with chronic pulmonary disease or cardiac disorders, or very young or old individuals. Sulfur oxides and particulates are generally considered to cause health effects as follows: the sulfur oxides and moisture combine to form sulfurous and sulfuric acids; these adhere to particulates which are inhaled and cause damage on contact with the respiratory tissues. [4]

Other Effects

Sulfur dioxide may cause acute or chronic leaf injury to plants. Acute injury, produced by exposures to high concentrations for relatively short periods, usually is in the form of injured tissue that dries to an ivory color; the injury sometimes results in a darkening of the tissue to a reddish-brown. Chronic injury, which results from lower concentrations over a number of days or weeks, leads to pigmentation of leaf tissue or to gradual yellowing or chlorosis, in which the chlorophyll-making mechanism is impeded. Both acute and chronic injury may be accompanied by the suppresion of growth and yield. [4]

Sulfur oxides contribute to the damage of electrical equipment of all kinds. They attack a wide variety of building materials— limestone, marble, slate, and mortar—as well as statuary and other works of art, causing discoloration and deterioration. Certain textile fibers--such as cotton, rayon, and nylon—are harmed by these oxides. Sulfur dioxide can cause some paint films to become soft and others brittle; both developments adversely affect durability. [4]

Particulates

Health Effects

Numerous epidemiological studies indicate an association between air pollution, as measured by particulate matter accompanied by sulfur dioxide, and health effects of varying severity. This association is most firm for the short-term air pollution episodes. [19] Persons with asthma or other respiratory diseases are generally more susceptible than are healthy persons.

Health effects of particulates are determined by their composition and size. [13, 19] Particulates larger than 10μ diameter generally do not enter the respiratory system at all. Particles larger than 5μ diameter enter the upper respiratory tract, affecting nose and throat, but are not drawn into the lungs. Particles less than 5μ diameter do enter the lungs.

Asbestos particulates have been claimed to be related to diseases such as mesothelioma and lung cancer. However, the transportation related source of asbestos particulates—the wearing of brake linings—is extremely small in relation to other sources, such as insulation and fireproofing materials. [19]

Other Effects

Particulates suspended in the air scatter and absorb sunlight, thereby reducing the amount of solar radiation reaching the earth, producing hazes and reduced visibility. These effects may have implications for the delicate heat balance of the earth's atmospheric system. Suspended particulates also play a signficant role in bringing about precipitation, and there is some evidence that rainfall in cities has increased as they have developed industrially.

Particulate matter damages textiles and buildings by soiling, either directly or when the dirt is removed.[13,19] It also appears to intensify the corrosion of metals, especially when in combination with a gaseous pollutant of an acidic nature.

Lead

Health Effects

It is reported that high lead concentration in the blood stream may interfere with some enzyme activities essential in the formation of hemoglobin in the red blood cell, and interfere with some liver and kidney functions. Lead intoxication occurs above 90 microgram (μg) of lead per 100 grams of blood.[20,21] (The blood lead level commonly found in persons in North America is between 13 and 30 μg lead per 100 grams of blood.) However, the health effects of airborne lead (about 15 percent of which is contributed by vehicle emissions) are somewhat controversial. First of all, 90 percent of all lead taken into the body comes from food and water, and not from the air.[22] Further, no one has contracted lead poisoning from breathing polluted air. One study has reported that workers in a tunnel carrying traffic experienced long-term exposure to air containing $44 \mu g/m^3$ of lead without exhibiting an increase of lead in the blood.

Other Effects

Lead in automotive fuels interferes with the function of catalytic converters, which are designed to reduce emissions of hydrocarbons and carbon monoxide.

It has been found that the marked effect of traffic on lead levels in the air and soil is limited to a rather narrow zone bordering the lee side of the highway. In this narrow zone, extending approximately 100 feet from the highway, the concentration of lead on the surface of foliage is proportional to the concentration of lead in air. On the protected portions of the plants (e.g., seeds and roots), which in almost all cases are the edible portions of the plants, little or no effect of lead in the air is noted.[23,24,25]

Photochemical Oxidants

Health Effects

Oxidants formed by the photochemical reactions of hydrocarbons with other reactive matters in the atmosphere irritate the mucous membranes, especially those of the nose and throat, and reduce resistance to respiratory infection.[26] The major physiological effects of ozone, which is the main constituent of photochemical oxidants, are on the respiratory system. Long-term ozone exposure tests have indicated no apparent effects at 0.2 ppm (for 3 hours a day, 6 days a week, for 12 weeks), while 0.5 ppm (for 3 hours a day, 6 days a week) caused a decrease in pulmonary efficiency.[26] Exposure to 0.3 ppm for 8 hours appears to be the threshold for nasal and throat irritation. The pulmonary function may be impaired by 0.6 to 1.0 ppm for 1 to 2 hours of exposure. Exposure to concentrations of from 1.0 to 3.0 ppm for 10 to 30 minutes is intolerable to most people; and exposure to 9.0 ppm will probably produce severe illness. For oxidants generally, long-term exposure to 0.25 ppm has been reported to cause an increase in the number of asthmatic attacks in about 5 percent of a group of asthmatic patients.[26]

Eye irritation has been associated with peak oxidant concentrations of 0.1 ppm and above.

Other Effects

Leaf injury to some sensitive plants, such as lettuce, bean, tobacco, and tomato, has been associated with exposure to ambient air containing oxidant concentrations of about 0.05 ppm for 4 hours.[26]

Many polymers, especially rubber, are extremely sensitive to very small ozone concentrations. Ozone also causes deterioration of cellulose and synthetic fibers, and the fading of dyes.[9]

ATMOSPHERIC CONCENTRATIONS OF POLLUTANTS

Carbon Monoxide (CO)

In relatively unpolluted air, the concentration of CO is in the range of 0.05 to 0.65 ppm.(10) This variability appears to be a characteristic of the air mass in transit and reflects its prior history.

In urban areas, diurnal patterns of CO concentrations generally correlate with the community traffic volume, there are usually two peaks in concentration corresponding to the morning and evening rush hours (Figure 2). Peak concentrations are higher on weekdays than on weekends and holidays because of the greater weekday rush-hour traffic volume. The mean concentration of CO is generally higher in autumn and summer than in spring and winter; this seasonal variation is due primarily to both traffic and meteorological variables.

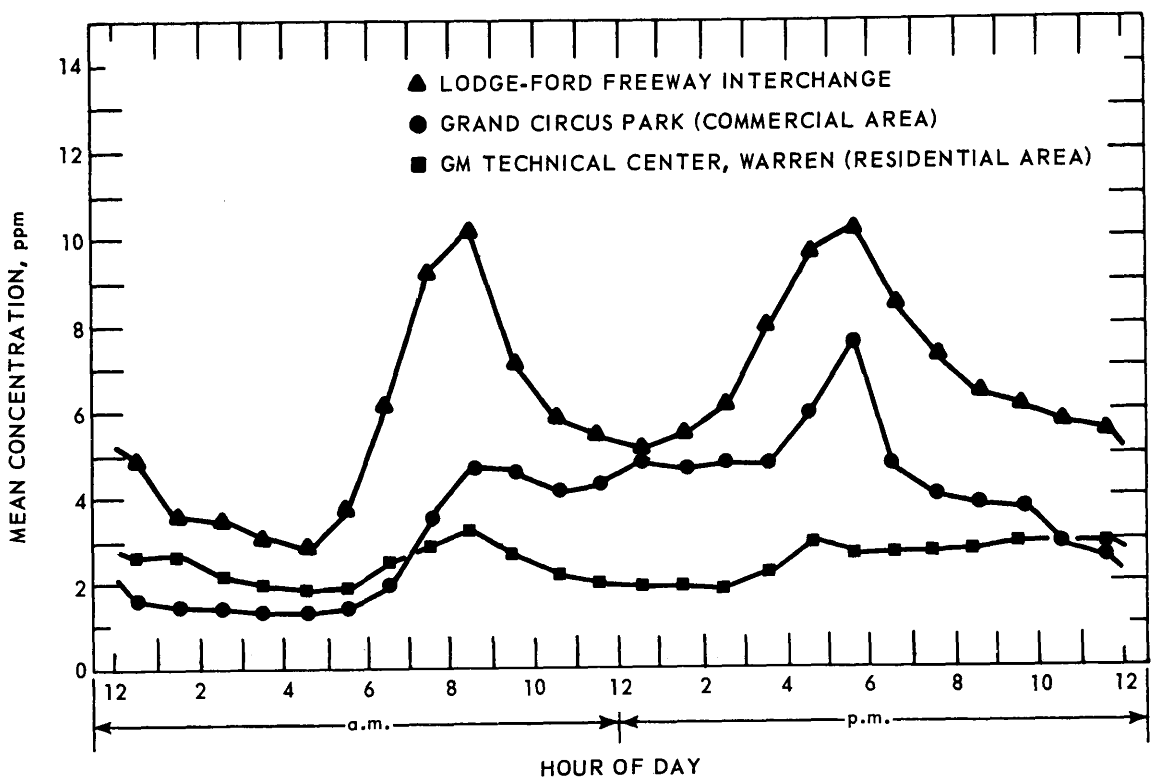

Figure 2. Diurnal variation of carbon monoxide levels on weekdays in Detroit.(27)

Recently, a statistical analysis of CO aerometric data from 30 technical papers was made in order to calculate the maximum 8 hour averaging time concentrations expected annually.[10] It is estimated that for the most polluted 5 percent of the urban sites the maximum annual 8 hour average in commercial areas would approximate 36 mg/m^3 (40 ppm), in motor vehicles in downtown traffic it would approximate 132 mg/m^3 (115 ppm), and in vehicles on expressways or arterial routes the value would be about 85 mg/m^3 (75 ppm). The CO concentrations in heavy traffic in city streets were almost 3 times the CO levels found in the central urban areas, and 5 times that found in residential areas (23 ppm).

Concentrations exceeding 100 mg/m^3 (87 ppm) have been measured in underground garages, in tunnels, and in buildings constructed over highways.

Hydrocarbons

Because of its relation to photochemical air pollution, there are factors that must be considered during the examination of atmospheric hydrocarbon concentration. First, there is an enormous variation in the tendency for different hydrocarbons to enter into the formation of photochemical air pollution. For example, the simplest hydrocarbon, methane, is virtually inert. Second, methane is often more abundant than all other hydrocarbons (oftenly referred to as nonmethane hydrocarbons) combined. It is important, then, in assessing photochemical air pollution to discriminate between methane and other more reactive hydrocarbons.

Although on occasion nonmethane hydrocarbons concentrations drop to unmeasurably low levels, methane does not. Numerous measurements suggest a worldwide minimum methane concentration of about 1.0 to 1.5 ppm.[14] In inhabited areas, methane levels are often much higher; values of 6 ppm or more have been observed.[14]

The diurnal variation of nonhydrocarbon concentrations resembles that of carbon monoxide in having maxima which appear around rush hours (Figure 3).

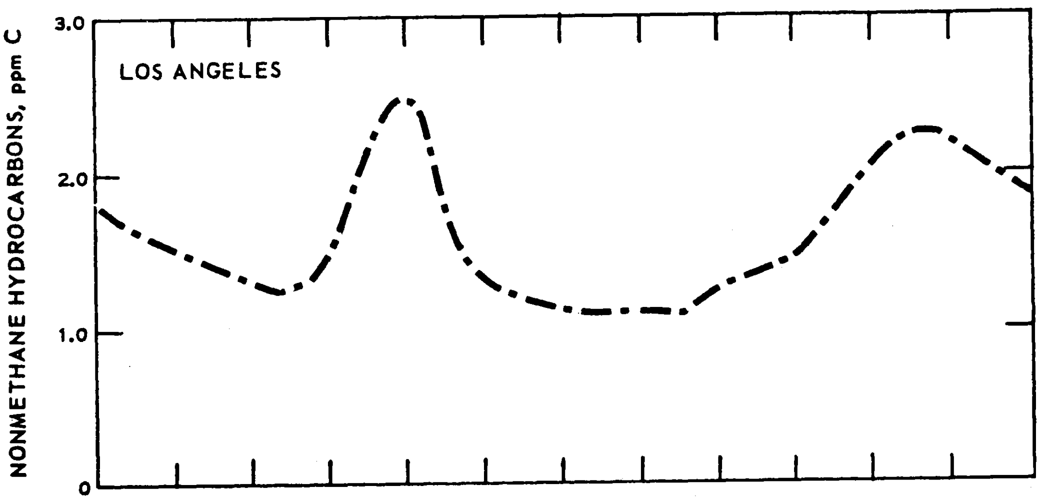

Figure 3. Nonmethane hydrocarbons concentration averaged by hour of day for Los Angeles County, Oct. 1966 through Feb. 1967. (14)

Oxides of Nitrogen (NOx)

In general, NOx concentrations in urban atmospheres are 10 to 100 times higher than those in rural atmospheres. Only a few data on background concentrations of NOx are available from scattered rural areas. From these data, it has been concluded that North American continental average levels of NO_2 are 4 parts per billion (ppb) and those of NO are about 2 ppb. (28)

Both NO and NO_2 concentrations display distinct diurnal variations dependent on the intensity of the solar-ultraviolet radiation, the amount of atmospheric mixing, and traffic patterns in the sampling area.

NO concentration shows a seasonal variation, with higher values occurring during the late fall and winter months. NO_2, however, does not display such distinct seasonal patterns. An analysis of limited air quality data for total NOx concentrations has not clearly indicated any yearly trends. (18)

Continuous measurement has indicated that peak values of NO above 1.23 mg/m^3 are common, but NO_2 concentrations have rarely been measured at this level. Most NO_2 concentrations measured in urban areas have been under 0.94 mg/m^3 (0.5 ppm). (18)

Oxides of Sulfur

Sulfur dioxide levels recorded in the Continuous Air Monitoring Project (CAMP) cities over a 6-year period show mean annual concentrations ranging from 0.01 ppm. in San Francisco to 0.18 ppm in Chicago.[4] Geographically, the highest values were recorded in the northeastern part of the United States, especially east of the Mississippi River and north of the Ohio River, where large quantities of sulfur-bearing fossil fuels are burned.

Particulates

Data from the National Air Surveillance Network (NASN) and state and local networks indicate that the annual geometric mean concentrations of suspended particulates ranges from $60 \mu g/m^3$ to about $200 \mu g/m^3$ in urban areas. In general, mean particulate concentrations correlate with urban population class, but there is a wide range of concentrations with each urban population class and many smaller communities have higher concentrations than larger ones. In non-urban areas, typical geometric mean concentrations range between $10 \mu g/m^3$ and $60 \mu g/m^3$.

For particles which readily settle out of the air, typical values encountered in urban areas range from 0.35 to 3.5 mg/cm^2-month (10-100 $tons/mi^2$-month), while values approaching 70 mg/cm^2-month have been measured close to very severe sources.[19]

Photochemical Oxidants

Oxidant concentrations exhibit a daily as well as a seasonal variation. The maximum concentration generally occurs around the noon hour, the period when the shorter wavelength solar radiation, which is photochemically important, reaches the surface of the earth with greatest intensity. The highest monthly mean concentrations occur during the period from late spring to early fall.

By analysis of oxidant concentration data for 4 years at 12 stations, the daily maximum 1 hour average concentration was shown to be equal to or exceed $290 \mu g/m^3$ (0.15 ppm) up to 41% of the time.[26]

AIR QUALITY STANDARDS

In order to achieve an atmosphere with no significant detectable adverse effects on health, welfare, and the quality of life, allowable air pollution levels — not to be exceeded during a specific time — must be established. On April 30, 1971, pursuant to the Clean Air Act,(29) as amended, the Environmental Protection Agency (EPA) promulgated two types of air quality standards:

1. Primary Standards — define levels of air quality which are necessary with an adequate margin of safety to protect the public health.

2. Secondary Standards — define levels of air quality which are necessary to protect against adverse effects on soil, water, vegetation, materials, animals, weather, visibility, and personal comfort and well-being.

These national primary and secondary ambient air quality standards are shown in Table 3. The responsibility for attaining these ambient air quality standards is with the states and local air quality control agencies.

Table 3

NATIONAL PRIMARY AND SECONDARY AMBIENT AIR QUALITY STANDARDS

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

Source: U.S. Environmental Protection Agency. A Mathematical Model for Relating Air Quality Measurements to Air Quality Standards, November 1971.

POSSIBLE SOLUTIONS TO MOTOR VEHICLE POLLUTION

The health effects of vehicular pollutants cannot be ignored nor can the building of roadways be abandoned in areas where large concentrations of people exist, and where the need for new highways is usually greatest. Therefore, until an absolutely pollution free vehicle can be produced, ways must be found to deal with the large share of pollution generated by motor vehicles in order to achieve a healthy environment. The reduction of this type of pollution would involve a combination of the approaches discussed in the following subsections.

Control of Vehicular Emissions

The immediate solution to the vehicle pollution problem lies in regulating the source, i.e., the motor vehicle itself. Pursuant to the 1970 Clean Air Act, the EPA has established emission standards[30] aimed at achieving 90% reduction from 1970 emission levels for 1975 cars.

In order to achieve the low emission standards required for the 1975 cars, vehicles will probably use one or more of the following control devices which are in development:[31]

a. Exhaust manifold reactor (thermal reactor)— Such a reactor is attached to the exhaust manifold to provide a longer detention period for exhaust gases at elevated temperatures. The greater detention time allows more complete oxidation of carbon monoxide and unburned hydrocarbons to harmless carbon monoxide and water.

b. Catalytic converter— This device uses a packed bed of catalyst to oxidize the exhaust hydrocarbons and carbon monoxide to a harmless form. Catalytic converters are adversely affected by lead so that non-leaded or low-leaded gasoline would be required with these devices.

c. Exhaust gas recirculation— This device redirects 10-20% of the engine exhaust from the exhaust pipe to the engine induction system. This recycled gas dilutes the air-fuel mixture drawn into the cylinders and lowers the peak combustion temperature so that less nitric oxide is formed.

The gasoline internal-combustion engine is inherently a producer of air pollution and because problems are being encountered in the development of control devices for exhaust gases of this type of engine, considerations are now being given to different types of cleaner automotive power plants. The possible alternatives to the internal-combustion engine are: Diesel, gas turbine, electric, steam, hybrid, Wankel, stratified-charge, and Stirling engines.[31] In addition, adapting conventional engines for use with substitute fuels such as liquified petroleum gas (LPG), liquified natural gas (LNG), and compressed natural gas (CNG), which burn cleaner, has received considerable attention and appears promising. However, supplies of these fuels are very limited compared to those of currently used fuels.

Environmental Consideration During Highway Location and Design

The constantly increasing national highway network leaves little doubt as to its impact on the environment. It must be recognized, therefore, that the responsibilities of highway location and design extend not only to the right-of-way, but also to whatever can be affected by the highway's presence. Proper environmental considerations during the location and design stages of a highway project can play a significant role in the long-term impact on the air quality of urban areas.

Location Consideration

In the location of new highways, consideration should be given to minimizing the impact of emissions from a highway on the air mass over a community. Areas where present levels of pollution are already high should be avoided; such areas may be identified by consideration of air pollution monitoring data or emission inventory data on existing large pollution sources.

Proper location of highways can be achieved by utilization of natural meteorological and topographic conditions to optimize the dispersion of air pollution. The dynamics of regional or local air currents should be considered to avoid locations in which air flows from the highway will be toward nearby heavily populated areas. Locating highways on elevated ridges or hills takes advantage of better natural ventilation, more diffusion capability due to increased wind velocities and fewer ground level obstacles, and increased vertical mixing.[32] Because of poor dispersion and because concave topography generally has a more extreme climate than other landforms, locating highways in inhabited valleys, particularly steep, narrow valleys, should be avoided.[33] These examples of location criteria are general in nature. Due to the many meteorological, geographic, and urban configurations possible, each proposed location for a new highway must be individually analyzed by the planner, highway engineer, and meteorologist to determine the optimal location.

Design Consideration

In building highways, buffer zones should be provided where possible to minimize the potential for exposure of people to high concentrations of pollutants. Figures 4 and 5 provide information on the decrease of carbon monoxide concentrations with horizontal

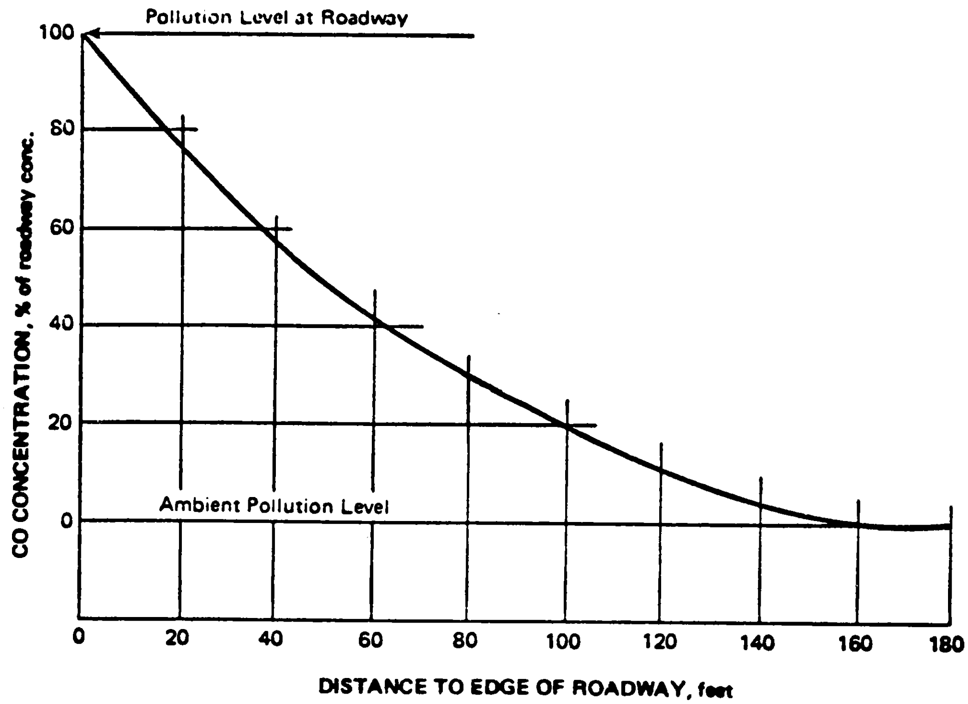

Figure 4. Pollution level versus distance to edge of roadway.(35)

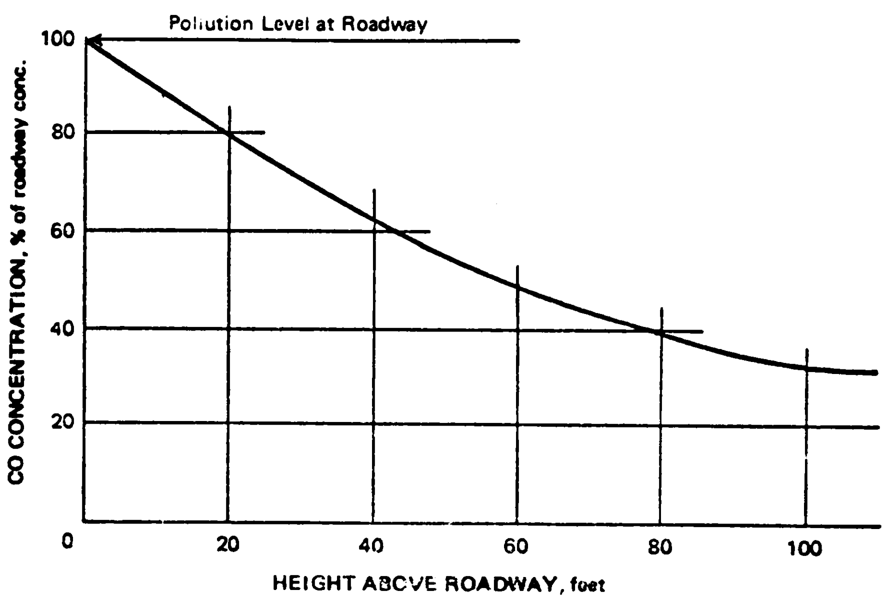

Figure 5. Pollution level versus height above Roadway.(35)

and vertical distances from a roadway in relation to the pollution level at the roadway.[34] Such information is useful in determining optimal separations between possible receptors and highways so that pollution levels will not exceed an acceptable value.

The decision to build a new highway as an elevated, at-grade or depressed facility can have a considerable effect on the pollution impact of the highway.[35] For example, from the standpoint of reducing neighborhood disruption and noise, depressing highways in urban areas is favored. However, a depressed highway provides little opportunity for local wind currents to disperse the emissions. Thus, the motorists on a depressed highway, as well as persons in adjacent areas, may be exposed to unusually high pollution levels.

The development of computer modeling techniques that can predict air pollution concentrations in the vicinity of a road as a function of traffic, meteorology, roadway design and topography surrounding the road is actively being pursued. Such techniques will enable highway planners to design highways which minimize pollution from automobile emissions.

Emission Reduction Through Improvement of Traffic Flow

It has been found that total vehicular emissions during idling, acceleration, and deceleration are many times higher than during constant speed conditions, and that pollution is created at a rate approximately inversely proportional to speed.[36] These findings suggest that improvements in the traffic flow characteristics on major streets and highways offer a very important tool for reducing air pollution. The following are techniques for improving traffic flow:[35,37]

A. Freeways

1. reverse lane operations
2. driver advisory displays
3. ramp control
4. interchange design

B. Arterials

1. alignment
2. widening intersections
3. parking restrictions
4. signal progression
5. reversible lanes
6. reversible one-way streets
7. helicopter reports

C. Downtown Distribution

1. traffic responsive control
2. one-way street operations
3. loading regulations
4. pedestrian control
5. traffic operations program to increase capacity and safety (TOPICS)

Emission Reduction Through Traffic Control

Any program that focuses exclusively on improving traffic flow to reduce air pollution is likely to be self-defeating. Since improvement in traffic flow may tend to induce more people to drive the net result might be increased trip lengths with greater amounts of pollutants. Therefore, it is necessary that techniques for regulating the number of vehicles set forth below be used concomitantly with improved traffic flow techniques to reduce the overall number and length of automobile trips in urban areas.

Currently, the best techniques for regulating auto traffic are:[35,37]

A. Transit Operations

1. bus lanes on city streets
2. bus lanes on freeways
3. one-way streets with two-way buses
4. park-ride and kiss-ride
5. service improvements and cost reductions

B. Regulations

1. parking bans
2. auto-free zones
3. gasoline rationing
4. idling restrictions
5. four-day, forty-hour week

C. Pricing Policy

1. parking policy
2. road-user tax
3. gasoline tax
4. car pool incentives

D. Planned unit development

Utilization of Green Belts

Recent findings have indicated that vegetation may be an important sink for many gaseous air pollutants.[38] Aside from providing fresh air, and thereby improving the ratio of fresh air to polluted air, some plants also remove certain pollutants from the atmosphere by absorption. By planting vegetation along freeways, therefore, the air quality can be improved. The appropriate types of vegetation must be planted, however, since different types exhibit different tolerances and absorption rates for various pollutants. Unfortunately, quantitative data on resistivity and absorptivity are still lacking.

Another factor that must be considered is how the green belts affect the air flow pattern over the surrounding space. From an air pollution viewpoint, green belts must not hinder wind flows which effect the dispersion of air pollutants. In general, grass or low profile plants make the best green belt; with these plants, gaseous absorption occurs while the beneficial wind flows are not greatly hindered. Contrary to this, tree stands are undesirable since they bring about a decreased wind speed that results in slower dispersion of the pollutants.

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APPENDIX A

Conversion Between Volume and Mass Units of Concentration

All measurements of air pollutant concentrations are corrected to a reference temperature of 25°C and to a reference pressure of 760 millimeters of mercury (1 atmosphere). For most pollutants, the concentrations may be expressed in either ppm (by volume) or in micrograms per cubic meter ($\mu g/m^3$). The following table shows the relationships between ppm and $\mu g/m^3$ for different pollutants.

Pollutant	Factor by which to multiply pollutant concentration in $\mu g/m^3$ to obtain concentration to ppm	Factor by which to multiply pollutant concentration in ppm to obtain concentration in $\mu g/m^3$
Carbon monoxide	8.7×10^{-4}	1150
Hydrocarbons	1.53×10^{-3}	655
Oxides of nitrogen (NO	8.1×10^{-4}	1230
Oxides of nitrogen (NO_2	5.3×10^{-4}	1880
Oxides of Sulfur (SO_2)	3.5×10^{-4}	2860
Photochemical Oxidants	5.1×10^{-4}	1960
Particulates	--	--
Lead	--	--

The measured concentrations of lead and other particulates are expressed in microgram per cubic meter, or some other convenient mass unit of concentrations.

APPENDIX B

GLOSSARY

Geometric mean — a measure of central tendency for a log-normal distribution; the value of a given set of samples above which 50 percent of the values lie.

Gram (gm) — a unit of mass 453.59 of which is equivalent to one pound.

Kiss-ride facility — it is a lane, used in conjunction with express bus or other transit services, set aside for autos to discharge or load commuters without impeding traffic flow. Its purpose is to provide effective transit services in low density residential areas. With this facility, the commuters are able to travel by car in less congested areas where bus service would involve a long walk or wait, but use transit for a portion of the trip where traffic is more difficult.

Mass concentration — concentration expressed in terms of mass of substance per unit volume of gas or liquid. Example is microgram per cubic meter of air ($\mu g/m^3$).

Microgram (μg) — a unit of mas equivalent to one millionth of a gram.

Micron (μ) — a unit of length equivalent to one millionth of a meter.

Milligram (mg) — a unit of mass equivalent to one thousandth of a gram.

Park-ride facility — used in conjunction with express bus, it includes a parking lot and express bus stop. Its purpose is similar to that of a kiss-ride facility, which is to provide effective transit services in low density residential areas.

Particle — any dispersed matter, solid or liquid, in which the individual aggregates are larger than single small molecules (about 0.000 2μ in diameter) but smaller than about 500μ in diameter.

Particulate — existing in the form of minute separate particles.

Parts per billion (ppb) — a unit of measure of the concentration of a gas in air (or any gaseous mixture) expressed as parts of the gas per billion (10^9) parts of air, normally both by volume.

Parts per million (ppm) — a unit of measure of the concentration of a gas in air (or any gaseous mixture) expressed as parts of the gas per million (10^6) parts of air, normally both by volume.

Photochemical reaction — any chemical reaction that is initiated as a result of absorption of light.

Photosynthesis — the formation of carbohydrate from carbon dioxide and water in the presence of chlorophyll and light, in plant tissues.

Planned unit development — locating major trip origins and destinations near to each other in order to minimize the need for vehicular travel. This is achieved by locating residential areas near shopping and employment areas.

Primary pollutant — one which is emitted directly into the atmosphere from a source.

Ramp control — a technique which consists of monitoring freeway traffic volumes, and by some form of traffic control, regulating the number of vehicles that can enter the freeway via its ramp system.

Reverse lane operation — one or more lanes are designated for movement in one direction during part of the day and in the opposite during another part of the day.

Secondary pollutant — a pollutant formed in the atmosphere from chemical reactions involving the primary pollutants. An example is ozone, which is formed by the photochemical reactions involving hydrocarbons and nitrogen oxides in the atmosphere.

Signal progression — coordination of signals along an arterial to permit continuous movement of vehicles through the system.

Synergism — a situation in which the combined action of two or more agents acting together is greater than the sum of the action of these agents separately.

TOPICS — a program developed by the federal government to obtain maximum efficiency and safety from the existing major street network in cities through a systematic application of traffic engineering techniques.

Topography — the configuration of an earth surface, including its relief and the position of its natural and man-made features.

Traffic responsive control — a use of computerized traffic control system to provide responsive optimal signal timing for meeting the varying demands of a street network.

Volume concentration — concentration expressed in terms of gaseous volume of substance per unit volume of air, usually expressed in percent, parts per million (ppm), or parts per billion (ppb).