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MEXICO EMISSIONS INVENTORY PROGRAM MANUALS

VOLUME VI - MOTOR VEHICLE INVENTORY DEVELOPMENT

FINAL

Prepared for:

Western Governors' Association
Denver, Colorado

and

Binational Advisory Committee

Prepared by:

Radian International
10389 Old Placerville Road
Sacramento, CA 95827

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PREFACE

Air pollution can negatively impact public health when present in the atmosphere in sufficient quantities. Most rural areas rarely experience air quality problems, while elevated concentrations of air pollution are commonly found in many urban environments. Recently, urbanization and industrial activity throughout Mexico has increased, resulting in air quality concerns for several regions.

Air pollution results from a complex mix of, literally, thousands of sources, from industrial smoke stacks and motor vehicles, to the individual use of grooming products, household cleaners, and paints. Even plant and animal life can play an important role in the air pollution problem. Due to the complex nature of air pollution, detailed regional plans are needed to identify the emission sources and to develop methods for reducing the health impact from exposure to air pollution. Examples of air quality planning activities include:

- Application of air quality models;
- Examination of the sources emitting air pollution for emissions control analysis, where necessary;
- Development of emission projections to examine possible changes in future air quality;
- Analysis of emission trends; and
- Analysis of emissions transport from one region to another.

Development of fundamentally sound emissions inventories is a key aspect for each of these air quality planning functions.

Developing emission estimates to meet air quality planning needs requires continual development and refinement; "one time" inventory efforts are not conducive to the air quality planning process. For lasting benefit, an *inventory program* must be implemented so that accurate emission estimates can be developed for all important geographic regions, refined over time, and effectively applied in the air quality planning and monitoring process. Therefore, a set of inventory manuals is being developed that can be used throughout the country to help coordinate the development of consistent emission estimates. These manuals are intended for use by local, state, and federal staff, as well as by industry and private consultants. The purpose of these manuals is to assist in implementing the inventory program and in maintaining that program over time so that emissions inventories can be developed in periodic cycles and continually improved.

The manuals cover inventory program elements such as estimating emissions, program planning, database management, emissions validation, and other important topics. Figure 1 shows the complete series of manuals that will be developed to support a comprehensive inventory program. The main purpose of each manual is summarized below.

Volume I—Emissions Inventory Program Planning. This manual addresses the important planning issues that must be considered in an air emissions inventory program. Program planning is discussed not as an "up-front" activity, but rather as an ongoing process to ensure the long-term growth and success of an emissions inventory program. *Key Topics*: program purpose, inventory end uses, regulatory requirements, coordination at federal/state/local levels, staff and data management requirements, identifying and selecting special studies.

Volume II—Emissions Inventory Fundamentals. This manual presents the basic fundamentals of emissions inventory development and discusses inventory elements that apply to multiple source types (e.g., point and area) to avoid the need for repetition in multiple volumes. *Key Topics*: applicable regulations, rule effectiveness, rule penetration, pollutant definitions (e.g., how to properly exclude nonreactive volatile compounds), point/area source delineation, point/area source reconciliation.

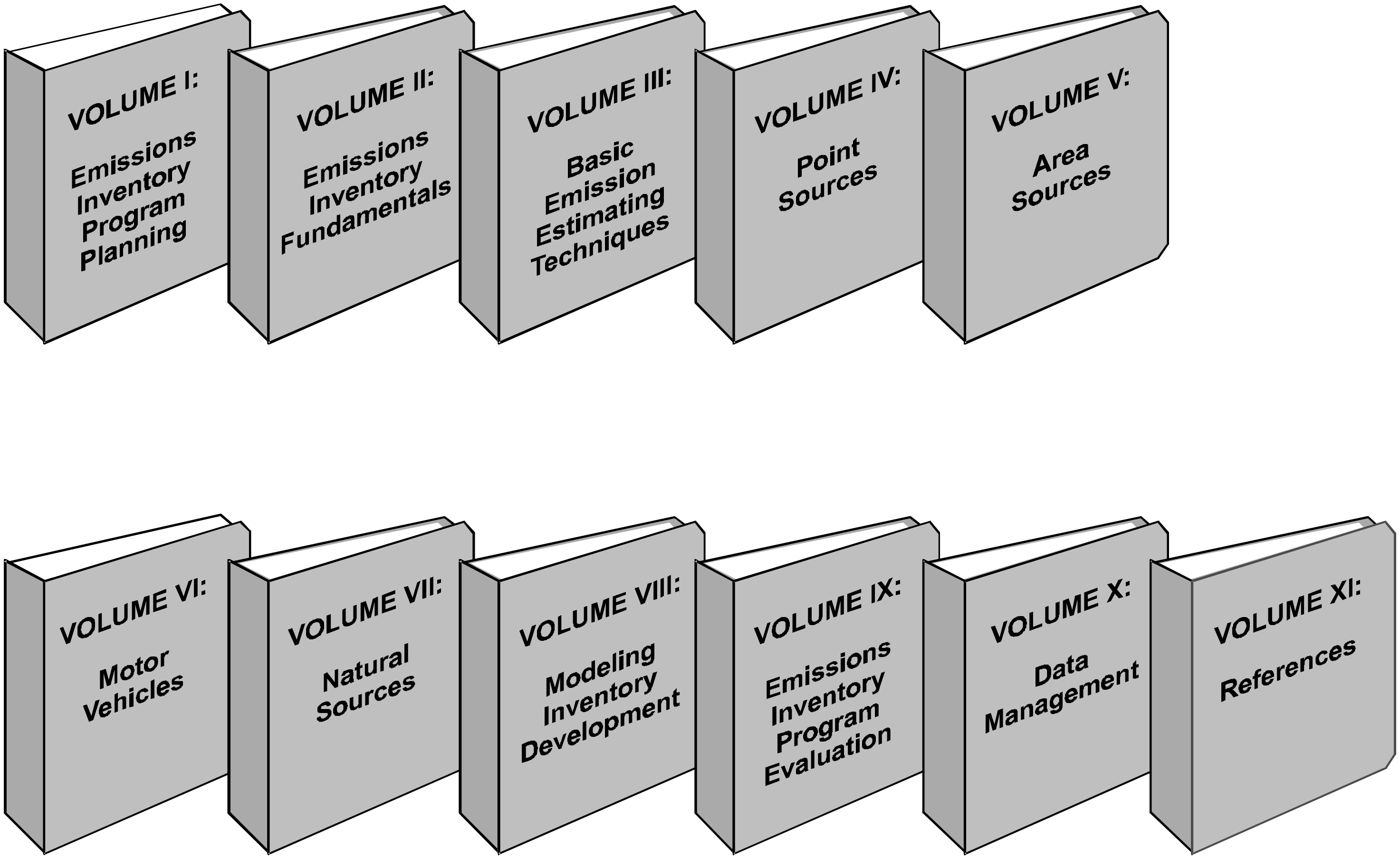

Figure 1. Mexico Emissions Inventory Program Manuals

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Volume III—Emissions Inventory Development: Basic Emission Estimating Techniques (EETs). This manual presents the basic EETs used to develop emission estimates, including examples and sample calculations. Inventory tools associated with each methodology are identified and included in Volume XI (References). *Key Topics*: source sampling, emissions models, surveying, emission factors, material balance, extrapolation.

Volume IV—Point Sources. This manual provides guidance for developing the point source emissions inventory. A cross-reference table is provided for each industry/device type combination (e.g., petroleum refining/combustion devices) with one or more of the basic EETs presented in Volume III. *Key Topics*: cross-reference table, stack parameters, control devices, design/process considerations, geographic differences and variability in Mexico, quality assurance/quality control (QA/QC), overlooked processes, data references, data collection forms.

Volume V—Area Sources (includes non-road mobile). This manual provides guidance for developing the area source emissions inventory. After the presentation of general area source information, a table is provided to cross-reference each area source category (e.g., asphalt application) with one or more of the basic EETs presented in Volume III. Then, source category-specific information is discussed for each source category defined in the table. *Key Topics*: area source categorization and definition, cross-reference table, control factors, geographic differences and variability in Mexico, QA/QC, data references, data collection forms (questionnaires).

Volume VI—Motor Vehicles. Because motor vehicles are inherently different from point and area sources, the available estimation methods and required data are also different. To estimate emissions from these complex sources, models are the preferred estimation tool. Many of these models utilize extensive test data applicable to a given country or region. This manual focuses primarily on the data development phase of estimating motor vehicle emissions. *Key Topics*: available estimation methods, primary/secondary/tertiary data and information, source categorization, emission factor sources, geographic variability within Mexico, QA/QC.

Volume VII—Natural Sources. This manual provides guidance for developing a natural source emissions inventory (i.e., biogenic volatile organic compounds [VOC] and soil oxides of nitrogen [NO_x]). In addition, this manual includes the theoretical aspects of emission calculations and discussion of specific models. *Key Topics*: source categorization and definition, emission mechanisms, basic emission algorithms, biomass determination, land use/land cover data development, temporal and meteorological adjustments, emission calculation approaches.

Volume VIII—Modeling Inventory Development. This manual provides guidance for developing inventory data for use in air quality models and addresses issues such as temporal allocation, spatial allocation, speciation, and projection of emission estimates. *Key Topics*: definition of modeling terms, seasonal adjustment, temporal allocation, spatial allocation, chemical speciation, projections (growth and control factors).

Volume IX—Emissions Inventory Program Evaluation. This manual consists of three parts: QA/QC, uncertainty analysis, and emissions verification. The QA/QC portion defines the overall QA/QC program and is written to complement source specific QA/QC procedures written into other manuals. The uncertainty analysis includes not only methods of assessing uncertainty in emission estimates, but also for assessing uncertainty in modeling values such as speciation profiles and emission projection factors. The emissions verification section describes various analyses that can be performed to examine the accuracy of the emission estimates. Examples include receptor modeling and trajectory analysis combined with specific data analysis techniques. *Key Topics*: description of concepts and definition of terms, inventory review protocol, completeness review, accuracy review, consistency review, recommended uncertainty EETs, applicable emission verification EETs.

Volume X—Data Management. This manual addresses the important needs associated with the data management element of the Mexico national emission inventory program. *Key Topics*: general-purpose data management systems and tools, specific-purpose software systems and tools, coding system, confidentiality, electronic submittal, frequency of updates, recordkeeping, Mexico-specific databases, reports.

Volume XI—References. This manual is a compendium of tools that can be used in emission inventory program development. Inventory tools referenced in the other manuals are included (i.e., hardcopy documents, electronic documents, and computer models).

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ACRONYMS

ARB	Air Resources Board
ATP	anti-tampering program
ATPFLG	ATP flag
BEF	basic emission factor
BER	basic emission rate
CMB	Chemical Mass Balance Model
C_3H_8	propane
CO	carbon monoxide
CO_2	carbon dioxide
COEF	composite fleet emission factor
EGR	exhaust gas recirculation
FEAT	Fuel Efficiency Automobile Test
FID	flame ionization detector
g	gram
GVW	gross vehicle weight
HC	hydrocarbon
HDDV	heavy-duty diesel vehicle (>3,857 kg)
HDGV	heavy-duty gasoline vehicle (>3,857 kg)
I/M	inspection and maintenance
IMFLAG	I/M flag
INE	National Institute of Ecology

IR	infrared
kg	kilogram
km	kilometer
kph	kilometer per hour
LAP	local area parameter
LDDT	light-duty diesel truck (>3,857 kg)
LDDV	light-duty diesel vehicle
LDGT1	light-duty gasoline truck (<2,727 kg)
LDGT2	light-duty gasoline truck (2,727-3,857 kg)
LDGV	light-duty gasoline vehicle
LPG	liquefied petroleum gas
MARI	Mexico City Air Quality Research Initiative
MC	motorcycle
Mg	megagram
mph	miles per hour
NMHC	non-methane hydrocarbons
NMHFLG	hydrocarbon emission factor flag
NMOC	non-methane organic compounds
NMOG	non-methane organic gases
NO_x	nitrogen oxides
OMS	Office of Mobile Sources
OUTFMT	output format flag

OXYFLG	oxygenated fuel flag
PCV	positive crankcase ventilation
PEMEX	Petróleos Mexicanos
PM	particulate matter
$PM_{2.5}$	particulate matter of aerodynamic diameter of 2.5 microns or less
PM_{10}	particulate matter of aerodynamic diameter of 10 microns or less
ppm	parts per million
psi	pounds per square inch
QA	quality assurance
QC	quality control
RFG	reformulated gasoline
ROG	reactive organic gases
RSD	remote sensing and detection
RVP	Reid vapor pressure
SCAQS	South Coast Air Quality Study
SEMOS	Southeast Michigan Ozone Study
SO_x	sulfur oxides
TAMFLG	tampering flag
TDM	travel demand model
TEMFLG	temperature flag
THC	total hydrocarbons
TOG	total organic gases

TTI	Texas Transportation Institute
U.S.	United States
U.S. EPA	United States Environmental Protection Agency
VKT	vehicle kilometers traveled
VOC	volatile organic compounds
wt	weight

1.0 INTRODUCTION

This manual addresses the development of emission estimates for on-road motor vehicles. On-road motor vehicles are those vehicles, such as autos, trucks, and buses, designed to operate on public roads. In most urban areas, on-road motor vehicles are major contributors of emissions of total organic gases (TOG), carbon monoxide (CO), nitrogen oxides (NO_x), sulfur oxides (SO_x), particulate matter (PM), air toxics, and visibility reducing species. Due to their large emissions magnitude and the special considerations required to develop emission estimates, on-road motor vehicles are addressed separately from other area sources.

Interest in obtaining estimates of the on-road motor vehicle contribution to regional emission inventories in Mexico has been increasing, leading to the development of motor vehicle emission inventories for Mexico City, Monterrey, Ciudad Juárez, and Leon (Espinosa, et al., 1996). The data available to develop these inventories have varied considerably. Through improved data collection techniques and estimation methodologies, future inventory efforts will increase in their accuracy and precision. The purpose of this manual is to present existing and near-term inventory methods as they could be applied in Mexico. In order to address the wide variations in the availability of emissions and activity data, a variety of methods are discussed.

This manual provides an overview of various inventory methods. Additional information can be obtained from the references that are extensively cited in this manual. Similarly, additional "hands-on" training with the motor vehicle emission factor models referenced in this manual (MOBILE and PART5) is essential for the creation of a quality motor vehicle emissions inventory.

This manual addresses only on-road motor vehicles. Non-road mobile sources (also referred to as off-road mobile sources) include vehicles designed for use off of public roads (e.g., aircraft, locomotives, marine vessels, forklifts, cranes, and construction equipment), and other mobile emission sources (e.g., portable electric generators). The estimation of emissions from non-road sources is addressed in *Volume V: Area Sources Inventory Development*. The remainder of this introduction summarizes the emission processes associated with on-road motor vehicles and discusses the classification of Mexican vehicles into the groups used for emission inventories. The manual is organized as follows:

- Section 2.0 presents an overview of the on-road motor vehicle emission inventory process, and discusses how emissions are calculated and how data development priorities are established;
- Section 3.0 discusses emission factor models and their application in Mexico;
- Section 4.0 discusses the development of activity data used in conjunction with emission factors to estimate emissions; and
- Section 5.0 presents quality assurance (QA) procedures that can be applied to check the reasonableness and accuracy of on-road motor vehicle emission estimates.

1.1 On-Road Motor Vehicle Emission Processes

Motor vehicle emissions consist of a large number of pollutants resulting from a number of different processes (see Figure 1-1). The most commonly considered are exhaust emissions, which result from fuel combustion and are emitted from the vehicle exhaust tailpipe. Key pollutants of concern from exhaust emissions include TOG, CO, NO_x, SO_x, PM, air toxics, (e.g., 1,3-butadiene, benzene, formaldehyde, etc.) and visibility reducing species (e.g., ammonia, sulfates, $PM_{2.5}$, etc.). In addition to exhaust emissions, there are a variety of evaporative emission processes from motor vehicles. Evaporative emission processes are solely limited to TOG emissions. These evaporative processes include:

- **Hot soak emissions** - Emissions occurring due to volatilization of fuel in the fuel delivery system following engine shut-off. Residual engine heat volatilizes the fuel.

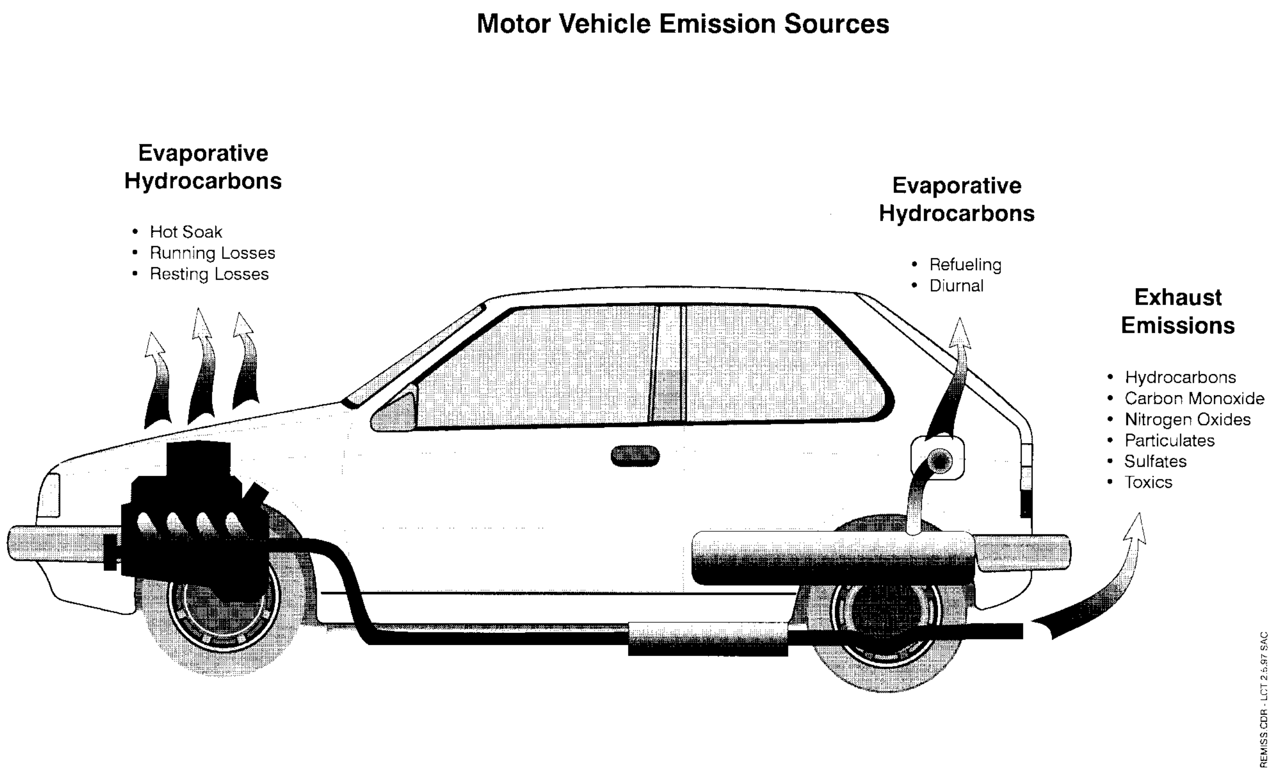

Figure 1-1. Motor Vehicle Emission Processes

- **Running evaporative emissions** - Evaporative emissions from liquid or vapor fuel leaks occurring while the engine is operating.

- **Refueling evaporative emissions** - Evaporative emissions displaced from the vehicle fuel tank during refueling. While the vehicle is the source of the emissions, they occur while the vehicle is stationary and at known locations, such as gasoline stations. Refueling is typically treated as an area source and discussed in *Volume V: Area Source Inventory Development*. Refueling emission factors can either be estimated using the MOBILE model or obtained from other sources such as AP-42.

- **Diurnal emissions** - Emissions from the vehicle fuel tank due to higher bulk liquid temperatures and fuel vapor pressure. These result from rising ambient temperatures heat input from the vehicle’s exhaust system, or heat reflected from the road surface.

- **Resting evaporative emissions** - Evaporative emissions other than hot soak, diurnal, and refueling emissions that occur while the engine is not operating. Resting losses occur primarily from fuel leaks and permeation of vapor through fuel lines.

There are also additional sources of PM emissions from motor vehicles. The largest of these is entrained road dust, which is dust picked up by the vehicle tires and suspended in the air by the wake turbulence from the vehicle. Entrained road dust emissions are treated as an area source and are discussed in *Volume V: Area Source Inventory Development*. Other non-exhaust PM sources include tire wear and brake wear. These sources are typically insignificant compared to exhaust PM and entrained road dust and, therefore, are sometimes omitted from emission inventories. Emission factors for tire and brake wear, however, can be estimated using the PART5 model (see Section 3.2).

1.2 Mexican Vehicle Classes

The large number of vehicles in an inventory region make it impractical to measure the emissions of each individual vehicle. Consequently, the motor vehicle inventory methodology relies on organizing vehicles into categories with common emission characteristics, then attempting to quantify the emissions for each group. Key variables used in this initial grouping of vehicles are vehicle type (auto, truck, bus, etc.), fuel type (gasoline, diesel, liquefied fuels, etc.), gross vehicle weight (GVW), and the level of emission control technology on the vehicle. GVW is the vehicle weight when carrying the maximum cargo allowed by the manufacturer with a full tank of fuel.

Emissions from different motor vehicles can vary by multiple orders of magnitude, depending upon many factors. In particular, the level of emission control technology on a vehicle greatly influences the magnitude of emissions. The level of control technology is determined by the emission standards applicable to the vehicle. New vehicles meeting the same standards will tend to have similar emissions in actual use relative to vehicles produced to meet different standards. When estimating emission factors from vehicles, vehicles are grouped by emission standards that apply to the vehicles when they are first manufactured.

In Mexico, the following new vehicle emission standards have been established:

- NOM-042-ECOL-1993 - Applicable for vehicles (400-3,857 kg GVW) powered by gasoline, natural gas, or other alternative fuels;
- NOM-044-ECOL-1993 - Applicable for vehicles (greater than 3,857 kg) powered by diesel; and
- NOM-076-ECOL-1994 - Applicable for vehicles (greater than 3,857 kg) powered by gasoline.

In addition, the following standards have been established for vehicles in actual use:

- NOM-041-ECOL-1993 - Applicable for vehicles (greater than 400 kg) powered by gasoline;
- NOM-045-ECOL-1993 - Applicable for vehicles (greater than 400 kg) powered by diesel (smog opacity only);

- NOM-048-ECOL-1993 - Applicable for motorcycles powered by gasoline or gasoline-oil;
- NOM-050-ECOL-1993 - Applicable for vehicles (greater than 400 kg) powered by natural gas or other alternative fuels; and
- NOM-EM-102-ECOL-1995 - Applicable for vehicles in use in the Mexico City Valley (greater than 400 kg) powered by gasoline or other alternative fuels.

The “in-use” vehicle standards are primarily designed to detect high-emitting vehicles during inspection and maintenance (I/M) testing. The above vehicle standards and their associated vehicle classes are discussed in more detail in Section 3.4.2.

2.0 OVERVIEW OF THE INVENTORY DEVELOPMENT PROCESS

Development of an on-road motor vehicle emissions inventory is an attempt to quantify the emissions occurring from a large population of vehicles with diverse emission characteristics. The basic equation used for estimating motor vehicle emissions involves multiplying activity data by an appropriate emission factor. For motor vehicles, activity data consist of vehicle kilometers traveled (VKT) which is the total distance traveled by motor vehicles within the inventory domain, while emission factors are expressed in units of grams of pollutant emitted per VKT. Ideally, VKT estimates should be developed directly from local data, such as transportation models or roadway traffic counts. However, in many cases, these data are not available and it becomes necessary to rely on alternate measures of vehicle activity, such as regional fuel consumption statistics. Emission factors should be estimated using an existing emission factor model that has been adjusted for local conditions.

The basic steps in the on-road motor vehicle inventory development process are shown in Figure 2-1. This process can be divided into five key steps:

- Collection of local vehicle activity data (direct VKT or fuel consumption statistics);
- Collection of area-specific data (ambient temperature data, fuel characteristics, vehicle fleet composition, vehicle kilometer accumulation rates, etc.);
- Generation of emission factors using an emission factor model;
- Calculation of preliminary emission estimates; and

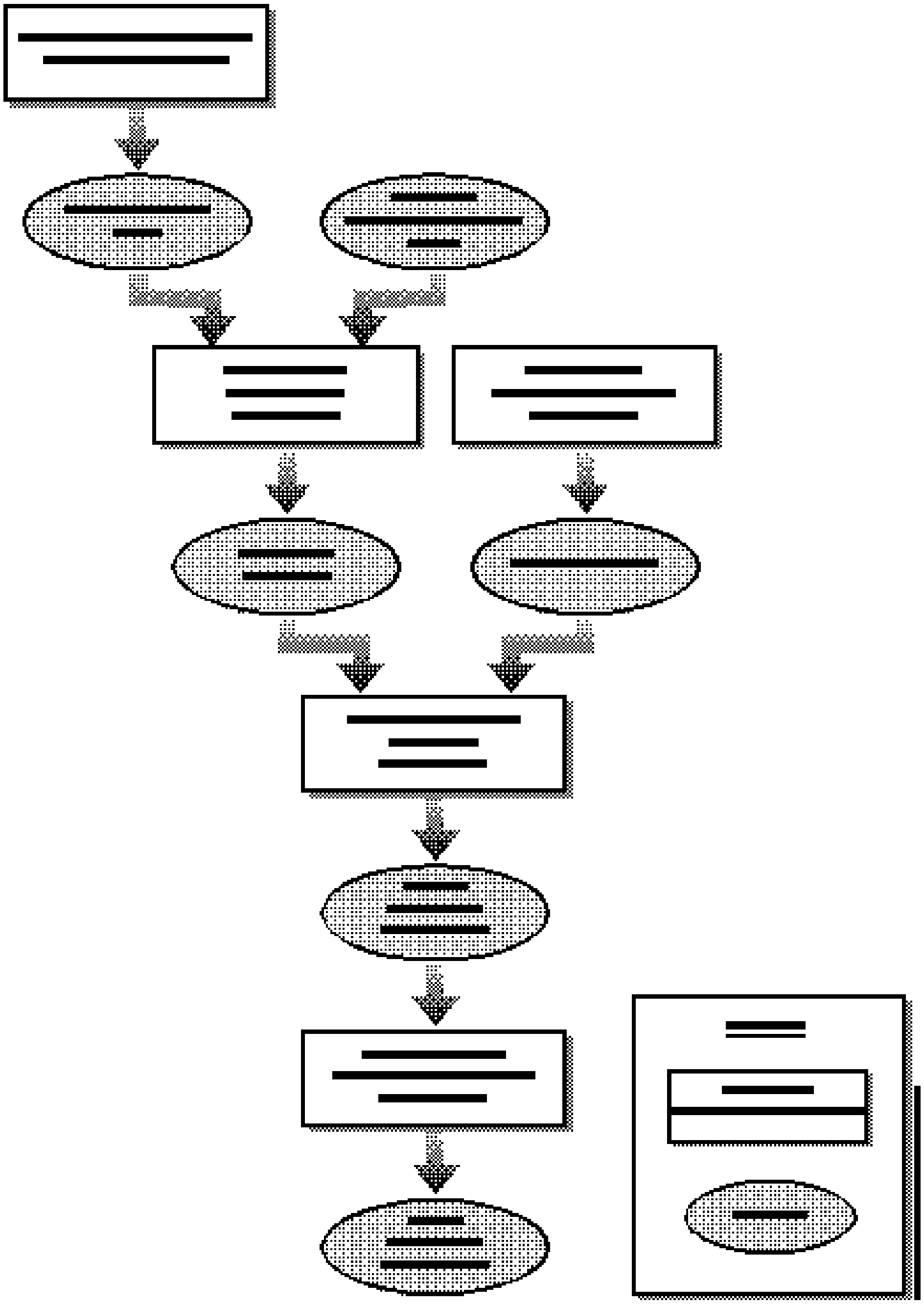

Figure 2-1. On-Road Motor Vehicle Inventory Development

- Implementation of quality assurance (QA) procedures to finalize the inventory estimates.

A typical motor vehicle emissions inventory for an urban area can include thousands, or even millions, of vehicles. The vehicle fleet includes a distribution of vehicles from each model year, and the level of emission controls varies significantly over the full span of model years currently in operation. Each vehicle is operated in a unique manner with different speeds and loads, under various driving conditions. In addition, vehicles are subject to varying levels of maintenance and tampering (e.g., disablement of emissions control systems). All of these elements can have significant impacts on the emission characteristics of a vehicle, resulting in large differences in emissions from otherwise similar vehicles.

Given present technology, it is not feasible to obtain emission measurements from each individual vehicle in a fleet. Consequently, other methods are needed to estimate motor vehicle emissions. Theoretical calculations, using fuel mass balances, for example, yield useful results for some pollutants such as SO_x and lead. For other pollutants, however, an emission factor model (such as MOBILE or PART5) is used to estimate emissions from various vehicle classifications. Emission factor models are based upon testing data collected from a statistically representative sample of the vehicle population. Input parameters are then adjusted to account for local conditions and variability.

Example calculations using both fuel mass balances and emission factor models are presented in Appendix A. These example calculations are based upon an actual emissions inventory conducted in Nogales, Sonora.

2.1 Basic Emission Estimation Methodology

The basic equation used for estimating motor vehicle emissions involves multiplying activity data by an appropriate emission factor. This is shown in Equation 2-1.

$$E_p = VKT \times EF_p \tag{2-1}$$

where:
E_p = Total emissions of pollutant p;
VKT = Vehicle kilometers traveled; and
EF_p = Emission factor of pollutant p.

For motor vehicles, activity data consist of vehicle kilometers traveled (VKT), while emission factors are expressed in units of grams of pollutant per VKT. VKT represents the total distance traveled by a vehicle population over a given period of time. VKT should preferably be estimated from transportation models or vehicle road counts. In some cases, however, VKT must be derived from fuel consumption statistics.

The basic emission estimation equation given above is applicable for most gaseous pollutants and particulate matter. For pollutants such as SO_x and lead, emissions are estimated using a fuel balance, assuming that all of the sulfur or lead contained in the fuel is emitted.

The equation describing the fuel balance for SO_x is:

$$E_{SO_x,f} = Fuel_f \times \rho_f \times S_f \times 2 \tag{2-2}$$

where:
$E_{SOx,f}$ = Emissions of SO_x for fuel f (gasoline or diesel);
$Fuel_f$ = Total fuel consumption of fuel f;
ρ_f = Fuel density of fuel f;
S_f = Fuel sulfur content (mass fraction) of fuel f; and
2 = Conversion factor from mass of sulfur to mass of SO_x (as SO_2).

A similar equation describing the fuel balance for lead is:

$$E_{Pb,f} = Fuel_f \times \rho_f \times Pb_f \tag{2-3}$$

where: Pb_f = Fuel lead content (mass fraction) of fuel f.

2.2 Data Development Priorities

Many different data need to be collected to generate a motor vehicle emissions inventory. These include VKT, fuel consumption statistics, vehicle speeds, vehicle registration data, vehicle class mixes, and fuel characteristics. In some cases, the data are absolutely critical to the inventory process and must be obtained to generate even the most preliminary estimates. In other cases, the data are used to refine the modeling, often by replacing default data with local information. This section lists some of the key data to be gathered and prioritizes the various data needs. Additional information describing these data categories is available in Sections 3.0 and 4.0.

The importance of the different data for developing an inventory can be defined by grouping data into three categories: primary, secondary, and tertiary. Primary data are the minimum required to generate a basic inventory. Secondary data replace key default parameters with local data. Tertiary data are included as available to further refine the inventory to local conditions. An initial inventory can be generated using only primary data. However, as additional secondary and tertiary data are added to the inventory, the level of confidence in the resulting estimates is improved.

Primary data needs include:

- Vehicle activity data covering the entire inventory region (typically VKT or fuel consumption) grouped to match the available emission factor data;
- Vehicle emission standards by model year;
- Average vehicle speeds;
- Emission factors, by vehicle type, fuel type, model year, and speed;
- Fuel composition data for the inventory region, by season, including sulfur content, oxygen content, lead content, and Reid vapor pressure;
- Vehicle population distribution by model year, including the fraction of unregistered and foreign-registered vehicles;

- Local conditions of altitude and ambient temperature; and
- Annual vehicle kilometer accumulation rates, by vehicle class and model year.

Secondary data needs include:

- Local vehicle inspection and maintenance (I/M) program and anti-tampering program (ATP) information; and
- Local vehicle tampering and misfueling rate survey data.

Tertiary data needs include:

- Local driving behavior survey data to identify average trip lengths, and time between engine starts; and
- Driving pattern survey data to identify local patterns of vehicle speeds, engine loads and acceleration rates.

3.0 MOTOR VEHICLE EMISSION FACTOR MODELS

As described in Section 2.0, motor vehicle emissions are calculated by combining emission factors with VKT. Instead of simple published emission factors, however, motor vehicle emission factors are derived from emission factor models. The reason for this is that emissions from motor vehicles are more complex and dynamic than most other source types. For example, changes in fuel characteristics, vehicle operating speeds, emission control technology, ambient temperature, and altitude can all affect emission factors. In order to account for these and other impacts, an emission factor model is normally used that includes the effects of many parameters.

This section describes various aspects of the motor vehicle models (MOBILE and PART5) that should be used to estimate motor vehicle emissions in Mexico. The MOBILE model will be the central focus of this section, although the PART5 model will also be discussed. Section 3.1 briefly describes the history of the MOBILE and PART5 models in both the U.S. and Mexico. Section 3.2 provides a short theoretical description of the algorithms used to estimate motor vehicle emission factors. Section 3.3 briefly explains both the input and output files used by the MOBILE model. Finally, Section 3.4 presents a discussion of several fundamental area-specific characteristics that can greatly influence motor vehicle emissions.

3.1 Emission Factor Model Historical Background

This section presents some historical background about the MOBILE and PART5 emission factor models that have been developed within the U.S. A brief description of the use of these two models within Mexico is also provided.

MOBILE Emission Factor Model

The MOBILE model consists of an integrated set of FORTRAN routines that generate hydrocarbon (HC), carbon monoxide (CO), and nitrogen oxide (NO_x) emission factors for gasoline- and diesel-powered on-road motor vehicles. Hydrocarbon emission factors can be expressed either as total hydrocarbons (THC), non-methane hydrocarbons (NMHC), volatile organic compounds (VOC), total organic gases (TOG), or non-methane organic gases (NMOG). These are defined in Table 3-1. It is recommended that TOG emission factors be chosen for all emission inventory efforts. All references in this manual will be for TOG. To adjust for reactivity, the following reactive organic gas (ROG) fractions can be used (ARB, 1993):

- Non-catalyst gasoline vehicle exhaust emissions - 92.4%;
- Catalyst gasoline vehicle exhaust emissions - 85.2%;
- Diesel vehicle exhaust emissions - 95.8%; and
- Gasoline vehicle evaporative emissions - 100%.

The first generation of the MOBILE model was created in the mid-1970s. The MOBILE model has subsequently undergone several updates and revisions in order to account for changing environmental legislation and technological advances. These updated versions also incorporate large amounts of newly collected emissions data in an attempt to more accurately estimate motor vehicle emissions. The most recent version of the MOBILE model (MOBILE5b) was released in September 1996 and MOBILE6 is expected to be released in mid-1998. The MOBILE model and other related motor vehicle emission inventory information can be downloaded from the U.S. EPA Office of Mobile Sources (OMS) Internet web-site (http://134.67.104.12/html/oms/modeutil.htm).

Table 3-1

Definition of Hydrocarbons

	Compounds Included in Hydrocarbon Emission Factors			
	FID Hydrocarbons[a]	Methane	Ethane	Aldehydes
Total Hydrocarbons (THC)	✓	✓	✓	
Non-Methane Hydrocarbons (NMHC)	✓		✓	
Volatile Organic Compounds (VOC)	✓			✓
Total Organic Gases (TOG)	✓	✓	✓	✓
Non-Methane Organic Gases (NMOG)	✓		✓	✓

[a] FID hydrocarbons refer to hydrocarbon emissions as measured by the flame ionization detector (FID) used in motor vehicle testing.

Because the MOBILE model is based upon emissions testing of U.S. vehicles, its direct use in regions outside of the U.S. will likely produce uncertain results. In order to account for possibly different vehicle fleets and driving behavior in Mexico, the MOBILE model has been modified for the Mexico City, Monterrey, and Ciudad Juárez metropolitan areas. The modified models for Mexico City (MOBILE-MCMA) and Monterrey (MOBILE-MMAp) utilize an emission control technology equivalence matrix that maps basic MOBILE emission factors to vehicles within the Mexican vehicle fleet on the basis of vehicle age and level of emission controls. A sample technology equivalence matrix for exhaust and evaporative emission factors is presented in Table 3-2. From Table 3-2 it can be seen that a 1994 Mexican light-duty gasoline vehicle (LDGV) would be equivalent to a 1988 U.S. LDGV. In some instances, a certain Mexican model year might be equivalent to one U.S. model year for exhaust control technology and another for evaporative control technology. For example, a 1990 Mexican LDGV would be equivalent to a 1980 U.S. LDGV for exhaust emissions and a 1977 U.S. LDGV for evaporative emissions.

The most recent modified MOBILE model (MOBILE-Juárez) continues to assign evaporative emission factors using a technology equivalence matrix, but uses actual IM240 testing data of 206 Ciudad Juárez vehicles as the basis of the exhaust emission factors (Radian, 1996a). At the current time, this is the preferred emission factor model to use in Mexico. However, as research related to motor vehicles in Mexico continues, the Mexican MOBILE model will continue to evolve. INE should be contacted concerning the most appropriate version of the emission factor model to be used in any future motor vehicle inventory efforts.

PART5 Emission Factor Model

The U.S. EPA PART5 emission factor model also utilizes FORTRAN routines that are similar to MOBILE to estimate particulate matter (PM) and sulfur oxide (SO_x) emission factors for motor vehicles. However, it is recommended that Mexico SO_x emission factors not be estimated using the PART5 model, due to several reasons, including the inability to adjust the

Mexican	U.S. Equivalent Model Year (Exhaust)								U.S. Equivalent Model Year (Evaporative)							
Model Year	LDGV	LDGT1	LDGT2	HDGV	LDDV	LDDT	HDDV	MC	LDGV	LDGT1	LDGT2	HDGV	LDDV	LDDT	HDDV	MC
1971	1968	1968	1968	1968	1968	1968	1968	1971	1968	1968	1968	1968	1968	1968	1968	1968
1972	1968	1968	1968	1968	1968	1968	1968	1972	1968	1968	1968	1968	1968	1968	1968	1968
1973	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971
1974	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971
1975	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971
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1980	1971	1971	1971	1971	1971	1971	1971	1971	1972	1972	1972	1972	1972	1972	1972	1972
1981	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972
1982	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972
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1985	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972
1986	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972
1987	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972
1988	1975	1974	1974	1974	1974	1974	1974	1974	1975	1975	1975	1975	1975	1975	1975	1975
1989	1975	1974	1974	1974	1974	1974	1974	1974	1975	1975	1975	1975	1975	1975	1975	1975
1990	1980	1974	1974	1974	1974	1974	1974	1974	1977	1977	1977	1977	1977	1977	1977	1977
1991	1980	1974	1974	1974	1974	1974	1974	1974	1977	1977	1977	1977	1977	1977	1977	1977
1992	1981	1974	1974	1974	1974	1974	1974	1974	1980	1980	1980	1980	1980	1980	1980	1980
1993	1988	1977	1977	1977	1977	1977	1977	1977	1981	1981	1981	1981	1981	1981	1981	1981
1994	1988	1981	1981	1981	1981	1981	1981	1981	1988	1988	1988	1988	1988	1988	1988	1988
1995	1989	1981	1981	1981	1981	1981	1981	1981	1988	1988	1988	1988	1988	1988	1988	1988
1996	1990	1981	1981	1981	1981	1981	1981	1981	1988	1988	1988	1988	1988	1988	1988	1988
1997	1990	1981	1981	1981	1981	1981	1981	1981	1990	1990	1990	1990	1990	1990	1990	1990
1998	1994	1985	1985	1985	1985	1985	1985	1985	1990	1990	1990	1990	1990	1990	1990	1990
1999	1995	1985	1985	1985	1985	1985	1985	1985	1990	1990	1990	1990	1990	1990	1990	1990
2000	1996	1985	1985	1985	1985	1985	1985	1985	1990	1990	1990	1990	1990	1990	1990	1990
2001	1997	1993	1993	1990	1993	1993	1990	1993	1990	1990	1990	1990	1990	1990	1990	1990

LDGV = Light-duty gasoline vehicle
LDGT1 = Light-duty gasoline truck (< 2,727 kg)
LDGT2 = Light-duty gasoline truck (2,727-3,857 kg)
HDGV = Heavy-duty gasoline truck (> 3,857 kg)
LDDV = Light-duty diesel vehicle
LDDT = Light-duty diesel truck (< 3,857 kg)
HDDV = Heavy-duty diesel vehicle (>3,857 kg)
MC = Motorcycle

Table 3-2. Typical Emission Control Technology Equivalence Matrix

fuel sulfur content to reflect local conditions. Instead, SO_x emissions should be estimated using fuel balances as described in Section 2.1. The latest version of the PART5 model was released in February 1995 (U.S. EPA, 1995). Although the PART5 model resembles the MOBILE model in several respects, it is at an earlier stage of development because less particulate emission data have been collected. This is mainly the result of ozone precursors (TOG, CO, and NO_x) being given higher priority than PM in the U.S. Consequently, some parameters that affect motor vehicle particulate emissions (e.g., temperature, inspection and maintenance [I/M] programs, fuel impacts) have not been modeled in PART5. Also, several assumptions in the model (i.e., driving cycles, fuel specifications, emission control systems, engine system deterioration rates) are valid only for the U.S. Unless conditions in Mexico are similar to these assumptions, the resultant emission factors will not accurately represent particulate emissions from Mexican motor vehicles.

At the present time, the PART5 model has <u>not</u> been modified for use outside of the U.S. It is expected that the level of effort needed to modify the PART5 model for use in Mexico would be similar to that expended in modifying the MOBILE model for use in Mexico City or Monterrey. Until a modified PART5 model has been developed for Mexico, it is recommended that the U.S. PART5 model be used. This is not an ideal solution, however, the U.S. PART5 model will serve as an interim methodology until a Mexico-specific version is developed. INE should be contacted concerning the most appropriate version of this emission factor model to be used in any future motor vehicle inventory efforts.

3.2 Theoretical Description of Emission Factor Models

Within the MOBILE and PART5 models, the ultimate goal is to calculate an <u>average</u> emission factor for each vehicle type. This section outlines some of the basic theoretical equations that are used to calculate the average emission factor for each vehicle type. The emission factor calculation methodology given below is presented as general background information for the model user. These theoretical equations will be invisible to the actual user of the emission factor model; however, these equations and the resulting emission factors will be influenced by various input parameters that are described within Sections 3.3 and 3.4.

The calculation of average basic emission rates (BERs) for each vehicle type and model year is the first step in estimating motor vehicle emission factors. The foundation of BERs is emissions test data from in-use vehicles measured under standardized test conditions (i.e., standard temperature, fuel characteristics, and driving cycles). However, emissions vary with vehicle age, so linear regressions that relate emissions data to odometer readings are performed. These linear regressions result in BER equations which incorporate a zero mile emission rate (the y-intercept of the regression) and a deterioration rate (the slope). The zero mile emission rate represents emissions from a new vehicle, while the deterioration rate describes how emissions increase with increased vehicle mileage.

The MOBILE model, in fact, uses two BER equations to describe different deterioration rates in different mileage regimes for light-duty gasoline vehicles and newer light-duty gasoline trucks. Two hypothetical BER equations are presented below:

$$\text{For CUMMIL} \le 50{,}000 \text{ miles, BER} = \text{ZML} + \left(\text{DET1} \times \frac{\text{CUMMIL}}{10{,}000}\right); \qquad (3\text{-}1)$$

$$\text{For CUMMIL} > 50{,}000 \text{ miles, BER} = \text{ZML} + (\text{DET1} \times 5) + \left(\text{DET2} \times \frac{[\text{CUMMIL} - 50{,}000]}{10{,}000}\right) \qquad (3\text{-}2)$$

where:
BER = basic emission rate;
ZML = zero mile emissions level (intercept);
DET1 = deterioration rate per 10,000 miles (slope) for accumulated mileage up to 50,000 miles;
DET2 = deterioration rate per 10,000 miles (slope) for accumulated mileage over 50,000 miles; and
CUMMIL = accumulated odometer mileage.

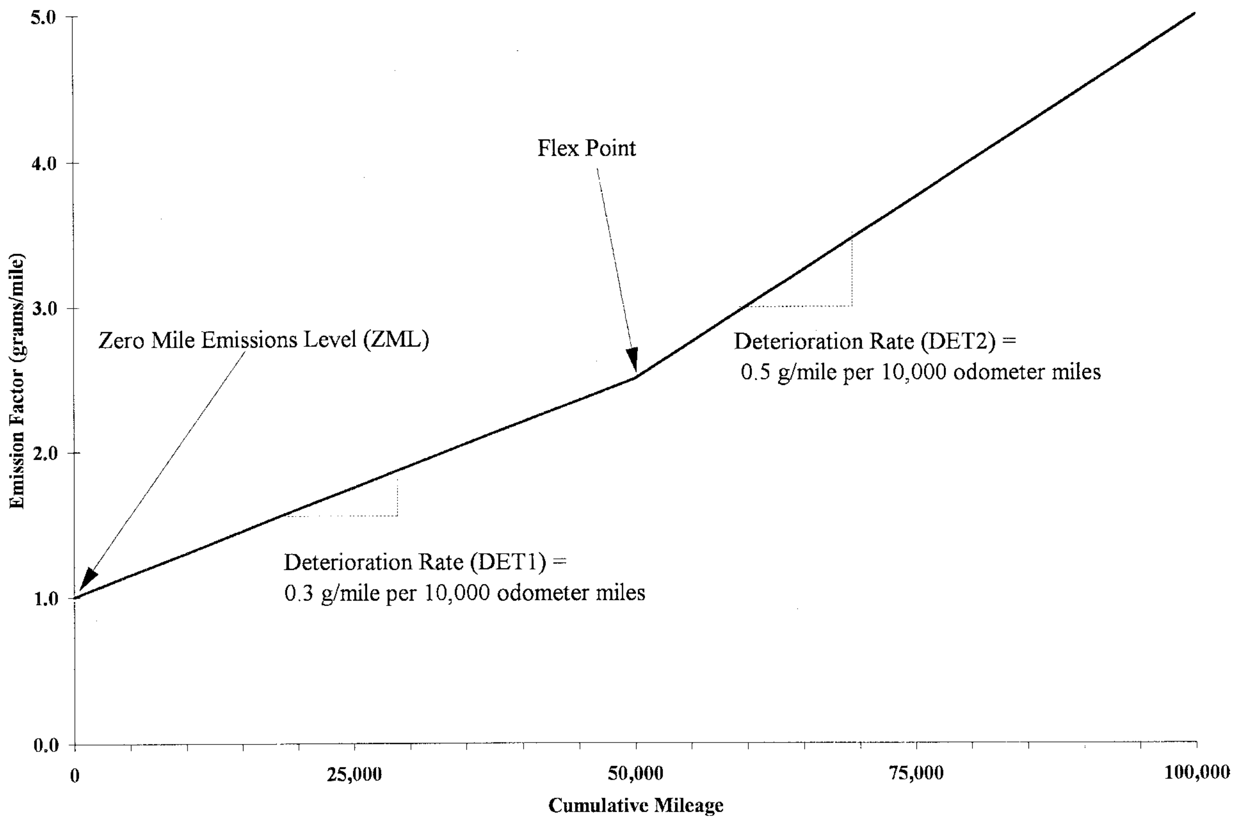

Figure 3-1. Hypothetical Basic Emission Rates (BERs)

These two hypothetical BER equations are plotted in Figure 3-1. In this figure, the zero mile emissions level and the two deterioration rates are indicated. Also, a hypothetical “flex-point” at 50,000 miles can clearly be seen where vehicles shift from one deterioration rate to another. In reality, the emissions test data from in-use vehicles might be extremely nonlinear. The MOBILE model utilizes one or two linear BER equations to keep the amount of calculations to a manageable level. Depending upon the distribution of emissions data in different data sets, the BER equations and the resulting flex-points might vary significantly. The convention of a 50,000 mile flex-point has been adopted in the MOBILE model for light-duty gasoline vehicles and trucks. For each vehicle type, a BER is assigned to 25 model years based upon the average mileage accumulation for each model year.

Base emission rates, however, do not exactly correspond to actual motor vehicle emissions. Rather, they represent emissions measured under highly controlled test conditions. To reconcile the differences that exist between test emissions and actual emissions, several adjustment factors must be applied to the actual emissions. In this way, a basic emission factor (BEF) for each vehicle type and model year can be calculated from the BER. This is shown below:

$$\mathrm{BEF} = (\mathrm{BER} \times \mathrm{OMTCF} \times \mathrm{PCLEFT}) + \mathrm{OMTTAM} \tag{3-3}$$

where:
BEF = basic emission factor, by model year;
BER = basic emission rate, by model year;
OMTCF = adjustment factor for effects of different temperatures, fuel Reid vapor pressures, and operating modes;
PCLEFT = adjustment factor for effect of I/M program; and
OMTTAM = adjustment factor for effects of tampering and anti-tampering programs.

The above equation shows only major adjustment factors that are applicable for all pollutant types in most typical situations. There are additional adjustment factors in MOBILE that are only applicable for specialized circumstances or one pollutant (e.g., low temperature CO correction). Information concerning these other adjustment factors can be found in the MOBILE5a User's Guide (U.S. EPA, 1994) and other related documentation (U.S. EPA, 1992).

After the BEFs for each model year have been calculated with appropriate adjustments made, an average or composite fleet emission factor for each vehicle type is calculated with the inclusion of an additional adjustment factor. The composite fleet emission factor (COEF) is given by the following equation:

$$\mathrm{COEF} = \sum_{my=1}^{25} (\mathrm{TF} \times \mathrm{SALHCF} \times \mathrm{BEF}) \tag{3-4}$$

where:
COEF = composite fleet emission factor;
my = model year;
TF = travel fraction (fraction of the overall VKT that each model year contributes);
SALHCF = adjustment factor for effects of speed, air conditioning use, extra load, and trailer towing; and
BEF = basic emission factor, by model year.

The additional adjustment factor (SALHCF) accounts for the effects of area-specific traffic speed characteristics, air conditioner use, extra load, and trailer towing. After this adjustment, each adjusted emission factor is weighted by the fraction of travel (in VKT) for that model year. Finally, the weighted emission factors for each of the 25 model years are summed together to produce a composite emission factor, which is the average emission factor for a specific vehicle type.

3.3 MOBILE Input and Output Formats

This section describes a sample MOBILE input file and its resultant output file. Actual MOBILE input and output files for an emissions inventory conducted in Nogales, Sonora are also presented in Appendix A. Once again, further information about MOBILE file formats can be found in the MOBILE User's Guide. Figure 3-2 presents a sample MOBILE5a input file and Figure 3-3 presents a portion of its resultant output file in spreadsheet format. The input file is an ASCII text file read by the MOBILE model's FORTRAN code. Because FORTRAN is extremely "sensitive" to errors, an extra space or misplaced character can have disastrous effects on the MOBILE run. For this reason, it is recommended that an existing MOBILE input file be modified, rather than creating an input file from scratch.

As indicated in Figure 3-2, the MOBILE input file consists of three separate sections: the Control section, the One-Time Data section, and the Scenario section. The Control section of the input file mainly consists of a number of flags that determine the content and format of the remainder of the input file, as well as the program's output file. The flags also affect how the MOBILE code is executed. All of these flags are necessary for the MOBILE model to run.

The One-Time Data section contains information that is area-specific. This detailed local information is entered only once into the input file and replaces default data that are built into the MOBILE model. The types of alternate information that can be entered into the One-Time Data section include:

- Tampering rates;
- VKT mixes;
- Annual mileage accumulation rates;

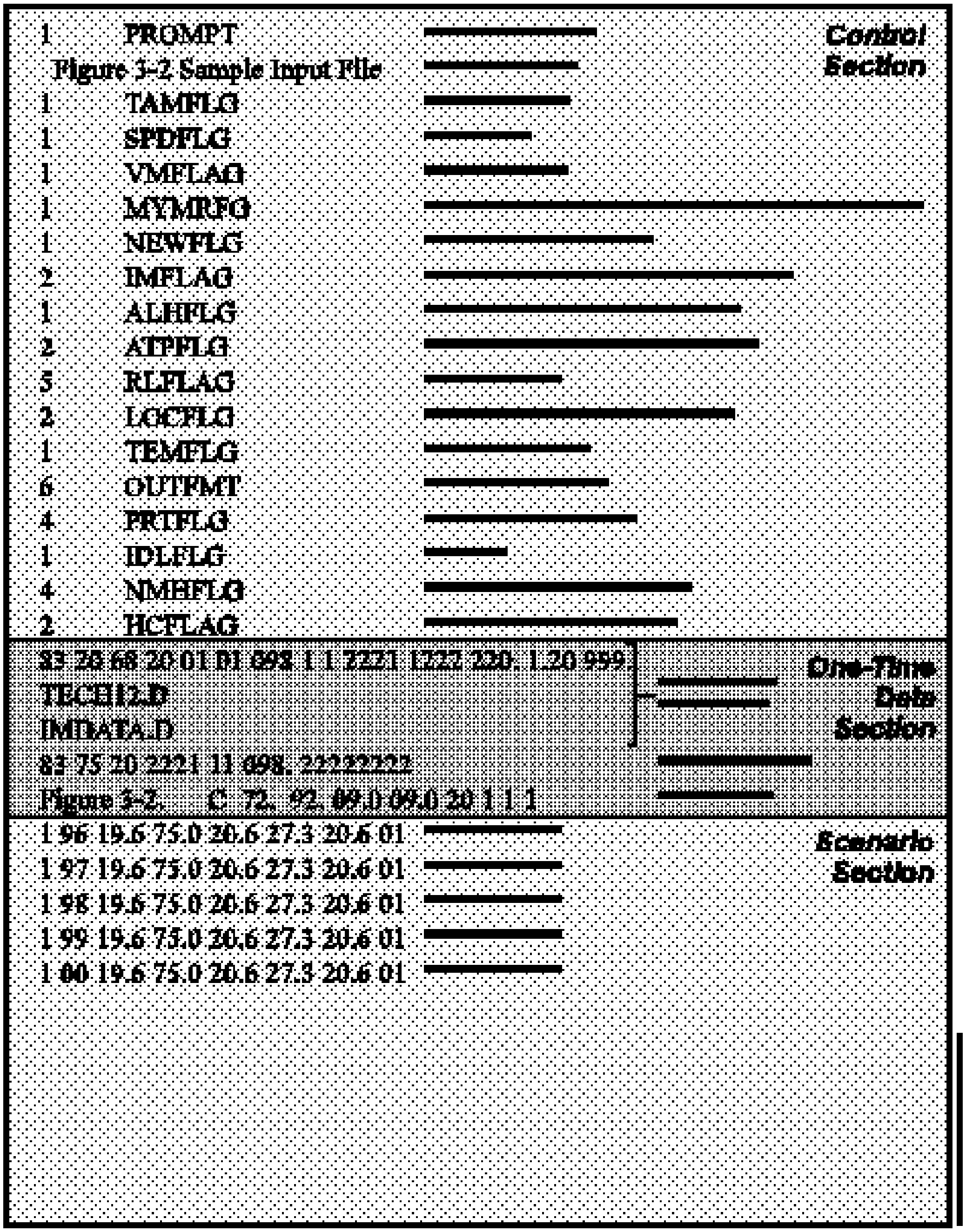

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 Figure 3-2 Sample Input File
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1       SPDFLG
1       VMFLAG
1       MYMRFG
1       NEWFLG
2       IMFLAG
1       ALHFLG
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3       RLFLAG
2       LOCFLG
1       TEMFLG
6       OUTFMT
4       PRTFLG
1       IDLFLG
4       NMHFLG
2       HCFLAG
83 28 68 20 01 01 098 1 1 2221 1222 220. 1 20 999.
TECH12.D
IMDATA.D
83 75 20 2221 11 098. 22222222
Figure 3-2.     C  72.  92. 09.0 09.0 20 1 1 1
1 96 19.6 75.0 20.6 27.3 20.6 01
1 97 19.6 75.0 20.6 27.3 20.6 01
1 98 19.6 75.0 20.6 27.3 20.6 01
1 99 19.6 75.0 20.6 27.3 20.6 01
1 00 19.6 75.0 20.6 27.3 20.6 01
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Figure 3-2. Sample MOBILE Input File

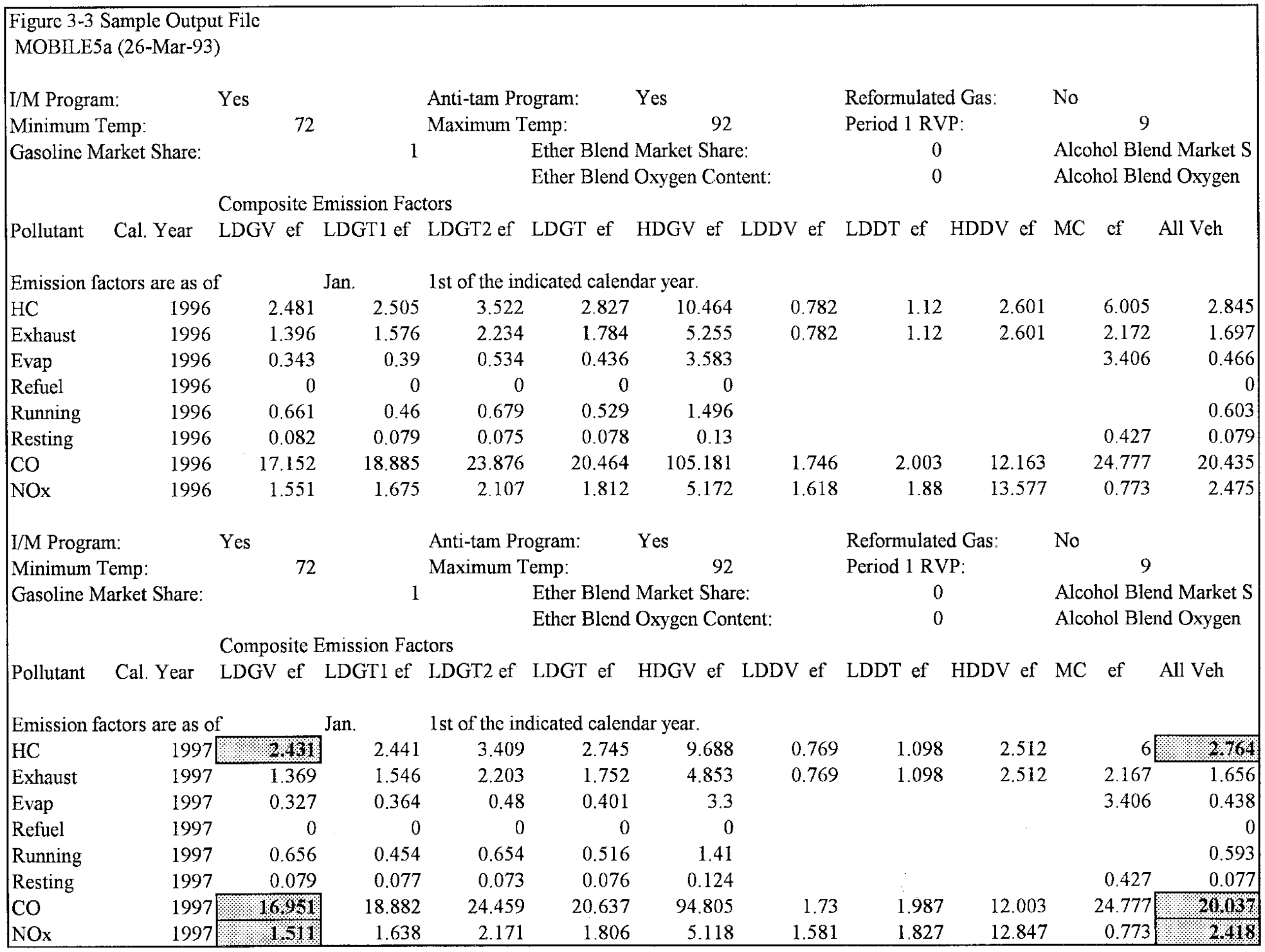


Figure 3-3 Sample Output File
MOBILE5a (26-Mar-93)

I/M Program: Yes
Anti-tam Program: Yes
Reformulated Gas: No
Minimum Temp: 72
Maximum Temp: 92
Period 1 RVP: 9
Gasoline Market Share: 1
Ether Blend Market Share: 0
Alcohol Blend Market S
Ether Blend Oxygen Content: 0
Alcohol Blend Oxygen

Composite Emission Factors

Pollutant	Cal. Year	LDGV ef	LDGT1 ef	LDGT2 ef	LDGT ef	HDGV ef	LDDV ef	LDDT ef	HDDV ef	MC ef	All Veh
Emission factors are as of		Jan.	1st of the indicated calendar year.								
HC	1996	2.481	2.505	3.522	2.827	10.464	0.782	1.12	2.601	6.005	2.845
Exhaust	1996	1.396	1.576	2.234	1.784	5.255	0.782	1.12	2.601	2.172	1.697
Evap	1996	0.343	0.39	0.534	0.436	3.583				3.406	0.466
Refuel	1996	0	0	0	0	0					0
Running	1996	0.661	0.46	0.679	0.529	1.496					0.603
Resting	1996	0.082	0.079	0.075	0.078	0.13				0.427	0.079
CO	1996	17.152	18.885	23.876	20.464	105.181	1.746	2.003	12.163	24.777	20.435
NOx	1996	1.551	1.675	2.107	1.812	5.172	1.618	1.88	13.577	0.773	2.475

I/M Program: Yes
Anti-tam Program: Yes
Reformulated Gas: No
Minimum Temp: 72
Maximum Temp: 92
Period 1 RVP: 9
Gasoline Market Share: 1
Ether Blend Market Share: 0
Alcohol Blend Market S
Ether Blend Oxygen Content: 0
Alcohol Blend Oxygen

Composite Emission Factors

Pollutant	Cal. Year	LDGV ef	LDGT1 ef	LDGT2 ef	LDGT ef	HDGV ef	LDDV ef	LDDT ef	HDDV ef	MC ef	All Veh
Emission factors are as of		Jan.	1st of the indicated calendar year.								
HC	1997	2.431	2.441	3.409	2.745	9.688	0.769	1.098	2.512	6	2.764
Exhaust	1997	1.369	1.546	2.203	1.752	4.853	0.769	1.098	2.512	2.167	1.656
Evap	1997	0.327	0.364	0.48	0.401	3.3				3.406	0.438
Refuel	1997	0	0	0	0	0					0
Running	1997	0.656	0.454	0.654	0.516	1.41					0.593
Resting	1997	0.079	0.077	0.073	0.076	0.124				0.427	0.077
CO	1997	16.951	18.882	24.459	20.637	94.805	1.73	1.987	12.003	24.777	20.037
NOx	1997	1.511	1.638	2.171	1.806	5.118	1.581	1.827	12.847	0.773	2.418

Figure 3-3. Sample MOBILE Output File

- Registration distributions by vehicle type and age;
- Basic emission rates;
- Inspection and maintenance (I/M) programs; and
- Anti-tampering programs (ATPs).

The One-Time Data section also contains the local area parameter (LAP) record which includes several important local data. These include minimum and maximum ambient daily temperature, as well as fuel Reid vapor pressure (RVP). Also, flags regarding alternate fuel mixes (diesel, oxygenated fuels, and reformulated gasoline) can be included in the LAP. With the exception of the LAP, all data in the One-Time Data section are optional. At least one LAP must be included in each MOBILE run. If the One-Time Data section does not contain any optional inputted data, then the MOBILE model will run using various default data. The sample input file presented in Figure 3-2 only includes the LAP record and I/M program and ATP information.

The Scenario section contains variables that represent scenario-specific information. Each scenario to be evaluated is associated with a group of Scenario section records. At a minimum, each scenario is represented by a record which identifies whether the region is low-altitude or high-altitude, the calendar year of evaluation, average speed, ambient temperature, operating mode fractions, and month of evaluation. Additional scenario section records may be needed, depending on the setting of various flags in the Control section. Multiple scenarios may be calculated in each MOBILE run. For instance, the Figure 3-2 input file includes five scenarios representing the years from 1996 to 2000. Multiple scenarios can be used to model the effects of fleet turnover, I/M programs, and anti-tampering programs over time.

After running the MOBILE model, an output file is generated. The format of this file is controlled by the output format flag (OUTFMT) in the Control Flag Section. Depending upon the value selected for this flag, the output file will be generated in 140- or 222-column numerical format, 80- or 112-column descriptive format, “by-model year” format, or spreadsheet format. The spreadsheet format was incorporated into MOBILE5 and allows modeled emission factors to be transferred into various spreadsheet programs (e.g., Excel, Lotus 1-2-3). This format simplifies further data manipulation and is the preferred output format.

Figure 3-3 presents a portion of the output file generated from the Figure 3-2 sample input file. The values included in Figure 3-3 are strictly hypothetical results and should not be used in real-life applications. The 1996 and 1997 HC (total and by component), CO, and NO_x emission factors for each of the eight vehicle types are indicated in Figure 3-3. For example, the 1997 light duty gas vehicle (LDGV) emission factors for HC (selected as TOG in the input file), CO, and NO_x are 2.431, 16.951, and 1.511 grams per mile, respectively. Fleet average emission factors (assuming default vehicle registration distributions) have also been calculated. In Figure 3-3, the 1997 fleet average emission factors for HC, CO, and NO_x are 2.764, 20.037, and 2.418

grams per mile. Sections of the output file not included in Figure 3-3 contain emission factors for the years 1998 through 2000 as well as summaries of input file data.

3.4 Effect of Local Characteristics

As indicated previously, adjustment factors are widely used in emission factor models to correct for non-standard operating conditions. These non-standard operating conditions are the result of various area-specific characteristics. Section 3.4.1 will address regional characteristics, while Section 3.4.2 will discuss fleet characteristics. These sections will only provide an overview of the effects of these characteristics on motor vehicle emissions; specific details, as well as information concerning lesser characteristics, can be found in the MOBILE User's Guide.

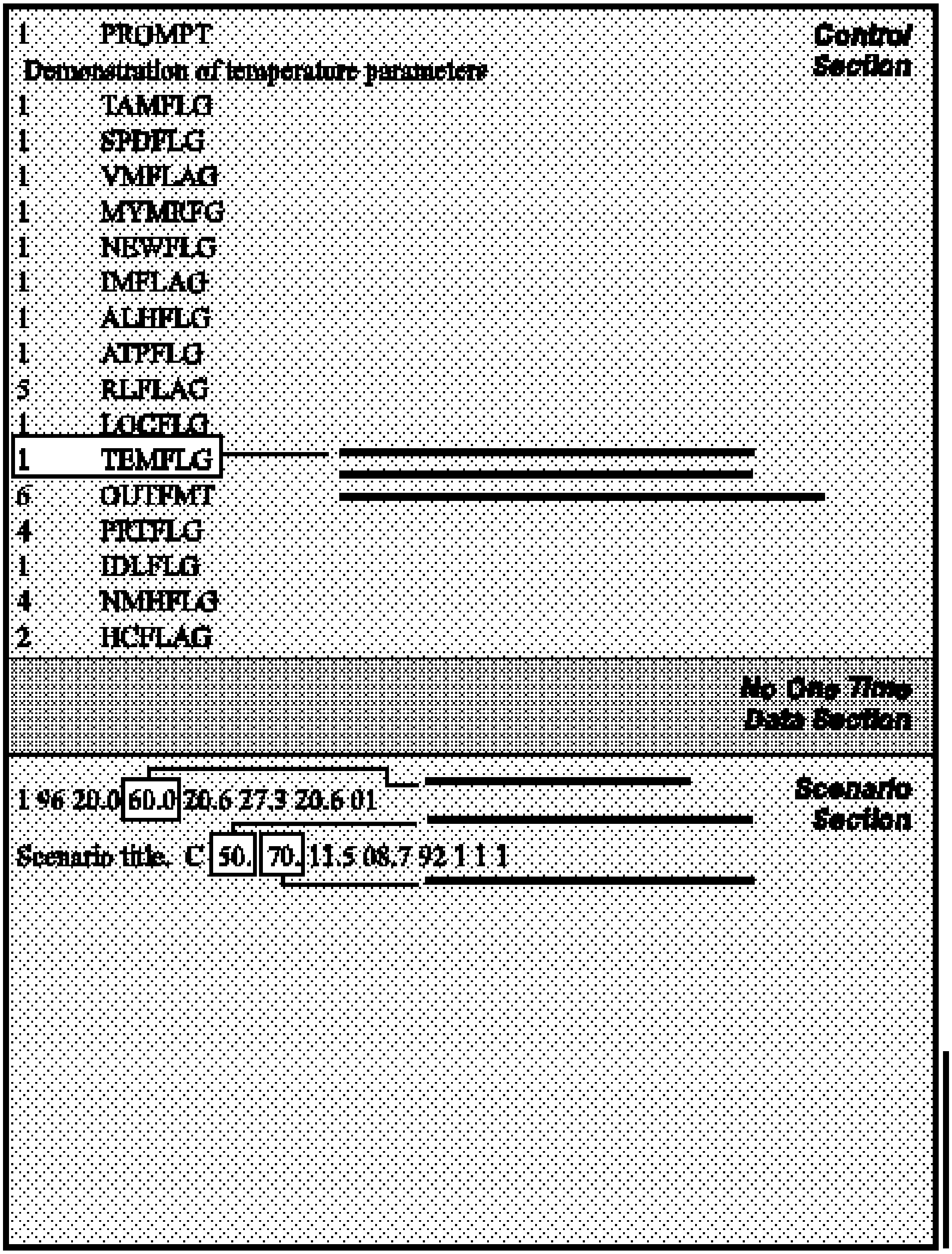
3.4.1 Regional Characteristics that Affect Emission Factors

Some of the regional characteristics that can effect motor vehicle emissions include physical characteristics (such as temperature or altitude), fuel characteristics, and regulatory programs (such as inspection and maintenance programs and anti-tampering programs). These are described below.

Temperature

Motor vehicle emissions (TOG, CO, and NO_x) are very dependent upon the surrounding air temperature. The standard operating temperature used in the determination of the MOBILE basic emission rates is 24 °C (75 °F); the modeling of emissions at any other temperature requires the use of temperature adjustment factors. In the MOBILE model, these temperature adjustment factors are determined by the temperature flag (TEMFLG) in the Control section, the minimum and maximum daily temperature in the local area parameter (LAP) record, and the ambient temperature in the scenario descriptive record. These data inputs are indicated on the sample MOBILE input file presented in Figure 3-4.

Depending upon the value chosen for TEMFLG, the adjustment factors for exhaust emissions, hot soak evaporative emissions, and resting and running loss emissions will be calculated using either the minimum and maximum daily temperature or ambient temperature. It is recommended that the minimum and maximum daily temperature option be used whenever possible. Regardless of the TEMFLG value, the adjustment factor for diurnal evaporative emissions will be calculated based on the minimum and maximum daily temperature. For some emission inventories, seasonal mobile source emissions are desirable. In these situations, a MOBILE run should be made for each season (spring, summer, fall, and winter) using average minimum and maximum daily temperature for each season.fects of high altitude should be considered carefully in regions such as Mexico City.



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1       TEMFLG
6       OUTFMT
4       PRTFLG
1       IDLFLG
4       NMHFLG
2       HCFLAG
1 96 20.0 60.0 20.6 27.3 20.6 01
Scenario title.  C 50. 70. 11.5 08.7 92 1 1 1
```

Figure 3-4. Sample Temperature Parameters in MOBILE

The temperature dependence of TOG (selected by setting the NMHFLG flag to “4”), CO, and NO_x emissions is shown in Figure 3-5, where the ambient temperature is varied and all other model parameters are held constant. From Figure 3-5, it is clear that TOG and CO emissions are greatly affected by ambient temperatures, while NO_x emissions are affected to a lesser degree.

Altitude

Another physical characteristic that has a significant effect on motor vehicle emissions is the altitude of the region. As altitude increases, the density of the ambient air decreases. The result of this decrease in air density is that vehicles calibrated to run at a stoichiometric air-to-fuel ratio will tend to run fuel-rich. This deviation from stoichiometry will result in additional pollutant emissions. Also, altitude can affect the mechanical efficiencies of motor vehicles, which in turn can change the amount of emissions. The effects of high altitude should be considered carefully in regions such as Mexico City.

Instead of using an adjustment factor to account for differences in altitude, the MOBILE model uses one set of BERs for low-altitude areas (representing conditions at approximately 150 meters above mean sea level) and another set of BERs for high-altitude areas (representing conditions at approximately 1,700 meters above mean sea level). The desired set of BERs is selected in the first data element of the scenario descriptive record (a “1” indicating low-altitude, and a “2” indicating high-altitude), as shown in Figure 3-6. The difference between low- and high-altitude emissions can be seen in the TOG, CO, and NO_x fleet average emission factors plotted in Figure 3-7, where all other model parameters are held constant. The TOG and CO fleet average emission factors at higher altitudes are approximately 15-20% higher than those at lower altitudes, while the NO_x fleet average emission factors decrease slightly.

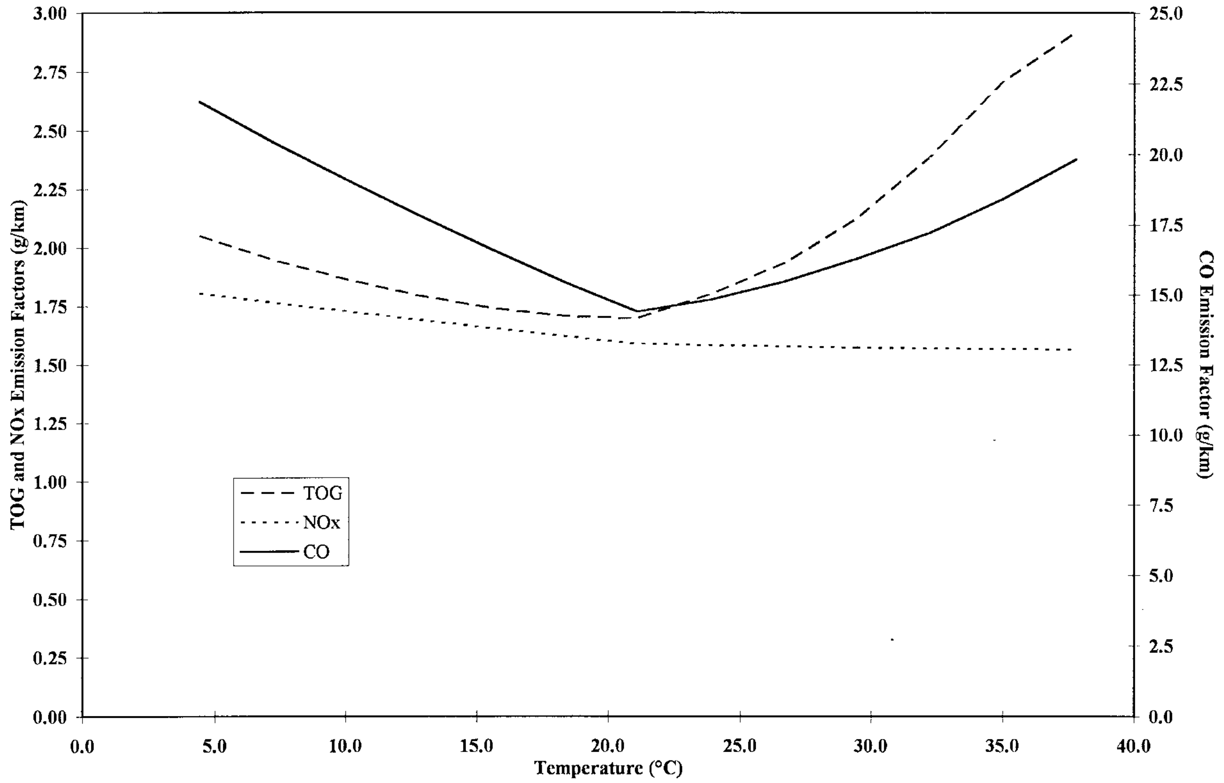
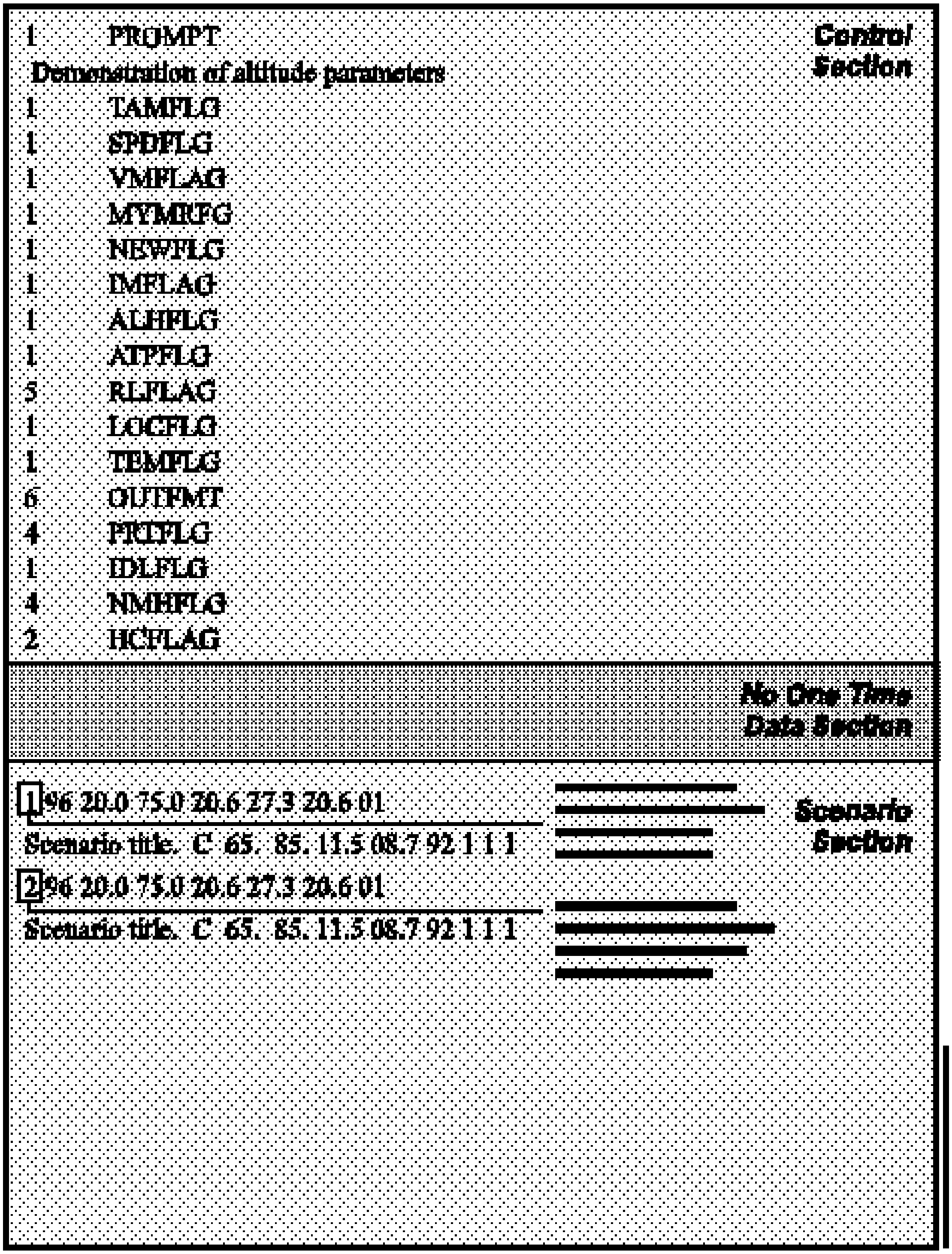


Figure 3-5. Fleet Average Emission Factors for TOG, CO, and NO_x with Varying Ambient Temperature



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1       TEMFLG
6       OUTFMT
4       PRTFLG
1       IDLFLG
4       NMHFLG
2       HCFLAG
1 96 20.0 75.0 20.6 27.3 20.6 01
Scenario title.  C  65.  85. 11.5 08.7 92 1 1 1
2 96 20.0 75.0 20.6 27.3 20.6 01
Scenario title.  C  65.  85. 11.5 08.7 92 1 1 1
```

Figure 3-6. Sample Altitude Parameters in MOBILE

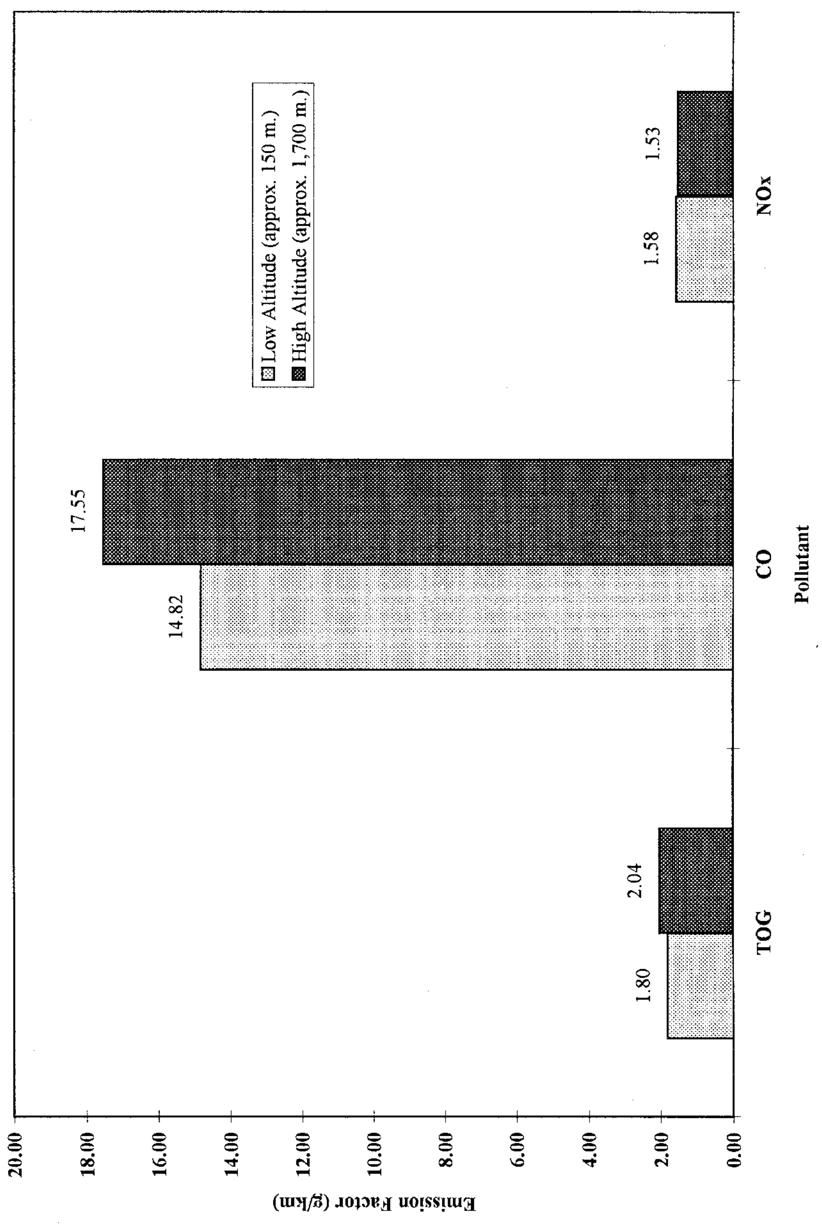
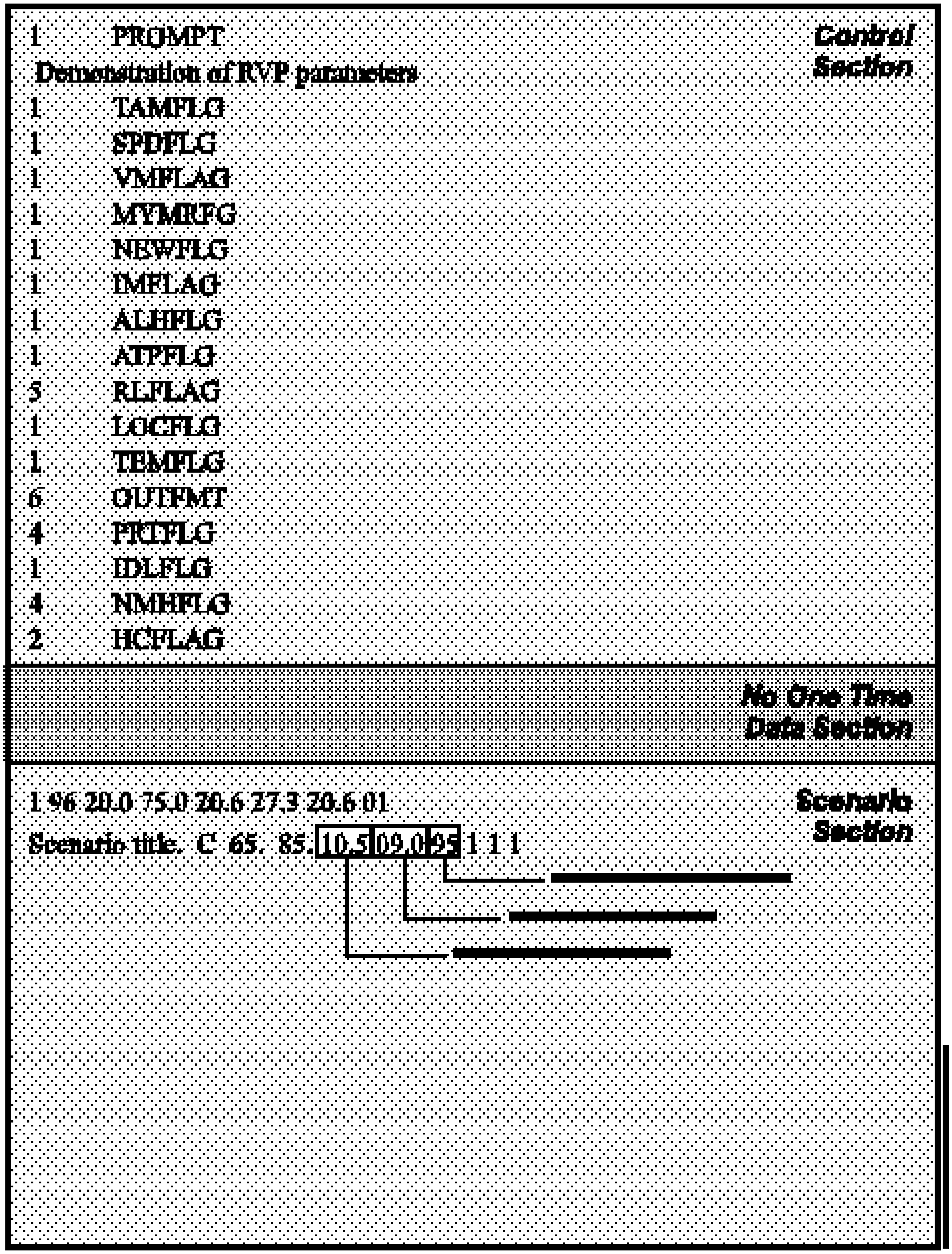


Figure 3-7. Fleet Average Emission Factors for TOG, CO, and NO_x at Low and High Altitude

Fuel Characteristics - RVP

Because motor vehicle emissions are the end result of the combustion and evaporation of gasoline and diesel fuel, fuel characteristics can significantly affect the amount of pollutants emitted. Fuel volatility, in particular, directly affects the amount of motor vehicle emissions. For the MOBILE model, as well as in many other applications, fuel volatility is expressed as a Reid vapor pressure (or RVP). The standard gasoline RVP used in the determination of basic emission rates for the MOBILE model is 9.0 pounds per square inch (psi); the use of any other gasoline RVP requires the use of RVP adjustment factors. Current fuel specifications require a fuel RVP of 6.5 to 8.5 in Mexico City and a fuel RVP of 6.5 to 9.5 in all other parts of Mexico. It is recommended that the area-specific RVP be requested from PEMEX. If this information is unavailable, then the upper end value of these fuel specification ranges should be used as the MOBILE input value. Because diesel has a very low volatility resulting in negligible evaporative emissions, a diesel RVP value is not used in MOBILE. The RVP adjustment factors are determined by three data inputs in the LAP record: Period 1 RVP (the RVP before a volatility control program takes effect), Period 2 RVP (the RVP after a volatility control program takes effect), and Period 2 start year (the year in which a volatility control program is implemented). Using these three data inputs, the MOBILE model can model an RVP control program or any other RVP-related change. If no volatility control program is to be modeled, then the Period 1 RVP and Period 2 RVP will be equal. These data inputs are indicated on the sample MOBILE input file presented in Figure 3-8.

In general, reduced volatility (or lower RVP values) will result in lower emissions. The dependence of emissions upon fuel RVP is shown in Figure 3-9, where the gasoline RVP is varied from 8.0 to 13.0 psi and all other model parameters are held constant. In Figure 3-9, the relationship between lower gasoline RVP and lower TOG and CO emissions is quite evident.



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1      ATPFLG
5      RLFLAG
1      LOCFLG
1      TEMFLG
6      OUTFMT
4      PRTFLG
1      IDLFLG
4      NMHFLG
2      HCFLAG

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Scenario title.  C  65.  85.10.509.095 1 1 1
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Figure 3-8. Sample Gasoline RVP Parameters in MOBILE

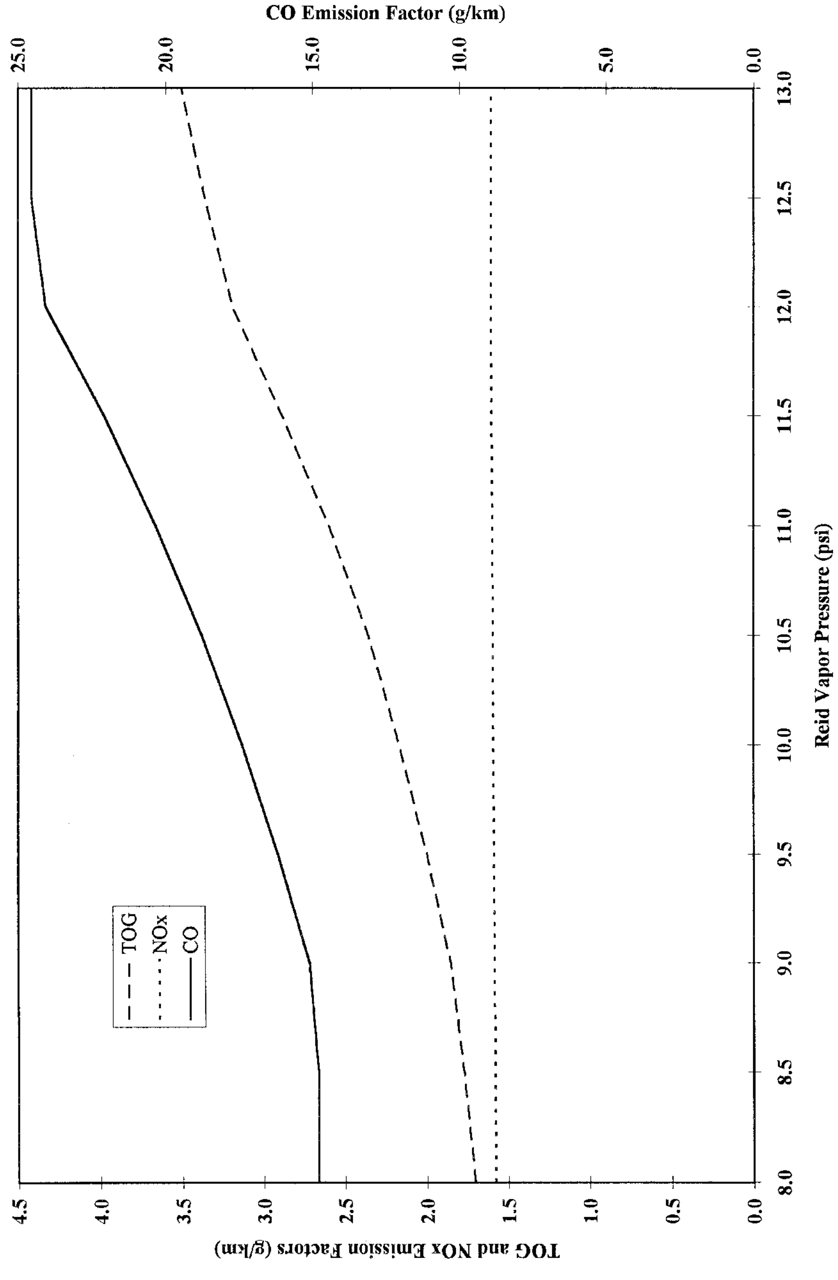


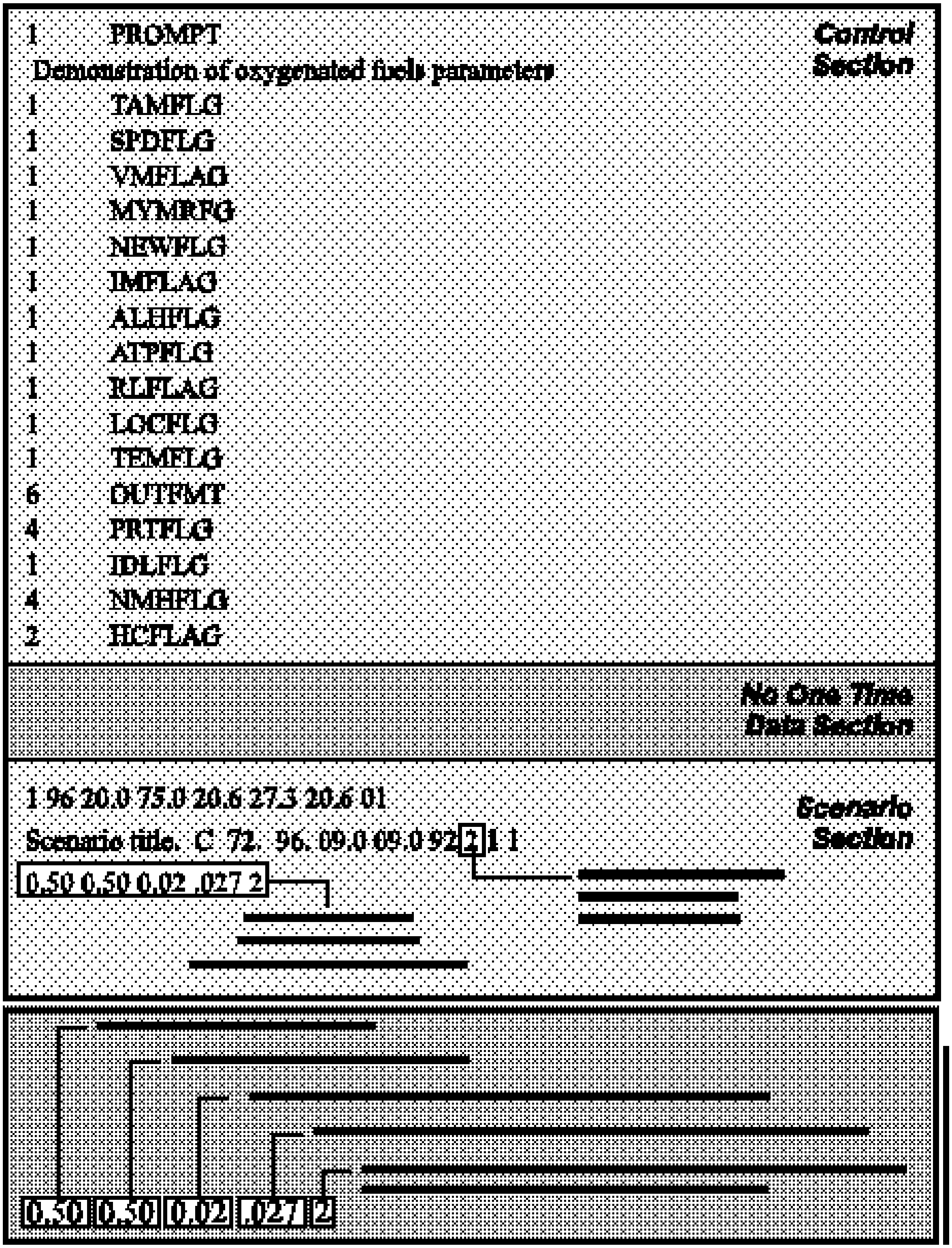
Figure 3-9. Fleet Average Emission Factors for TOG, CO, and NO_x with Varying Reid Vapor Pressure

Fuel Characteristics - Oxygenated Fuels

Another fuel characteristic that can affect the amount of pollutants emitted by motor vehicles is the introduction of oxygenated fuels (either gasoline/alcohol blends or gasoline/ether blends) into the overall fuel mix. Oxygenated fuels are typically introduced to reduce CO emissions. The higher oxygen content of oxygenated fuels improves combustion efficiency, thereby reducing CO emissions. The adjustment for oxygenated fuels is controlled by the oxygenated fuel flag (OXYFLG) in the LAP record and an oxygenated fuels descriptive record which immediately follows the LAP record. The oxygenated fuels record includes market shares and oxygen contents of ether blend and alcohol blend fuels. These data inputs are indicated on the sample MOBILE input file presented in Figure 3-10.

The effects of oxygenated fuels can be seen in Figure 3-11. The emission factors plotted in Figure 3-11 represent a somewhat unrealistic scenario (i.e., 50% of all fuel used by motor vehicles is an alcohol blend with the other 50% being an ether blend). A more typical scenario would probably have a smaller amount of oxygenated fuel sales, but the overall effect of oxygenated fuel, namely significant reductions in CO emissions and virtually unchanged TOG and NO_x emissions, can be seen in this example.

In addition to the fuel characteristics described above, reformulated gasoline (RFG) may be introduced into Mexico in the future as an emissions control measure. Simply stated, RFG is similar to conventional gasoline, except that several fuel characteristics (e.g., RVP, benzene content, aromatics content, oxygen content, distillation points) have been adjusted. Because emissions are affected differently by changes in each of these fuel characteristics, the estimation of emissions from RFG is not a simple task. MOBILE5a does have an RFG flag; however, its estimation methodology is overly simplistic and does not accurately account for all of the effects of RFG. Information on the existing RFG flag can be found in the MOBILE5a User’s Guide. MOBILE6 (to be released in mid-1998) is expected to provide a more complete representation of the effects of RFG. If Mexico plans to implement



```
1       PROMPT
 Demonstration of oxygenated fuels parameters
1       TAMFLG
1       SPDFLG
1       VMFLAG
1       MYMRFG
1       NEWFLG
1       IMFLAG
1       ALHFLG
1       ATPFLG
1       RLFLAG
1       LOCFLG
1       TEMFLG
6       OUTFMT
4       PRTFLG
1       IDLFLG
4       NMHFLG
2       HCFLAG
1 96 20.0 75.0 20.6 27.3 20.6 01
Scenario title.  C  72.  96. 09.0 09.0 92 2 1 1
0.50 0.50 0.02 .027 2
```

Figure 3-10. Sample Oxygenated Fuel Parameters in MOBILE

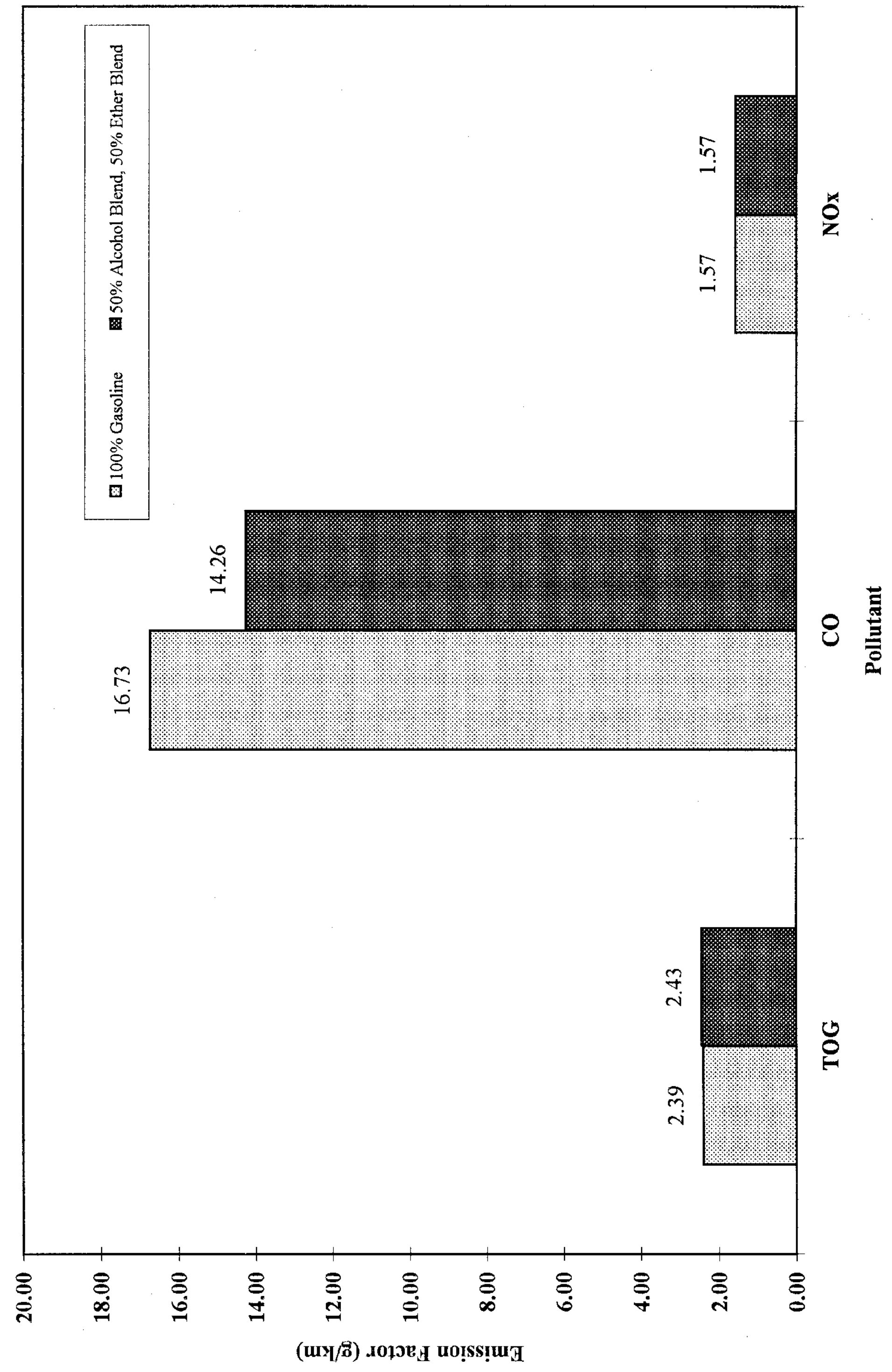


Figure 3-11. Fleet Average Emission Factors for TOG, CO, and NO_x With and Without Oxygentated Fuels

RFG as an emission control strategy in the future, then further detailed examination of the MOBILE models and other research is warranted.

In Mexico, fuel property data is compiled by Petróleos Mexicanos (PEMEX). Government agencies can request data from:

Unidad Central de Coordinación Operativa de PEMEX
Torre Ejecutiva Piso 40
Marina Nacional No. 329
Col. Huasteca
Telephone: 250-55-96, 531-97-00
Fax: 203-55-66

Inspection and Maintenance (I/M) Programs

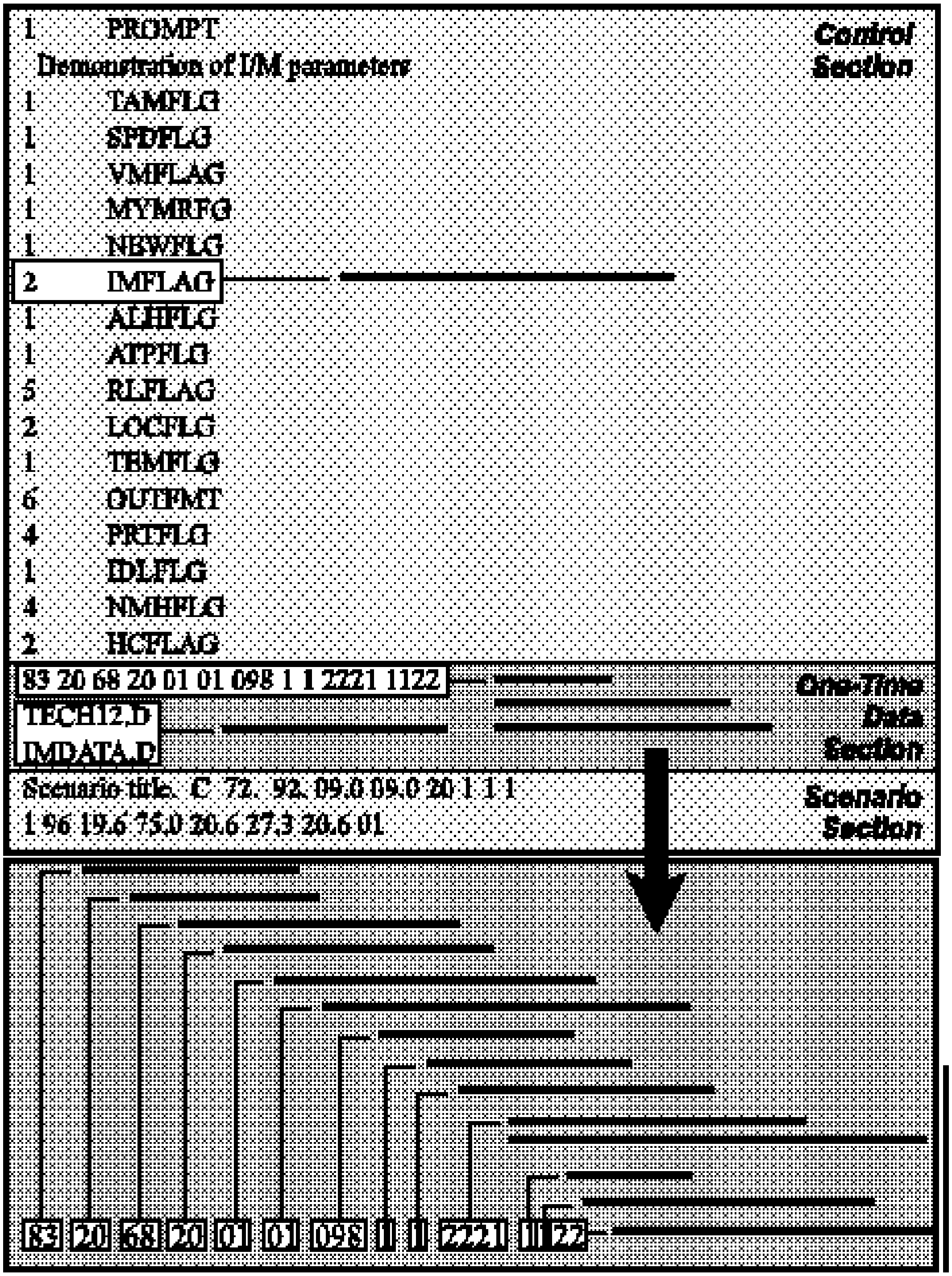
To reduce motor vehicle emissions, regional regulatory programs are often implemented. The most common regulatory program is an inspection and maintenance (I/M) program. As a vehicle's mileage increases, exhaust and evaporative emissions also increase due to the gradual degradation of the vehicle's emission control system. The purpose of I/M programs is to minimize these excess emissions by using emissions testing performed at regular time intervals. Emissions testing is sometimes used as a requirement for vehicle registration. Those vehicles whose emissions exceed established emission standards are required to be repaired. As explained in Section 3.2, BER data do not include the effects of I/M programs. Adjustment factors, based upon I/M-related input parameters, are used to adjust BER data.

Because the specific requirements for I/M programs vary from region to region, there are many possible I/M program variations. The I/M flag (IMFLAG) located in the Control section allows the effects of zero, one, or two I/M programs to be modeled. Although single I/M programs represent the most common situation, sometimes two I/M programs (e.g., a conventional program for some earlier model years and an "enhanced" program for later model years) are to be modeled concurrently. Each I/M program that is to be modeled requires an I/M program descriptive record which is located in the One-Time Data section. The I/M program descriptive record includes the following parameters:

- I/M program start year;
- Stringency level, or the percentage of vehicles failing the first test;
- First and last model years subject to I/M program;
- Waiver rates, or the percentage of vehicles granted an exemption from repairs;
- Compliance rate, or the percentage of the overall subject vehicle population participating in the program;
- Program type (inspection only, inspection and repair [manual], or inspection and repair [computerized]);
- Frequency of inspection (annual or biennial);
- Types of gasoline-fueled vehicles subject to the I/M program;
- Test type (idle, 2500/idle, loaded/idle, or transient); and
- Use of non-default emission cutpoints.

All of these data inputs are indicated on the sample MOBILE input file presented in Figure 3-12.

The effects of I/M programs are shown in Figure 3-13. The fleet average emission factors plotted in Figure 3-13 represent three typical I/M scenarios: no I/M program, one I/M program, and two I/M programs. The parameters for each of these scenarios do not represent the most stringent I/M programs possible, but instead represent typical I/M programs. Obviously, actual I/M programs will use different parameters that will alter the estimated emission factors somewhat, but the overall emissions reduction trend from I/M programs can be seen from this example. This example also demonstrates that some of the benefit derived from I/M programs is realized only over time. Currently, I/M programs have been implemented in Mexico City, Monterrey, and Ciudad Juárez.



```
1       PROMPT
 Demonstration of I/M parameters
1       TAMFLG
1       SPDFLG
1       VMFLAG
1       MYMRFG
1       NEWFLG
2       IMFLAG
1       ALHFLG
1       ATPFLG
5       RLFLAG
2       LOCFLG
1       TEMFLG
6       OUTFMT
4       PRTFLG
1       IDLFLG
4       NMHFLG
2       HCFLAG
83 20 68 20 01 01 098 1 1 2221 1122
TECH12.D
IMDATA.D
Scenario title.  C  72.  92. 09.0 09.0 20 1 1 1
1 96 19.6 75.0 20.6 27.3 20.6 01
```

Figure 3-12. Sample I/M Parameters in MOBILE

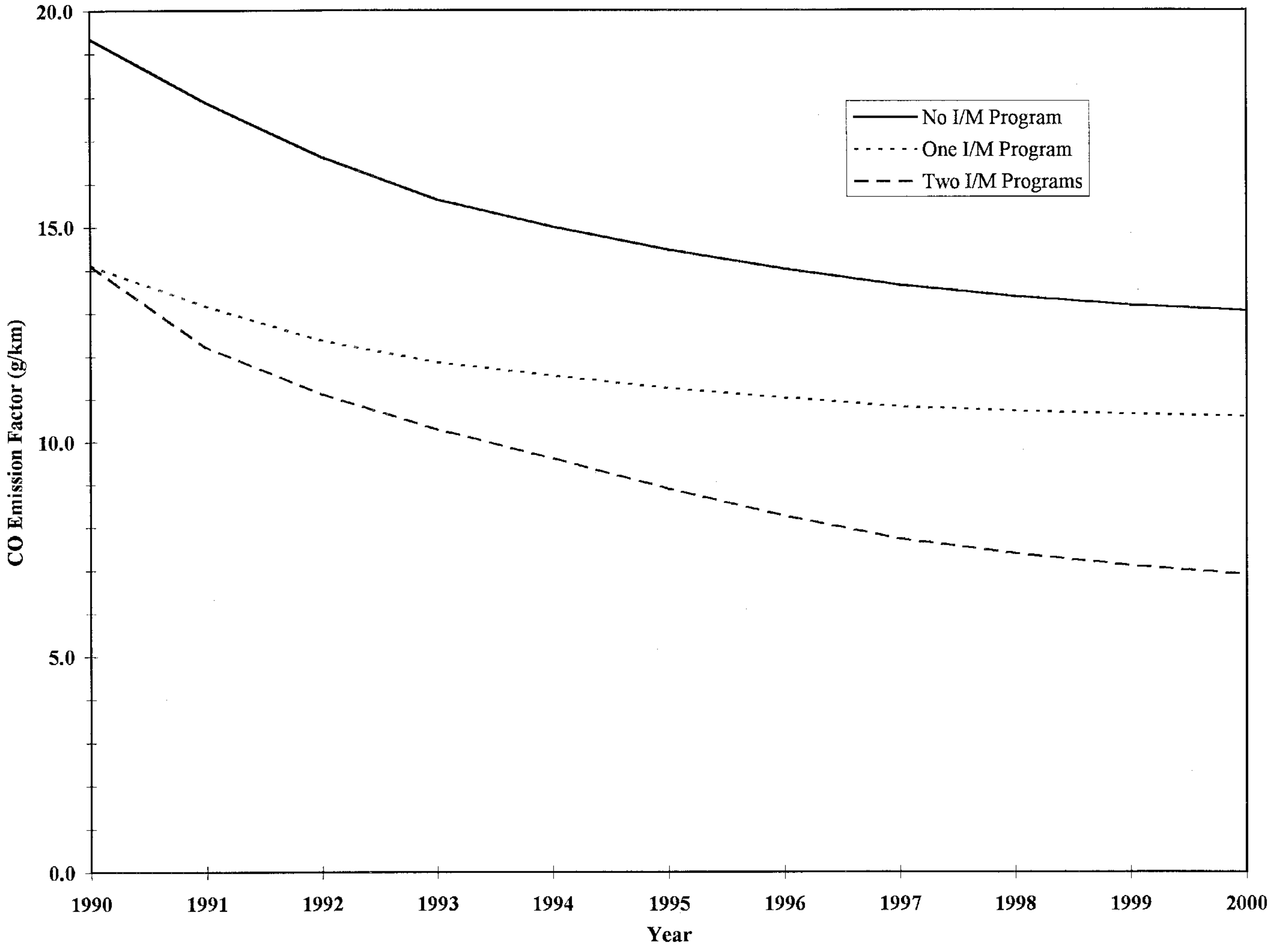


Figure 3-13. Light Duty Gasoline Vehicle CO Emission Factors Under Three Different I/M Scenarios

Anti-Tampering Programs

Another type of regulatory program that can be implemented is an anti-tampering program (ATP). Tampering refers to vehicle misfueling, removal or disablement of catalytic converters, or otherwise reducing the efficiency of a vehicle's emission control system. The reasons for tampering are varied, but the overall effect is to cancel out some of the emissions reductions achieved through I/M programs or other technological advances. Tampering can be intentional or unintentional. As the name suggests, ATPs are implemented to counter the effects of tampering. ATPs consist of inspections of various vehicle components that are used to control emissions. These vehicle components include the catalytic converter, fuel inlet restrictor, gas cap, and others. For purposes of convenience, ATP inspections are typically performed in conjunction with periodic I/M testing.

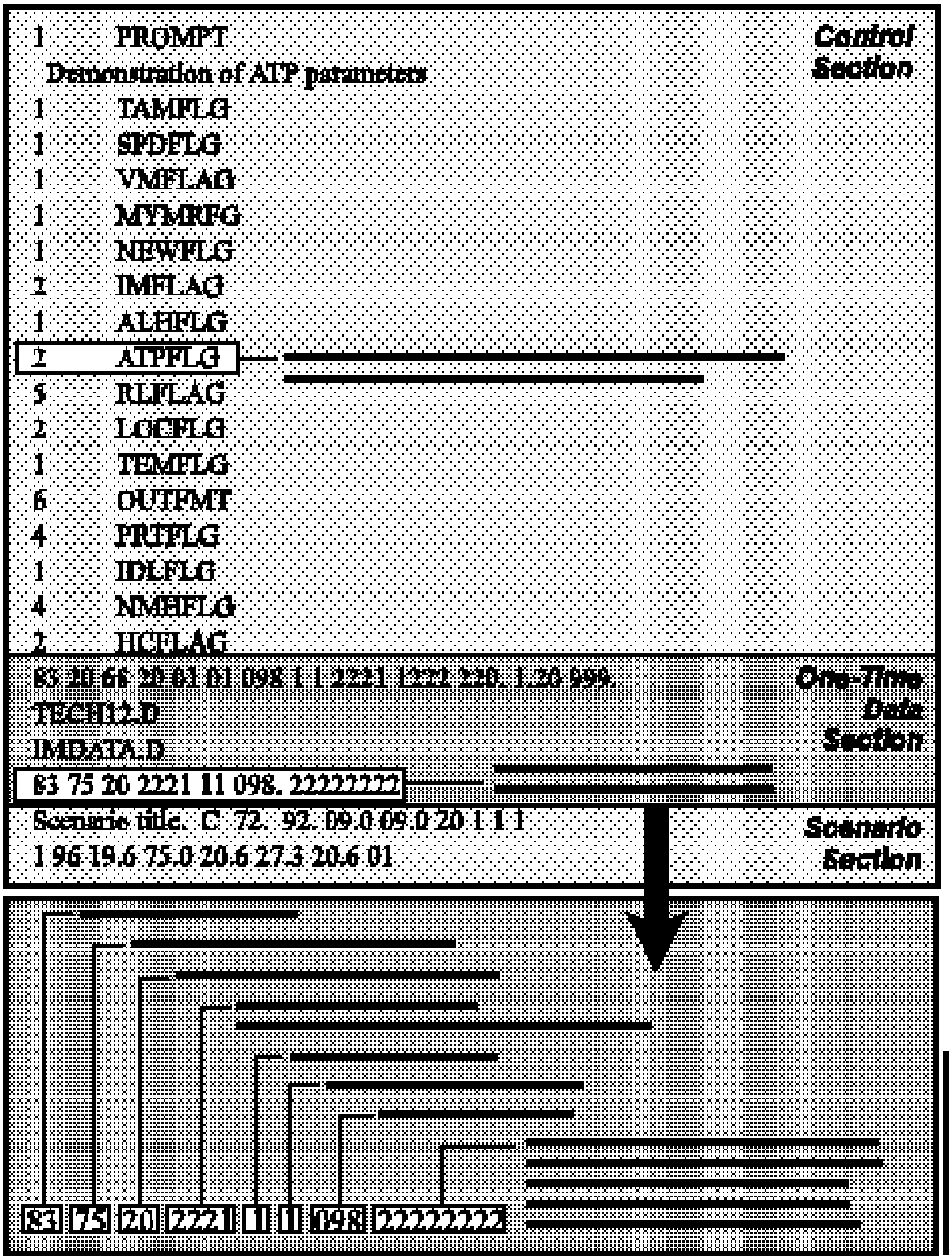
The necessity of an ATP is dependent upon the actual level of tampering within a specific region. In order to quantify actual tampering levels, a tampering survey should be performed. If tampering levels are found to be low, then an ATP might not be the appropriate regulatory program to reduce motor vehicle emissions. However, if tampering levels are determined to be high, then the implementation of an ATP might provide significant emission reductions. For example, previous studies have indicated that over 80 percent of Mexican vehicles with catalysts in Ciudad Juárez have been misfueled with leaded fuel, thereby "poisoning" the catalyst and eliminating virtually all possible emissions reductions.

Overall default tampering levels for U.S. vehicles are currently encoded into the MOBILE model. If tampering survey results indicate significantly different tampering levels in Mexico, then alternative tampering rates can be inserted into the MOBILE model by adjusting the tampering flag (TAMFLG) located in the Control section. For instance, a 1990 tampering rate survey of Ciudad Juárez vehicles was used in the development of MOBILE-Juárez. Additional details concerning the format of these alternative tampering rates can be found in the MOBILE User's Guide (U.S EPA, 1994).

If regional tampering levels warrant the implementation of an ATP, the effects of the ATP can be modeled using the MOBILE model. Much like I/M programs, there are many different possible ATPs that can be implemented. Consequently, there are many parameters that must be specified in order to define a particular ATP. The ATP flag (ATPFLG) located in the Control section allows the effects of an ATP to be modeled. In addition to ATPs, certain values of the ATPFLG allow functional purge and pressure checks of the evaporative emission control system to be modeled. These tests are not described in this document; additional information can be found in the MOBILE User's Guide. Each ATP that is to be modeled requires an ATP descriptive record which is located in the One-Time Data section. The ATP descriptive record includes the following parameters:

- ATP start year;
- First and last model years subject to ATP;
- Types of gasoline-fueled vehicles subject to ATP;
- Program type (inspection only or inspection and repair);
- Frequency of inspection (annual or biennial);
- Compliance rate; and
- Eight types of ATP inspections (Air pump system, catalytic converter, fuel inlet restrictor, tailpipe lead detection, exhaust gas recirculation [EGR] system, evaporative control system, positive crankcase ventilation [PCV] system, and gas cap).

All of these data inputs are indicated on the sample MOBILE input file presented in Figure 3-14. different result and emission reductions. However, the differential reduction of emissions due to an ATP added to an I/M program can be seen in this example.



```
1        PROMPT
 Demonstration of ATP parameters
1        TAMFLG
1        SPDFLG
1        VMFLAG
1        MYMRFG
1        NEWFLG
2        IMFLAG
1        ALHFLG
2        ATPFLG
5        RLFLAG
2        LOCFLG
1        TEMFLG
6        OUTFMT
4        PRTFLG
1        IDLFLG
4        NMHFLG
2        HCFLAG
85 20 68 20 01 01 098 1 1 2221 1222 220. 1.20 999.
TECH12.D
IMDATA.D
83 75 20 2221 11 098. 22222222
Scenario title.  C  72.  92. 09.0 09.0 20 1 1 1
1 96 19.6 75.0 20.6 27.3 20.6 01
```

Figure 3-14. Sample ATP Parameters in MOBILE

The effects of an ATP are shown in Figure 3-15. The fleet average emission factors plotted in Figure 3-15 represent a typical I/M program with and without an ATP. The ATP used in Figure 3-15 assumes that all eight equipment inspections listed above are performed. Obviously, ATPs characterized by different ATP input parameters will have different result and emission reductions. However, the differential reduction of emissions due to an ATP added to an I/M program can be seen in this example.

3.4.2 Fleet Characteristics

In order to use an emission factor model, it is necessary to estimate the travel characteristics of each vehicle type. These travel characteristics include:

- **Vehicle speed.** The average vehicle speed by vehicle class (and preferably by road type) must be determined because emission factors are affected by vehicle speed.
- **Vehicle class VKT distributions (or mixes).** Overall VKT data must be distinguished by vehicle class in order to assign appropriate emission factors.
- **Mileage accumulation rates and registration distributions (fraction of total registered vehicles) for each model year in a vehicle class.** This is used to determine the travel fraction of each model year within a vehicle class.

Vehicle Speed

Average vehicle speed estimates are an important data element for determining the appropriate emission factors for on-road motor vehicle emission inventories. In the MOBILE model, emission factors represent travel at an average speed. The emission factors are developed from test cycles where the vehicle speed is not constant but is varied around an

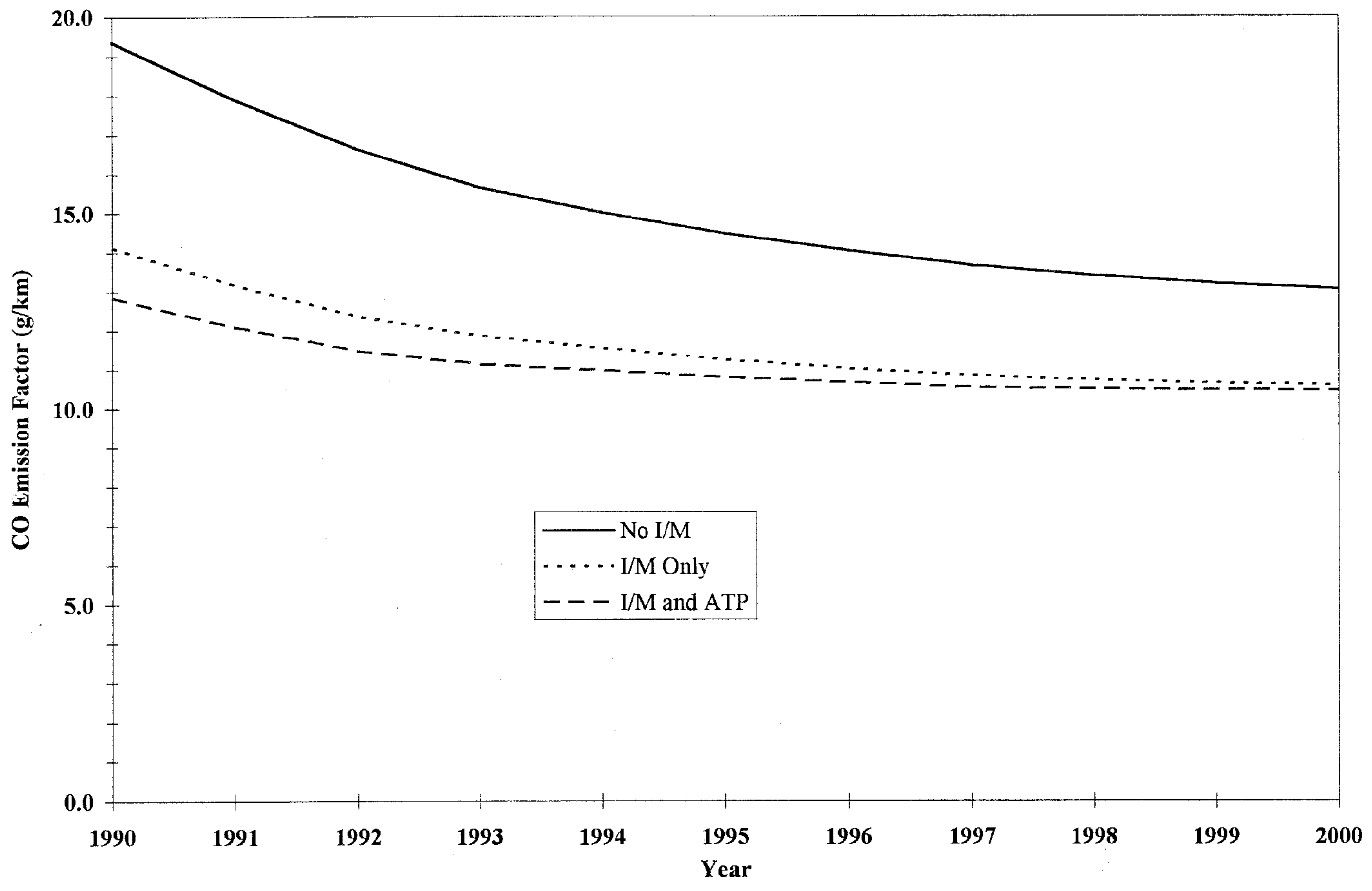


Figure 3-15. Light Duty Gasoline Vehicle CO Emission Factors Under Three Different ATP Scenarios

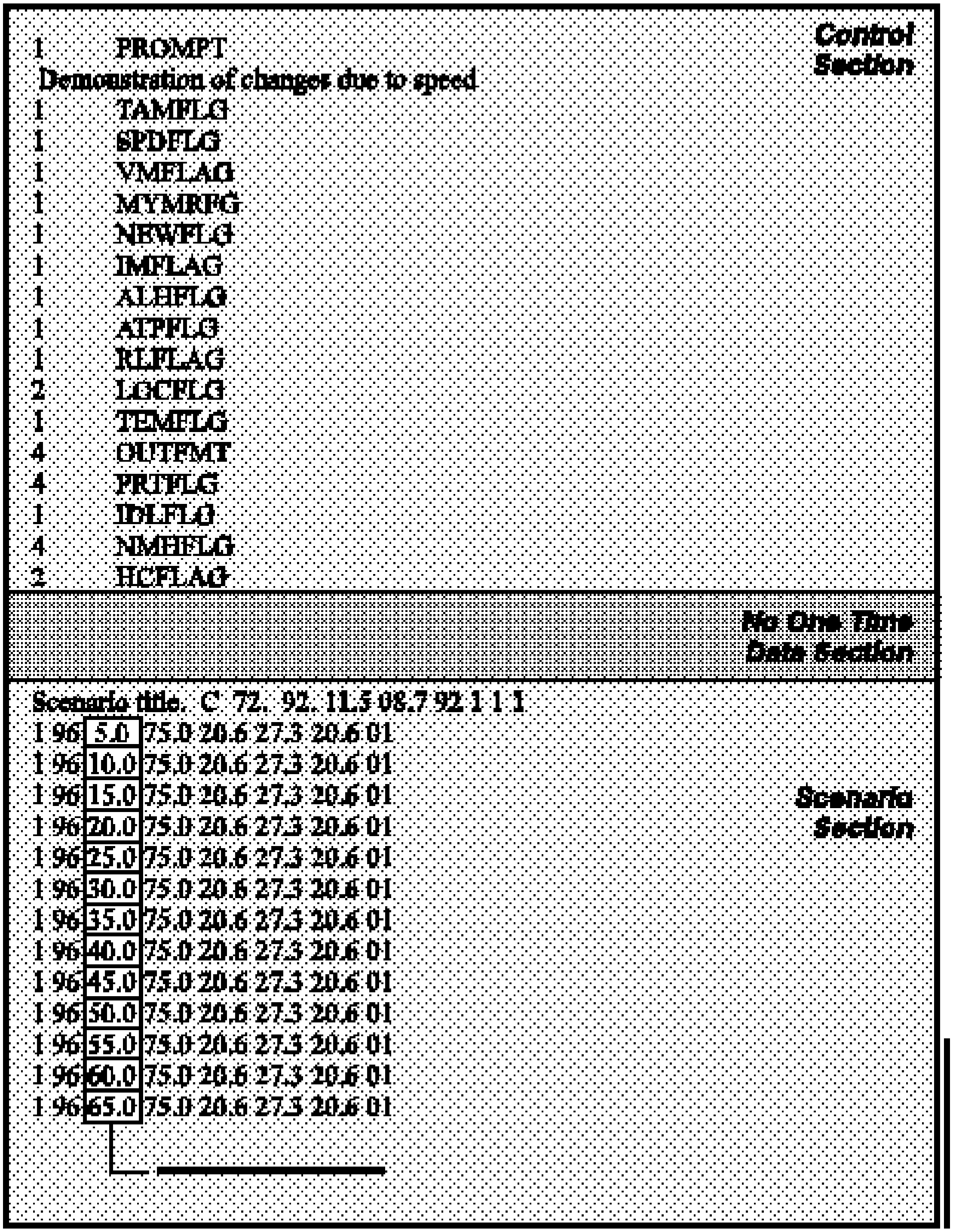
average. Consequently, the goal in developing speed estimates is to determine average vehicle speeds rather than instantaneous speeds. As mentioned in Section 3.2, a speed adjustment factor is applied to the basic emission factors to account for the variability of emissions at different speeds. Average speeds are entered into the scenario descriptive record of the MOBILE input file. These average speeds are indicated on the sample MOBILE input file presented in Figure 3-16. Figure 3-17 presents example emission factors versus average vehicle speed. Note that the emission rate changes significantly with variations in speed, particularly at low and high speeds. Consequently, knowledge of vehicle speeds is important for producing accurate emission inventories.

Estimating average vehicle speeds can be a challenging portion of the inventory data collection effort because many factors can affect speeds on a roadway at any given time. The key factors include:

- **Road type and characteristics -** Speeds vary significantly by road type. For example, freeways and expressways will have higher average speeds than boulevards and arterials, which have higher average speeds than local roads. Road conditions will also have an impact, with paved roads having higher average speeds than unpaved roads.

- **Road location -** The area surrounding a road impacts the average speeds. For example, urban expressways usually have lower average speeds than rural expressways due to higher levels of traffic congestion. In general, for two roads of the same type, average speeds in urban roads are lower than for rural roads.

- **Time of day and season -** In urban areas, variations in traffic congestion will significantly affect the average speeds on a road. Each road has a free-flow speed that is attained when congestion is low. As congestion increases, average speeds are reduced. Seasonal variations can occur in some areas as changes in weather alter road conditions and the average speeds.



```
1       PROMPT
Demonstration of changes due to speed
1       TAMFLG
1       SPDFLG
1       VMFLAG
1       MYMRFG
1       NEWFLG
1       IMFLAG
1       ALHFLG
1       ATPFLG
1       RLFLAG
2       LOCFLG
1       TEMFLG
4       OUTFMT
4       PRTFLG
1       IDLFLG
4       NMHFLG
2       HCFLAG
Scenario title. C 72. 92. 11.5 08.7 92 1 1 1
1 96  5.0 75.0 20.6 27.3 20.6 01
1 96 10.0 75.0 20.6 27.3 20.6 01
1 96 15.0 75.0 20.6 27.3 20.6 01
1 96 20.0 75.0 20.6 27.3 20.6 01
1 96 25.0 75.0 20.6 27.3 20.6 01
1 96 30.0 75.0 20.6 27.3 20.6 01
1 96 35.0 75.0 20.6 27.3 20.6 01
1 96 40.0 75.0 20.6 27.3 20.6 01
1 96 45.0 75.0 20.6 27.3 20.6 01
1 96 50.0 75.0 20.6 27.3 20.6 01
1 96 55.0 75.0 20.6 27.3 20.6 01
1 96 60.0 75.0 20.6 27.3 20.6 01
1 96 65.0 75.0 20.6 27.3 20.6 01
```

Figure 3-16. Sample Average Speeds in MOBILE

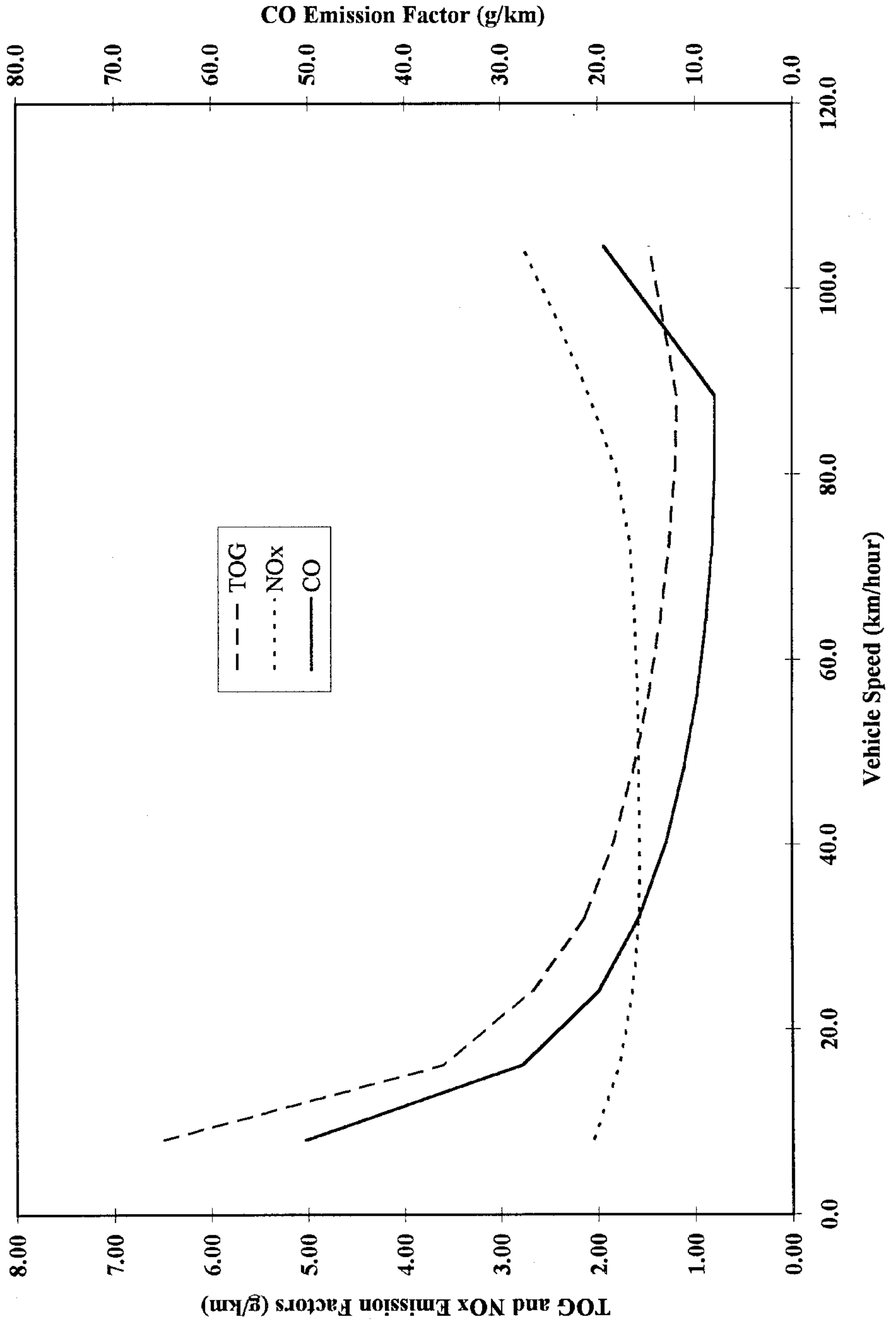


Figure 3-17. Fleet Average Emission Factors for TOG, CO, and NO_x with Varying Vehicle Speed

- **Vehicle type** - Average speeds are often different between different vehicle types. For example, passenger cars and light trucks often have higher speeds than heavy-duty trucks and buses. This is particularly true in urban environments involving stop-and-go traffic.

A variety of options are available for developing speed estimates. Many of these techniques are also useful for collecting vehicle travel information. Hence, if an effort is to be made to determine vehicle travel characteristics in a region, vehicle speed data can also be collected as part of the same study. More detailed information on speed data collection studies is available from the Institute of Transportation Engineers (ITE, 1994).

When such detailed speed estimates are not required, or not available, the goal is to divide VKT into appropriate average speed groupings. One common set of groupings is to classify VKT by road type (expressway, arterials, collector roads, and local roads) and area type (urban and rural), if sufficient data are available. One average speed is assigned for each class of road type and area type, based on survey data or other data sources. This classification assigns the same speed to all vehicle types and to all time periods of the day. Other classifications may be preferable depending upon the level of data available. For example, speed data could be collected as part of an instrumented vehicle study (described below). In this case, the amount of time spent at specific speeds would be known for individual vehicles. While such a study would not define speeds on specific roads, the range of speeds could be divided into groups and the amount of time spent within each group could be calculated.

For initial regional inventories when detailed speed data are not yet available, posted speed limits can be used as a first approximation. Posted speed limits, however, may not represent average vehicle speed under free-flowing conditions where vehicles often exceed posted speed limits. Conversely, areas with heavy congestion, traffic signals, or other intersection controls may have significantly lower average speeds than posted speed limits. These initial estimates can be supplemented with speed surveys collected from a sample of the roads in the inventory region. Speed surveys utilize a variety of measurement techniques.

These include the following:

- **Pneumatic traffic counters** - Pneumatic tubes are placed across traffic lanes and are connected to recorders, which time-stamp the passage of vehicles. These are commonly used to collect traffic flow data as part of traffic management studies. Multiple counters can also be used to measure vehicle speeds. However, this method only measures speeds at a defined point, not average speeds along a roadway.

- **Radar gun studies** - Similar to the pneumatic tube method, radar is used to measure instantaneous vehicle speeds. The radar can be operated in a manned or unmanned mode.

- **Observer or video studies** - Two observers or video cameras are placed at different locations a measured distance apart. A random selection of vehicles are selected and the time they pass each location is recorded. The distance between the locations is divided by the difference in the time marks to estimate average speed.

- **Floating car studies** - An observer car selects vehicles at random and follows the vehicle for a set period of time to measure their speed. In a similar method designed to measure the median speed, the observer car travels at a set speed and notes the fraction of vehicles being passed and the fraction of vehicles passing the observer car.

- **Instrumented car studies** - A random selection of vehicles are procured from the vehicle population. These vehicles are fitted with automated speed recorders which record the vehicle speed at regular intervals (i.e., once per second). The vehicles are released to the owner and returned after a period of operation, perhaps one week. The recorders are removed and the speed data are downloaded. The program can also include diaries to be completed by the vehicle owners where they record their driving activity during the survey period. This method does not provide information on speeds for specific locations, but can be used to estimate region-wide speed distributions.

VKT Mixes

The VKT mix describes the distribution of the total fleet VKT by each vehicle class. When estimating motor vehicle emissions, total VKT in a region or on an individual road is determined first. Then the VKT mix is used to disaggregate the total VKT into different vehicle classes to assist in calculating emissions. The VKT mix can be estimated if vehicle populations and mileage accumulation rates for each vehicle class are known. Both parameters are necessary because different vehicle classes tend to be driven at different rates. For example, commercial heavy-duty trucks generally have higher mileage accumulation rates than passenger cars. The publication *Techniques for Estimating MOBILE2 Variables* (EEA, 1980) outlines general methods for calculating the VKT mix.

If the vehicle populations and mileage accumulation rates are not available, then the next option is to estimate VKT mix from local surveys. In the survey method, observers are stationed at a number of locations in the inventory region. The observers classify a random sample of cars passing the location based on their vehicle class. Alternatively, photographs of vehicles and/or their license plates can be taken for later classification to distinguish fuel type (gasoline versus diesel). This technique provides an estimate of the VKT mix since the number of vehicles in a class passing a location should be proportional to the overall VKT contribution for that class. This data collection method was used to estimate the VKT mix for the 1993 Ciudad Juárez inventory (TTI, 1994).

The MOBILE model vehicle classes coincide with U.S. vehicle emission standard classifications. Fortunately, Mexico vehicle emission standards are also set up in similar classifications to the U.S., which simplifies the use of the existing MOBILE vehicle classes. A comparison of the Mexico new vehicle emission standard classifications and the MOBILE model vehicle classes is shown in Figure 3-18. Mexico has established new vehicle emission standards for six vehicle classes covering passenger cars, light-duty trucks, heavy-duty trucks, and buses. These classes map to five of the MOBILE vehicle classes. There are also other vehicles present in the Mexico fleet for which no new vehicle emission standards have been established, including light-duty diesel-powered cars and trucks, and gasoline-powered motorcycles. In addition to these new vehicle emission standards, Mexico has also established “in-use” vehicle emission standards, which are described in Section 1.2. Figure 3-19 shows an example distributions of VKT activity among the eight MOBILE classes from motor vehicle inventories in Monterrey and Ciudad Juárez. While the distribution of activity between the vehicle classes will vary, for most regions the activity is dominated by light-duty vehicles and light-duty trucks. Light-duty diesel-powered cars and trucks, and gasoline-powered motorcycles are present in the fleet, but as shown in Figure 3-19, they collectively constitute less than 2 percent of the total fleet VKT activity.

Registration Distributions

Registration distributions give the fraction of vehicles in a particular model year relative to the overall vehicle class population. Some uncertainty exists because the overall vehicle population includes both registered and unregistered vehicles, while any registration distribution, by definition, only includes registered vehicles. The registration distribution and mileage accumulation rates are used together to calculate the travel fraction in MOBILE. The travel fraction is the portion of VKT accumulated by one model year of vehicles in a vehicle class relative to the total VKT for the entire vehicle class. This calculation is performed using the following equation:

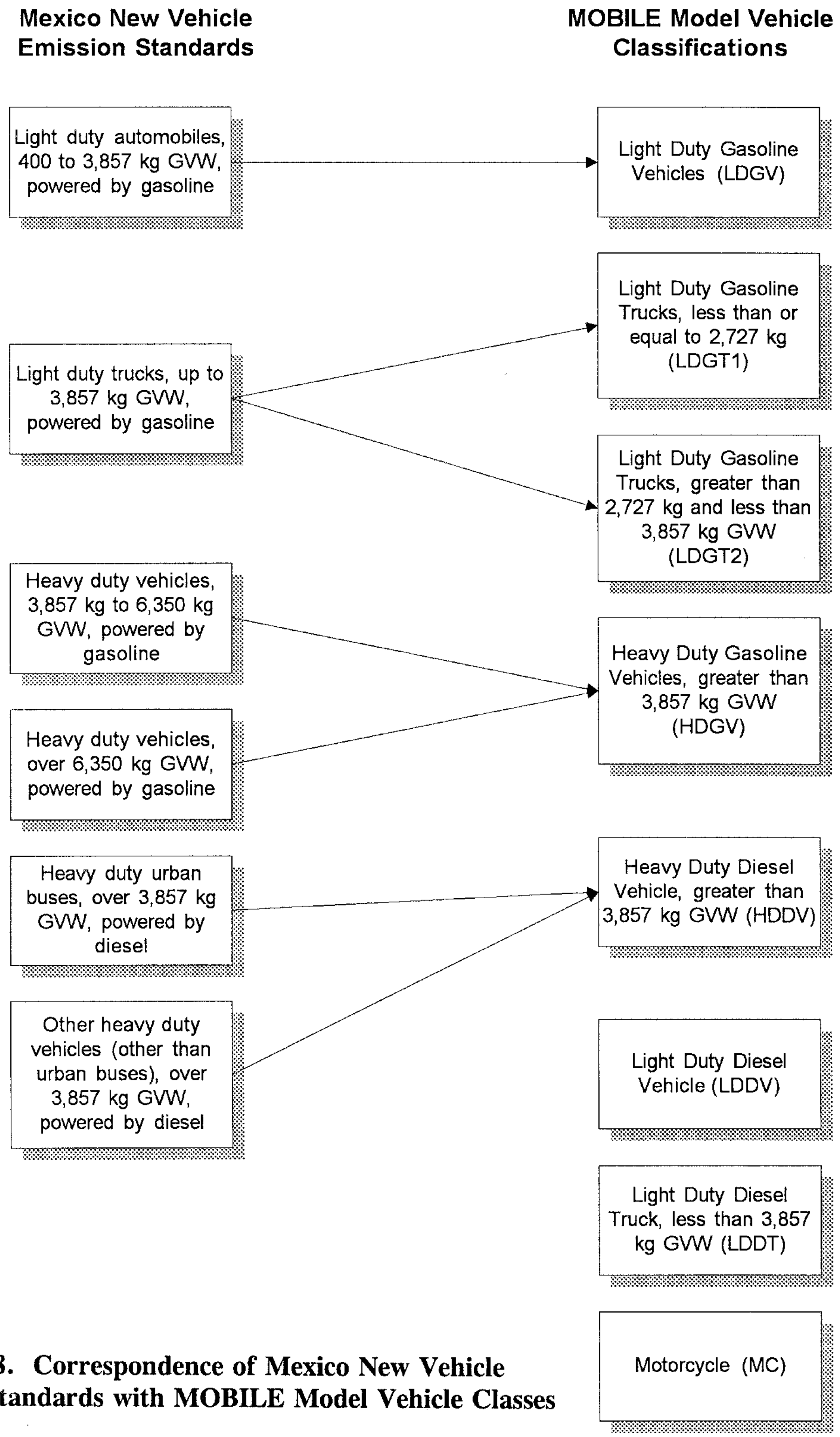


Figure 3-18. Correspondence of Mexico New Vehicle Emission Standards with MOBILE Model Vehicle Classes

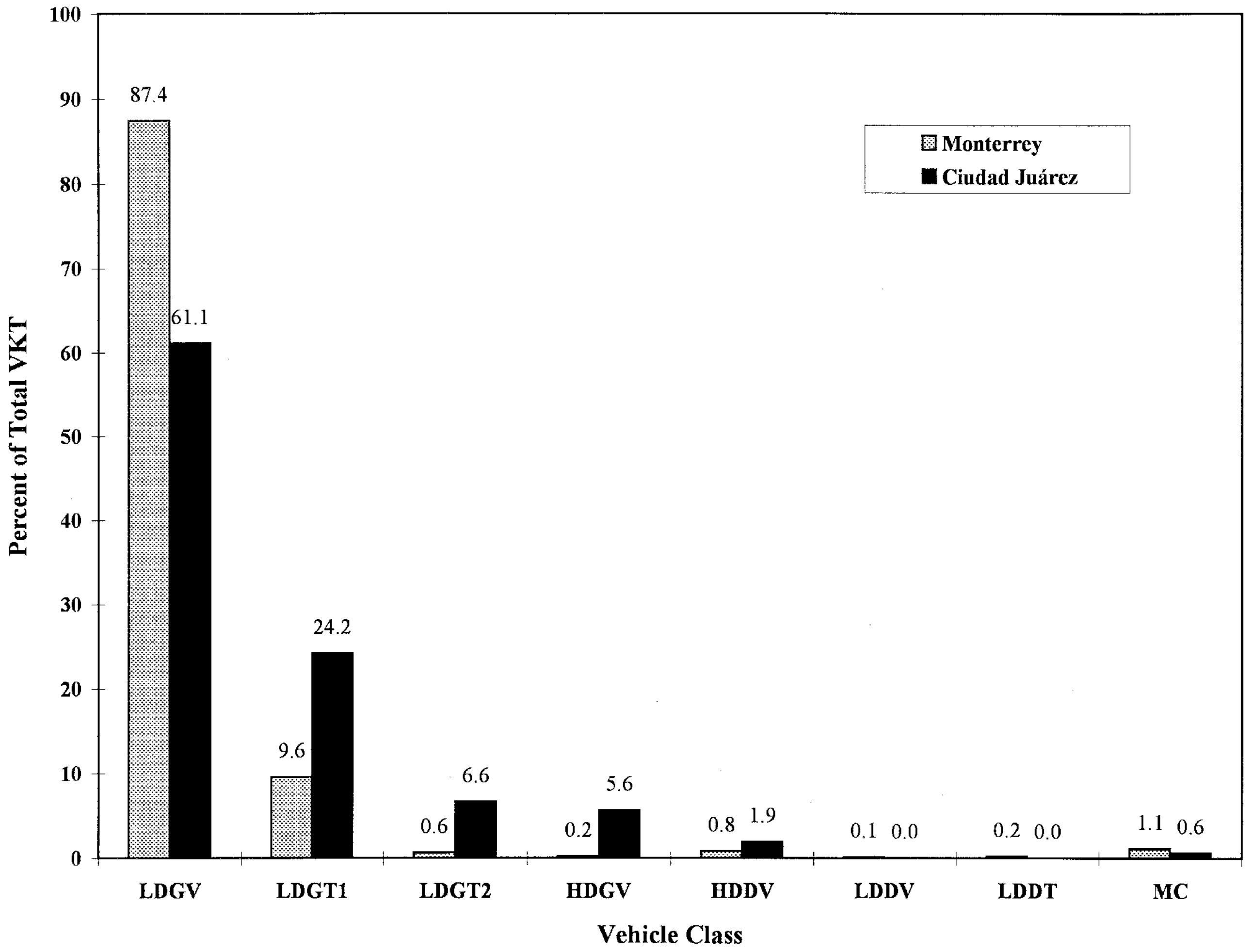


Figure 3-19. Monterrey and Ciudad Juárez Vehicle Kilometers Traveled (VKT) Distributions

where: TF_i = Travel fraction for model year, i, within a vehicle class;
RF_i = Fraction of total vehicle class registrations for model year, i; and
MAR_i = Mileage accumulation rate for vehicles in model year, i.

In Mexico, vehicle registration data are typically compiled by individual states or municipalities. Detailed vehicle registration data should provide the model year of each vehicle which then can be used to estimate registration distributions. However, in some areas vehicle registration data might be limited to the overall vehicle population and, possibly, the number of vehicles in each vehicle class. In such instances, surveys would need to be conducted in order to estimate registration distributions and mileage accumulation rates. Alternatively, information from other regions in Mexico could be used (subject to increased uncertainty) in similar regions. For example, some information used in the development of MOBILE-Juárez (Radian, 1996a) will be used to estimate motor vehicle emissions for an emissions inventory in Nogales, Sonora.

In some areas of Mexico, unregistered and/or U.S.-registered vehicles form a significant proportion of the vehicle population. In Ciudad Juárez, for example, 23% of the vehicles observed during vehicle surveys were unregistered and 15% were registered in the U.S. (TTI, 1994). In this case, registration distributions calculated from official registration records will be underestimated. A direct survey of vehicle populations may be more appropriate to improve the registration distribution estimate.

Mileage Accumulation Rates

Mileage accumulation rate is the annual amount of VKT accumulated by vehicles of one model year and one vehicle class. This parameter is one of the most difficult to determine since it cannot be estimated from traffic observations. The U.S. EPA document *Techniques for Estimating MOBILE2 Variables* (EEA, 1980) discusses methods for obtaining mileage accumulation rate estimates. However, the methods described in this document are dependent upon use of U.S.-specific information sources that may not apply to Mexico. Three options for estimating mileage accumulation rates are available:

- **Travel surveys of vehicle owners.** These can be home interview questionnaires taken of vehicle owners asking their annual mileage accumulation rates. In more detailed travel surveys, a sample of vehicle operators is solicited to complete a log of all travel made over a set period of time. From these results, annual mileage accumulation rates can be estimated.

- **Use of vehicle inspection data.** If the region has a vehicle I/M or safety inspection program in place where vehicle odometer readings are recorded, mileage accumulation rates could be calculated. This calculation is based on the difference in odometer readings for individual vehicles recorded over multiple inspections. A less accurate rate could be estimated from single odometer readings and the age of the vehicle, if the mileage is assumed to be accumulated at an even rate over the life of the vehicle.

- **Use of mileage accumulation rates from other regions.** U.S. mileage accumulation rates should not be used. Mileage accumulation rates from other similar regions in Mexico can be used if site-specific data cannot be obtained. The resultant emission estimates, however, will contain an additional amount of uncertainty because driving patterns are likely to vary from region to region.

4.0 DEVELOPMENT OF ACTIVITY DATA

As described in Section 2.0, vehicle kilometers traveled (VKT) estimates are combined with emission factors to yield emission estimates. In Mexico, there are two methods to derive VKT estimates. These two methods are:

- Direct traffic-based VKT estimates; and
- Fuel consumption statistics.

There are definite differences in the quality of the VKT estimates available through the use of these two methods. The choice of the activity data to be used will primarily be determined by which types of data are available and the overall quality of the data. In general, direct traffic-based VKT estimates tend to provide a better representation of vehicle activity than VKT estimates from fuel consumption statistics.

In major urban areas, some sort of traffic-based VKT estimate is often available. Outside of major urban areas, however, such VKT estimates are not likely to be available, leading to the use of fuel consumption data. Even if direct traffic-based VKT estimates are available, VKT estimates derived from fuel consumption statistics can be used as an effective quality assurance tool. Traffic-based VKT estimates are discussed in Section 4.1, while VKT estimates derived from fuel consumption statistics are presented in Section 4.2.

4.1 Traffic-Based VKT Estimates

There are two primary types of traffic-based VKT estimates: detailed estimates for specific roads obtained from travel demand models (TDMs), and regional VKT estimates developed from traffic measurement programs or other means.

4.1.1 VKT Estimates from Travel Demand Models

Travel demand models (TDMs) are computer model representations of the road network in an urban area. Currently, TDMs are only used in the larger urban areas (i.e., Mexico City and Monterrey). TDMs are used to model traffic flows for traffic improvement and congestion management studies. In TDMs, the region to be modeled is divided into zones of similar demographic characteristics. Roads or groups of roads are represented in the model as a network of connected links. These links provide the means to track traffic flow between zones. To model travel behavior, the number, origin, and destination of vehicle trips are assigned to appropriate zones. The travel on the links is then calculated to produce the shortest estimated travel times between zones. Outputs from TDMs provide estimated travel time and traffic flows on the individual links. TDMs are not created explicitly for use as emission inventory tools, but if they are comprehensive and up-to-date, the results can serve as a source of detailed vehicle travel and speed estimates for use in emission inventories. For a description of the TDM development process and the use of TDMs in emission inventories, see *Procedures for Emission Inventory Preparation, Volume IV: Mobile Sources*, Section 3.4.2 (U.S. EPA, 1992). Many texts are also available that discuss the TDM process in detail, including *Urban Travel Demand Modeling* (Oppenheim, 1995).

A considerable investment or resources and time is necessary to gather the data to support TDMs. Consequently, they are usually only developed for major urban areas where traffic improvement studies are frequently needed to maintain the transportation infrastructure. As mentioned above, only the largest urban areas in Mexico currently operate TDMs. Smaller urban areas must rely on other sources of VKT estimates.

From the estimates of distance and volume on TDM links, VKT on a single link can be estimated from the equation:

$$\mathrm{VKT} = \frac{\mathrm{Volume}}{\mathrm{Distance}} \qquad (4\text{-}1)$$

where:
VKT = Vehicle kilometers traveled per time period;
Volume = Number of vehicles on a link for a given time period; and
Distance = ... Distance of the link, in kilometers.

Regional estimates of VKT can be developed by summing VKT over all links or links of a given type and area designation.

The data obtained from a TDM must be analyzed to determine how applicable they are to the emissions inventory being developed. Two key issues for emission inventories are the extent of coverage of the overall road network and the representativeness of the data to the inventory year. Frequently, TDMs are developed to model travel on the larger roads in the road network only, and do not include travel on smaller local roads and streets. It is important to determine the limits of the TDM coverage. In cases where the coverage is not complete, separate estimates must be developed for the local roads.

The TDM process depends on survey data of local travel behavior. These survey results are important because they help estimate the amount and location of trip generating activity. Therefore, the TDM inputs should be based on survey data taken as close to the inventory year as possible. Ideally, the survey should be conducted within five years of the inventory year. Survey results older than five years will introduce additional uncertainty to the inventory.

4.1.2 Regional VKT Estimates

Many urban areas are likely to have developed regional VKT estimates as part of the transportation planning process. While not as spatially detailed as VKT estimates from TDMs, these regional estimates can equal or exceed the precision of the TDM estimates on a regional level if they are based on a sufficient number of actual measurements.

Regional VKT estimates are normally based on direct measurements of vehicle volumes passing a single point on a road. VKT on the road is then estimated from the vehicle volumes and the length of the road. Ideally, direct measurement of traffic volumes would be made on a large sample of roads in the area. However, it is cost-prohibitive to frequently measure the traffic volumes on the large number of roads in an urban area. Measurements are instead taken from a sample or subset of the roads in the region and the results are extrapolated to estimate the regional VKT total. As part of this process, the road network is first classified into a system where roads of the same class are expected to have similar traffic volumes. Measurements are taken from a sample of the roads in each class. A regional estimate can then be developed by extrapolating the sample results based on the ratio of the length of roads in the class sampled to the total length of roads in the class. Additional adjustments may be necessary if measurements taken over a number of years are being combined to estimate regional VKT.

Further information on techniques for measurement of vehicle volumes can be obtained from *Manual of Transportation Engineering Studies* (ITE, 1994). For purposes of emission inventory development, spot measurements of vehicle volumes may be made to validate regional estimates or to supplement existing data. Sampling methods can include both automated and manual data collection. These studies can be designed to also collect speed data at the same time (see Section 3.4.2).

National estimates of traffic volumes for Mexico are available for paved roads and are compiled by road type (federal, toll, and state roads). These data are available in the publication *Anuario Estadístico del Sector Comunicaciones y Transportes* (SCT, 1993). It is uncertain whether these data have been disaggregated to the regional or sub-regional level.

4.2 VKT Estimates Derived from Fuel Consumption Data

In the absence of direct VKT estimates from TDMs and regional data collection programs, VKT may be estimated indirectly from fuel consumption data. If these other sources of direct VKT estimates are available, fuel consumption data can also be used to check the validity and accuracy of the estimates.

Fuel sales and consumption statistics typically are much more widely used and available than direct VKT estimates. These statistics are usually kept to track fuel sales and consumption because gasoline and diesel are valuable commodities. In Mexico, fuel consumption or local sales data can be obtained from Petróleos Mexicanos (PEMEX). For a smaller inventory region, fuel sales from individual service stations may also be requested.

Government agencies can request data from:

Unidad Central de Coordinación Operativa de PEMEX
Torre Ejecutiva Piso 40
Marina Nacional No. 329
Col. Huasteca
Telephone: 250-55-96, 531-97-00
Fax: 203-55-66

Using fuel consumption data, a regional estimate of VKT can be obtained that represents the entire fleet of vehicles using one type of fuel:

$$VKT_f = Sales_f \times KPL_f \qquad (4\text{-}2)$$

where:
VKT = Vehicle kilometers traveled;
Sales = Total fuel sales (liters);
KPL = Fleet average fuel efficiency (kilometers/liter) (Mexico-specific values or U.S. default values); and
f = Fuel type (gasoline or diesel).

The use of VKT data from TDMs or regional estimates is preferred over the use of fuel data. In general, it is preferable to use fuel sales or fuel consumption data to check existing direct VKT estimates, but if needed, fuel sales or fuel consumption data can be used to estimate VKT. Several issues increase the uncertainty in VKT estimates derived from fuel statistics. These include:

- Fuel sold within the inventory region may not be consumed within the region. This may be particularly true where there are large differences in fuel prices between geographic areas or where there is a large amount of commuting traffic into an urban area.
- Fuel sales or consumption data may include off-road equipment, (particularly for diesel).

There are some inventory regions where the location of fuel purchases and fuel consumption could differ significantly. In other words, fuel purchased in one area might be used in a different area. Within small inventory regions, this can create major discrepancies between fuel purchases and fuel consumption. However, in larger inventory regions, these discrepancies tend to cancel each other out and become less significant.

It is also important to determine the end use of the fuel. Regional fuel consumption data will likely include consumption by both on-road motor vehicles and off-road equipment, particularly for diesel fuel. Inclusion of fuel consumed by off-road equipment will inflate the VKT estimate. If possible, off-road equipment fuel consumption should be subtracted from total fuel consumption.

5.0 QUALITY ASSURANCE/ QUALITY CONTROL PROCEDURES

The final necessary step in developing accurate and useful emission estimates is to assess the overall accuracy of the estimates. Historically, developing independent assessments of the accuracy of motor vehicles emission estimates has been a difficult process because of the large number of sources, the geographic scope of their operation, and the diversity of emissions from individual vehicles. In spite of this difficulty, motor vehicle emissions must receive proper quality assurance/quality control (QA/QC) review. Motor vehicles represent a major source of emissions and the procedures used to develop the emission estimates require the use of large and complex data sets. Because no single QA measure is available that can assess the accuracy and bias of motor vehicle emission estimates, successful QA programs attempt to assess the inventory through as many independent measures as possible. This section presents specific procedures that can be used to evaluate the accuracy of motor vehicle emission estimates. These procedures include:

- Comparison of motor vehicle emissions to overall emissions inventory;
- Comparison of per capita emissions;
- Comparison of emissions versus VKT;
- Comparison of motor vehicle activity data to fuel consumption statistics;
- Remote sensing surveys of exhaust emissions; and
- Use of ambient sampling data.

5.1 Comparison of Motor Vehicle Emissions to Overall Inventory

A useful QA check on an emission inventory is the comparison of emissions from motor vehicles to emissions from all anthropogenic sources. The motor vehicle fraction of total emissions will vary by pollutant and location. There is no one single fraction that applies globally. Ideally, inventory results can be compared to historical results for the same area, or compared to results from other areas believed to have similar motor vehicle and stationary source emissions. This check will only provide an approximate estimate of the reasonableness of the emissions estimates. Further investigation is warranted if the motor vehicle fractions are noticeably different than results from similar regions. Discrepancies may be due to errors in the inventory or unknown differences in the characteristics of the two regions.

An example of the use of relative percentage emission contributions for assessing the reasonableness of emission estimates is given in Table 5-1. In this table, the relative proportion of motor vehicle emissions as a percentage of total emissions is presented for six regions, two in the United States (Atlanta and Los Angeles), two in Mexico (Mexico City and Monterrey), and two in Asia (Bangkok and Hong Kong). Emission estimates from motor vehicles vary between the six locations. The relative proportion of the motor vehicle contribution to overall VOC emissions ranges from 35 percent for Atlanta to 80 percent for Mexico City. This amount of variation is reasonable given different vehicle fleet mixes, vehicle emission standards, and levels of industrialization in each area.

The comparisons for CO and NO_x highlight Bangkok as noticeably different from the other regions. In the other five locations, NO_x emissions range from 20 percent to 75 percent of the overall anthropogenic emissions inventory. Bangkok, on the other hand, is estimated to have only 1 percent of its NO_x emissions contributed by mobile sources. Likewise, the CO percentage for Bangkok appears to be a statistical outlier at 35 percent compared to the other four locations with percentages between 70 percent and 98 percent. Part of the difference

Table 5-1

Relative Contribution of Motor Vehicle Emissions to Overall Anthropogenic Emission Estimates in Selected Cities

Location	Inventory Year	Reference	Estimated Motor Vehicle Emissions as a Percentage of Anthropogenic Emissions		
			VOC	CO	NO_x
Bangkok, Thailand	1992	MSTE, 1994	55	35	1
Hong Kong	1991	EPD, 1994	N/A	80	25
Monterrey, Mexico	1995	Radian, 1996b	70	95	30
Mexico City, Mexico	1989	LANL and IMP, 1994	80	98	75
Atlanta, Georgia	1995	Georgia DNR, 1995	35	70	20
Los Angeles, California	1990	SCAQMD, 1994	50	80	60

CO = carbon monoxide
NO_x = nitrogen oxides
VOC = volatile organic compounds
N/A = not available

between Bangkok and the other regions may be due to different mixes of vehicles. The Bangkok vehicle fleet includes a large proportion of two-cycle engines which have lower NO_x emissions than comparable four-cycle engines that predominate in the other areas. However, this does not explain the total extent of the difference in NO_x emissions, or the difference in CO emissions.

The above percentages do not indicate whether the Bangkok motor vehicle or anthropogenic emission estimates are potentially faulty; only that one or both of the CO and NO_x emission estimates are likely to be biased. The conclusion from this example analysis is that more detailed review of the overall inventory for Bangkok is warranted to determine if there are indeed biases in the emission estimates. As more emission estimates are generated in Mexico, they can be used in a similar fashion to identify potential outliers such as the Bangkok data presented in Table 5-1.

5.2 Comparison of Per Capita Emissions

Motor vehicle emissions are usually developed from traffic-based VKT estimates or VKT estimates derived from fuel consumption statistics. Per capita motor vehicle emissions can be calculated and compared to results from other regions to check for reasonableness of the results.

To illustrate this process, Figure 5-1 presents estimates of per capita motor vehicle emission estimates for 12 western states in the United States. Emission estimates are aggregated at the state level and are compared to state-wide population estimates. Both emission estimates and population are for 1990.

There is not a clear relationship between population and per capita emissions. California, with the largest population, has one of the lowest per capita emission rates for each of the four pollutants presented. Texas, the next most populous state presented, has a per capita emission rate that is in the middle. Wyoming, the least populous state represented, has the highest per capita emission rates for all pollutants.

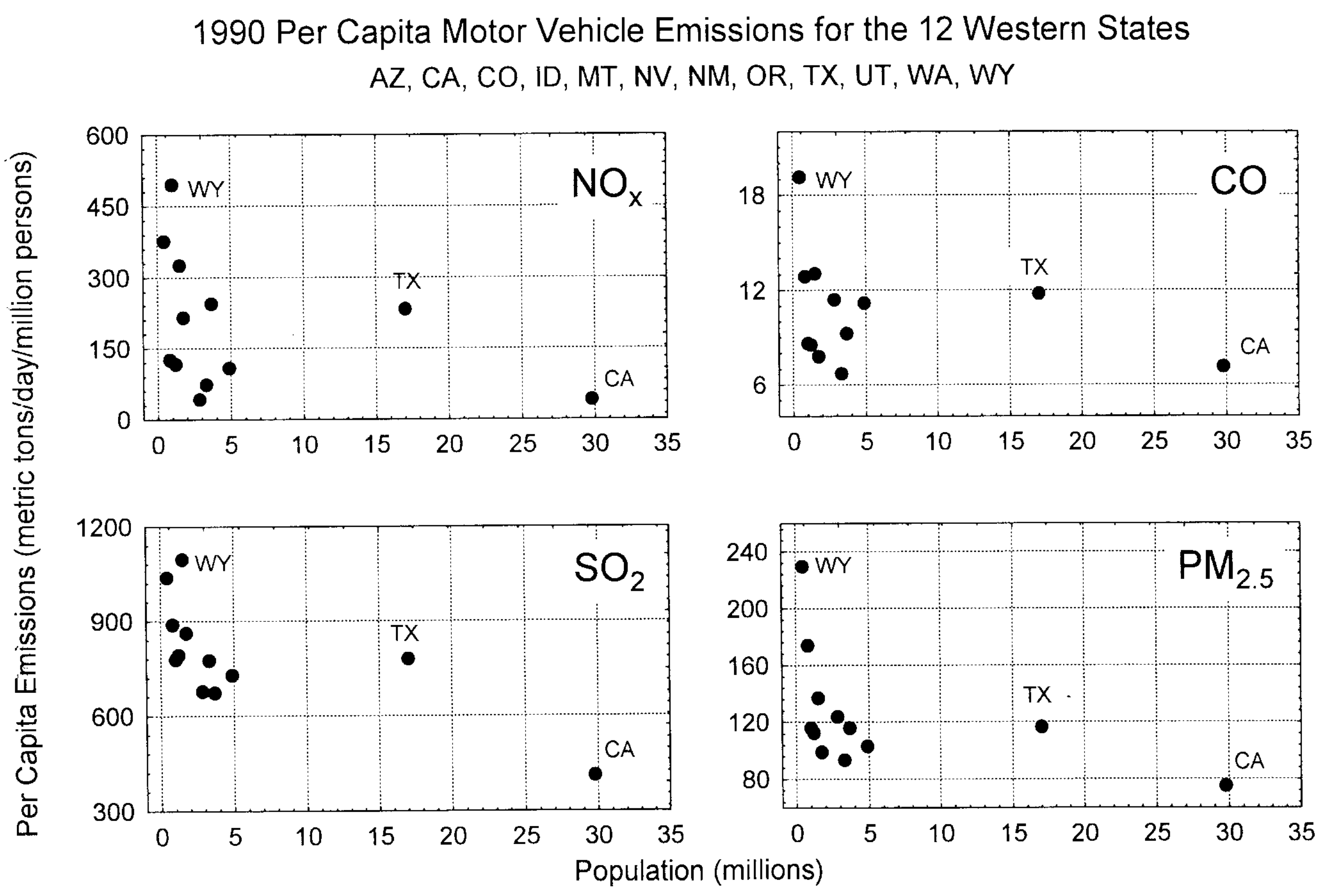


Figure 5-1. 990 Per Capita Motor Vehicle Emissions for the 12 Western States AZ, CA, CO, ID, MT, NV, NM, OR, TX, UT, WA, WY

Because of the large difference in the emission estimates between California and Wyoming, the natural question is what is the cause of the difference. Unless the reason for the observed differences can be readily explained, a potential bias in the emission estimates might be suspected. In the present example, the high per capita emissions rate in Wyoming is likely explained by the fact that Wyoming is a very rural state with large distances between urban areas. Average travel distances are large, resulting in more emissions per vehicle and relatively larger per capita emissions when compared to the other states. On the other hand, California has high traffic volumes and travel distances, but these factors are counterbalanced by the most stringent motor vehicle emission limits in the United States. As a result, there are relatively low per capita emissions from motor vehicles. This demonstrates the need to examine differences and provide reasonable explanations for these differences. If an explanation cannot be provided, then an error or bias might exist in the estimates.

Figure 5-2 presents plots of motor vehicle emissions and VKT for 43 counties in central Georgia, including metropolitan Atlanta and surrounding areas. Unlike the previous plot of per capita emissions, there appears to be a linear relationship between emissions and population and between VKT and population. In this plot, the four counties containing the bulk of the Atlanta area population appear to be outliers in the upper right corner of each plot. However, if these four counties were removed from the plot, the resulting plot of emissions versus population would be much less linear. This plot provides an example of the need to examine plots and data closely to ensure that initial impressions are correct and that no obvious systematic differences or errors are present in the data that may skew the conclusions.

5.3 Comparison of Emissions Versus VKT

Motor vehicle emission estimates are calculated by multiplying an emission factor by VKT. A simple comparison of estimated emissions to VKT can often identify computational errors.

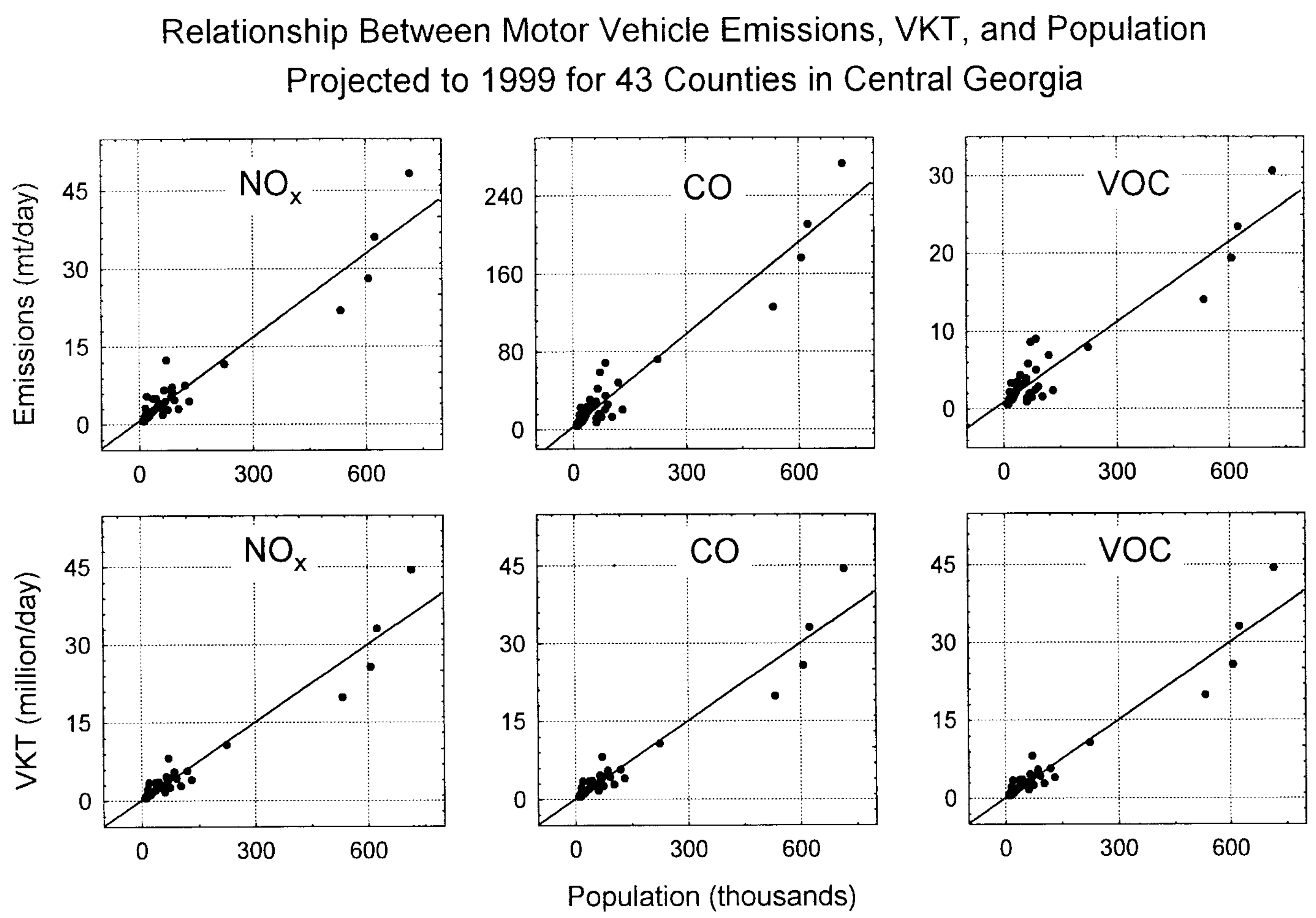


Figure 5-2. Relationship Between Motor Vehicle Emissions, VKT, and Population Projected to 1999 for 43 Countries in Central Georgia

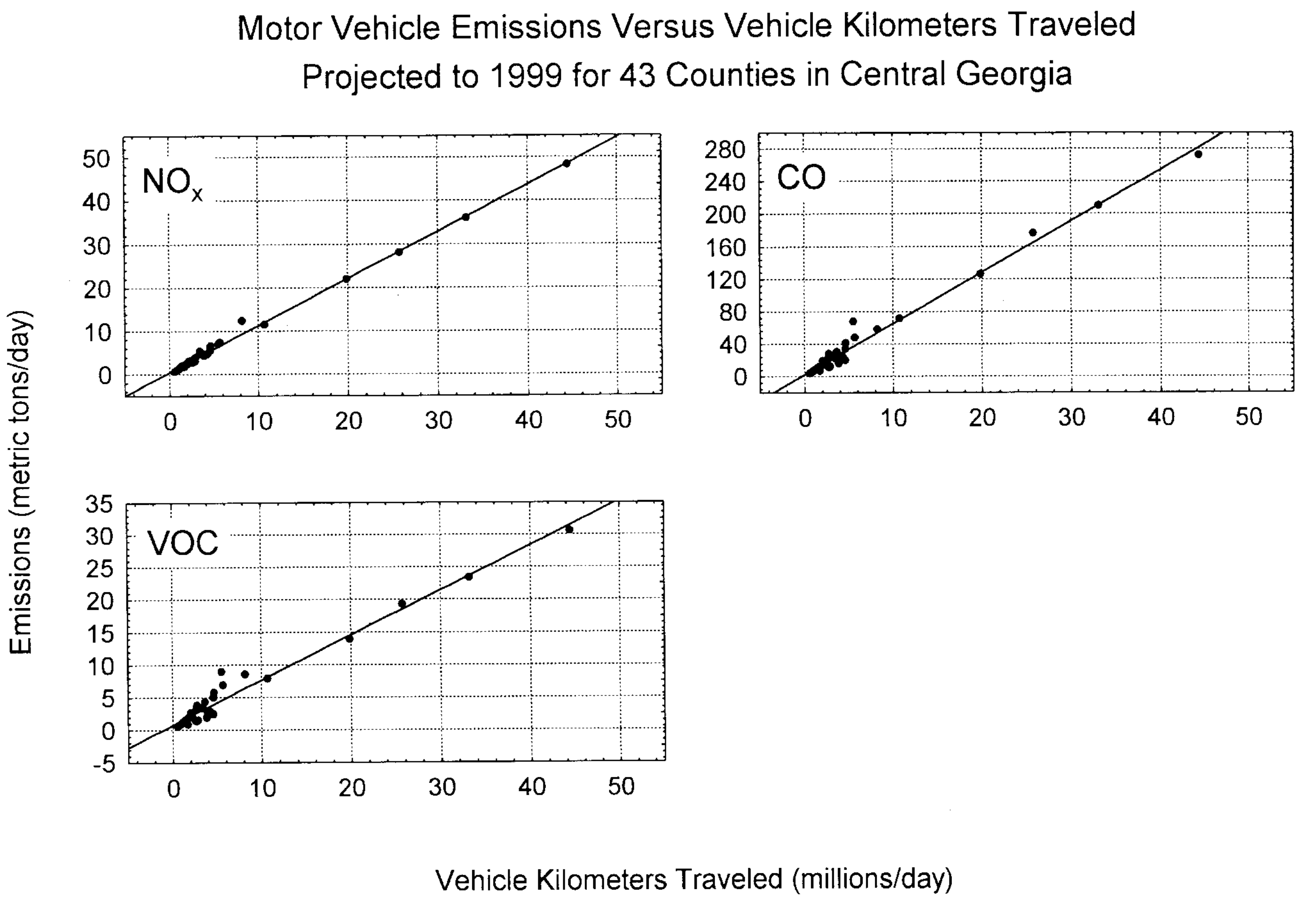
Figure 5-3 presents a plot of motor vehicle emissions versus VKT for 43 counties in central Georgia. Since VKT was used to estimate Atlanta emissions, this does not qualify as an independent check of emissions. Given that emissions are linearly proportional to VKT, a linear relationship is expected in Figure 5-3. Some deviations away from an exact linear correlation are to be expected due to differences in fleet mix, fuel characteristics, inspection and maintenance (I/M) programs, and other factors. However, significant deviations from the linear relationship (beyond differences seen in Figure 5-3, for example) would indicate the need to recheck the accuracy of the inventory calculations.

5.4 Comparison of Motor Vehicle Activity Data to Fuel Consumption Statistics

Fuel consumption statistics can be used to check the reasonableness of motor vehicle emission estimates, unless the original VKT estimates were themselves derived from fuel consumption statistics. VKT estimates used for comparison should be derived using fuel statistics as described in Section 4.2. Also, the uncertainty described in Section 4.2 resulting from off-road mobile equipment use and other factors should also be considered when this QA method is utilized.

5.5 Remote Sensing Surveys of Exhaust Emissions

The basic data used in motor vehicle emission factor models (e.g., MOBILE or PART5) are collected from vehicles operating on dynamometers according to prescribed driving patterns. Even though large quantities of data can be generated under these test conditions, the data are limited in their ability to recreate “real world” driving conditions. To the extent that basic data used in an emission factor model do not match real world conditions, the predicted average emission factors from the emission factor model are biased. For example, the basic data used to populate previous versions of the MOBILE model have resulted in an underestimation of VOC and CO emissions. The current driving cycle used in the dynamometer tests does not account for all high speed driving as well as hard accelerations and decelerations. In addition,



Motor Vehicle Emissions Versus Vehicle Kilometers Traveled Projected to 1999 for 43 Counties in Central Georgia

Figure 5-3. Motor Vehicle Emissions Versus Vehicle Kilometers Traveled Projected to 1999 for 43 Counties in Central Georgia

the basic data used in the MOBILE model do not always represent "super emitters" (i.e., vehicles that have much higher emission rates than are typically found within the vehicle fleet). U.S. EPA, California Air Resources Board (ARB), and other organizations are working to address these deficiencies in upcoming versions of MOBILE and EMFAC (ARB's motor vehicle emission factor model) models. However, the presence of the deficiencies points to the continued need for independent measures of motor vehicle emissions.

The concept of remote sensing and detection (RSD) as a method to identify "super emitters" and to provide a check of the motor vehicle emissions inventory was developed in Denver, Colorado during 1987. While RSD technology and use are still developing, RSD has rapidly evolved into a relatively efficient QA tool for motor vehicle emission estimates. Although this is a relatively straightforward technology, special expertise and equipment are nonetheless required to obtain useable RSD results. The following material provides an overview of this technology and how it can be used as a QA tool for motor vehicle emission estimates. Additional detail can be found in Bishop et al. (1993 and 1994) and Cadle et al. (1993).

This technology applies an infrared (IR) remote monitoring system that measures the ratios of carbon monoxide (CO) and hydrocarbons (HC) to carbon dioxide (CO_2). This technology can identify improperly tuned or misfiring vehicles, which when repaired will result in improved fuel economy. Therefore, this technology has been termed the Fuel Efficiency Automobile Test (FEAT). An IR beam is transmitted across a single lane of traffic, approximately 25 centimeters above the road surface. A calibrated detector receives the beam and reports the CO, CO_2, and HC data on a percent basis.

In order to use RSD measurements for QA, additional steps are involved to convert the RSD measurements into a form that can be combined with fuel consumption data. RSD results provide ratios of exhaust concentrations (i.e., CO/CO_2 and HC/CO_2), rather than absolute measurements of pollutant concentrations. The derivation of emission factors in grams of pollutant per unit volume of fuel consumed from RSD measurements is detailed by Singer and Harley (1996). Using a carbon balance, estimates of the pollutant of interest can be derived from the equation below:

$$E_P = \frac{[P]}{[CO_2] + [CO] + 3[HC]} \times \frac{MW_P}{MW_C} \times WF_C \times \rho_f \tag{5-1}$$

where: E_P = Emissions of pollutant P;
$[P]$ = Exhaust concentration of pollutant P;
MW_P = Molecular weight of pollutant P;
MW_C = Molecular weight of carbon;
WF_C = Weight fraction of carbon in the fuel; and
ρ_f = Density of fuel, f.

The sum of the concentrations of CO, CO_2, and HC in the denominator represents the concentration of carbon atoms in the exhaust. The equation assumes that hydrocarbons have been measured as propane, C_3H_8, hence the factor of 3 is applied to the exhaust HC concentration. If the RSD results are reported as ratios to CO_2, then the equations can be re-written as:

$$E_P = \frac{[Q_P]}{[1] + [Q_{CO}] + 3[Q_{HC}]} \times \frac{MW_P}{MW_C} \times WF_C \times \rho_f \tag{5-2}$$

where: $[Q_P]$ = $[P]/[CO_2]$;
$[Q_{CO}]$ = $[CO]/[CO_2]$; and
$[Q_{HC}]$ = $[HC]/[CO_2]$.

In Equations 5-1 and 5-2, the HC term is usually ignored unless [HC] is high enough to influence desired accuracy (e.g., [HC]~1000 ppm).

The FEAT has been used to measure the emissions of more than 500,000 vehicles in Denver, Chicago, Los Angeles, Toronto, Sweden, and Mexico (Bishop et al., 1993). For Mexico, this technology was used to evaluate the motor vehicle emissions in Mexico City (Beaton et al., 1992). Results of the study indicate that the exhaust characteristics of the Mexico City vehicle fleet are very different than any other region ever tested with this technology. This QA tool, therefore, provides a warning that the indiscriminate application of the MOBILE model to areas vastly different from the United States might lead to highly biased emission estimates.

Results of the Mexico City analysis include measurements of over 30,000 vehicles. The data were then reduced to provide gram per gallon emission factors for HC and CO. These data can be combined with gasoline sales data and used to calculate alternative emission estimates that can be used as a QA check of the emission estimates calculated using the predicted emission factors from the MOBILE model.

It must be remembered that there may be significant uncertainty associated with emission estimates based upon the FEAT or other remote sensing devices. These devices only provide an instantaneous measurement of emissions and fail to capture the variations of emissions over time and various driving conditions. Consequently, these alternative emission estimates should be used for QA purposes only. It is not recommended that they be used directly for emission estimation in inventory efforts.

5.6 Use of Ambient Sampling Data

Ambient sampling data can also be used to validate and perform QA on emission inventory estimates. Ambient sampling data provide a measurement of reality that can be compared to predicted emissions estimates. Three of the more commonly used methods are receptor modeling, concentration ratios, and three-dimensional grid models. The major benefit of these QA methods is that they provide information independent from the methodology used to estimate motor vehicle emissions. A drawback of these methods is the generally limited nature of ambient monitoring data available for use in the analysis. The ambient data are only representative of the conditions and source types that were present during the field measurements. If the conditions for which the emission estimates are valid differ from those encountered during the field measurements, then there will be inherent uncertainty in the results of any comparison that is made between the ambient data and the emission estimates.

5.6.1 Receptor Modeling

Receptor modeling, also called source apportionment, uses statistical methods and ambient monitoring data to estimate the relative contribution of emissions from a series of source categories to the observed ambient concentrations in an area. It is a “top-down” QA method because it uses information about the entire inventory and modeling domain to estimate the relative contribution of emissions from each source category, rather than building up contribution estimates on a source-by-source basis. The Chemical Mass Balance Model (CMB) (Watson et al., 1984) is a widely used model for performing receptor modeling.

In receptor modeling, least squares estimation is used to obtain the best fit of emissions from each source modeled that reproduces the chemical composition of observed monitoring data at a given monitoring site. The two key input requirements for receptor modeling are the chemical composition of ambient monitoring data and the chemical composition (“fingerprints”) of emissions from each source category that corresponds to the same level of detail as the monitoring data.

The model is only able to resolve contributions from source categories that have unique chemical compositions. In addition, only relative impacts are produced by the model indicating the relative contribution from each source class. Typical source categories used in receptor modeling may include motor vehicle exhaust, fuel combustion, electric utilities, construction activities, marine aerosol, and fugitive dust of geological origin.

Historically, receptor modeling has been used primarily for examining sources of relatively stable (or non-reactive) pollutants such as particulate matter. For example, Chow et al., (1992) used the CMB to examine PM_{10} source apportionment in the San Joaquin Valley in California. They concluded that fugitive dust of geological origin (e.g., fugitive dust from agricultural tilling, roadways, and construction activity) exceeded 50% of the observed PM_{10} at Bakersfield in the summer and fall. On-road motor vehicle exhaust, on the other hand, contributed only approximately 10% of the observed PM_{10}.

Much recent work has been performed to apply receptor modeling to reactive pollutants. For example, Scheff et al. (1995) applied the CMB to evaluate emissions of non-methane organic compounds (NMOC) for the Southeast Michigan Ozone Study (SEMOS). Based upon the assumption of relatively low travel times, and hence limited time for chemical reactions to occur, chemical species with relatively low reactivity were selected for use in the modeling. In this study, the relative proportion of the observed NMOC concentrations was found to be consistent with current estimates of emissions for some categories, such as architectural coating and coke oven sources. However, there were significant differences between the CMB results and the current inventory on the relative proportion of emissions from other categories, such as refineries and graphic arts.

As mentioned at the beginning of Section 5.5, a major strength of using the CMB approach for emissions inventory QA analysis is that it is completely independent of the methods used to estimate the emissions. These statistical methods rely on ambient monitoring data alone to estimate the relative contribution of emissions sources. Thus, this method provides the ability to independently verify the relative distribution of emissions estimated through the inventory process and to identify potential problem areas.

A potential limitation of the methodology is that the resolution available from the CMB model is limited by the quality of the available source emission composition profiles. Because of differences between sources (and, potentially, from test to test for a given source), these profiles are highly variable. Consequently, great care must be exercised to ensure that the most representative source profiles are used as input to the CMB model. In addition, the monitoring data used in CMB modeling must be representative of ambient concentrations in the area in which the emissions are occurring. These monitoring data cannot be dominated by local sources for which source profiles are not available.

5.6.2 Ambient Sample Ratios

Specific emission sources tend to have somewhat fixed ratios of the emissions of various pollutants. By analysis of these ratios, it is possible to derive information as to the probable contribution of specific emission sources to observed monitoring data. A good example of the use of ambient monitoring data in this manner is a study by Fujita et al. (1992) in Los Angeles, California. Similar analyses have been performed in the Chicago and Central California areas (Korc et al., 1995). Fujita et al. compared ratios of various pollutants developed from emission inventories and ambient monitoring data collected in 1987 during the South Coast Air Quality Study (SCAQS).

Table 5-2 presents the results of Fujita et al. in which ambient and emission inventory ratios of CO/NO_x and NMOG/NO_x were compared. Included on Table 5-2 are the adjustment factors to the motor vehicle exhaust portion of the emission inventory that would be required to bring the emission inventory ratios to equality with the observed ambient ratios (i.e., remove a potential bias). Because the NMOG/NO_x ratios require a larger motor vehicle adjustment factor compared to the CO/NO_x ratios, it appears that NMOG has been underestimated.

Conducting this type of analysis on a routine basis as part of the emissions inventory development process is not recommended. However, as Mexico emissions inventories continue to develop, the amount of ambient field measurements will increase, which will allow more widespread use of this analysis technique.

5.6.3 Three-Dimensional Grid Models

Three dimensional grid models are also being used more frequently to help evaluate the uncertainty in the emissions inventory process (Chang et al., 1993; Mulholland and Seinfeld, 1995). Current three-dimensional grid models include the effects of atmospheric chemistry and varying meteorological conditions. Emission inventory estimates are then used as data inputs for the three-dimensional grid models. After the model has been run, the predicted atmospheric concentrations are compared to actual measured concentrations at various monitoring sites. In this way, the inventory uncertainty can be ascertained. A recent example is the Mexico City Air Quality Research Initiative (MARI). In the MARI study, staff of Los Alamos National Laboratory and the Mexican Petroleum Institute concluded that the estimated VOC inventory for Mexico City is low by nearly a factor of four (LANL and IMP, 1994). This conclusion was reached through data analysis techniques, including trajectory analysis, as part of the model performance evaluation. As with receptor modeling and ambient sample ratios, the current applicability of three-dimensional grid models is somewhat limited. However, as emission inventories develop and mature in Mexico, advanced techniques such as three-dimensional grid models will see increased use.

Table 5-2

Comparison of Ambient and Inventory Ratios of CO/NO_x and$NMOG/NO_x$ for Los Angeles for 1987

Pollutant Ratio	Season	Time (Pacific Standard Time)	Ambient/Inventory Ratio[a]	Required Motor Vehicle Adjustment Factor[b]
CO/NO_x	Summer	06 - 08	1.4	1.5
		20 - 08	1.6	1.9
	Fall	06 - 08	1.1	1.2
		20 - 08	1.4	1.7
$NMOG/NO_x$	Summer	06 - 08	2.5	4.4
		20 - 08	3.0	5.5
	Fall	06 - 08	1.7	2.8
		20 - 08	2.3	4.0

[a] Ratio of the pollutant ratio estimated from ambient monitoring data to that estimated from the motor vehicle emissions inventory.

[b] Adjustment factor required to bring the hot exhaust motor vehicle emissions inventory ratio to equality with the ambient ratio.

Source: Fujita et al., 1992.

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APPENDIX A

SAMPLE MOTOR VEHICLE EMISSIONS CALCULATION

Appendix A - Sample Motor Vehicle Emissions Calculation

Objective - To demonstrate the calculation of motor vehicle emissions using both emission factor models and mass balances. Total organic gas (TOG) and sulfur oxide ($SO_{x)}$ emissions will be estimated in this sample calculation.

Description -This sample calculation is based upon actual emission calculations performed for an air toxics inventory in Nogales, Sonora, Mexico (Radian, 1997). Emissions will be estimated for four vehicle classifications using gasoline: light-duty gasoline vehicles (LDGV), light-duty gasoline trucks (LDGT), heavy-duty gasoline vehicles (HDGV), and motorcycles (MC).

TOG emissions were calculated as an intermediate step prior to air toxics speciation. The TOG emission factors were calculated using MOBILE-Juárez (a MOBILE5a model modified using data for Ciudad Juárez). SO_x emissions were not calculated as part of the air toxics inventory; however, they can be easily derived from fuel consumption statistics.

It has been assumed that the PEMEX fuel statistics presented below represent fuel that is used in Mexican cars in Nogales, Sonora. Though not entirely true, this assumption was a necessary simplification used in the air toxics inventory. The calculations of the average fleet fuel efficiency and vehicle kilometers traveled (VKT) distribution by road type are too complicated for this sample calculation and have not been included. Only the results for average fleet fuel efficiency and VKT distribution are included in this sample calculation.

TOG Emissions - Estimation of Emission Factors

Step 1: Construct MOBILE-Juárez input file. The input file prepared for the spring scenario in Nogales, Sonora is presented in Figure A-1. In order to account for temperature changes from season to season, four separate input files were prepared for spring, summer, fall, and winter. In general, seasonal scenarios are optional. Each line of the input file is briefly explained in Table A-1. The line numbers included in Figure A-1 are not part of the actual input file, but are used as a referencing aid.

Step 2: Run the MOBILE-Juárez model.

Step 3: Extract emission factors from the MOBILE-Juárez output file. The portion of the resulting output file containing emission factors for the spring scenario in Nogales, Sonora is shown in Figure A-2. The emission factors for each speed and vehicle classification are indicated.

Step 4: Calculate annual average emission factors. Annual average emission factors are calculated using the spring emission factors shown in Figure A-2, as well as similar emission factors for the other three seasons that are not shown here. This calculation is summarized in Table A-2.

TOG Emissions - Estimation of VKT

Step 1: Calculate total fuel consumption. Monthly 1994 fuel consumption statistics (both leaded and unleaded gasoline) were obtained from PEMEX. Yearly totals are calculated in Table A-3. Total unleaded gasoline consumption was 51,169,901 liters, while total leaded gasoline consumption was 10,571,891 liters. Overall total gasoline consumption was 61,741,792 liters.

Step 2: Calculate VKT. Using registration and mileage accumulation data (by model year) from the MOBILE-Juárez model and model year fuel efficiencies from the United States, it was determined that the 1994 average fleet fuel efficiency for Nogales was 6.788 kilometers per liter of gasoline. Dividing the overall total gasoline consumption by this fuel efficiency results in approximately 419,100,000 total VKT for Nogales, Sonora.

Step 3: Distribute VKT by vehicle classification. The overall Ciudad Juárez VKT mix indicated the following: LDGV - 61.1% of total VKT, LDGT - 30.8%, HDGV - 5.6%, and MC - 0.6%. However, this VKT mix includes diesel vehicle VKT as well. Normalizing for gasoline VKT results in the following: LDGV - 62.3% of gasoline VKT, LDGT - 31.4%, HDGV - 5.7%, and MC - 0.6%. After applying this normalized VKT fraction, total VKT is divided into vehicle classes as shown below:

LDGV	261,100,000 VKT
LDGT	131,600,000 VKT
HDGV	23,900,000 VKT
MC	2,500,000 VKT

Step 4: Distribute VKT by vehicle speed. Based upon a site visit in Nogales, Sonora and engineering judgment, it was estimated that 23.3% of all VKT occurred at 24.1 kilometers per hour (15 mph), 70.0% occurred at 40.2 kilometers per hour (25 mph), and 6.7% occurred at 56.3 kilometers per hour (35 mph). The VKT distribution by vehicle speed is shown in Table A-4.

TOG Emissions - Calculation of emissions

As indicated in Section 2.1 of this manual, TOG emissions are calculated by multiplying the MOBILE-Juárez emission factor by the VKT estimate. This is shown in Table A-4 for each vehicle classification and each of the three vehicle speeds. Total TOG emissions for gasoline-powered vehicles have also been summed at the bottom of Table A-4.

Total TOG emissions were estimated to be 2,866 Mg/yr or 7.85 Mg/day.

SO_x Emissions - Calculation of emissions

As indicated in Section 2.1 of this manual, SO_x emissions are estimated using a fuel balance.

Step 1: Obtain fuel consumption statistics. From the TOG emission calculation above, it was determined that 51,169,901 liters of unleaded gasoline and 10,571,891 liters of leaded gasoline were consumed.

Step 2: Obtain fuel sulfur contents. From PEMEX fuel specifications, the maximum fuel sulfur content for unleaded gasoline is 0.1% (wt) and for leaded gasoline is 0.15% (wt).

Step 3: Determine the density of gasoline. Based on previous experience, a typical density of gasoline is 0.731 kg/liter (6.09 lbs/gallon).

Using the fuel balance equation for SO_x (see Equation 2-2 of this manual):

$$E_{Unleaded} = (51{,}169{,}901\ \ell) \times (0.731\ kg/\ell) \times 0.001 \times 2 = 74{,}810\ kg\ SO_x = 74.8\ Mg\ SO_x$$

$$E_{Leaded} = (10{,}571{,}891\ \ell) \times (0.731\ kg/\ell) \times 0.0015 \times 2 = 23{,}184\ kg\ SO_x = 23.2\ Mg\ SO_x$$

Total SO_x emissions are 98 Mg/year or 0.268 Mg/day.

Table A-1
Explanation of MOBILE-Juárez Input File for Nogales, Sonora

Line Number	Data Element	Explanation	Comments
1	1	PROMPT flag - Input data entered without prompting in vertical format.	Also known as batch file input. This option is recommended.
2	Entire Line	PROJID - Input file identification.	None.
3	1	TAMFLG - MOBILE-Juarez default tampering rates used.	This option should be used unless local tampering survey performed.
4	1	SPDFLG - One average speed for all vehicle types (for each Scenario Descriptive Record).	This option should be used unless detailed transportation speed information is available.
5	3	VMFLAG - One VKT mix assigned for all scenarios.	VKT mix from Ciudad Juárez/El Paso assumed to be applicable for Nogales, Sonora.
6	1	MYMRFG - MOBILE-Juarez default mileage accumulation rates and registration distributions used.	This option should be used unless local mileage accumulation and registration distribution data are collected.
7	5	NEWFLG - MOBILE-Juarez BERs used with all new Clean Air Act requirements disabled.	This option should be used for all applications of the MOBILE-Juarez model.
8	1	IMFLAG - No inspection and maintenance (I/M) program to be modeled.	This option should be used unless an I/M program has been implemented.
9	1	ALHFLG - No corrections made for air conditioning usage, extra vehicle load, trailer towing, and humidity.	This option should normally be used.
10	1	ATPFLG - No anti-tampering program (ATP) to be modeled.	This option should be used unless an ATP has been implemented.

Table A-1

(continued)

Line Number	Data Element	Explanation	Comments
11	5	RLFLAG - No refueling emission factors calculated.	This option should be used unless refueling emissions are not estimated as an area source.
12	1	LOCFLG - One Local Area Parameter (LAP) record for each scenario.	This option is typically used.
13	1	TEMFLG - Emission factors adjusted using minimum and maximum daily temperatures.	This option should be used unless minimum and maximum daily temperatures are not available.
14	4	OUTFMT - 80-column descriptive output format.	The MOBILE-Juarez model has been customized to accept only this option.
15	1	PRTFLG - Only hydrocarbon emission factors included in output.	This option was selected to meet the requirements of the Nogales, Sonora air toxics inventory.
16	1	IDLFLG - No idle emission factors calculated.	This option should normally be used.
17	4	NMHFLG - Hydrocarbon emission factors given as total organic gases (TOG).	This option should normally be used.
18	3	HCFLAG - Total, component, and detailed evaporative emission factors included in output.	This option should normally be used.

Table A-1

(continued)

Line Number	Data Element	Explanation	Comments
19	.611	VKT fraction for light-duty gasoline vehicles (LDGV).	VKT fraction estimated for Ciudad Juárez assumed to be applicable for Nogales, Sonora.
	.242	VKT fraction for light-duty gasoline trucks <2,727 kg (LDGT1).	VKT fraction estimated for Ciudad Juárez assumed to be applicable for Nogales, Sonora.
	.066	VKT fraction for light-duty gasoline trucks >2,727 kg and <3,857 kg (LDGT2).	VKT fraction estimated for Ciudad Juárez assumed to be applicable for Nogales, Sonora.
	.056	VKT fraction for heavy-duty gasoline vehicles >3,857 kg (HDGV).	VKT fraction estimated for Ciudad Juárez assumed to be applicable for Nogales, Sonora.
	.000	VKT fraction for light-duty diesel vehicles (LDDV).	VKT fraction estimated for Ciudad Juárez assumed to be applicable for Nogales, Sonora.
	.000	VKT fraction for light-duty diesel trucks <3,857 kg (LDDT).	VKT fraction estimated for Ciudad Juárez assumed to be applicable for Nogales, Sonora.
	.019	VKT fraction for heavy-duty diesel vehicles >3,857 kg (HDDV).	VKT fraction estimated for Ciudad Juárez assumed to be applicable for Nogales, Sonora.
	.006	VKT fraction for motorcycles (MC).	VKT fraction estimated for Ciudad Juárez assumed to be applicable for Nogales, Sonora.
20	1	Low altitude region.	This option should be used except for high altitude regions (>1,676 meters).
	94	1994 inventory year.	The inventory year for the Nogales, Sonora inventory. This data will vary depending upon inventory year.

Table A-1

(continued)

Line Number	Data Element	Explanation	Comments
20 cont	24.1	Vehicle speed of 24.1 kilometers per hour (15 miles per hour).	One of the vehicle speeds estimated for Nogales, Sonora during a site visit. For MOBILE-Juarez, this value must be in units of kilometers per hour.
	25.0	Ambient temperature.	This temperature is typically not used because TEMFLG (see Line Number 13) is set to “1”. However, the ambient temperature must be set between the minimum and maximum daily temperatures. The value of 25.0 °C was arbitrarily chosen. For MOBILE-Juarez, this value must be in units of °C.
	19.6	PCCN operating mode variable.	Operating mode variables estimated for Ciudad Juarez assumed to be applicable for Nogales, Sonora.
	19.7	PCHC operating mode variable.	Operating mode variables estimated for Ciudad Juarez assumed to be applicable for Nogales, Sonora.
	30.0	PCCC operating mode variable.	Operating mode variables estimated for Ciudad Juarez assumed to be applicable for Nogales, Sonora.
	1	Emission factors calculated for January of inventory year.	This option should normally be used.

Table A-1

(continued)

Line Number	Data Element	Explanation	Comments
21	Nogales Spring	Scenario name.	None.
	A	Fuel volatility class.	This option should normally be used.
	3.6	Minimum daily temperature.	Average minimum daily temperature for March, April, and May derived from meteorological data for Nogales, Arizona. For MOBILE-Juarez, this value must be in units of °C.
	25.4	Maximum daily temperature.	Average maximum daily temperature for March, April, and May derived from meteorological data for Nogales, Arizona. For MOBILE-Juarez, this value must be in units of °C.
	09.5	Period 1 RVP.	Upper end of PEMEX RVP range assumed to be applicable for Nogales, Sonora.
	09.5	Period 2 RVP.	Upper end of PEMEX RVP range assumed to be applicable for Nogales, Sonora.
	93	Period 2 start year.	Because the Period 1 and Period 2 RVPs are identical, the Period 2 start year is not used. The entered 93 value is arbitrary.
	1	Oxygenated fuel flag.	This option should be used unless oxygenated fuels are to be modeled in the region.
	1	Diesel sales fraction flag.	This option should be used unless alternate diesel sales fractions are to be used.
	1	Reformulated gasoline flag.	This option should be used unless the effects of reformulated gasoline are to be modeled.

Table A-1

(continued)

Line Number	Data Element	Explanation	Comments
22	Entire Line	Identical to the Scenario Descriptive Record presented in Line 20 except that vehicle speed has been changed to 40.2 kilometers per hour.	None.
23	Entire Line	Identical to the Local Area Parameter Record presented in Line 21.	None.
24	Entire Line	Identical to the Scenario Descriptive Record presented in Line 20 except that vehicle speed has been changed to 56.3 kilometers per hour.	None.
25	Entire Line	Identical to the Local Area Parameter Record presented in Line 21.	None.

Table A-2
Calculation of Annual TOG Emission Factors (g/km) for Nogales, Sonora

Vehicle Class	Speed (kph)	Spring	Summer	Fall	Winter	Average
LDGV	24.1	8.17	9.93	8.20	8.45	8.69
	40.2	5.79	7.35	5.90	5.84	6.22
	56.3	4.65	6.15	4.80	4.57	5.04
LDGT	24.1	8.04	9.54	8.07	8.28	8.48
	40.2	5.80	7.20	5.89	5.87	6.19
	56.3	4.71	6.08	4.84	4.68	5.08
HDGV	24.1	11.50	16.36	12.10	10.58	12.64
	40.2	7.41	11.76	8.05	6.45	8.42
	56.3	5.68	9.82	6.34	4.70	6.64
MC	24.1	6.92	8.91	7.32	6.03	7.30
	40.2	5.60	7.65	6.03	4.58	5.97
	56.3	4.92	7.02	5.37	3.85	5.29

Table A-3
1994 Fuel Consumption Statistics for Nogales, Sonora

Month	Magna Sin (Unleaded) (liters)	Nova Plus (Leaded) (liters)
January	3,510,000	1,348,600
February	3,464,800	1,246,800
March	3,990,000	1,461,500
April	3,830,000	932,500
May	4,180,000	992,500
June	4,141,930	751,645
July	4,238,970	689,935
August	4,724,500	719,761
September	4,575,179	607,200
October	4,489,828	621,450
November	4,794,593	615,000
December	5,230,101	585,000
Total	**51,169,901**	**10,571,891**

Table A-4
Calculation of Annual TOG Emissions (Mg) for Nogales, Sonora

Vehicle Class	Speed (kph)	Emission Factor (g/km)	VKT	Emissions (Mg/yr)
LDGV	24.1	8.69	60,836,300	528.7
	40.2	6.22	182,770,000	1136.8
	56.3	5.04	17,493,700	88.2
LDGT	24.1	8.48	30,662,800	260.0
	40.2	6.19	92,120,000	570.2
	56.3	5.08	8,817,200	44.8
HDGV	24.1	12.64	5,568,700	70.4
	40.2	8.42	16,730,000	140.9
	56.3	6.64	1,601,300	10.6
MC	24.1	7.30	582,500	4.3
	40.2	5.97	1,750,000	10.4
	56.3	5.29	167,500	0.9
Total	**-**	**-**	**419,100,000**	**2866.2**