Transportation/Air Quality Background Information

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Introduction

To develop effective strategies for the control of mobile source emissions, it is important to have a basic understanding of the relationships between transportation, mobile source emissions, and the overall problem of air pollution which affects the U.S. environment. This chapter provides a general overview of mobile source emissions. Included is an explanation of the nature of mobile source emissions, their cause and effect, the variables which determine the effectiveness of control strategies, how these emissions contribute to pollution problems in general, and how the extent of these emissions is measured and regulated. By providing a context for the understanding of mobile source emissions, the chapter is intended to provide required background information on the role and need for transportation control measures (TCMs) as effective strategies for control of air pollution.

Air Quality/Transportation Legal Requirements

Clean Air Act

The earliest air pollution legislation in the United States included the Air Pollution Control Act of 1955, a 1959 extension to that act, and the Motor Vehicle Exhaust Study Act of 1960. These acts provided for federal grants and subsidies to state and local institutions for research on various air pollution issues. Through this period, all authority on air pollution issues remained with state and local governments. The federal role was largely to encourage and support research.

Then, in 1963, the federal Clean Air Act was enacted. It is the central air pollution control legislation at the federal level. While the major provisions of the 1963 act continued to be research-based, this act extended the research concept to the publication of "criteria" documents and encouraged states to pursue their own efforts through matching grants for the development of control programs. Although the original provisions of the Clean Air Act did not attempt to regulate the states, it signaled that federal policy on air pollution was moving in the direction of regulation.

The Motor Vehicle Control Act of 1965 was the first federal policy that relied on a regulation-based approach. This Act gave the federal government the authority to set standards for motor vehicle emissions and caused automobile manufacturers to install air pollution control devices on vehicles. Most authority, however, still remained with the states. Since that time, new motor vehicles sold in the U.S. have been subject to increasingly stringent standards, which have resulted in significant decreases in emissions per vehicle mile travelled.

Partly as a result of the slow progress in air pollution control that was being made and also due to broad public support for pollution control legislation, the federal government assumed major responsibility for setting standards and deadlines for compliance under the Clean Air Act Amendments of 1970. The 1970 amendments included the following provisions:

- Established National Ambient Air Quality Standards (NAAQS) for six pollutants – carbon monoxide (CO), hydrocarbons (HC), nitrogen dioxide, photochemical oxidants, sulfur oxides, and total suspended particulates (TSP). It also distinguished between primary pollutants which are emitted directly into the air by a source and secondary pollutants which are formed in the atmosphere by a chemical reaction between various pollutants. Areas which fail to meet these standards are labeled "nonattainment areas." These standards are shown in Table 1.

- Established the Federal Motor Vehicle Emissions Control Program (FMVECP) which set emissions standards for new motor vehicles.

- Required states to develop State Implementation Plans (SIPs) which are federally enforceable plans which demonstrate how designated non-attainment areas which exceeded air quality standards would attain and maintain the NAAQS by 1975. As a result, implementation responsibilities were now shared with the states.

While previous legislation had called for incremental change, the 1970 Amendments were considered innovative, particularly in their attempts to have polluters meet standards for which the control technology had not yet even been developed. This essentially "forced" the development of new technology and has subsequently resulted in radical innovations in motor vehicle design and technology.

Although significant progress was made toward improving air quality as a result of the 1970 amendments, persistent problems relating in part to both CO and ozone caused Congress to develop new legislation with specific emphasis on mobile source emissions. The Clean Air Act Amendments of 1977 required nonattainment areas to prepare revised SIPs demonstrating how attainment would be achieved by the end of 1982, or, in cases of severe ozone or carbon monoxide problems, by the end of 1987. In order to qualify for this extension of the attainment deadline, certain programs needed to be implemented in severe non-attainment areas, such as vehicle inspection/maintenance (I/M). The Clean Air Act Amendments of 1977 required the consideration of TCMs in SIPs for areas unable to meet standards for ozone or carbon monoxide. It specified a process for developing TCMs which involved the cooperative efforts of public and private interests, as well as elected officials, to assure that the area's TCM program is politically feasible. State and local transportation agencies have responsibility for the

Table 1. National Ambient Air Quality Standards (Micrograms Per Cubic Meter)

		Standard			
Contaminant	Averaging Period	Primary		Secondary	
Carbon Monoxide (CO)	8-hour[1]	10,000	(9.0 ppm)	10,000	
	1-hour[1]	40,000	(35.0 ppm)	40,000	
Sulfur Dioxide (SO_2)	Annual	80	(0.03 ppm)		
	24-hour[1]	365	(0.14 ppm)		
	3-hour[1]			1,300	(0.5 ppm)
Nitrogen Dioxide (NO_2)[2]	Annual	100	(0.05 ppm)	100	
Ozone (O_3)	1-hour[1]	240	(0.12 ppm)	240	
PM_{10}	Annual	50		50	
	24-hour[1]	150		150	
Lead (Pb)	3-month	1.5		1.5	

[1] Not to be exceeded more than once a year per site.

Sources: EPA, National Primary and Secondary Ambient Air Quality Standards (40 CFR 50).

implementation of TCMs through the SIP. The EPA contributed to this effort by providing financial and technical assistance.

The 1977 Amendments gave the EPA the authority to impose "sanctions" in instances where acceptable SIP programs are not planned or implemented. These sanctions included the withholding of federal funds to state agencies for highway construction and the withholding of permits for construction of new stationary sources.

The Amendments also called for the coordination of air quality planning with transportation planning at the regional, state, and federal levels. The "conformity" requirement stipulates that all transportation planning and activities must conform to the requirements set forth in the SIP and that Metropolitan Planning Organizations (MPOs), in submitting their Transportation Improvement Program (TIP) to receive federal funding for transportation improvements, are prohibited from approving any transportation project, program, or plan which does not conform to the SIP. As a result, the 1977 Amendments induced state and local governments to develop plans that would assure attainment and maintenance of NAAQS, thereby reducing the federal government's role in the attainment planning process.

The 1990 Amendments to the Clean Air Act address air toxics, acid rain, and stratospheric ozone as well as mobile sources. The contribution of mobile sources to the carbon monoxide and atmospheric ozone nonattainment problems, though, represents a central thrust of the legislation, with major new or enhanced provisions affecting motor vehicles, fuels, and transportation control measures.

A key feature of the new law is that it classifies CO and ozone nonattainment areas into different levels of severity. For ozone, there are five categories. For CO and PM-10, there are two classes. The deadline for ozone attainment varies from 3 years for marginal areas to 20 years for extreme areas. The boundaries of serious and above ozone nonattainment areas must include the entire metropolitan statistical area or the consolidated metropolitan statistical area.

A major new requirement of the act is the specification of incremental as well as a final attainment schedule. For all but marginal ozone areas, there must be a total net reduction of 15% in VOC emissions during the first six years and 3% per year thereafter. It is noteworthy that the benefits of the federal motor vehicle emissions program and other federal programs can not be counted towards this incremental reduction.

Specifically with respect to mobile sources, tailpipe emission standards are tightened starting in 1994, with the option of going to even lower "Tier II" standards in 2004. These standards include a separate cold temperature carbon monoxide standard, and new diesel particulate standards and schedules for urban buses. Enhancements to current vehicle inspection/maintenance programs are mandated. Evaporative emissions, which may account for as much as two-thirds of NMHC emissions from automobiles, will now be controlled, along with requirements covering the installation of onboard vapor recovery systems.

Important attention is given to fuels in the new act. Oxygenated fuels are required during the winter months beginning in 1992 in the 41 CO nonattainment areas. Only reformulated gas is to be sold in the nine worst ozone urban areas beginning in 1995. A clean fuels program is applicable to fleets of 10 or more vehicles in 26 metropolitan areas.

Transportation programs may be particularly affected by changes in the Act regarding sanctions, conformity, and the forecasting of vehicle miles of travel. The enforcement and sanction provisions have been restructured so that highway sanctions can be applied for failure to meet any major milestone, including the failure to implement SIP provisions. The requirements for conformity of transportation and air quality actions are now defined in considerable detail, with a shift from the conformity of plans to a conformity of "purpose." The emissions from transportation plans and programs must now be consistent with the emissions contained in the SIP projections and schedules. Section 187 adds a new requirement to forecast and monitor vehicle miles of travel for certain CO nonattainment areas. If actual VMT proves to be higher than forecast, then pre-specified contingency measures must be implemented.

Requirements regarding transportation control measures are generally regarded as being strengthened in the new act, consistent with the overall emphasis on mobile sources. Sixteen separate TCMs are listed in Section 108(f). In ozone areas classified as serious or above, employers with 100 or more employees are required to implement trip reduction programs designed to reduce commute-related vehicle miles of travel by raising average vehicle occupancy for employee work trips at least 25% above the area average.

A central thrust of the 1990 Clean Air Act Amendments is an emphasis on market-based principles oriented to economic incentives and disincentives. Concepts based on emission fees and offsets are encouraged. With respect to transportation, this creates opportunities for innovative forms of economic pricing even though pricing is not explicitly listed as a Section 108(f) transportation control measure. For example, employer-provided free parking could be replaced with an equivalent transportation allowance that could then be applied by an employee to any mode of travel.

In summary, the 1990 Amendments to the Clean Air Act do more than just define another round of air quality planning. They certify the important inter-relationships between highway transportation and air quality, defining a set of actions and requirements aimed at reducing mobile source emissions.

Intermodal Surface Transportation Efficiency Act of 1991

The Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) represents landmark transportation legislation with potentially far reaching implications for helping to achieve the objectives of the Clean Air Act. The Act provides significantly increased funding flexibility with respect to how monies can be used for highway, transit, and other transportation improvements. Increased authority is given to metropolitan planning organizations and local governments for selecting projects to be implemented. The current Federal-aid primary, secondary, and urban system program categories are replaced with a single block grant Surface Transportation Program. A new National Highway System includes the Interstate Highway System and other urban and rural principal arterials judged to be of national significance.

Several provisions of the ISTEA have direct and immediate ramifications for transportation-related air quality planning. These include the following:

- A $6 billion Congestion Mitigation and Air Quality Improvement Program is created to help implement projects and programs that will contribute to achieving attainment of the National Ambient Air Quality Standards. Eligible projects include Clean Air Act Section 108(f) transportation control measures and projects contained in a State Implementation Plan (SIP). "No funds may be provided under this section for a project which will result in the construction of new capacity available to single occupant vehicles unless the project consists of a high occupancy vehicle facility available to single occupant vehicles only at other than peak travel times."

- Each state is to develop and implement systems for managing traffic congestion, public transportation facilities, and intermodal transportation systems. This is to include a traffic monitoring system for highways.

- Urbanized areas over 200,000 population are designated as Transportation Management Areas. Each such area is to have a congestion management system that provides for "use of travel demand reduction and operational management strategies." Transportation Management Areas that are classified as nonattainment for either ozone or carbon monoxide may not use federal funds "for any highway project that will result in a significant increase in carrying capacity for single occupant vehicles unless the project is part of an approved congestion management system." The Department of Transportation will establish a phase in schedule for the congestion management system, including the restriction on single occupant vehicle projects.

- The long-range transportation plan for metropolitan areas which are nonattainment for either ozone or carbon monoxide is to be coordinated with the process for developing transportation control measures for the Clean Air Act's State Implementation Plan (SIP).

- Requirements for a statewide long-range transportation plan and associated improvement program are created, with the stipulation that these efforts are consistent with the corresponding metropolitan area plans and programs. A statewide transportation plan is to include plans for bicycle transportation and pedestrian walkways for appropriate areas. A state transportation improvement program shall include projects "which in areas designated as nonattainment for ozone or carbon monoxide under the Clean Air Act conform with the applicable State Implementation Plan developed pursuant to the Clean Air Act."

- The act identifies factors that should be considered at a minimum in a state and/or metropolitan area transportation planning process. These include:
    - "strategies designed to make the most efficient use of existing transportation facilities;"
    - "methods to reduce traffic congestion and to prevent traffic congestion from developing in areas where it does not yet occur, including methods which reduce motor vehicle travel, particularly single-occupant motor vehicle travel;"
    - "methods to expand and enhance transit services;"
    - "the effect of transportation decisions on land use and development, including the need for consistency between transportation decision-making and the provisions of all applicable short-range and long-range land use and development plans;" and
    - access to "ports, airports, and intermodal transportation facilities."
- Supportive of the Act's increased emphasis on congestion management, a $25 million per year Congestion Pricing Pilot Program is created to encourage implementation of time-of-day based transportation pricing. Up to five awards can be made to fund projects proposed by state and local governments and public authorities. No more than three of these projects can involve the use of tolls on the Interstate System.

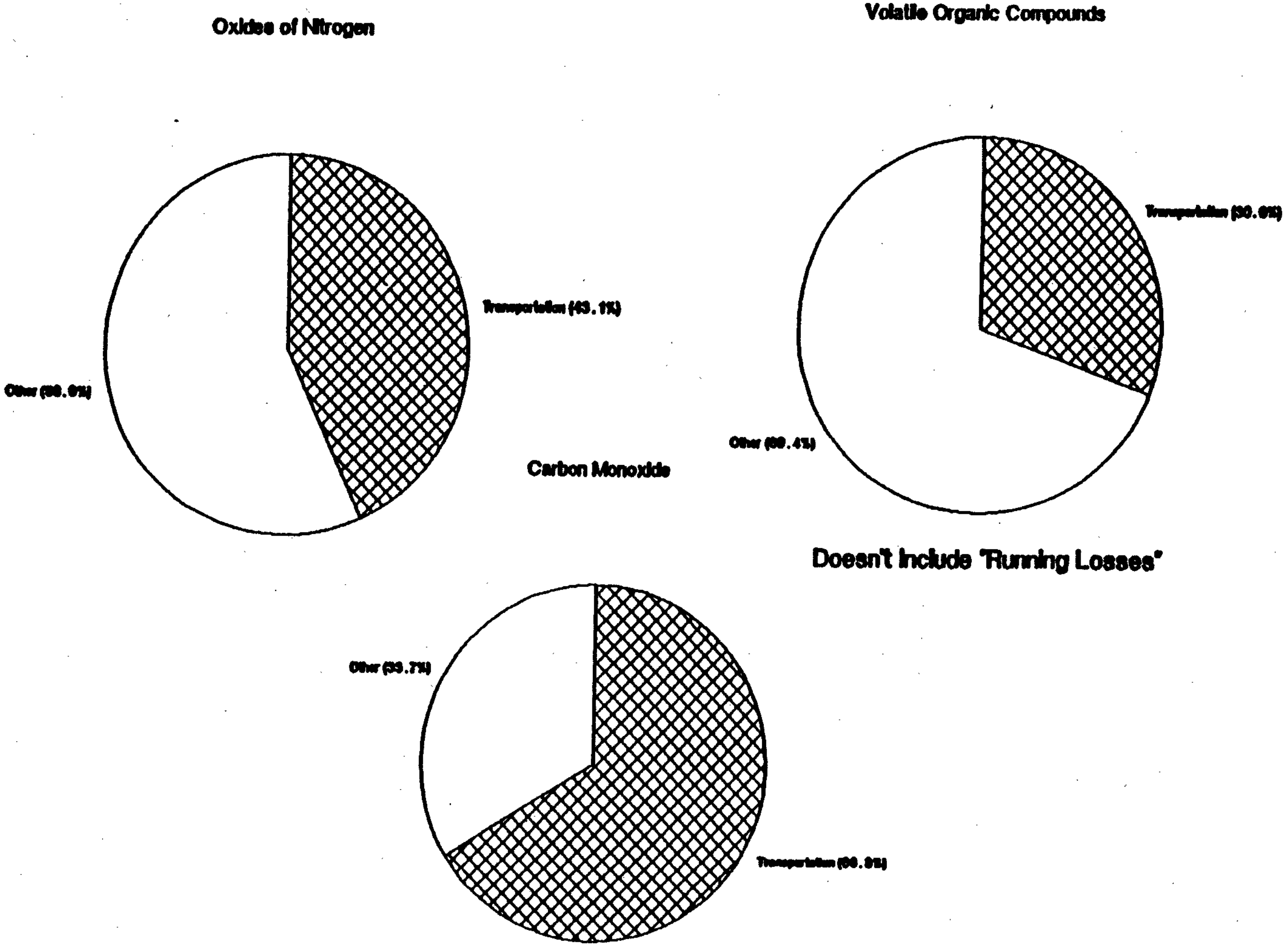
In summary, the Intermodal Surface Transportation Efficiency Act is very much supportive of the transportation related provisions of the Clean Act Amendments of 1990. Coordination between the transportation and air quality planning processes is required. Funding flexibility is provided to help states and urban areas develop and implement the transportation portions of a State Implementation Plan. The provisions involving congestion management and the efficient utilization of existing transportation infrastructure are consistent with the Clean Air Act's intent of minimizing vehicular emissions through improved management of intermodal transportation systems.

■ Harmful Effects of Transportation-Produced Pollutants

Pollutants Produced by Transportation

Motor vehicles are the dominant source of many air pollutants which contribute to environmental problems today (Figure 1). In 1985, nationwide, transportation sources were responsible for 70% of the carbon monoxide, 45% of the NOx, 34% of the hydrocarbon (HC), 18% of the particulate, and 73% of the lead emissions (Walsh, 1988). Ozone, also known as smog, is produced by the photochemical reaction of hydrocarbons and NOx emissions, and is therefore primarily a transportation-related pollutant. In

Figure 1. 1987 Nationwide Emissions From Transportation



Doesn't Include "Running Losses"

Source: EPA

some urban areas, the extent of the contribution of mobile sources to local air quality problems is even higher. Transportation is also a significant contributing source of other toxic air pollutants such as benzene and formaldehyde.

Carbon monoxide, or CO, is a colorless, odorless gas which is produced through the incomplete combustion of organic fuels. It combines with the hemoglobin in the blood, reducing the ability of blood to carry oxygen. At high enough concentrations, CO can be fatal to humans. At concentrations generally found in urban air, CO is not necessarily fatal, but can aggravate cardiovascular diseases and impair mental functions. Forty-one major metropolitan areas currently exceed the air quality standard for CO.

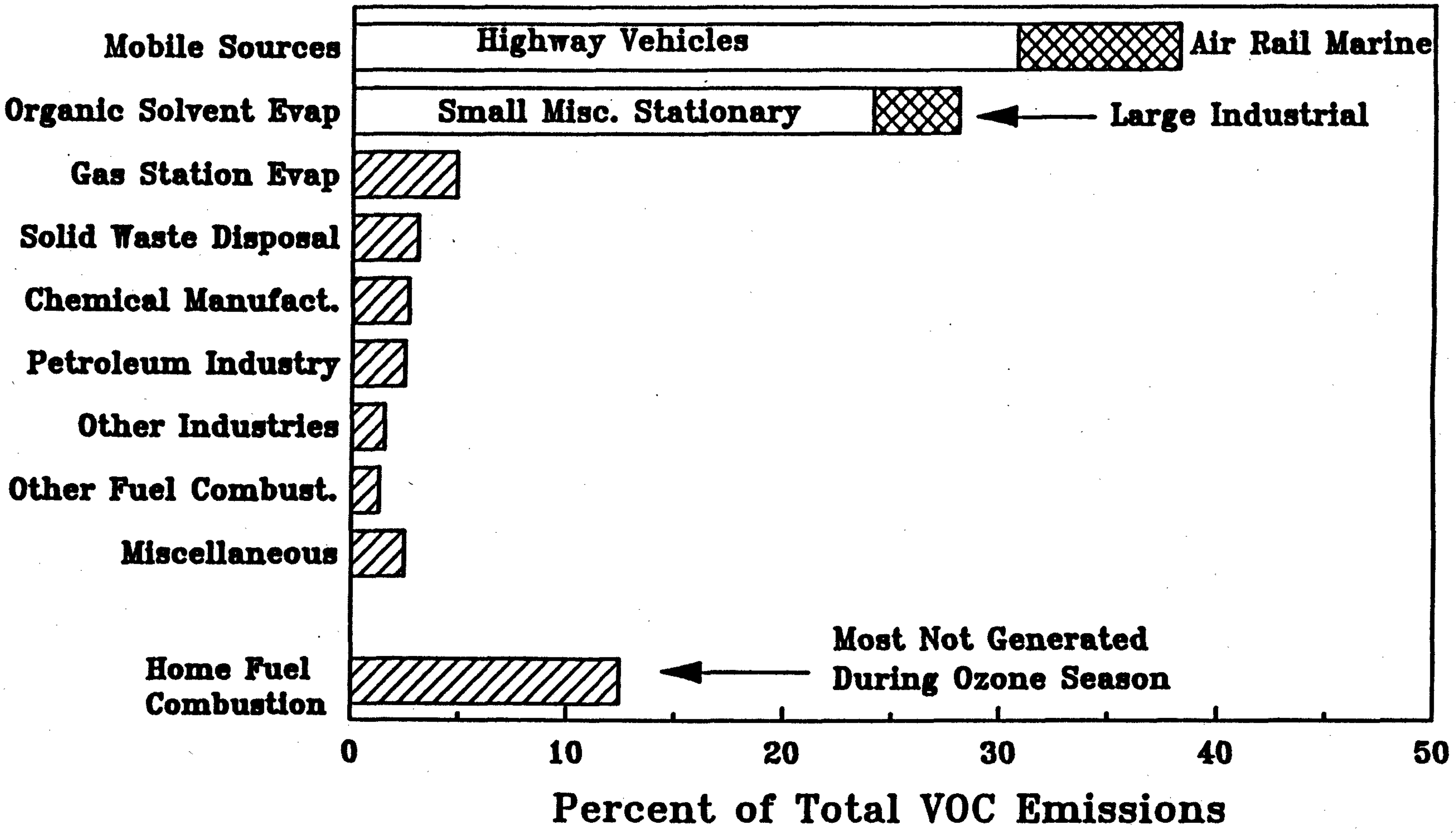
Nitrogen oxides, or NOx, represent a number of compounds produced during combustion. NO_2 is a brownish gas with a pungent odor. It is a cause of the brownish color of the sky in many smoggy areas and is produced in fossil-fueled electrical power plants as well as automobiles. NO_2 is a pulmonary irritant and short exposures to it may increase susceptibility to acute respiratory diseases. In school age children, NO_2 has been found to produce such respiratory problems as coughing, runny nose, and sore throat. NOx can react chemically in the air to form various compounds, including nitric acid, and is a contributor to acid rain. NOx, as a result, can harm vegetation and also affect a wide variety of materials such as fabrics, plastics, and rubber.

Hydrocarbons, or HC, are compounds of carbon and hydrogen. In air quality studies, HC also refers to volatile organic compounds (VOCs), such as aldehydes and alcohols, in addition to true hydrocarbons. HC from transportation sources is primarily unburned fuel which escapes in motor vehicle exhaust (Figure 2). In urban air, HC is not directly harmful. Its importance as an air pollutant is due to the role of "nonmethane hydrocarbons" (NMHC) in atmospheric chemical reactions that produce nitrogen dioxide and ozone. (Methane, though a common hydrocarbon, does not participate in these reactions.) Hydrocarbons that participate in chemical reactions that form NO_2 and ozone are referred to as "reactive hydrocarbons."

Particulates, as a category, include all solid particles and liquid droplets in the air, except pure water and encompass a wide variety of distinct substances. The National Ambient Air Quality Standards are established for particulate matter as PM-10, which are fine particles small enough to enter the lungs and impair their function. Transportation contributes to the production of particulate matter through diesel fuel exhaust, and includes substances such as unburned hydrocarbons, sulfur dioxide, and sulfuric acid. The damaging effect of particulate matter depends on the size of the particle and its composition. Recent studies indicate that particulate emissions can cause respiratory cancer. Beyond their health effects, particulate matter can impair visibility (by absorbing and scattering light) and also cause corrosion and soiling of exposed materials.

Lead is a poisonous heavy metal that damages the nervous system and kidneys. It is also a cause of impaired mental function, particularly among young children. The primary source of lead in the atmosphere is the combustion of gasoline that contains lead antiknock compounds. As a result of the phase-out of leaded fuels, significant progress is being made toward eliminating transportation sources of lead, resulting in a substantial decline in ambient levels of lead.

Figure 2. 1985 VOC Emissions by Source Category



Source: April 1988 OTA

Contribution of Transportation to Major Environment Problems

Ozone, or O_3, is a colorless gas with a pungent odor. Ozone is not a direct emission from transportation sources. Instead, it is a secondary pollutant formed by photochemical reactions involving HC and NOx in sunlight. Ozone formed naturally in the stratosphere helps filter infrared rays of sunlight, actually protecting the environment from harmful effects of sunlight. However, in the atmosphere, ozone and its related "photochemical oxidants" are referred to as "smog," which contains a number of compounds which are harmful to living organisms and materials. Ozone is a strong pulmonary irritant which can affect lung functions and cause chest discomfort in sensitive individuals. The effects of ozone are not limited to people with preexisting respiratory problems, but also affect people in good health by producing measurable reductions in normal lung function. It also causes eye irritation, is toxic to plants, damages many materials. Recent studies have demonstrated the damage which ozone causes to forest ecosystems and its impact on the growth of certain crops. Damage to annual crop yield in the U.S. alone has been estimated in the billions of dollars. Almost 80 million Americans currently reside in areas which do not meet the air quality standard for ozone; the problem is so widespread as a result of the long-range transport of ozone that levels of ozone in rural areas can approach levels experienced in urban areas.

Acid rain is the phenomenon of rain, interacting with pollution carried in the air, having greater acid content than natural rain. The deposition of acid rain has adverse effects on aquatic systems, crops, forests, materials, human health, and visibility. In forests, these pollutants fall to earth dissolved in rain and can damage the needles of firs, spruces, and pines, allowing nutrients to escape. They may also acidify the soil, destroying nutrients and fine root systems. Weakened trees become more susceptible to drought, diseases, and insects. Research is continuing to learn more about the causes and effects of acid rain. Transportation emissions which are considered precursors for acid rain formation include VOCs, NOx, and SO_2. The presence of ozone and other oxidants in the air contribute to converting the precursor SO_2 and NOx into sulfuric and nitric acids which then fall to earth dissolved in rain.

An environmental issue receiving considerable current international attention is global warming or the so-called "greenhouse effect." Although not currently regulated as a criteria pollutant, carbon dioxide, or CO_2, is a by-product from the burning of fossil fuels. In part, as a result of the burning of fossil fuels such as gasoline, there has been a dramatic increase in the amount of CO_2 in the atmosphere. As a result of its high rate of fossil fuel consumption, the United States is the largest single producer of CO_2 emissions worldwide, with transportation responsible for roughly one-third of all U.S. CO_2 emissions. Scientists believe that increases in the level of CO_2 and other greenhouse gases could change the earth's climate. Similar to panes of glass in a greenhouse, CO_2 allows solar radiation to enter the earth's atmosphere but then traps it, preventing heat from escaping into space. As CO_2 levels increase, enough heat may be trapped to warm the atmosphere. Even a slight rise in the earth's mean temperature could affect rainfall patterns, producing floods and drought. Some scientists even predict the possible melting of the polar ice caps, causing a rise in sea level and potential flooding in numerous cities and farm regions.

Economic Impacts of Air Pollution

Various approaches can be taken to evaluate the economic impacts of air pollution to society. One can assign a monetary value to each of the adverse physical effects of pollution. Or, alternatively, one can determine how much society is willing to pay in order to avoid what are considered the harmful effects of air pollution. Transportation-related emissions have been shown to result in harmful effects on human health, vegetation, materials, and visibility. However, because there are many uncertainties regarding the significance or severity of these effects, it is difficult to place a monetary value on them.

A National Academy of Sciences (NAS) study estimated that a nationwide 90% reduction in auto emissions from 1973 levels would prevent 200 million person days/year of oxidant exposure symptoms and between 800 and 4,400 NO_2-induced deaths/year. The NAS study arbitrarily estimated the value of oxidant exposure symptoms to be between $1 and $10/person day of discomfort and the value of human life to be $200,000 (1973 dollars). As a result, the health benefits of a 90% reduction in auto emissions was estimated to be $0.36-3 billion/year. NAS also estimated that this reduction would prevent between $0.6 and $1.8 billion/year in damage to vegetation and materials. This is equivalent to a total of approximately $1.6-8.8 billion/year in 1980 dollars.

A more recent estimate of the health costs of motor vehicle air pollution has been developed by the Institute of Transportation Studies of the University of California at Berkeley. As part of a 1987 analysis of future transportation fuels, the annual health costs of vehicular air pollution were estimated to be in the range of $4.03 to $84.99 billion, expressed in 1985 dollars.

Other studies based on the willingness of households to pay to improve air quality have determined that households in Boston would be willing to pay from $22 to $470 (1980 dollars) to reduce auto emissions by 90% from 1970-71 levels. Households in Los Angeles would be willing to pay from $110 to $970. (The range of these values illustrates the difficulty in producing estimates based on willingness to pay, especially accounting for the separate influence of transportation pollutants and pollutant concentrations.)

■ Behavior of Pollution

An important element in understanding how to control pollution is an understanding of how various factors affect the accumulation of pollution in the environment. These factors include the rate of emission, proximity of the source to receptors, and various external factors such as temperature, wind speed, and topography. Depending upon the specific pollutant, these variables can affect the production and accumulation of pollution differently.

Concentrations of CO, O_3, and NO_2, the major transportation-related pollutants, are sensitive to emissions rates of the primary pollutants, the proximity of receptors to sources of primary pollutant emissions, and meteorological conditions. However, the degree of sensitivity varies significantly. These variables and their effect on the behavior of pollution imply that different approaches are needed to control emissions of each pollutant.

Carbon Monoxide

The concentration of CO at a given location is primarily a function of the rate of emissions from nearby CO sources; meteorological variables such as wind speed and direction and atmospheric turbulence; and topographical features. CO concentrations are higher near congested roadways and high traffic locations and decrease rapidly as distances from these traffic sources increase. Furthermore, CO concentrations tend to be consistent with daily variations in traffic volume, having their highest levels during peak traffic periods when traffic volumes and congestion are greatest and average travel speeds are slowest. NAAQS are established for both 1-hour and 8-hour averaging periods for CO to account for peak period conditions when CO levels are highest and for longer term exposure to more persistent concentrations of CO.

Meteorological variables, however, can moderate the influence of traffic and cause large fluctuations in CO concentrations, even if the volume of CO emissions is unchanged. Topographical factors, such as the proximity of tall buildings or the depression of a roadway below grade, further affect CO concentrations by affecting the patterns in which air circulates. As a result, CO concentrations at a given location can vary widely depending upon the time of day, or, at the same time of day, can vary widely between two nearby locations.

There is a strong linear relationship between CO concentrations and traffic volumes, with high traffic volumes producing high CO levels. Furthermore, as vehicle speeds decrease, CO emissions rates increase. Therefore, CO concentrations tend to be higher in proximity to congested urban roadways and intersections than near locations where traffic flows freely.

Wind direction is also significant because the concentration of a pollutant is higher downwind of the emissions source than upwind. Increases in wind speed means a greater volume of air passes an emissions source during a fixed unit of time, thereby reducing pollutant concentrations. As a result, it is possible to have high traffic volumes without significant CO concentrations if high wind speeds are present, causing wider dispersion and mixing of the air mass in proximity to the pollutant source. Conversely, low wind speeds and reduced levels of atmospheric turbulence produce stable conditions in which mixing of air masses is limited, resulting in higher concentrations of pollutants.

Automobiles emit higher volumes of CO in cold weather than in warm weather, Due to combustion characteristics of internal combustion engines. However, because winds tend to be higher in winter than in fall, the highest measured concentrations of CO tend to be in the fall, when stable atmospheric conditions tends to reduce dispersion of emissions.

Because of the localized nature of CO concentrations, most control strategies are oriented toward alleviation of high traffic volumes and congestion at specific locations, known as "hot spots." Typically, a hot-spot strategy involves improvements to traffic flow at a location experiencing unusual traffic congestion or high traffic volumes. This could involve simply the retiming of a traffic signal or the redirecting of traffic to alternate routes. However, as more is learned about the nature of CO violations, CO is increasingly being viewed as an areawide problem, requiring broader-based strategies oriented toward the transportation network as a whole. In this way, by alleviating a traffic problem at a single location, the CO problem would not be transferred to another location as result of traffic being redirected to different roads or intersections.

Ozone

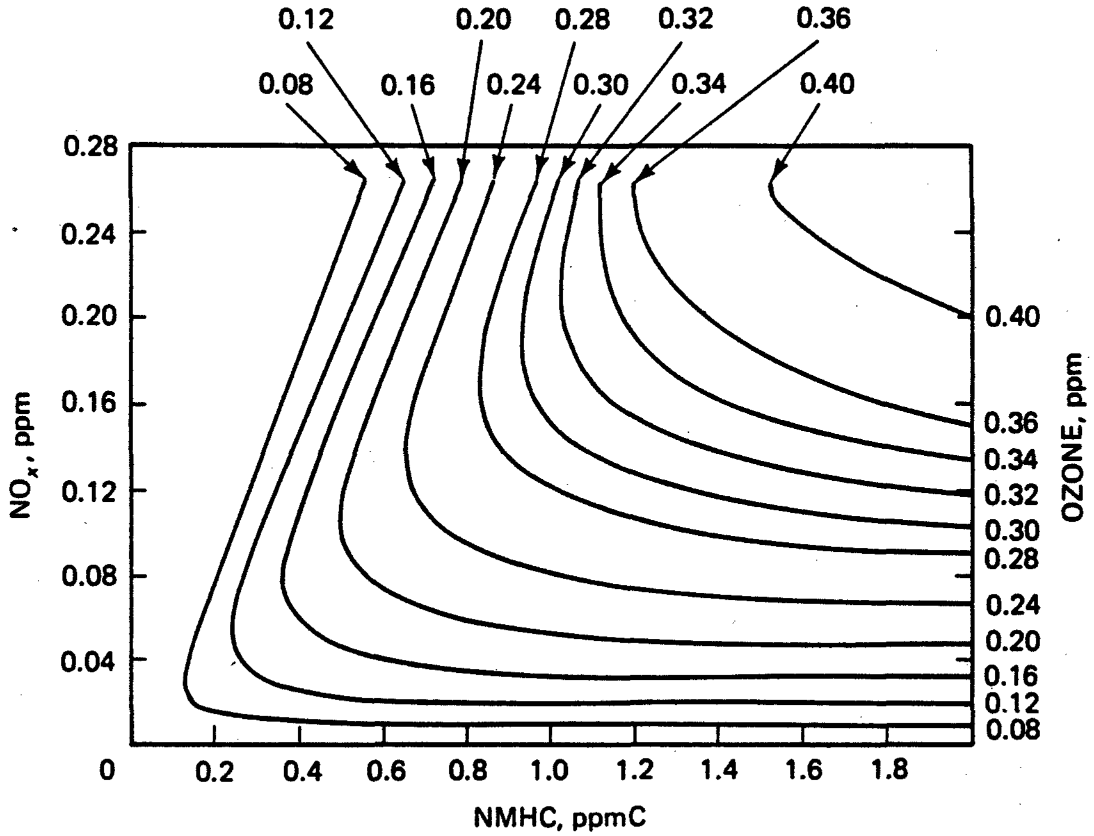
The most important factor affecting the behavior of ozone is that it has no single emissions source, but is instead a secondary pollutant for which excessive concentrations in the lower atmosphere are the result of chemical reactions involving "precursor" emissions of HC and NOx. As a result, unlike CO, the relationship between emissions of HC and NOx, and pollutant concentrations of O_3 is nonlinear. Also, unlike CO, spatial variations in O_3 are more gradual. If O_3 levels are excessive at any given monitoring site, they will generally be excessive over a large area, possibly covering an area encompassing hundreds or thousands of square miles.

O_3 concentrations, like CO, are sensitive to meteorological variables such as wind speed and direction, atmospheric stability, and temperature. A further important meteorological variable is the intensity of solar radiation which contributes to the photochemical reaction. O_3 concentrations increase with increased solar intensity. The relationship between these precursors and concentrations of O_3 is highly complex but as indicated in Figure 3, reductions in precursor emissions do not necessarily cause a reduction in maximum O_3 levels. There is, in fact, no proportional relationship between concentrations of precursors and O_3 levels.

The formation of O_3 takes place over periods ranging from several hours to several days, depending upon meteorological conditions. Mixing and wind movement over these periods cause emissions from a large number of HC and NOx sources distributed over a large area to be combined into the same air mass. As a result, high O_3 concentrations generally cannot be attributed to individual HC or NOx sources.

The chemical reactions that form O_3 and the role of sunlight in driving the reactions result in diurnal variations in O_3 concentrations. O_3 concentrations tend to peak during the late morning or early afternoon hours in many cities. Chemically, this appears to be a result of the amount of time required for the chemical reactions to occur. However, meteorological conditions cause the "transport" of polluted air masses over time into

Figure 3. Minimum One-Hour Average O_3 Concentration as a Function of the Initial HC and NO_x Concentrations in a Simple Photochemical System



Source: Horowitz

areas where additional precursors are produced, causing the chemical reaction process to continue. Wind speed and turbulence also affect the ways in which precursors are dispersed, affecting overall concentrations of O_3. Seasonal variations in meteorological conditions, particularly solar intensity and temperature, produce seasonal variations in O_3 levels. As shown in Figure 4, high ozone levels are directly related to higher ambient temperatures. A number of large scale regional ozone studies are currently underway to model the behavior of this complex pollutant in order to identify the interactive nature of ozone precursors and atmospheric conditions.

Atmospheric mixing and movement during the formation of O_3 can cause O_3 concentrations to be high at large distances from the sources of the O_3 precursors. O_3 can become "trapped" in the atmosphere and be transported for long distances. As a result, high concentrations of O_3 have been measured in rural areas located far from the source of precursor emissions. For example, O_3 violations have been annually recorded at Arcadia National Park on the coast of Maine. As a result, unlike CO, due to the spatial characteristics of O_3, control programs for O_3 must be designed on at least a metropolitan scale to be effective.

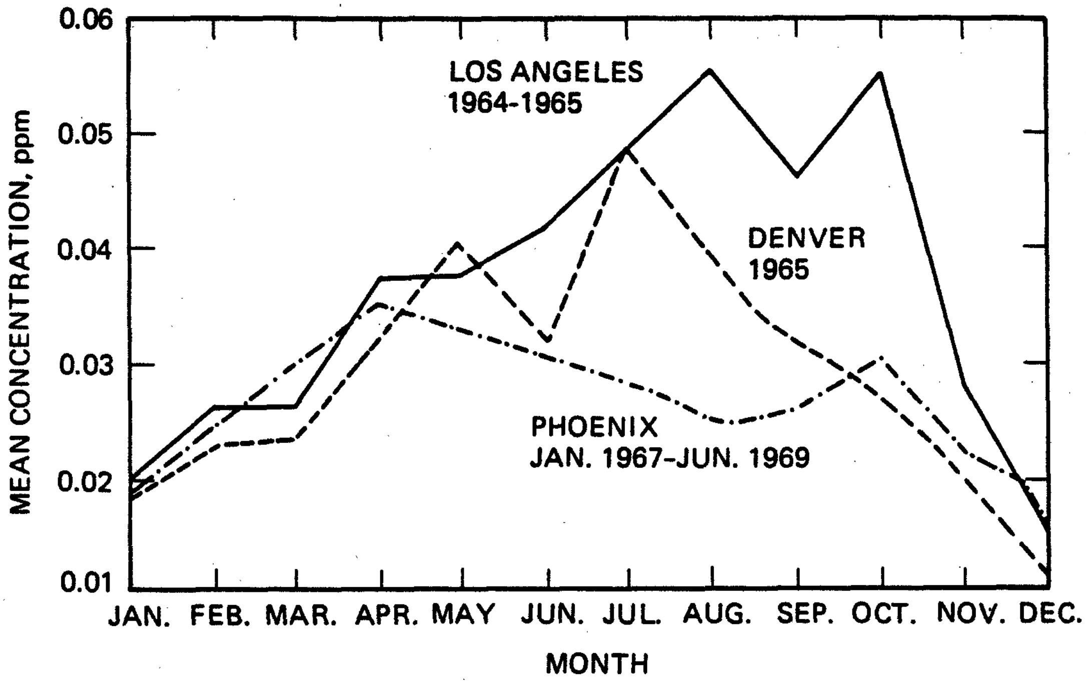
Nitrogen Oxides

Man-made NOx emissions consist of both NO and NO_2, of which NO accounts for 90-95% of the total. Although NO_2 itself is produced as a primary pollutant, its high concentrations in the atmosphere are caused by the oxidation of NO to NO_2 through the chemical reactions that also produce O_3. Atmospheric mixing during the formation of NO_2 tends to cause NO_2 concentrations to be dispersed from large NO sources. However, there can also be sharp peaks in NO_2 levels near NO sources such as the downwind side of busy highways. Because of the areawide nature of NOx emissions, control strategies are generally designed at the metropolitan or regional level.

Similar to O_3, NO_2 concentrations decrease with higher wind speeds and turbulence and increase with higher temperatures. However, the relationship of NO_2 to the intensity of solar radiation is more complex. Although sunlight is needed in the photochemical reactions that produce NO_2, sunlight also can destroy NO_2 by a process of photolysis. Therefore, solar intensity can either increase or decrease NO_2 concentrations, depending upon its intensity and the stage of the chemical reaction process.

Daily and seasonal variation in NOx concentrations are somewhat difficult to characterize and appear to be inconsistent in different cities. In areas of significant photochemical activity, NO_2 levels generally peak in mid-morning and early evening. The extent of the peaking appears to be influenced by meteorological factors and by the extent of O_3 generated during the day. On days with limited photochemical activity, indicated by limited production of O_3, NO_2 peaking is less evident. Although NO concentrations vary seasonally in various cities in similar patterns, NO_2 concentrations do not exhibit the same consistency. In general, NO concentrations are higher in winter but NO_2 concentrations can peak in either the summer or winter, depending upon the

Figure 4. Monthly Variation of Mean Hourly Oxidant Concentrations in Three Cities



Source: Horowitz

city being analyzed. This is due to the sensitive relationship between meteorological factors and photochemical activity.

NO_2, like O_3, can be carried in urban smog plumes. However, NO_2 concentrations decrease quickly downwind of urban areas and approach background levels in relatively short distances from these areas. This is due to the chemical conversion of NO_2 into other compounds. As a result, NO_2 concentrations are generally low in rural areas, even if O_3 concentrations are high.

Sources of Pollutant Emissions

Categories of Emissions Sources

Air pollutants are produced by numerous sources of emissions which can be categorized in various ways. Emissions sources generally are classified as point, area, or line sources, depending upon their magnitude and geographic distribution. A point source is a large, concentrated source of emissions such as a coal-fired power plant. An area source is a collection of smaller, dispersed emission sources which, individually, are insignificant, but are significant collectively. Examples include residential and commercial space heaters or the overall street system of a city. Line sources generate emissions more or less uniformly along a line, such as an urban highway. Air pollution source can also be defined more broadly as" stationary," i.e. from a fixed location, or "mobile," meaning transportation-related. Mobile or transportation sources include highway vehicles, off highway vehicles, aircraft, railroad locomotives, and marine vessels. The focus of these Information Documents is on emissions from highway vehicles.

Highway-Related Sources

Highway-related mobile sources of air pollutants include a wide range of vehicle types, each with unique characteristics relevant to the categories and volume of pollutants which are produced. Key variables include the age of the vehicle and the type of fuel which is utilized. The category of emissions generated by mobile sources differentiates between highway vehicles and off-highway vehicles. Off-highway sources include sources such as farm equipment, industrial and construction sites, and recreational vehicles.

For the purpose of analyzing or regulating highway vehicle emissions, the following vehicle classes are generally used:

- Light-duty gasoline fueled vehicle
- Light-duty gasoline fueled trucks
- Heavy-duty gasoline fueled vehicles
- Light-duty diesel vehicles
- Light-duty diesel trucks
- Heavy-duty diesel vehicles
- Motorcycles

Each of these vehicle classes has its own emissions characteristics and its own set of emissions standards. The new 1990 Clean Air Act motor vehicle emission standards are shown in Table 2, with the complete set of new tailpipe emission standards provided as Table 3. The CO standard of 3.4 grams/mile is retained; a new cold temperature (20 degrees F) CO standard of 10 grams/mile, however, is defined beginning with 1994 models. The HC standard is reduced from .41 to .25 grams/mile and the NO_x standard is reduced from 1.0 to 0.4 grams/mile. The new tailpipe emission standards are phased in over time. In 1994, 40% of the vehicles sold must comply with the new standard. By 1996, all new vehicles sold must attain these lower emission limits. Light-duty gasoline fueled vehicles, or automobiles, comprise the largest source of transportation-related pollutants, due to their widespread use. Passenger cars alone currently account for nearly 20% of Volatile Organic Compound (VOC) emissions produced by mobile and stationary sources combined (Walsh, 1988 - Fig. 33). The California Air Resources Board estimates that cars and trucks contributed 43% of all HC, 57% of all NOx, and 82% of all CO in the major urban areas of California in 1987.

Production of Highway Vehicle Emissions

Vehicles produce emissions both through the combustion process and through evaporation of fuel and lubricants. Emissions from conventional gasoline-powered vehicles are generated from 3 sources: the crankcase, the fuel system, and the exhaust. The crankcase and fuel system are sources of hydrocarbons; exhaust is a source of hydrocarbons, carbon monoxide, and NOx. There are three distinct phases of vehicle operation, during which vehicles emit differing levels of pollutants: the cold start mode, the hot soak evaporative mode, and the hot stabilized mode. Cold start emissions occur during the first few minutes of operation when the vehicle and its catalytic converter are cold. Hot soak emissions occur when a previously operated vehicle is parked and the hot engine causes gasoline still in the carburetor or fuel system to evaporate or "boil off." Evaporative emissions of hydrocarbons occur whenever fuel is exposed to the air although there are a number of processes at work. Fueling emissions occur when fuel

Table 2. 1990 Clean Air Act Light Duty Vehicle (Automobile) Tailpipe Standards

Contaminant	Standard (Grams per Mile)
NMHC	0.25
CO	3.4
NO_x	0.4
Model Year Phase-In	**% of Vehicles Sold**
1994	40%
1995	80%
1996 and after	100%

Table 3. Motor Vehicle Tailpipe Standards

Summary of Tier 1 Tailpipe Certification Standards**

Vehicle Type	GVWR (lbs)	Fuel	LVW (lbs)	ALVW (lbs)	Half Life (years/miles)	Half Life Standards (g/mi) NMHC*	CO	NOx	PM	Full Life (years/miles)	Full Life Standards (g/mi) NMHC*	CO	NOx	PM	Minimum Phase-in Percentages*** MY1994	MY1995	MY1996	MY1997	MY1998	MY1999
LDV	all	non-diesel	all	all	5/50,000	0.25	3.4	0.4	---	10/100,000	0.31	4.2	0.60	---	40	80	100	100	100	100
	all	diesel	all	all	5/50,000	0.25	3.4	1.0	---	10/100,000	0.31	4.2	1.25	---	40	80	100	100	100	100
	all	all	all	all	5/50,000	---	---	---	0.08	10/100,000	---	---	---	0.10	40	80	100	100	100	100
Light LDT	0-6000	non-diesel	0-3750	all	5/50,000	0.25	3.4	0.4	---	10/100,000	0.31	4.2	0.60	---	40	80	100	100	100	100
		diesel	0-3750	all	5/50,000	0.25	3.4	1.0	---	10/100,000	0.31	4.2	1.25	---	40	80	100	100	100	100
		non-diesel	3751-5750	all	5/50,000	0.32	4.4	0.7	---	10/100,000	0.40	5.5	0.97	---	40	80	100	100	100	100
		diesel	3751-5750	all	5/50,000	0.32	4.4	---	---	10/100,000	0.40	5.5	0.97	---	40	80	100	100	100	100
		all	all	all	5/50,000	---	---	---	0.08	10/100,000	---	---	---	0.10	0	40	80	100	100	100
Heavy LDT	>6000	non-diesel	all	3751-5750	5/50,000	0.32	4.4	0.7	---	11/120,000	0.46	6.4	0.98	0.10	0	0	50	100	100	100
		diesel	all	3751-5750	5/50,000	0.32	4.4	---	---	11/120,000	0.46	6.4	0.98	0.10	0	0	50	100	100	100
		non-diesel	all	>5750	5/50,000	0.39	5.0	1.1	---	11/120,000	0.56	7.3	1.53	0.12	0	0	50	100	100	100
		diesel	all	>5750	5/50,000	0.39	5.0	---	---	11/120,000	0.56	7.3	1.53	0.12	0	0	50	100	100	100

Summary of Tier 1 Tailpipe In-Use (Recall) Standards**

Vehicle Type	GVWR (lbs)	Fuel	LVW (lbs)	ALVW (lbs)	Half Life (years/miles)	Half Life Standards (g/mi) NMHC*	CO	NOx	PM	Full Life (years/miles)	Full Life Standards (g/mi) NMHC*	CO	NOx	PM	Minimum Phase-in Percentages*** MY1994	MY1995	MY1996	MY1997	MY1998	MY1999	Standards Group
LDV	all	non-diesel	all	all	5/50,000	0.32	3.4	0.4	---	---	---	---	---	---	40	80	max 60	max 20	0	0	Tier 1i
	all	diesel	all	all	5/50,000	0.32	3.4	1.0	---	---	---	---	---	---	40	80	max 60	max 20	0	0	Tier 1i
	all	non-diesel	all	all	5/50,000	0.25	3.4	0.4	---	10/100,000#	0.31	4.2	0.60	---	0	0	40	80	100	100	Tier 1
	all	diesel	all	all	5/50,000	0.25	3.4	1.0	---	10/100,000#	0.31	4.2	1.25	---	0	0	40	80	100	100	Tier 1
	all	all	all	all	5/50,000	---	---	---	0.08	10/100,000#	---	---	---	0.10	40	80	100	100	100	100	Both
Light LDT	<=6000	non-diesel	0-3750	all	5/50,000	0.32	5.2	0.4	---	---	---	---	---	---	40	80	max 60	max 20	0	0	Tier 1i
		diesel	0-3750	all	5/50,000	0.32	5.2	1.2	---	---	---	---	---	---	40	80	max 60	max 20	0	0	Tier 1i
		non-diesel	3751-5750	all	5/50,000	0.41	6.7	0.7	---	---	---	---	---	---	40	80	max 60	max 20	0	0	Tier 1i
		diesel	3751-5750	all	5/50,000	0.41	6.7	1.7	---	---	---	---	---	---	40	80	max 60	max 20	0	0	Tier 1i
		non-diesel	0-3750	all	5/50,000	0.25	3.4	0.4	---	10/100,000#	0.31	4.2	0.60	---	0	0	40	80	100	100	Tier 1
		diesel	0-3750	all	5/50,000	0.25	3.4	1.0	---	10/100,000#	0.31	4.2	1.25	---	0	0	40	80	100	100	Tier 1
		non-diesel	3751-5750	all	5/50,000	0.32	4.4	0.7	---	10/100,000#	0.40	5.5	0.97	---	0	0	40	80	100	100	Tier 1
		diesel	3751-5750	all	5/50,000	0.32	4.4	0.97	---	10/100,000#	0.40	5.5	0.97	---	0	0	40	80	100	100	Tier 1
		all	0-5750	all	5/50,000	---	---	---	0.08	10/100,000#	---	---	---	0.10	0	40	80	100	100	100	Both
Heavy LDT	>6000	non-diesel	all	3751-5750	5/50,000	0.40	5.5	0.88	0.10	---	---	---	---	0.10	0	0	50	100	max 50	0	Tier 1i
		diesel	0-3750	3751-5750	5/50,000	0.40	5.5	1.2	0.10	---	---	---	---	0.10	0	0	50	100	max 50	0	Tier 1i
		diesel	3751-5750	3751-5750	5/50,000	0.40	5.5	1.7	0.10	---	---	---	---	0.10	0	0	50	100	max 50	0	Tier 1i
		non-diesel	all	>5750	5/50,000	0.49	6.2	1.38	0.12	---	---	---	---	0.12	0	0	50	100	max 50	0	Tier 1i
		diesel	0-3750	>5750	5/50,000	0.49	6.2	1.2	0.12	---	---	---	---	0.12	0	0	50	100	max 50	0	Tier 1i
		diesel	3751-5750	>5750	5/50,000	0.49	6.2	1.7	0.12	---	---	---	---	0.12	0	0	50	100	max 50	0	Tier 1i
		non-diesel	all	3751-5750	5/50,000	0.32	4.4	0.7	0.10	11/120,000##	0.46	6.4	0.98	0.10	0	0	0	0	50	100	Tier 1
		diesel	all	3751-5750	5/50,000	0.32	4.4	0.98	0.10	11/120,000##	0.46	6.4	0.98	0.10	0	0	0	0	50	100	Tier 1
		non-diesel	all	>5750	5/50,000	0.39	5.0	1.1	0.12	11/120,000##	0.56	7.3	1.53	0.12	0	0	0	0	50	100	Tier 1
		diesel	all	>5750	5/50,000	0.39	5.0	1.53	0.12	11/120,000##	0.56	7.3	1.53	0.12	0	0	0	0	50	100	Tier 1

The total HC standards from the existing regulations for LDVs and LDTs remain in place.
* Any previous standards remain in effect until the more stringent standards outlined here apply.
** Phase-in compliance is based on three vehicle classes -- LDV, Light LDT, Heavy LDT -- irrespective of fuel type, engine cycle, or weight within a class; LDVs and Light LDTs may optionally be combined for phase-in of NMHC, CO and NOx.
Percentages are minimums unless otherwise noted.
Manufacturers have liability to the levels shown here; EPA may only test to 7/75,000.
Manufacturers have liability to the levels shown here; EPA may only test to 7/90,000.

GVWR = gross vehicle weight rating
curb weight = nominal unloaded vehicle weight
LVW = loaded vehicle weight = curb weight + 300 lbs
ALVW = adjusted loaded vehicle weight = (curb wt + GVWR)/2

LMB EPA/OAR/OMS/CD/CB ver 1.14 6/20/91

note: see June 5, 1991 Federal Register (56 FR 25724) for complete Tier 1 final rule entering the fuel tank displaces fuel vapors into the air. Diurnal losses occur as a result of diurnal temperature variations on the fuel and fuel vapors in the fuel tank. In the hot stabilized mode, after the engine and catalytic converter have warmed up to normal operating temperature, running exhaust emissions are produced as the vehicle is operated.

During engine operation, some of the gases in the engine cylinders escape past the pistons and enter the crankcase, producing "blow-by" emissions. These gases consist, in large part, of unburned gasoline, primarily HC. Fuel system emissions are due to evaporation and the refueling process, also producing HC. Crankcase emissions account for approximately 20% of the HC emissions from automobiles without emissions controls. Normal warming processes on warm days, by causing the expansion of fuel and fuel vapors in the fuel tank, causes diurnal evaporation. Emissions from the carburetor occur while the engine is still hot from recent operation. The fuel left in the carburetor is hot and can evaporate rapidly. Excluding fueling losses, evaporation from the fuel system accounts for another 20% of the HC emissions from uncontrolled automobiles. Some estimates of the relative total volume of evaporative emissions indicate that they can be responsible for as much as one-third of total hydrocarbon emissions from gasoline fueled vehicles. Exhaust emissions are responsible for all CO and NOx emissions and, in automobiles without emissions controls, approximately 60% of HC emissions.

The volume of running exhaust emissions are a function of the length and speed of a given trip, although relatively low levels of pollution are emitted for each mile driven. Due to the high volume of emissions produced during cold start and hot soak phases, a 5 mile trip produces nearly the same volume of hydrocarbon emissions as a 10 mile trip (Figure 5). Regardless of distance, the volume of trip end emissions remains the same. This points out the fact that it is as important to reduce the total number of trips as it is to reduce their distance. Traffic congestion, on the other hand can have a significant bearing on total running emissions. Air pollution increases as a direct result of increased vehicle hours of operation due to delays in traffic. For example, a 10-mile trip taking 30-minutes produces 350% more running exhaust HC emissions than the same trip if it were to take 11-minutes. Given a trend toward increasing congestion nationwide, this has serious implications for the ability of many areas to meet air quality standards for transportation-related emissions.

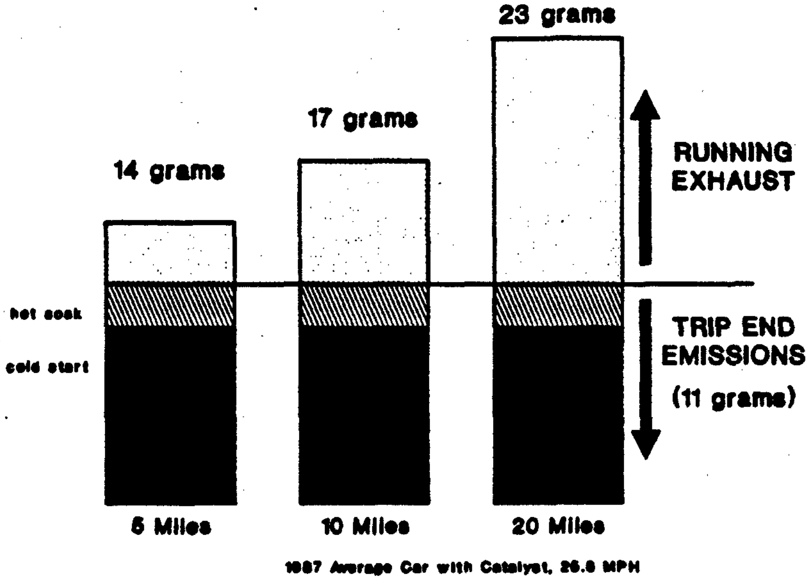
■ Variables Affecting Vehicle Emission Rates

Specification of Key Variables

Temperature

Fuel tends to not vaporize well in a cold engine. As a result, unburned or partially burned fuel passes through the engine and into the exhaust. Furthermore, catalytic

Figure 5. Hydrocarbon Emissions by Trip



Source: California Air Resources Board converters do not function well when they are cold. As a result, vehicles in the cold start phase of operation have higher HC and CO emissions and lower fuel economy than warmed-up vehicles. The temperature of an engine during a cold start is generally the same as the temperature of the surrounding air. Therefore air temperature directly affects the magnitude of cold start emissions. Decreases in the air temperature cause an increase in these emissions which is particularly apparent in vehicles equipped with catalytic converters. Temperature is a critical variable in the production of CO emissions. Most violations of the CO standard occur during wintertime, at temperatures below 50 degrees F.

Vehicle Age and Maintenance

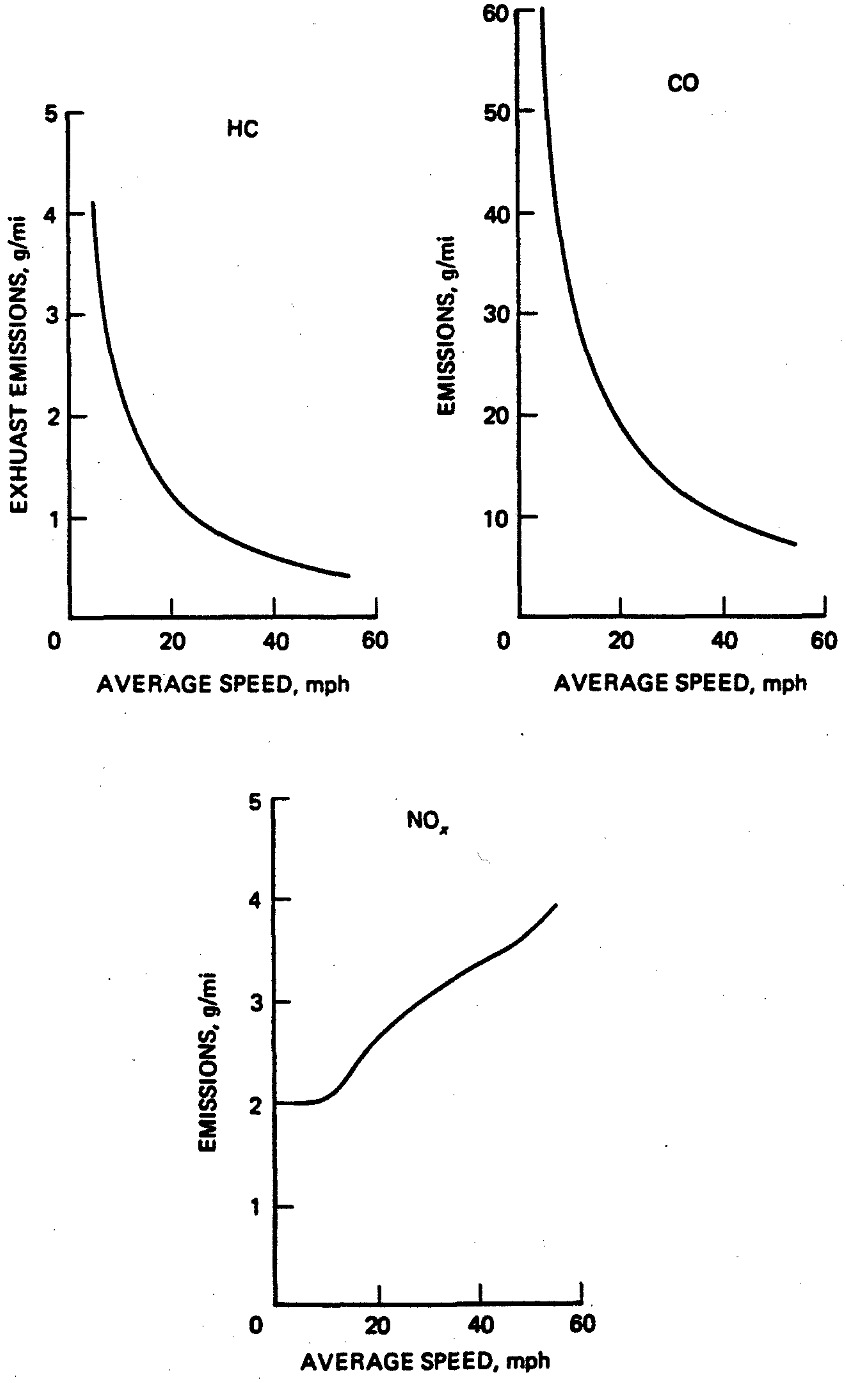
As a vehicle ages, there is an increase in the wear and deterioration of engine parts and emission controls. Over the life of a vehicle, wear and deterioration of engine parts and emission control equipment can cause emissions to increase. Prior to passage of the 1990 Amendments, for most passenger vehicles on the road today automotive emission control equipment was covered by a manufacturer's warranty for the first 50,000 miles of operation or 5 years, whichever occurs first. Under the 1990 Clean Air Act Amendments, separate vehicle emission standards are specified for certification or warranty at 100,000 miles or 10 years. These are 0.31, 4.2 and 0.6 grams per mile for NMHC, CO, and NO_x respectively. The increase in both mileage and time recognizes the practical useful life of vehicles on the road today. Over a vehicle's full lifetime, emissions levels can be far in excess of current standards and there is considerable concern today with so-called superemitters; i.e., a small percentage of vehicles causing a disproportionate large percentage of highway vehicle emissions.

Proper vehicle maintenance can significantly reduce the increase in emissions as a vehicle ages but cannot guarantee that a vehicle will not exceed standards over time. Maintenance practices vary greatly between owners. What is considered normal maintenance is not necessarily proper maintenance. Data from tests conducted by EPA on in-use vehicles show that properly maintained vehicles increasingly exceed their standards the longer their operating life, and that normally maintained vehicles produce significantly higher levels of emissions.

Speed

The rate at which emissions are produced is directly related to the speed at which a vehicle is operating (Figure 6). The frequency of acceleration and deceleration for an operating vehicle, particularly a vehicle operating in congested conditions, can also significantly affect the rate of emissions. Carbon monoxide and HC emissions are higher at slower speeds, especially below 20 mph, which are typical speeds on urban streets and congested highways. It is important to understand that the relationship between vehicle speed and emissions is non-linear, that is, at speeds below 20 mph, emission rates increase at a greater rate as speeds continue to decrease. NOx, on the other hand, decreases with reductions in vehicle speed. Recent evidence indicates that CO and HC emissions may once again increase with vehicle speeds above 50 mph.

Figure 6. Speed-Emissions Relations for Warmed-Up 1975 Model Year Automobiles in 1975



Source: Horowitz

Relative Importance of Key Variables on Emissions Rates

EPA has estimated the sensitivity of emissions to the many variables that affect their rate of production by applying variable input data to MOBILE4, EPA's mobile source emission factor model (Figure 7). Comparisons were made between standardized emission inventories, using variable conditions relative to speed, temperature, proportion of hot and cold starts, mileage accumulation, and average age of the vehicle fleet. Separate analyses were performed under summer and winter conditions, for NMHC, CO, and NOx.

Under summer conditions, as speed decreases from the the Federal Test Procedure (FTP) average of 19.6 mph, the increase in emissions of NMHC becomes more non-linear. The effect of a highly congested speed of 7.1 mph produces an 83% increase in emissions. At speeds above 19.6 mph, the impact is much less significant. Changes in temperature, above and below the FTP value of 75 degrees F also causes an increase in NMHC, although not as significant as those observed from speed variations. The effect of variation in the average age distribution of the fleet also has a significant bearing on NMHC production. Older vehicles may have lower levels of annual travel than newer vehicles, but also produce more emissions per mile. Emissions of NMHC are highly sensitive to changes in the age composition of the fleet. On the other hand, variation in the proportion of hot and cold starts does not appear to be as significant a variable.

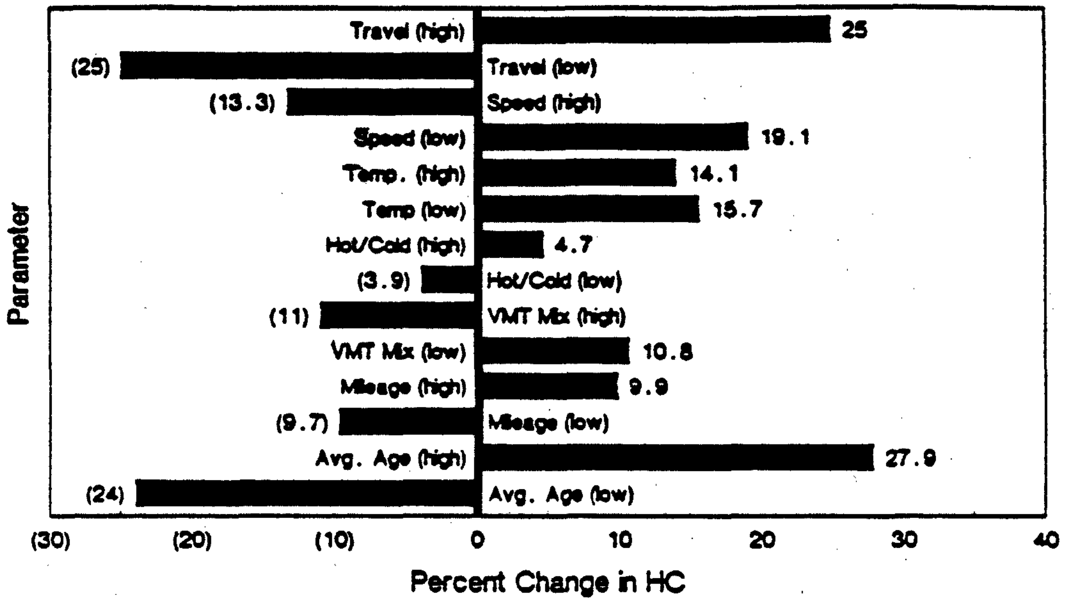
CO emission levels appear to be subject to the same trends as NMHC, although the magnitude of sensitivity to changes in speed and temperature is much greater. While it is known that CO emissions increase with lower ambient temperatures, high temperatures (for this analysis, 95 degrees F was used) also produced increased CO emissions. A wintertime analysis of CO emission variable also was conducted which showed even higher levels of CO production occur when speeds are reduced, in comparison to summer operating conditions.

NOx emissions exhibit a different pattern than NMHC and CO. NOx is relatively insensitive to changes in speed and decreases in temperature. However, increases in temperature produce significant reductions in emissions.

■ Available Control Technologies

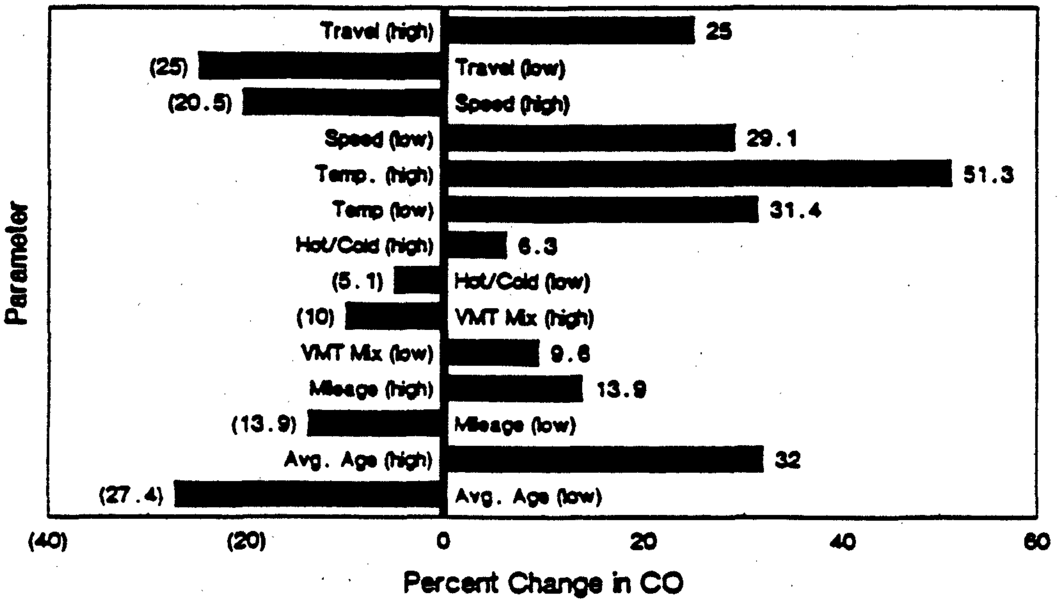
There are basically two ways in which vehicle emissions can be controlled. One way is to manage emissions at their source. That is, reduce emissions from the vehicle by controlling the way in which the vehicle produces emissions (Figures 8, 9). This includes various mechanical control technologies such as catalytic converters, recirculation of exhaust gases, and evaporative controls. An important aspect of the ability of this technology to reduce emissions is the monitoring of emission control equipment to assure that it is functioning properly. This control technology also includes measures to control emissions at the gas pump during refueling, as well as improvements in the

Figure 7A. Sensitivity in NMHC Emission Inventory Estimate to a 25 Percent Variation in Selected Input Parameters



Note: Based on MOBILE3 computations for 1987.

Figure 7B. Sensitivity in CO Emission Inventory Estimate to a 25 Percent Variation in Selected Input Parameters



Source: Sierra Research, (1989)

Figure 7C. Sensitivity in NO_x Emission Inventory Estimate to a 25 Percent Variation in Selected Input Parameters

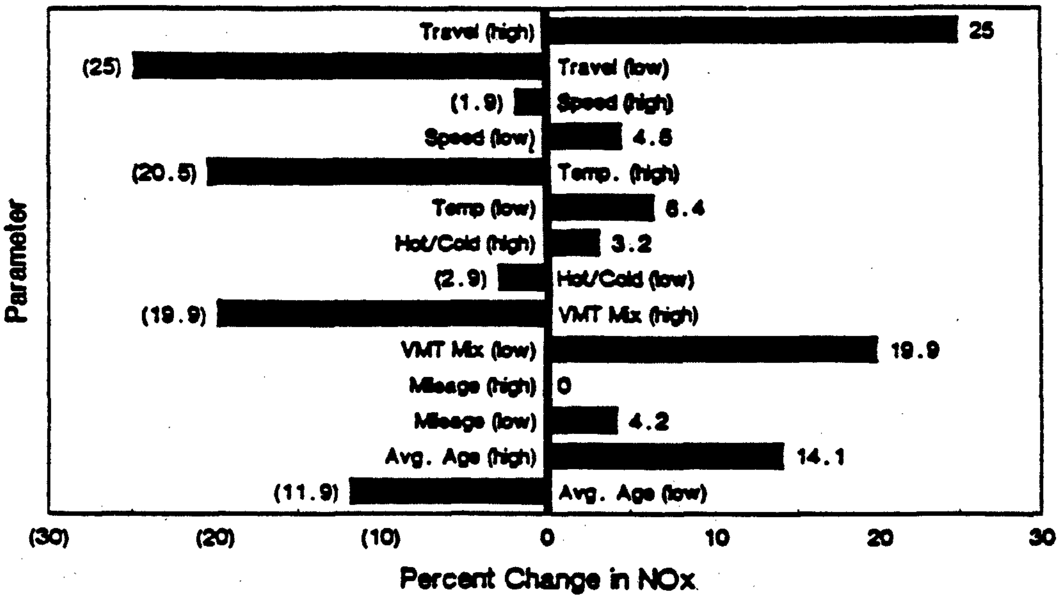
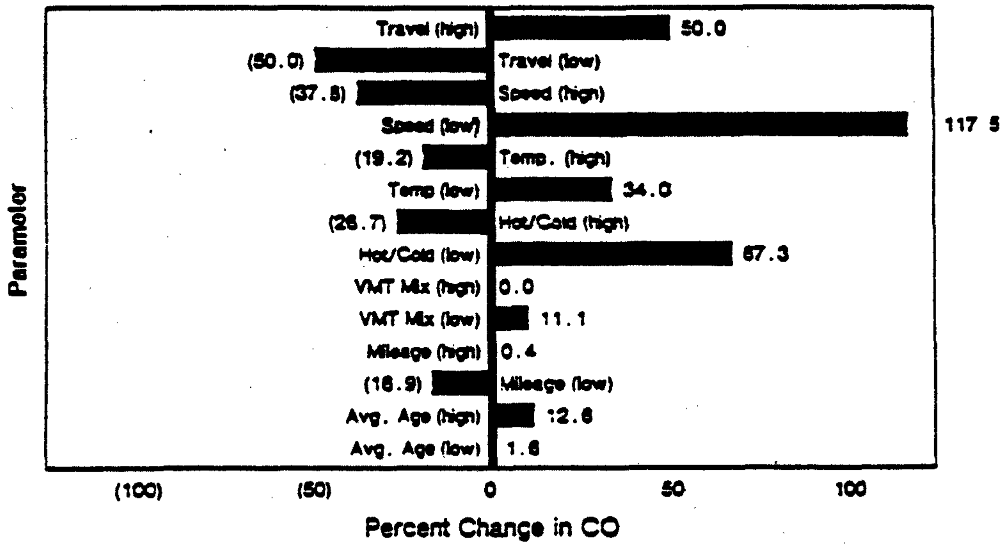


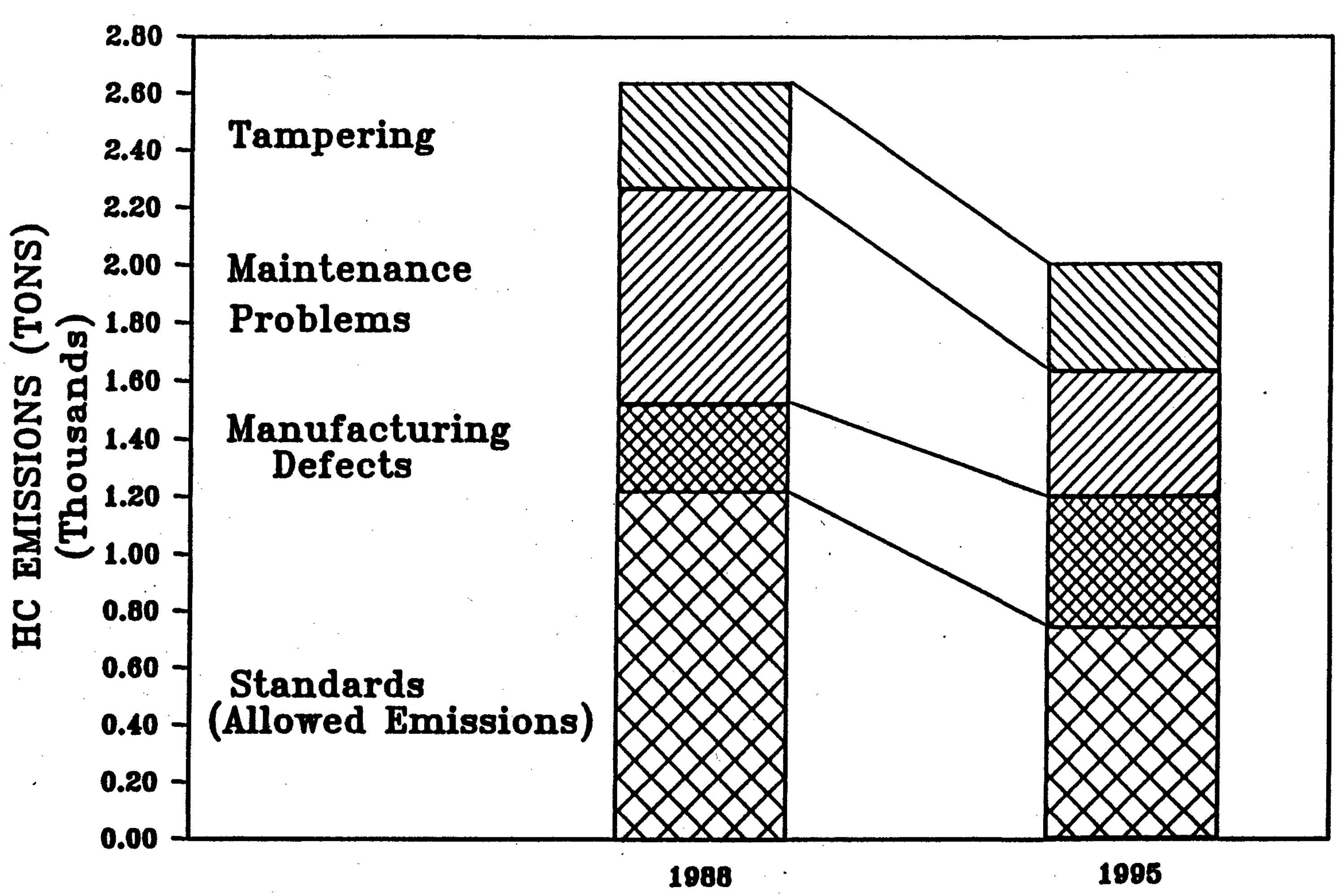
Figure 7D. Sensitivity in CO Emission Inventory Estimate to Variations in Selected Input Parameters (Wintertime Conditions)



Note: Based on MOBILE3 computations for 1987.

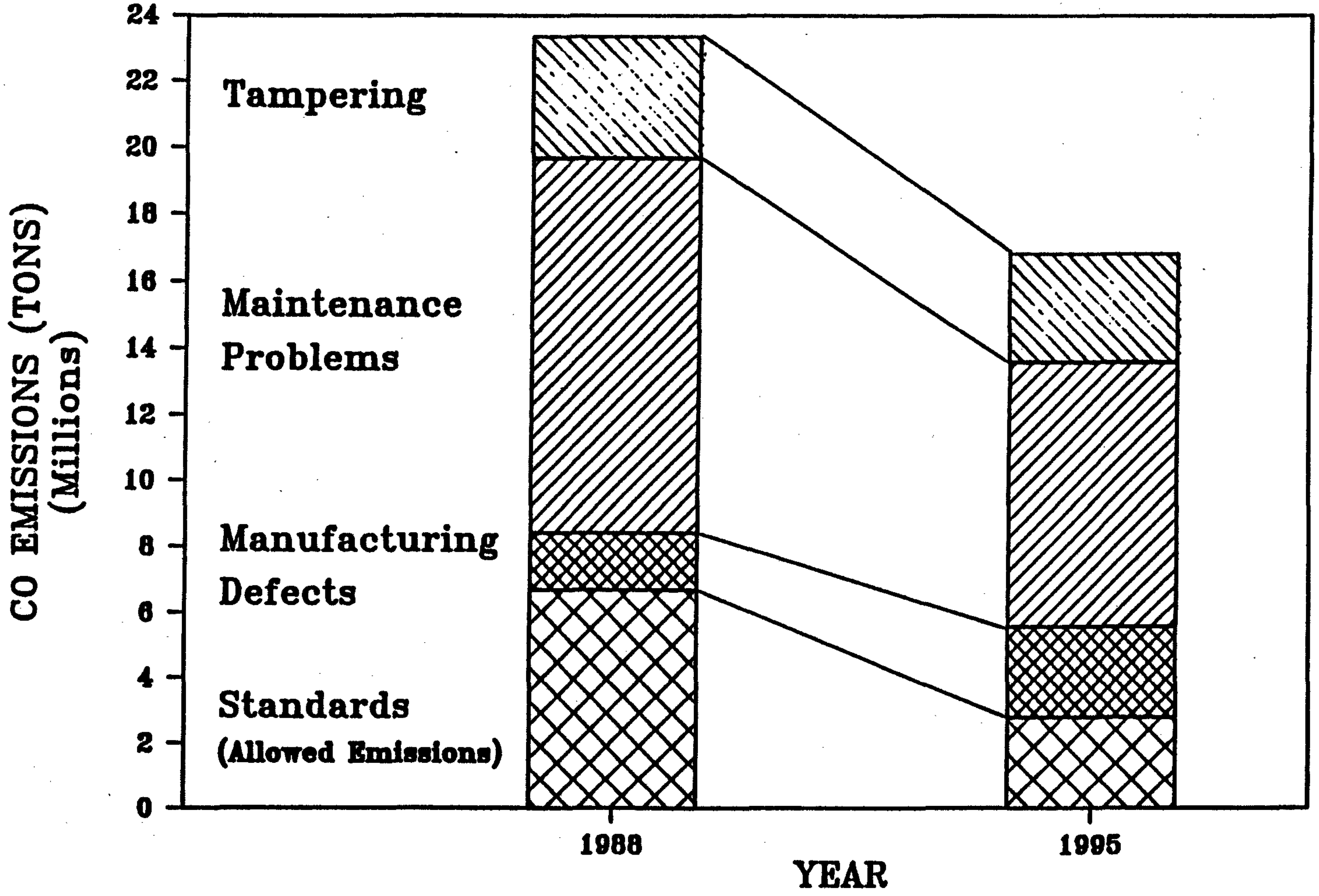
Source: Sierra Research, (1989)

Figure 8. Attributes of Automotive HC Emissions, National Inventory Estimates



Source: EPA

Figure 9. Attributes of Automotive CO Emissions, National Inventory Estimates



Source: EPA

composition of the fuel itself. These technologies also include the use of alternative fuels.

A second approach to managing emissions produced by motor vehicles is to manage how the vehicle itself is used. This includes measures to reduce both total trips and total vehicle miles travelled, including measures to assure that while in use a vehicle is used as efficiently as possible.

On-Board Controls and New Car Standards

On-board controls and new car standards are approaches to controlling emissions which depend primarily on automotive technology. Since the early 1960's, new motor vehicles sold in the U.S. have been subject to increasingly stringent emissions control requirements. These requirements regulate both exhaust and evaporative emissions. To comply with these requirements, automakers have made extensive technological improvements through innovations in vehicle design and operations, and by the installation of emissions control devices on vehicles.

The EPA enforces these standards through the testing of prototype vehicles prior to their production by sampling vehicles taken from the assembly line. Under the Clean Air Act, vehicles are protected from defects in emissions control equipment by a manufacturers warranty for a period established by EPA. Once vehicles are sold, they are subject to manufacturers' recalls if defects in emissions control systems develop.

Although emission control technology varies between automakers and by vehicle models, certain equipment is common to most gasoline engine vehicles. The most commonly recognized emissions control device is a catalytic converter. When heated to a high temperature, metals within the catalytic converter, such as platinum, create a chemical reaction which converts hydrocarbons and CO from engine exhaust into CO_2 and water. Catalytic converters and improvements to gasoline have, in combination, reduced emissions from modern automobiles by about 95% compared to the lowest-emitting models of 20 years ago. Other control technology includes "positive crankcase ventilation" (PCV) systems which aid in the recirculation of crankcase emissions, evaporative emissions controls which collect evaporative emissions from the fuel system in a canister, and exhaust gas recirculation systems. Most new cars also utilize microcomputer technology which controls and coordinates ignition and fuel systems, as well as the operation of emission control equipment, to minimize exhaust emissions under varying driving conditions. Diesel engine vehicles are also subject to emissions standards and employ technologies designed to reduce particulate and NOx emissions.

As a result of Clean Air Act requirements, the national vehicle fleet has gotten progressively cleaner through implementation of the Federal Motor Vehicle Emissions Standards. It should be noted, however, that overall increases in vehicle miles travelled are projected to eventually cancel out the gains achieved through the FMVES, in large part due to a greater number of total vehicles in operation.

Inspection and Maintenance (I/M)

Inspection and Maintenance programs are intended to identify vehicles with excessive emissions through a regularly scheduled inspection program. Once these vehicles are identified, they are either repaired or removed from the active fleet. I/M is a means of encouraging proper vehicle maintenance, assuring that emission control equipment is properly functioning, and deterring tampering and misfueling. Tampering with emission control equipment to disable it and reduce its effectiveness or using leaded gasoline in catalytic equipped automobiles can produce significant increases in emissions. I/M programs work hand-in-hand with programs for improved emission control technology by monitoring the effectiveness of control equipment on in-use vehicles and identifying problems relevant to the durability of equipment.

I/M is required under the Clean Air Act for areas which were unable to comply with standards for CO or Ozone. By 1987, approximately 30% of the national vehicle fleet participated in some type of I/M program. The actual operation of I/M programs varies between areas with regard to the standards which are enforced, the way in which the inspection is conducted, and the responsibility for conducting the inspection. Significant reductions of mobile source HC and CO emissions have been demonstrated to be feasible through I/M.

Transportation Control Measures (TCM)

Transportation Control Measures, or TCMs, are transportation strategies intended to both reduce vehicle miles of travel (VMT) and to make the VMT which is travelled more efficient. A basic precept of TCM programs is to reduce overall dependency on automobile use by diverting potential auto trips to other modes such as public transit, ridesharing, bicycling or walking or by reducing overall demand for travel by adding to the cost of tripmaking. For auto travel which does occur, TCM strategies are aimed at reducing cold-starts and delay and improving overall travel times, thereby reducing the frequency and amount of time the vehicle is in use. By reducing the total number of miles travelled by motor vehicles and by making those miles which are travelled more efficient, the total volume of mobile source emissions is reduced. TCM strategies illustrate the direct link between transportation and air quality planning.

The transportation control measures cited in Table 4 and described in these information documents include those identified in Section 108(f) of the new Clean Air Act. The chapters which follow discuss these measures in detail, describing implementation strategies, their effectiveness, and the costs associated with these TCM measures.

The term "transportation control measure" or TCM encompasses elements of both "transportation system management" (TSM) and "transportation demand management" (TDM). Transportation system management strategies generally refer to the use of low capital intensive transportation improvements to increase the efficiency of transportation facilities and services. These can include carpool and vanpool programs, parking management, traffic flow improvements, preferential treatment for high occupancy

Table 4. Available Transportation Control Measures

Trip Reduction Ordinances
Employer-Based Transportation Management Programs
Work Schedule Changes
Area-wide Rideshare Incentives
Improved Public Transit
High Occupancy Vehicle Lanes
Traffic Flow Improvements
Parking Management
Park-and-Ride/Fringe Parking
Bicycle and Pedestrian Programs
Special Events
Vehicle Use Limitations/Restrictions
Activity Centers
Accelerated Retirement of Vehicles
Extended Vehicle Idling
Extreme Low-Temperature Cold Starts

vehicle, and park-and-ride lots. The TSM term also is applied to techniques used to reduce the demand for travel within an area. Transportation demand management generally refers to policies, programs, and actions that are directed towards increasing the use of high occupancy vehicles (transit, carpooling, and vanpooling) and the use of bicycling and walking. TDM also can include activities that encourage commuting outside the congested peak period, and that encourage telecommuting as an alternative to driving. In practice, there is considerable overlap among these three concepts and the terms TCM, TSM, and TDM often are used interchangeably.

Re-Fueling Controls

During the refueling of a vehicle, gasoline entering the fuel tank displaces fuel vapors which can escape into the air. Also, gasoline which is unintentionally spilled during refueling evaporates into the air. Emissions from refueling generally are localized at service stations but contribute to an area's total HC emissions.

Approximately 90% of all refueling emissions are the result of gasoline vapors being displaced by incoming fuel. The volume of these emissions is largely a function of temperature, tank size, and fuel volatility. Various approaches to controlling these emissions have been found to be effective. However there continues to be debate over how these controls should be implemented. Control technology can either be incorporated into the fuel system of the individual vehicle, adding to the cost of each vehicle, or incorporated into the design of the fuel pumping system, adding costs to the fuel distribution system.

Alternative Fuels

A great deal of research is currently being conducted in the areas of alternative and clean fuels. Researchers are hopeful of finding alternatives to gasoline and diesel fuels which do not produce the evaporative or combustion emissions of these fuels while not substantially adding to the cost of vehicle operation. Given such a scenario, it would be possible to operate environmentally "clean" vehicles without necessarily limiting their miles of travel.

Unleaded fuel is now required to be sold in the United States, thereby allowing for the operation of catalytic converters and also reducing the amount of lead in the air. Fuel volatility, as measured by Reid vapor pressure (RVP), affects evaporative emissions and, to a lesser extent, exhaust emissions. In recent years, gasoline manufacturers have increased RVP levels, thus contributing to higher levels of vehicle emissions. The fuel volatility provisions of the new Clean Air Act require the promulgation of regulations that gasoline marketed during the high ozone season must have a RVP of 9.0 psi or less, beginning no later than 1992.

In addition to changing the composition of gasoline, alternative fuels such as alcohol, compressed natural gas (CNG), and electricity could become practical alternatives to petroleum-based fuels. Fuel manufacturers are also developing and testing blends of "clean gasoline" which would have emissions characteristics comparable to alternative fuels.

There is currently a great deal of interest in methanol fuels – M85 (a blend of 85% methanol and 15% gasoline) and M100 (neat methanol). These fuels have a low ozone-forming potential compared to gasoline. However, there is significant difference of opinion surrounding methanol due, in part, to the potential impact on the petroleum and automobile manufacturing industries resulting from conversion to methanol and also due to its potential costs.

Tests have indicated that conversion from gasoline to methanol fueled light duty vehicles would result in a 50% reduction in emissions of reactive organic compounds, leading to a decrease in ozone production from vehicle emissions, and a 40% reduction in CO. There is no effective change in emissions levels of nitrogen oxides. For diesel-fueled vehicles, conversion to methanol virtually eliminates particulate matter and reduces NOx emissions by 50%. On the other hand, formaldehyde is found in significant quantities in methanol exhaust emissions because it is a primary oxidation product of methanol. Formaldehyde is classified as a probable human carcinogen. Other health and safety concerns regarding the widespread availability of methanol include its acute toxicity when ingested or absorbed through the skin; its colorless, odorless, and tasteless nature (which could lead to more incidences of accidental ingestion); and its tendency to burn with an invisible flame. Proponents of methanol claim that its potential hazards are different from, but not necessarily worse than, those of gasoline.

Other fuels receiving attention include hydrogen, liquefied petroleum gases (LPG), and ethanol made from farm products. Although electric vehicles have been produced and are in limited general use in some European countries, driving distances between battery charges is limited and cost-efficient electrical storage systems are still being perfected. Although CNG presents a number of issues relevant to its delivery system and refueling process, there are already 30,000 CNG vehicles operating in the U.S. Reformulated gasoline, as a liquid fuel comparable to gasoline, would have limited impact on fuel delivery systems and vehicle design. However, it could require a sizable investment in modifications to the petroleum refinement industry.

■ Transportation/Air Quality Planning and Modeling

The transportation/air quality planning process involves a variety of interrelated activities for which the ultimate goal is to reduce emissions from transportation sources and improve overall air quality. To summarize these activities, the process involves:

1. Quantification of the problem;

2. Design of control strategies; and

3. Demonstration of future NAAQS attainment with an ongoing program of monitoring and maintenance.

The process is encompassed within the State Implementation Plan, or SIP, which is the comprehensive document that quantifies current emissions and air quality conditions, and presents federally enforceable commitments to implement measures that are sufficient to achieve the national ambient air quality standards by a designated date. Reinforcing the SIP process is the requirement for annual reporting of "reasonable further progress" (RFP) toward achieving attainment of standards; in effect verifying a non-attainment area's continuing efforts to improve air quality.

Quantification of the Problem

Monitoring

In order to collect air quality data to determine whether an area has attained air quality standards for a criteria pollutant or is in violation of NAAQS, air quality is monitored by mechanical devices which collect and test samples of the air. Specific procedures have been developed for scientifically sampling ozone, carbon monoxide, NOx, and other criteria pollutants. Data are normally collected throughout the year in order to represent the full range of temperature and weather conditions, as well as spatial and time-of-day variations. For carbon monoxide, monitors are located so as to isolate background levels from pollution caused directly by specific traffic conditions. These monitoring data are used to calibrate the air quality models that are used to predict changes in future air quality.

Inventories

While the monitoring of air quality can quantify air quality conditions within a given area, air quality inventories quantify the sources of emissions of criteria pollutants within an area. Emissions inventories are developed through the SIP process for all significant mobile, stationary, and area sources of pollutants. Inventories are developed for both a designated base year and a projected future year, providing a baseline condition against which the effectiveness of alternative control programs can be measured. Mobile source inventories include all transportation-related sources of emissions – highway vehicles, off-highway vehicles, aircraft, railroads, and marine vessels. Emissions from highway vehicles are further disaggregated by vehicle type and are based on estimates of vehicle miles of travel by both vehicle type and roadway classification. The accuracy of mobile source inventories is closely correlated with the level of detail at which data is analyzed. Geographic and temporal disaggregation, for example, at the traffic analysis zone and peak travel period levels of detail are desirable.

A variety of techniques are used to develop highway emissions inventories, including traffic counts (such as those developed for the Highway Performance Monitoring System (HPMS)) and computer-based transportation network analysis. Use of the Federal Highway Administration's UTPS (Urban Transportation Planning System) model, or one of the many microcomputer variations, is common. However, because these systems were not generally developed for air quality analyses, care must be taken in their application, often involving collection of supplementary data and adjustments to the model. For example, local roads which may carry small volumes of traffic may not be represented in traffic network models but must be accounted for in a comprehensive air quality inventory. Because emission production is closely correlated with vehicle speeds, an accurate assessment of vehicle travel times and speeds is critical.

Emission Factor Models

A key component in the quantification process is the conversion of vehicles miles of travel, vehicle speeds, and vehicle types into estimates of emissions. This is done using an emissions factor model such as EPA's MOBILE4.1. MOBILE4.1 is a complex computer program that has evolved over time that accounts for the many variables which affect production of emissions by motor vehicles. Factors taken into consideration include fuel volatility, temperature, range of daily ambient temperature, altitude, humidity, vehicle type, age of the vehicle, accumulated miles of vehicle travel, vehicle speed, characteristics of an area's inspection/maintenance program, the effects of tampering and anti-tampering programs, and analysis year. Based on inputs into the program accounting for these and other variations in vehicle and travel characteristics affecting emission production, MOBILE4.1 can be used to calculate a range of emission factors in grams of pollutant per mile, which is then multiplied by the appropriate vehicle miles of travel to determine total emissions.

Design of Control Strategies

The development of an emissions control strategy for inclusion in the State Implementation Plan must differentiate between the three primary categories of emissions: stationary, area, and mobile. It must also account for existing versus future sources. If an area can attain NAAQS from limits on **new** stationary and mobile sources, then no further strategies are warranted. If, however, limitations on new sources are insufficient, which is generally the case in urbanized areas, then, through the inventory process, agencies must identify all **existing** sources of emissions and the volumes of pollutants emitted. Projections must also be made of how these sources might increase over time as a result of growth.

Local officials must then determine the costs and technological feasibility of controlling these sources of emissions. If adequate reductions can be accomplished through stationary and area source measures, mobile source controls may not be necessary. Generally, the most effective control programs involve the replacement of older, less efficient emission sources with newer, cleaner processes or by retrofitting existing sources. However, for carbon monoxide and ozone precursors, in particular, stationary source controls alone plus new vehicle controls are expected to be insufficient in many cases.

In those cases when an urbanized area cannot show attainment of NAAQS for ozone or carbon monoxide, transportation control measures may be needed to supplement reductions achieved through other source controls. In order to assure that such measures have a high feasibility for implementation, rather than placing the sole authority for the planning of transportation control measures with state environmental agencies, the Clean Air Act Amendments of 1977 required that local officials be made part of the planning process. The mechanism for local official involvement is the metropolitan planning organization (MPO), the organization of local elected officials responsible for the "continuing, cooperative, and comprehensive" (3C) planning process for the area, as established through the Federal Aid Highway Act.

With the participation of a MPO, communication involving transportation agencies environmental agencies and groups, business organizations, citizen groups, and other potentially affected interests can be facilitated, making implementation of TCMs more likely. Through a process of consultation and planning, the MPO prepares plans and capital programs which are incorporated into the Transportation Improvement Program (TIP) for an area, which must be approved by the MPO's governing board of elected officials. When the plans finally receive local approval, they are submitted to the State air agency for review and incorporation into the SIP. State and local transportation agencies are then responsible for implementation of TCMs included in the SIP.

Demonstration of Attainment

Once a strategy and implementation schedule is determined by a non-attainment area for meeting NAAQS, the SIP must demonstrate that the strategy will be successful in accomplishing its goals. Many air quality-related transportation analyses operate with emissions as the basic unit of analysis. This approach assumes that air quality will be improved in relatively the same proportion as the magnitude of reduced emissions. This is referred to as a "rollback" approach. However, this approach generally cannot account for temporal and meteorological factors which can have significant influence on pollutant levels. "Atmospheric dispersion models," on the other hand, can be used to convert geographic and temporal distributions of emissions into estimates of atmospheric concentrations of air pollutants. Dispersion analyses often utilize complex grid-based mathematical computer simulations which account for meteorological conditions in combination with estimates of mobile, stationary, and area source emissions to estimate pollutant concentrations by time of day.

Regional or mesoscale dispersion models are commonly used in developing an areawide ozone plan. Microscale dispersion models, such as CALINE, are used for project-level CO analyses and are applied at a more localized scale. However, dispersion modelling is complex, involving a significant commitment of time and budget. As a result, simplified approaches to regional modelling, such as EKMA (Empirical Kinetic Modelling Approach), often have been used for transportation analyses. EKMA includes a detailed approach to atmospheric chemistry but also simplifies many variables within a modeled area, thereby limiting its accuracy. As a result, more and more areas are tending toward use of grid-based models such as the Urban Airshed Model (UAM). This model simulates the physical and chemical processes in the atmosphere that affect pollutant concentrations. It is capable of calculating both summertime ozone concentrations and wintertime carbon monoxide concentrations. Because UAM accounts for spatial and temporal variations as well as differences in reactivity of emissions, it is well suited for evaluating effects of emissions control strategies on urban air quality.

As required through the SIP process, the demonstration of "reasonable further progress" involves an examination of current air quality trends to determine year-to-year changes in air quality. Ideally, this is done through combinations of monitoring, air quality modelling, and development of annual inventories. However these techniques are expensive and time-consuming, making annual analysis at this level of detail impractical. Important criteria for emissions trends analyses are consistency and timeliness. Consistent data and methodologies should be used to ensure year-to-year comparability; and the analysis should be able to be accomplished relatively quickly in order to provide meaningful information to local officials. Therefore, trends analyses typically take the form of a simplified inventory using easily obtainable data as basic input variables. Fuel sales data is often analyzed, based on either direct sales reports or tax receipts, and converted into estimates of vehicle miles of travel and emissions. Traffic counts also can be utilized, with conversion into measures of VMT and emissions. These procedures can be disaggregated by month, year, or geographic subdivision as appropriate.

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