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# EIIP Volume IV

# Mobile Sources Preferred and Alternative Methods

STAPPA • ALAPCO • EPA
emission inventory
improvement program
EIIP

# PREFACE

As a result of the more prominent role given to emission inventories in the 1990 Clean Air Act Amendments (CAAA), inventories are receiving heightened priority and resources from the U.S. Environmental Protection Agency (EPA), state/local agencies, and industry. More than accountings of emission sources, inventory data are now providing the prime basis for operating permit fee systems, State Implementation Plan (SIP) development (including attainment strategy demonstrations), regional air quality dispersion modeling assessments, and control strategy development. This new emphasis on the use of emissions data will require significantly increased effort by state/local agencies to provide adequate, accurate, and transferrable information to meet various agency and regional program needs.

Existing emission inventory data collection, calculation, management, and reporting procedures are not sufficient or of high enough quality to meet all of these needs into the next century. To address these concerns, the Emission Inventory Improvement Program (EIIP) was created. The EIIP is a jointly sponsored endeavor of the State and Territorial Air Pollution Program Administrators/Association of Local Air Pollution Control Officials (STAPPA/ALAPCO) and the U.S. EPA, and is an outgrowth of recommendations put forth by the Standing Air Emissions Work Group (SAEWG) of STAPPA/ALAPCO. The EIIP Steering Committee and technical committees are composed of state/local agency, EPA, industry, consultant, and academic representatives. In general, technical committee participation is open to anyone.

The EIIP is defined as a program to develop and use standard procedures to collect, calculate, store, and report emissions data. Its ultimate goal is to provide cost-effective, reliable, and consistent inventories through the achievement of the following objectives:

- Produce a coordinated system of data measurement/calculation methods as a guide for estimating current and future source emissions;
- Produce consistent quality assurance/quality control (QA/QC) procedures applicable to all phases of all inventory programs;
- Improve the EPA/state/local agency/industry system of data collection, reporting, and transfer; and
- Produce an integrated source data reporting procedure that consolidates the many current reporting requirements;

EIIP goals and objectives are being addressed through the production of seven guidance and methodology volumes. These seven are:

- Volume I: Introduction and Use of EIIP Guidance for Emissions Inventory Development
- Volume II: Point Sources Preferred and Alternative Methods
- Volume III: Area Sources Preferred and Alternative Methods
- Volume IV: Mobile Sources Preferred and Alternative Methods
- Volume V: Biogenics Sources Preferred and Alternative Methods
- Volume VI: Quality Assurance Procedures
- Volume VII: Data Management Procedures

The purpose of each volume is to evaluate the existing guidance on emissions estimation techniques, and, where applicable, to identify the preferred and alternative emission estimation procedures. Another important objective in each volume is to identify gaps in existing methods, and to recommend activities necessary to fill the gaps. The preferred and alternative method findings are summarized in clear, consistent procedures so that both experienced and entry-level inventory personnel can execute them with a reasonable amount of time and effort. Sufficiently detailed references are provided to enable the reader to identify any supplementary information. Users should note that the number of source categories or topics covered in any volume is constantly expanding as a function of EIIP implementation and availability of new information.

It is anticipated that the EIIP materials will become the guidance standard for the emission inventory community. For this reason, the production of EIIP volumes will be a dynamic, iterative process where documents are updated over time as better data and scientific understanding support improved estimation, QA, and data management methods. The number of individual source categories addressed by the guidance will grow as well over time. The EIIP welcomes input and suggestion from all groups and individuals on how the volumes could be improved.

VOLUME IV: CHAPTER 2

# PREFERRED AND ALTERNATE METHODS FOR GATHERING AND LOCATING SPECIFIC EMISSION INVENTORY DATA

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# DISCLAIMER

This document was furnished to the Emission Inventory Improvement Program and the U.S. Environmental Protection Agency by EVIRON Corporation, Novato, California, and Sonoma Technology, Inc., Santa Rosa, California. This report is intended to be a final document and has been reviewed and approved for publication. The opinions, findings, and conclusions expressed represent a consensus of the members of the Mobile Sources Committee of the Emission Inventory Improvement Program. Any mention of company or product names does not constitute an endorsement by the U.S. Environmental Protection Agency.

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# 1
# INTRODUCTION AND SUMMARY

As part of the Emission Inventory Improvement Program (EIIP), The U.S. Environmental Protection Agency (EPA) is developing a number of guidance documents to provide information on potential ways of improving emission inventories. Two volumes present guidance on ways to improve the estimation of motor vehicle emissions. This volume presents guidance on the use of three specific data sources for use in developing distributions used in the MOBILE emission factor model. These distributions include registration, mileage accumulation, travel distributions, fuel consumption, and vehicle miles traveled (VMT). Volume II covers the use of transportation models to estimate variables such as VMT, reconciliation of VMT with the highway performance monitoring system (HPMS), speeds, trip durations, and operating mode weighting factors.

In this document, methodologies and example calculations of the estimation of local on-road vehicle fleet characteristics and activity from inspection and maintenance (I/M) program, remote sensing, and fuel sales data are presented. These data resources provide a relatively untapped source for the evaluation of local fleet characteristics and activity data. Specific evaluations include the estimation of mileage accumulation rates, registration distributions, diurnal travel distributions and regional vehicle miles traveled (VMT). This guidance is separated into three topics according to the type of data being evaluated:

- development of registration distributions and mileage accumulation rates from I/M program data;
- development of registration distributions, diurnal travel distributions, VMT mix, fleet registration information, and I/M program status from remote sensing program data; and
- development of fuel consumption and VMT from tax revenue and other data sources.

The provision of guidance on the three areas listed above is not intended to imply there are not other data sources, nor that all areas will be able to utilize the sources discussed. For example, some areas may not have remote sensing programs or have only small pilot programs. Others may have I/M programs that do not collect all the data needed for developing registration or mileage accumulation distributions. As another example, there are data sources such as the Truck Inventory and Use Survey, which is performed by the U.S. Department of Commerce. This survey is a source of data for registration and mileage accumulation for light, medium, and heavy-duty trucks. However, coverage of such sources is not within the scope of this document.

The remainder of this section briefly summarizes the methodologies covered in this report.

# DEVELOPMENT OF REGISTRATION DISTRIBUTIONS AND MILEAGE ACCUMULATION RATES FROM I/M PROGRAM DATA

Inspection and Maintenance (I/M) program data can be used to develop registration distributions and mileage accumulation rates for use in the MOBILE model. I/M programs are required in moderate and worse ozone nonattainment areas as well as in carbon monoxide nonattainment areas. The programs generally cover light- and medium-duty vehicles and sometimes include heavy-duty vehicles as well.

Registration distributions describe, for each vehicle class (i.e., light-duty autos), the fraction of vehicles of various ages (i.e., percent of light-duty autos that are 10 years old). The distribution is used in weighting the fleet emission factors. The default registration distribution in the MOBILE model is commonly used. This distribution represents the 1990 national average, derived from registration data maintained by R. L. Polk, and may be inappropriate for some areas of the U.S. Many areas have unique characteristics and may have significantly more older or newer vehicles than the national average. Since the registration distribution affects not only the calculated emission factors but also the calculated effectiveness of mobile source control measures, it is useful to have a locality-specific distribution. For example, a locality with many older vehicles would have a higher benefit from a retired vehicle program than would be estimated for this area if they used a national default registration distribution.

The vehicle mileage accumulation rates also affect calculated emission factors. Mileage accumulation, expressed as annual miles driven is used to calculate deterioration of the emissions as the vehicle ages. The mileage accumulation is also used in the calculation of vehicle travel fractions. There are significant differences between urban and rural areas, as well as among different areas of the U.S. in mileage accumulation by age. The default national mileage accumulation rate used in MOBILE was developed using national travel survey results.

The data collected by I/M programs generally include sufficient information to develop locality-specific distributions. As a part of registration requirements, most light-duty vehicles in nonattainment regions are required to submit to an I/M test. These data provide a logical opportunity for developing locality-specific registration and mileage accumulation distributions. The data collected in I/M programs that may be used to determine mileage and registrations distributions include:

- vehicle class (i.e., truck or auto),

- vehicle model year,
- license plate or Vehicle Identification Number (VIN),
- county of registration,
- date of test (useful since the data recorded on retests are often not as carefully recorded as the initial test), and
- odometer reading.

Some areas have already used I/M data to develop locality-specific mileage accumulation rate. California is an example of one state that has recently developed I/M-based rates. In California, the Bureau of Automotive Repair and the Air Resources Board (ARB) have developed distributions for various purposes, including use with California's emission factor model EMFAC to estimate mobile source emissions. A study was also performed for the EPA in 1985 that developed locality-specific distributions in Arizona, Connecticut, and Washington. Section 2 of this document reviews relevant literature on the use of I/M data for this purpose.

Section 2 also presents a detailed methodology for estimating the registration distributions and mileage accumulation rates, including data collection and initial analysis. This methodology is briefly summarized below. It is relatively straightforward to develop the distributions from the I/M data. For registration distributions, vehicle data from a given time period of an I/M program (i.e. a quarter or a year) are analyzed. Examining either license plates or VIN numbers, vehicles with more than one record in the data (due to retests, for example) are removed. Then, vehicles are grouped together by vehicle class. For each vehicle class, the number of vehicles of that class of a given age is divided by the total number of vehicles of that class to derive the fraction of the vehicles that are of a given age. The set of fractions is the registration distribution for a given vehicle class.

For mileage accumulation distributions similar steps are followed, except that two time periods of I/M data are needed. For example, in a biennial program, at least two years would be needed (for example, 1992 and 1994). After removing retests from each individual year, the number of miles accumulated on the odometer between the two years is divided by the number of days between tests and multiplied by 365 to estimate annual miles driven. Then vehicles of the same age are grouped together. For each group, the annual miles for each vehicle are summed together and this sum divided by the number of vehicles in the group to calculate the average annual miles for the age group.

When calculating annual mileage accumulation rates, there are several ways to handle unusual odometer readings. Many researchers remove odometer readings that indicate very low or very high accumulated mileage in a given time period. There is great variation in what is considered very low or high. It is recommended that the accumulated mileage be graphed before making these decisions to see whether there are obvious break points in the distribution. Odometer rollover may be indicated if the odometer reading from a later test is lower than for an earlier test. If 100,000 miles are added to the later reading and the estimated annual miles accumulated is within the limits decided upon, then rollover can be assumed. More detailed discussion of this issue is provided in Section 2.

# DEVELOPMENT OF FLEET CHARACTERISTICS AND ACTIVITY FROM REMOTE SENSING PROGRAM DATA

Data from large-scale remote sensing programs offer a valuable source of information that can be used to generate regional fleet characteristics data for input into the MOBILE emission factor model and mobile source emission inventory development. Vehicle license plates are typically recorded using video cameras as part of remote sensing programs. The license plates can be cross checked with state motor vehicle records providing valuable information on the characteristics of the local fleet. The potential areas of evaluation include vehicle registration distributions, fleet VMT mix, diurnal travel distributions, diesel sales fractions, evaluation of unregistered vehicles, and evaluation of vehicle county/state of origin to determine vehicle I/M status. Combining the license plate data with site location data allows for the evaluation of fleet data by region, subregion, or by facility class (i.e., roadway classification). Although there are physical limitations in the remote sensing apparatus that restrict its use to certain roadway facility and vehicle classes, the data can accurately evaluate the light-duty vehicle classes in several types of on-road locations.

The following data are typically collected in a remote sensing program and can be used to evaluate activity and characteristics of the vehicle fleet:

- site description and location,
- time of day,
- date of measurement,
- vehicle license plate,
- vehicle identification number (VIN),
- vehicle model year,
- vehicle class,
- vehicle fuel type,
- county and/or state of registration, and

- registration expiration date.

Of these, the last five items generally need to be determined from state registration records and/or through decoding the vehicle identification number (VIN). Complications may arise due to variation of state maintained data or due to VIN decoding limitations; these are discussed further in Section 3.

Section 3 of this document presents the methodologies and example calculations of the evaluation of fleet activity and characteristics data from remote sensing programs. In addition, this section also includes background information on related previous work in the form of a literature review. The methodology included in Section 3 provides step-by-step instructions for completing the evaluations and handling potential biases and limitations of the remote sensing database. The example calculations are based on remote sensing data recently collected as part of the California Pilot I/M Program. These data are from a large-scale remote sensing program completed in the city of Sacramento from July to September 1994. Over three hundred sites were evaluated and approximately two million valid remote sensing readings were obtained. Combining the remote sensing data with state records produced 1,329,694 remote sensing records with matched department of motor vehicle records; 47 percent coverage of the eligible Sacramento vehicle population was achieved.

## DEVELOPMENT OF FUEL CONSUMPTION AND VMT FROM TAX REVENUE AND OTHER DATA SOURCES

Section 4 describes procedures to estimate VMT based on fuel consumption and fuel economy. VMT estimates are an integral part of any mobile source emission inventory. Unfortunately, VMT estimates are also subject to substantial uncertainty, and can vary depending upon the tools used to develop current estimates and forecast future travel. Therefore, emission modelers may wish to use a simple screening tool in order to independently verify their VMT estimates. The fuels-based screening tool described in Section 4 can help analysts get a "ballpark" estimate for VMT based on how much fuel is consumed in a given area, and the expected fuel economy (in miles-per-gallon) of the vehicle fleet. This estimate can then be compared to VMT estimates produced through transportation demand modeling, the Highway Performance Monitoring System (HPMS), or other methods used locally. Major discrepancies between the ballpark estimate and traditionally generated VMT statistics should signal a need for further review and analysis. It should be noted that this screening method serves as a double-check, not as a replacement, for other estimation techniques.

The methodology to estimate VMT includes five steps:

1. Estimate on and off-road fuels use using Federal Highway Administration (FHWA) data. Fuel use is distinguished between gasoline and other fuels such as diesel.
2. Disaggregate state data for use at the county level using economic and population statistics.

3. Adjust fuel consumption figures to account for refueling losses using EPA or ARB data to make these adjustments. (Since the modifications made by this step are usually small, this step can be eliminated in most cases; the methodology includes this to be complete.)

4. Calculate fleet fuel economy using EPA data unless local data are available.

5. Estimate VMT based on the fuel consumption and fuel economy information developed in steps 1 through 4.

To better describe the methodology, Section 4 includes sample calculations for two metropolitan areas: Sacramento County, California and Maricopa County, Arizona.

# 2
# USE OF LOCAL I/M DATA TO DEVELOP REGISTRATION AND MILEAGE ACCUMULATION DISTRIBUTIONS

Two key inputs to the MOBILE model are the mileage accumulation rates and registration distributions. These distributions can significantly affect the calculated emission factors. Many nonattainment areas use the default registration and mileage accumulation distributions in the MOBILE model when developing emission factors. These default distributions are national and are not necessarily accurate for a given locality. The use of locality-specific registration and mileage accumulation distributions can increase the accuracy of the emission factors calculated by MOBILE. Inspection and Maintenance (I/M) program data can be used to develop area-specific registration distributions and mileage accumulation rates for use as MOBILE inputs. I/M program data bases normally include odometer readings, vehicle age, vehicle class, and data necessary to estimate miles accumulated between annual or biennial I/M tests. This section presents a literature review, describes the methodology for using I/M data to develop locality-specific registration and mileage accumulation distributions, and provides example calculations using a subset of a state I/M data base. While other data sources such as remote sensing data or surveys may also be used, they are not the subject of this chapter.

## INTRODUCTION

Mileage accumulation rates describe the average number of miles driven per year for a given vehicle class and age. Typically, vehicles are driven more when they are newer and less frequently as they age. The mileage accumulation rate is the main factor affecting the emission deterioration rate; the more miles on a vehicle the higher the predicted MOBILE5a emission rate.

Registration distributions describe the fraction of vehicles on the road by vehicle class and age. Registration distributions are combined with mileage accumulation rates to determine the weighting factors for each model year required for estimating total emissions by vehicle class. These weighting factors, also called travel fractions, describe the fraction of total vehicle miles traveled (VMT) for each model year and vehicle class. The distribution significantly affects emission rates; the age distribution of a given vehicle class determines the average emission rate from that vehicle class.

I/M data can be used to develop locality-specific registration and mileage accumulation distributions. I/M data from either centralized or decentralized areas can be used. Both maintain I/M data at a central location, and the I/M data collection methods are relatively standard. In this section we first review existing documents that describe such calculations or provide related guidance. We then describe in detail the methods of analysis that can be used to develop the registration and mileage accumulation distributions from local I/M data.

# LITERATURE REVIEW

The literature review covers areas that have used I/M data in developing registration data and mileage accumulation rates and other relevant literature. The first three references are summarized very briefly as they do not discuss specifically how to use I/M data in the development of registration distributions and mileage accumulations. However, they do provide a context for this type of analysis.

The following references were reviewed:

1. *Software Requirement Specification for TAS260 Vehicle Miles Traveled (BAR, 1994)*

2. *Analysis of Data from the California Enhanced I/M Program* (EPA, 1995),

3. *On-Road Motor Vehicle Activity Data Volume II: Vehicle Age Distribution and Mileage Accumulation Rate by County* (CARB, 1994),

4. *Methodology for Estimating Emissions from On-Road Motor Vehicles Volume II: Weight (E7FWT) by California Air Resources Board* (CARB, 1993); and

5. *Estimation of Mileage Accumulation Rates and I/M Failure Rates from I/M Program Data (EEA, 1985)*

6. *Volume IV: Mobile Sources, Procedures for Emission Inventory Preparation* (EPA, 1992),

7. *MOBILE5a User's Guide* (EPA, 1994),

8. *Federal Test Procedure Review Project Preliminary Technical Report* (EPA, 1993),

A review of these sources follows.

## SOFTWARE REQUIREMENT SPECIFICATION FOR TAS260 VEHICLE MILES TRAVELED (BAR, 1994)

This report discusses how the California Bureau of Automotive Repair (BAR) developed mileage accumulation estimates and registration distributions using I/M data. They use these distributions primarily for developing reports on vehicle miles traveled that summarize the number of vehicles, average miles traveled, standard deviation and error, average current and previous HC and CO readings, and the percent failing. These summaries are provided for five model year groupings for light-duty autos (1955-1971, 1972 - 1974, 1975-1979, 1980-1989, 1990 and newer). Totals are listed for light-duty trucks, medium-duty trucks, heavy-duty trucks.

BAR's methodology was to first match vehicles by license plate number using the earliest and the latest test dates when a license plate had more than one test in a given year. They then calculated the number of days between the tests and eliminated tests less than 300 days apart or more than 1100 days apart. If any of the following conditions occurred the data were also discarded:

- The vehicle was less than two years old and odometer showed more than 60,000 miles traveled in a year.
- The vehicle was two years old and odometer showed more than 50,000 miles traveled in a year.
- The vehicle was more than two years old and odometer showed more than 40,000 miles in a year.

The document does not discuss how this procedure was derived. Presumably it is intended to account for the fact that newer vehicles are driven more than older vehicles and therefore should have higher cut-offs. No tests were conducted for unusually low mileage. However, if the odometer showed fewer miles in a later test, than an earlier test, then the following adjustments were made:

1. 100,000 miles were added to the odometer reading in the current year.
2. The previous year odometer reading was subtracted from the current year reading.
3. If the result in Step 2 was greater than 100,000; 100,000 was subtracted from the result.

In order to calculate the number of miles traveled in a year, the odometer reading (plain or adjusted according to the above three steps) was divided by the number of days between the earliest and latest tests and multiplied by 365 to determine the vehicle miles traveled per year.

### ESTIMATION OF MILEAGE ACCUMULATION RATES AND I/M FAILURE RATES FROM I/M DATA (EEA, 1985).

The primary objective of this study was to derive annual mileage accumulation rates of light-duty autos and trucks as a function of age using I/M data. The report notes that the default mileage accumulation rates (in MOBILE2) were derived from a 1979 voluntary survey of families living in single unit households. The study utilized I/M data from Arizona, Washington, and Connecticut, which tested between 1.2 and 4.2 million vehicles per year. Energy and Environmental Analysis (EEA) used data from initial tests (as opposed to retests). Inspections were matched using the Vehicle Identification Number (VIN), vehicle make, license plate, and model year. In most cases the VIN number alone generated matches. In cases where VIN matching failed, the license plate, make, and model were matched. All three of these variables had to match in order for a match to be considered successful. The distinction between light-duty trucks and light-duty autos was made using VIN decoder software developed by the Highway Loss Data Institute called VINDICATOR. In cases where the VIN decoding software could only determine the model year within a range of years, the model year recorded by the I/M program was used to verify the results.

Data editing procedures focused on anomalous odometer readings. It was found that Arizona and Connecticut recorded only three-digit odometer readings in thousands of miles. The third digit was recorded only if the motorist told the inspector that the odometer had rolled over. In addition, it was found that in Seattle a two-digit odometer reading was recorded and listed as 99 if the motorist told the inspector that the odometer had rolled over. Therefore EEA deleted all odometer readings of 99. They also deleted odometer readings greater than 200,000 because they were concerned that higher readings indicated that the reading had potentially been shifted accidentally (as in 700,000 being recorded for 70,000).

In analyzing the data, EEA found high growth in the number of vehicles with low odometer readings as vehicles aged. This was a result of owners not reporting rollover to the inspectors. They also noted that there was a chance that an owner could report an odometer rollover in one year but not the next, potentially leading to an erroneous deduction of a second rollover.

EEA assumed that vehicles driving less than 500 miles per year were suspect, and eliminated vehicles which had over 60,000 miles per year.

They present an example calculation of mileage accumulation, which has the following steps:

1. Subtract latest odometer reading from previous reading.

2. If the difference is negative, add 100.

3. Determine the interval between test dates (in days).

4. Multiply the odometer reading by the ratio of 365 to the number of days calculated in step 3 to calculate the accumulation rate.

EEA found significant differences between states in mileage accumulation rates. For example, new Arizona light-duty autos traveled over 12,000 miles per year; the same vehicle classes in Seattle and Connecticut traveled over 14,000 per year (14,319 and 14,738, respectively). Cars more than twelve years old traveled 6,798 miles per year in Connecticut, 7,981 in Seattle, and 7,428 in Arizona.

**ON-ROAD MOTOR VEHICLE ACTIVITY DATA VOLUME II: VEHICLE AGE DISTRIBUTION AND MILEAGE ACCUMULATION RATE BY COUNTY (ARB, 1994).**

This study was performed by Valley Research Corporation (VRC) for the California Air Resources Board. The objectives of the study were to develop county level registration distributions and mileage accumulation rates based on California's I/M data. VRC used California Department of Motor Vehicle (DMV) registration records, BAR's I/M data, and the DMV's VIN decoding software in this effort.

Annual mileage accumulations were calculated using a pair of odometer readings from the same vehicle that were at least six months apart. The statewide average mileage accumulation rate was 11,061 miles per year and tended to be higher in urban than in rural areas.

VRC used the VIN number not only to match vehicles but also, whenever possible, to determine vehicle class, weight, and model year. The BAR data do include indicators for model year, whether auto or truck, fuel type, and gross vehicle weight; however, VRC believed the data were not necessarily correct although they do not indicate the reason for this belief. In order to determine the model year, VRC used the VIN number; when the VIN result produced an illogical result, the DMV data on the first year sold was used. For some reason, roughly only half the vehicles in the BAR database were matched and had more than one odometer reading (out of 24 million records, only 13 million were matched).

### VOLUME IV: MOBILE SOURCES, PROCEDURES FOR EMISSION INVENTORY PREPARATION (EPA, 1992).

This document discusses procedures for generating emissions for mobile sources, including on-road vehicles, aircraft, and locomotives. It also provides guidance on selecting MOBILE inputs such as registration distributions and mileage accumulation. Locality-specific mileage accumulation rates by age require 200 input values: for each of the 25 model years for each of the eight vehicle classes, the estimated annual mileage accumulation must be supplied. The same number of inputs is required for locality-specific registration distributions: for each vehicle type, a set of 25 values would be used to represent the fraction of all vehicles of that type that are a given age.

This volume cautions that local mileage accumulation data sources can be subject to sampling bias or data entry errors and recommends that local annual mileage accumulation rates should not change from one evaluation year to the next. It does not discuss recommended sample sizes.

### MOBILE5A USER'S GUIDE

The MOBILE users guide provides a detailed summary of the record formats for mileage accumulations rates and the registration distribution records. Once locality-specific mileage accumulation rates and registration distributions are developed, an agency may refer to these tables and the text from these sections of the users guide) particularly 2.2.3 in order to incorporate the distributions into the MOBILE model.

### FEDERAL TEST PROCEDURE REVIEW PROJECT PRELIMINARY TECHNICAL REPORT (EPA, 1993).

This report discusses the Federal Test Procedure, in-use driving emissions, driving survey methods, and test cycle development methods. It was suggested for review but does not contain information useful for this work effort.

## METHODOLOGY FOR CALCULATING REGISTRATION AND MILEAGE ACCUMULATION DISTRIBUTIONS USING INSPECTION AND MAINTENANCE PROGRAM DATA

This section presents methodologies for using Inspection and Maintenance (I/M) data to develop locality-specific registration distributions and mileage accumulation rates by vehicle class. The use of I/M data, which is usually available for virtually all registered vehicles in an area, can

provide a significant improvement in accuracy over the use of default values or of distributions developed using sampling methods such as traffic counts. These improvements can result in more accurate emission inventories and provide insight as to the most appropriate control measures. For example, if the locality-specific registration distribution shows a higher fraction of older light-duty vehicles than the defaults, the effect of a vehicle scrappage program will be shown to be higher. These methods are straightforward although there are some variations in the manner in which anomalies in the data can be identified and addressed.

In this section, data collection methods and issues are first described, including issues that should be considered when obtaining the data, data costs, formats, and initial processing. The initial processing is needed both for the development of mileage accumulation rates and registration distributions. Next, the methodology for developing registration distributions, including data processing procedures and the handling of issues such as unregistered or out-of-state vehicles is discussed. Finally, the methodology for developing mileage accumulation distributions, including data processing procedures, and how to identify and address anomalous odometer readings is described. Included in the methodology for calculating mileage accumulation distributions are suggested procedures that may be used to address anomalous odometer readings. A more qualitative evaluation of the odometer data can be substituted for these procedures to obtain reasonable results that are significant improvements over the use of default distributions.

## DATA COLLECTION

Obtaining I/M data will usually take at least one month after formally ordering the data from the appropriate agency. In most cases it is best to allow for approximately two to three months to fulfill the data request. It will also take time to identify the correct personnel and procedures for ordering.

There is great variation in the electronic media, format, costs, and staff availability to fill data requests. As these issues can become time consuming to the point that they over-ride technical considerations in actually developing the distributions, they are discussed in some detail below.

### *Ordering the Data*

Start by identifying the agency responsible for the I/M program in the state of interest. Often the best way to proceed will be to contact personnel with responsibility for mobile source issues at the state air agency. In some states the air agency itself will collect the data; in others the state Department of Motor Vehicles; in others, a private contractor responsible for the program. If a private contractor is responsible it will be helpful to alert the state air agency to your efforts to collect the data. This will give the agency the opportunity to monitor the contractor's procedures for transferring data as well as information on who in the state is developing local-specific data.

It is important to identify the appropriate office from which to order the data. For example, in New York state, the DMV Freedom of Information Office is responsible for I/M data.

It is also important to find out exactly what vehicles are tested and what data fields are available. Although I/M programs are legally required only for light-duty vehicles, some states also test medium and heavy duty vehicles. When this is the case, additional information regarding the extent and type of the program, the representation of diesel vehicles, and representation of vehicles registered out-of-state (if any) should be discussed.

***Data Costs***

There will often be a charge for the data, even if the data is requested by other agencies. In addition, the I/M program may not always collect the information necessary to differentiate between autos and trucks. This issue should also be discussed before ordering the data. Some states charge a flat fee for each month or quarter. For example, Arizona currently charges $185 per month of data. Others charge a nominal flat fee, often less than $10 plus any time used by a programmer to fulfill the request. Other states do not have established procedures and treat each request on a case-by-case basis.

***Data Formats***

Initially, consideration should be given to the quality of the data. Some areas have long periods for which the tape media upon which the data are recorded has been corrupted and cannot be used at all. Data needed for developing a registration distribution by county include vehicle age, vehicle class (LDA or LDT), and county of residence. Many I/M programs record these items directly. It is critical to be able to differentiate between autos and trucks, and the manner in which this is done should be discussed. If I/M data for vehicle class are missing or suspect, information from the VIN can be used. In 1980, an internationally used VIN number system was adopted by most auto manufacturers and can be used for 1981 and later vehicles. This system readily identifies a vehicle's model year, vehicle class, and gross vehicle weight. For vehicles manufactured prior to 1981, VIN decoding software such as the California Bureau of Auto Repair's VINI program or the Highway Data Loss Institute's VINDICATOR software can be used to determine the model year and vehicle class. However, VIN decoding software can be difficult to acquire and VRC rated its results as unreliable.

Many agencies routinely analyze the I/M data in various ways and therefore have the ability to develop subsets of the data. This can be helpful, as most raw I/M data records have close to one hundred fields and can be very awkward to manipulate. It is not uncommon to test a million cars a month; the volume of data is quite substantial. Given this, it can be very helpful to order only the data needed for the analysis (if the agency has the ability to provide it in this way).

The media upon which the data are supplied needs to be discussed with the providing agency. It is critical to know the precise characteristics of the data and media your agency or company can handle and be sure they are compatible with those of the agency providing the data. It is difficult to provide the data on floppy disks; even when compressed, millions of records can require numerous floppies. Common media are direct file transfer through modem or the Internet, 4 mm DAT tapes, 8 mm exobyte tapes, or 9 track tapes. Electronic mail should not be used to transfer large data sets because most electronic mail software cannot conveniently handle very large file sizes. Unless it is certain that your operating system and software are compatible with that being used by the transmitting agency, data are most easily transferred when written in ASCII format.

It is also important that data formats are understood. For example, some agencies record the odometer reading in thousands rather than the entire reading. A model year may be recorded as a four or a two-digit number. Similarly, missing data codes should be understood, listed in writing, and checked after receipt of the data. It is not uncommon for a missing data code to be useable as actual data (i.e. an odometer reading of "99").

Specific data needed for developing a registration distribution for a given time period (i.e. a year or a quarter) are:

- vehicle class (whether passenger car or truck, and the weight class for trucks),
- model year,
- test date,
- license plate and/or VIN code, and
- county of registration.

It is recommended that only the counties within the nonattainment area of interest be used (as opposed to the entire state). If there is a mix of both rural and urban counties in the nonattainment area it may even be desirable to develop two registration distributions, one for the urban and one for the rural counties.

Conceptually, to develop a registration distribution all that is needed are the vehicle class and model. However, vehicles will be tested more than once in a given time period if they fail a test or are sold. Inclusion of all records would thus bias the distributions. Data from the first test date should be used as records for the first test may often be more carefully completed than for a re-test. The license plate and/or VIN code can be used to identify vehicles that have been tested more than once.

A reasonable registration distribution can often be developed using less than one full year of data. Exceptions are areas where large numbers of vehicles of a certain type are registered at a particular time. For example, trucks in Arizona must be registered by the end of the year so that in November and December there is a disproportionate number of trucks being registered.

To develop a mileage accumulation distribution for two full time periods (i.e., two consecutive years for an annual program or four years for a biennial program), data needs are the same as listed above, with the addition of the odometer reading. For mileage accumulation, the test dates are critical since they establish the number of days between tests and therefore the information needed to calculate the number of miles driven per year. The license plates or VIN numbers are needed to match vehicles at two points in time.

### *Initial Processing*

It is recommended that after obtaining the data set, some basic checks be made to verify the written description of the data format, to verify missing data codes, and to check for biases that may be introduced due to entry practices. For example, it can be very useful to print out data records for retests to see whether vehicle data on retests is entered as completely as for initial tests. It would not be unusual to find the same odometer reading on a retest as on the initial test, even for tests several days or weeks apart. Simply to print out several records of the fields that are most critical for developing the distributions can be very helpful to look at questions such as: How are the odometer readings listed? How are the test dates shown? How do the listed vehicle class and weight classes correspond? Do the model years match the year first sold field?

## METHODOLOGY FOR REMOVING VEHICLES TESTED MORE THAN ONCE IN A TEST CYCLE FROM THE DATA SET

Repeated records for the same vehicle in a given test cycle (one year for annual program, two for a biannual program) need to be removed. For the registration distribution, vehicles that have been retested need to be removed because otherwise they will be counted twice in the registration distribution. Since most retests involve a failure of the emission test, not removing retests from the data will over-represent those vehicles which fail the first test and therefore bias the distributions. It is likely that many of these vehicles will be older vehicles. For the mileage accumulation, it is necessary to have a long period between retests in order to evaluate the average miles accumulated over a period of time. Most retests are performed within a month of the first test, which is not long enough to adequately represent annual miles accumulated since there is often several variation in travel. Some retests (i.e., for vehicles that have been sold in between cycles) may occur over six months apart, which may used to calculate a reasonable representation of annual miles, but attempting to retain these data is likely to entail more effort than justified by the benefit of including this small number of vehicles.

In order to determine whether more than one record for the same vehicle is present, the license plate number, the VIN number, or both can be compared. If the license plate alone is compared there is a smaller likelihood of data entry error than for the VIN number, which is much longer. If both the license plate and the VIN number are used to match, the likelihood of one of those being misrecorded is roughly the square of the likelihood that one would be in error.

If the license plate alone is compared, vehicles that have new license plates or license plates that have been entered in error will be counted twice. If there are license plate entries that erroneously duplicate the license plate of another vehicle, one will be mistakenly removed from the data set. If the VIN number alone is compared, vehicles will be counted twice if one of the test records is erroneous. If there are VIN number entries that are erroneously duplicated, the VIN number of another vehicle will be mistakenly removed from the data set. This latter case is less likely to occur (because of the size of the VIN number) than for license plates. If the combination of VIN and license plate numbers is used to indicate unique vehicles, it is very unlikely that any vehicles would be counted twice. However, a large number of vehicles may be removed from the data set due to data entry errors for either the VIN or the license plate. Since the number of data entry errors is highest when matching on both the VIN and license plate number, and higher when matching on the VIN than on the license plate, it is recommended that license plate matching alone be performed. This will minimize the amount of data thrown out when a valid match could have been made.[1]

In the absence of data base software that can generate unique record identifiers, the simplest approach for removing retested vehicles is to write a brief computer program that stores the data for each record. The license plate or VIN number (or both) on each new record is compared to the stored records to check whether that license plate or VIN number has been recorded before. If it has, and the record is for a later test that record would not be used. If the license plate or VIN number has been stored already but the test date is earlier, then the record with the newer test date should be removed from the data set.

## METHODOLOGY FOR DEVELOPING THE REGISTRATION DISTRIBUTION

The registration distribution is a series of percentages of vehicles by age and class. For example, the portion of the registration distribution for light-duty passenger autos will list, for each vehicle age, the percent of light-duty autos that are of that age. Perhaps six percent would be one year old vehicles, eight percent would be two year old vehicles, and so forth; the percentages by age sum up to 100 percent. The methodology for developing the registration distribution is relatively straightforward. The steps to be followed are described here.

[1] Another factor to consider is the availability of "vanity" plates. In states where vanity plates are available, VIN matching may be preferable if vanity plates are popular (because converting from a regular plate to a vanity plate will create a mismatch).

### *Evaluate the Overall Characteristics of the Data*

Calculate the total number of light-duty autos and light-duty trucks in the data set. If there are other vehicle classes represented, total these also. From these values, calculate the fraction of light-duty autos, trucks and any vehicle classes that are present. Ensure that these are reasonable before proceeding further. A typical light-duty vehicle class distribution is 75 percent autos and 25 percent trucks although some areas may have higher percentages of trucks, such as Montana or Wyoming. If the distributions seem unreasonable, the vehicle class information in the data may not be accurate. In this case the agency providing the data should be contacted and the data reevaluated in light of the new information obtained.

Calculate the number of vehicles of each age and vehicle class and then divide the total by the number in that vehicle class to obtain the registration distribution. This is shown by the following equation.

$$MYDist_{I,\ unadjusted} = \frac{\sum POP_I}{\sum POP}$$

where:

*MYDist* is the model year registration distribution for a given vehicle class for model year I, and

*POP* is the vehicle population for that vehicle class for model year I.

For light-duty vehicles, MOBILE requires a combined registration distribution for diesel and gasoline vehicles. MOBILE has diesel and gasoline sales fractions it will use to adjust these vehicle classes internally to the model. Any vehicles greater than 25 years old should be counted as 25 years old. Also note that MOBILE does not distinguish emission factors for motorcycles more than twelve years old. Therefore, any motorcycles that are more than twelve years old should be included in the count for twelve-year old motorcycles.

### *Adjust the Distribution to July 1*

The distribution needs to be adjusted to a July 1 distribution to reflect vehicle sales in the months prior to the model year and fleet turnover during the year. Specifics of the calculations needed for this adjustment are provided in Section 3. Write out the fractions in the format specified for MOBILE in Table 2-1. Note that there will be 200 values entered: fractions for each of the 25 model years for all vehicle classes except motorcycles. For motorcycles, write ".000" for

motorcycles aged 13 to 25. If I/M data are not available for a particular vehicle class, write out the MOBILE defaults for that class unless a registration distribution for that class has been developed through an alternate method. Compare the calculated fractions to the default values in MOBILE or to previously developed distributions to ensure that they appear reasonable.

### *Unregistered Vehicles*

I/M data will of course not be available for non-registered vehicles, out-of-state vehicles, and out-of-country vehicles. Such vehicles could contribute disproportionately to the actual registration distribution and hence to estimated emissions but are difficult to account for.

A recent survey in California showed that roughly nine percent of the vehicles on the road are unregistered (Sierra, 1992). However, this does not mean that all of these vehicles will never be registered. As shown in Figure 2-1, many unregistered vehicles are registered within a few months of expiration and nearly all unregistered vehicles are registered within two years of expiration. This figure does not account for out-of-state vehicles. In areas located along the Mexican border, it may be especially useful to account for out-of-state vehicles.

The only accurate way to account for unregistered and out-of-state vehicles is to perform a survey. The Sierra (1992) survey for California's Air Resources Board looked at the registration status of approximately 30,000 vehicles in parking lots in the Los Angeles area. While this survey focused on registration tags, it would be straightforward to modify a similar survey to include out-of-state vehicle counts. No such studies were identified in the course of preparing this document.

## METHODOLOGY FOR DEVELOPING THE MILEAGE ACCUMULATION DISTRIBUTION

Development of the mileage accumulation distribution is more complex than development of the registration distribution. Data required include vehicle age, vehicle class, and two or more odometer readings from each vehicle. This methodology focuses on mileage accumulation by vehicle age (i.e., a ten-year-old vehicle is assumed to drive the same number of miles in the year 2000 as a ten-year-old vehicle in 1995), as is currently required in MOBILE5a. In California, county-specific mileage accumulation rates that are also model-year specific were developed for use in the EMFAC7F model (which calculates California-specific motor vehicle emission factors). Development of model-year specific mileage accumulation distributions can capture important variability in specific years as well as any trends in driving patterns (for example average driving distances to work becoming longer). However, this approach would necessitate updating mileage accumulation distributions annually. Further, model-year specific mileage accumulation rates cannot be readily incorporated into the current version of the MOBILE model.

Briefly, the methodology entails averaging annual miles accumulated by vehicles of a given age and listing out the average for each vehicle age in the format specified in Table 2-2. The basic procedure is described below. Procedures for addressing anomalous odometer readings are then described. Note that the steps described should not be applied until anomalous odometer readings have been either adjusted or removed from the data set.

***Developing Data Sets of Unique Vehicles and Initial Processing***

Develop, for each year of data, a data set containing only unique vehicles using one of the approaches described above. It is recommended that a count of vehicles by model year and vehicle class also be made at this time to evaluate whether the number of vehicles of a given age is large enough to yield a reliable estimate of average annual miles driven by a vehicle of that age: the more vehicles in a given age group, the more reliable the average annual miles will be. Typically the oldest age groups will have the smallest fraction of vehicles; it is recommended that the data base be large enough to have at least hundred vehicles in each of the age groups.[2]

Additional data summaries should also be examined, including:

- the range of raw odometer readings,
- a frequency distribution of raw odometer readings, and
- average odometer readings by vehicle age

This summary information can be valuable in determining whether the data set will be adequate to develop the distribution, and whether there are particular vehicle ages in the data set that have a high frequency of unusual odometer readings or significantly higher variation in the odometer readings than other vehicle ages. Note that the variation in odometer readings is likely to be larger for older vehicles.

***Calculate the Annual Miles Driven by Each Vehicle***

Subtract the earliest odometer reading from the later reading and divide by the number of days between the two readings. If the difference between the odometer readings is negative, add 100,000 to account for odometer rollover. The value of the average daily miles is equal to the number of miles driven between retests divided by the number of days between tests.

Subtracting the earliest odometer reading from the latest odometer reading and subtracting the corresponding test dates (counting January one of the first test year as day one and January 1 of

[2]Based on our analysis of the example Arizona I/M data base, approximately 200 vehicles would be required in each age group in order to estimate the average annual mileage for each group within an uncertainty range of plus or minus 1000 miles.

the second test year as day 366 as long as the first test year was not a leap year), then multiplying by 365 will yield the annual miles for a vehicle. If annual miles are less than a specified minimum or maximum (see section on anomalous odometer readings) the record can be removed from the data.

To calculate average annual miles across vehicles within an age group, first group the vehicles by age. It is recommended that vehicles older than 25 years be included in the set of 25-year old vehicles.

Next, sum the annual miles for all vehicles in a group (i.e., sum annual miles for all 10-year-old vehicles). Lastly, divide the sum of the annual miles by the number of vehicles in the age group.

Write out mileage accumulation to input into MOBILE according to the format specified in Table 2-2. Compare them to the default mileage accumulation rates currently used in MOBILE5 are listed in Table 2-3. For comparison, mileage accumulation rates calculated using California I/M data are presented in Table 2-4. Note: mileage accumulation rates for one-year old vehicles cannot be calculated. However, they may be estimated by fitting an exponential curve to the data for the 2 year and older vehicles.

### ANOMALOUS ODOMETER READINGS

When developing the mileage accumulation rates it is likely that some of the odometer readings will not make sense. Some readings will imply unusually high or low miles per year; some are recorded incorrectly; some individuals tamper with the odometers; and some odometers only have five digits and do not register rollover after 100,000 miles. Table 2-5 presents some examples of how researchers have addressed these issues. It is recommended that three general factors be considered when addressing anomalous odometer readings:

1. The annual mileage accumulation will be an average for a large number of vehicles and should not be unduly influenced by a few outliers that are incorrectly handled due to the procedures used to address outliers. Any reasonable procedure for identifying unusual odometer readings will be able to correct most of them. No procedure will be able to identify and correct for all the anomalous readings.

2. The specific procedure chosen should be guided by the data itself. It is useful to graph (at a minimum for all vehicle ages combined) annual mileage accumulation at different ranges (for example in 2,000 mile increments) and the percentage (and/or absolute number) of vehicles driving at each range. In most cases it will be obvious what the outliers are; the graph will tail off smoothly at the higher accumulations and suddenly there will be a jump. When there is an obvious point at which the distribution seems to "jump", which will generally be in the

neighborhood of 50,000 miles per year, that can be used as the maximum annual mileage allowed in the data set.

3. In a few cases, more detailed analysis may be helpful. If the distribution does not break at any particular point and there are many vehicles which drive unusually high numbers of miles, one can fit a distribution to the data and use the fitted distribution to approximate at least the upper tail. An example of data where there is no obvious place to "break" the distribution is presented in Figure 2-2.

Later in this chapter an example mileage accumulation calculation is presented using each of the four sets of decision criteria listed in Table 2-5. It is noted there that using a mileage cut-off of 100,000 miles resulted in a distribution significantly higher from all the others. In addition, the distribution implied that as vehicles aged, they drove more miles per year than newer vehicles. The use of such a high cut-off can introduce bias since it is so much higher than the average miles driven (approximately 12,000 miles per year). The other three sets of decision criteria resulted in distributions that were similar in shape to each other and to the MOBILE default. Therefore it is recommended that one of these be used.

***Odometer Rollover***

Odometer rollover is likely when a later odometer reading is lower than the earlier reading. It is also possible that a lower odometer reading indicates odometer tampering, or there could be a data entry error. If after adding 100,000 to the difference in odometer readings the annual miles calculated falls within the limits decided upon in the steps above, it is recommended that the reading be assumed reliable.

# EXAMPLE APPLICATION

This subsection presents examples of calculating registration and mileage accumulation distributions from I/M data using data from Arizona's I/M program. Several states and both centralized and decentralized programs were considered for use in the example. The decision to use Arizona data for the example was based on the fact that it was the first state for which two usable years of I/M data were obtained and not because of any lack of data quality in the other states considered.

## DESCRIPTION OF THE ARIZONA I/M DATA

Arizona has maintained an annual basic I/M program for many years. Arizona tests medium and heavy duty vehicles in addition to light duty autos and trucks. In 1995 they began a biennial enhanced I/M program for 1981 and newer vehicles, run by a contractor. Electronic files are maintained by the contractor for 12 months after collection and are then transferred to the Arizona Department of Environmental Quality (ADEQ) for storage in archives.

Data were obtained for March, 1994 and 1995 for the example. If the data were intended for use in actual inventory development it would be advisable to use at least three consecutive months in each of two years to increase the number of vehicles in the database. This will increase the sample size by including I/M tests made in the month before or after the month for which they are scheduled. In this example this is particularly important because of the 1995 implementation of the biennial enhanced program, which tested 50 percent of 1981 and newer vehicles in 1995. The effect was to lessen the sample size of 1981 and newer vehicles. In states where a biennial program has been in place for a number of years, it would be preferable to obtain three years worth of data; in Arizona two consecutive years were useable since the program had just begun and since 1981 and older vehicles were still subject to annual tests.

Data used in this example included the test date, vehicle identification number, license plate, vehicle make, vehicle model year, vehicle style, vehicle fuel code, indicator for initial or retest, weight class, number of cylinders, and odometer reading. It was initially expected that these data would be sufficient to differentiate between light duty autos and light duty trucks but this was not actually the case. In a real-world application, VIN decoding software or access to DMV data would need to be utilized in order to differentiate between autos and trucks as there may be significant differences in mileage accumulation and often in the registration distributions as well. For the purpose of this example calculation this step was not taken.

There were 196,132 records in the March, 1994 data and 159,028 in the March, 1995 data. After deleting retested vehicles there were roughly 164,000 records for 1994 and 131,000 for 1995. 62,007 vehicles, or approximately 47 percent, were matched based on the VIN number. This match rate would be increased if more than a single month were used[3]. The match rate was also lowered due to the implementation of the biennial program so that only half the 1981 and newer vehicles were tested in 1995, whereas all had been required to be tested in 1994. Of these 62,000

[3] For example, an analysis of two full years of British Columbia Inspection and Maintenance Program data conducted for this document showed that roughly 50 percent of vehicles are matched when one month is used and 75 percent when neighboring months are used. For example, a 75 percent match rate was observed when vehicles from February-April were matched against vehicles tested in March of a different year. This is the result of individuals having their vehicles tested earlier or later than the deadline.

matches, 4,311, or seven percent, had invalid odometer readings (defined as zero or blank entries in the odometer field).

## EXAMPLE APPLICATION FOR REGISTRATION DISTRIBUTION

A registration distribution for all light duty vehicles was estimated for 1993 and older vehicles using the 1994 data. The 1995 data was not used for developing a registration distribution as only 50 percent of the 1981 and newer vehicles were present in the data. In a real-world application involving a partially annual and partially biennial program it would be necessary to calculate distributions separately for vehicles subject to the annual program and to the biennial program and then normalize them in order to combine them into one distribution.

Before developing the registration distribution, obvious anomalies in the data were identified and deleted. For example, there were two vehicles with obviously invalid model years of 1995 and 1999 in the March, 1994 data. Repeated records for the same vehicle, such as retests were also removed.

As discussed previously, the Arizona I/M program data does not explicitly differentiate between autos and trucks. This is quite common; an informal survey revealed that most states rely on VIN decoding software to distinguish between autos and trucks although some are planning to change the I/M program to require that a distinction be made on the I/M record. It is reportedly not always possible to make this distinction through visual inspection alone.

MOBILE calculates emission factors for vehicles up to 25 years old. Vehicles older than 25 years are placed in the 25 year old category. In keeping with this, all vehicles older than 25 years were counted as 25 year old vehicles.

Figure 2-3 presents a comparison of the MOBILE5 registration distribution for all light duty vehicles with the registration distribution calculated using the Arizona data. The MOBILE light duty autos and trucks were combined together by weighting them according to the default light duty auto and light duty truck travel fractions assumed in MOBILE. In this example, the differences are significant in the older vehicles which also have the highest prevalence of high emitting vehicles. There are striking differences in the later model years, with the Arizona registration distribution being either much higher or much lower than the default MOBILE distribution for corresponding years.

Note that the distribution does not include 1993. In Arizona, as well as many other states, vehicles are not required to undergo an I/M test in their first year unless they are resold.

## EXAMPLE APPLICATION FOR MILEAGE ACCUMULATION

The data were first examined for odometer changes that were clearly anomalous. A simple anomaly was when the difference in odometer readings between the two years was negative or zero. Fully seventeen percent of the records had such differences. A visual inspection showed that some were clearly rollovers while others were apparently errors or the result of tampering.

The odometer readings were then processed so that any mileage difference that was negative was assumed to be due to odometer rollover and 100,000 miles were added to the reading. After doing this, 1.1 percent were still negative and 3.7 percent were still greater than or equal to 100,000 miles.

The annual miles calculated after adding 100,000 miles to negative mileages are presented in Figure 2-4. Most of the vehicles are seen to drive near the national average annual miles driven although the distribution has a long tail showing very high annual miles.

Mileage accumulation distributions were then calculated using each of the sets of decision criteria listed in Table 2-5. These are graphed in Figures 2-5 and 2-6. Figure 2-5 shows all four distributions along with the MOBILE default distribution. Each distribution shows higher miles per year than the MOBILE default. The VRC truncation approach, which accepts as valid vehicles listed as driving up to 100,000 miles per year, is significantly higher that all the other distributions. The average miles driven per year with the VRC approach is 20,000 miles. The average of the next highest approach, that of BAR, is 11,300. The high number of older vehicles with calculated high annual miles is thought to be due to a higher incidence of tampering and errors in entering the odometer reading. Since odometers are more likely to be tampered in older vehicles, the fraction of high calculated mileages (i.e., between 40,000 and 100,000 miles) for older vehicles would also increase; this is what was observed in the Arizona data.

Figure 2-6 presents the EEA, BAR, and CARB distributions graphed on a scale that allows the differences between them to be more clearly seen. The MOBILE default distribution forms a smooth curve downward, starting at approximately 14,000 miles per year. The CARB distribution is lower than the MOBILE default for newer vehicles up to five years old and is higher for all later model vehicles. The EEA and BAR distributions are higher than the MOBILE distribution for all years. The BAR distribution is slightly higher in the first year than the EEA distribution because the BAR distribution allows for higher mileage the first year than the EEA distribution does.

**Table 2-1**
**Summary of registration distribution by age Records**
**(required if MYMRFG = 3 or 4)**

| Record | Field | Content and Description | Format | Allowable Value |
|---|---|---|---|---|
| 1 | 1-10 | Registration distribution fractions[2] for LDGVs[3] of ages 1,2,...,10 | 10F5.3/ | 0.0 - 1.0 |
| 2 | 1-10 | Registration distribution fractions[2] for LDGVs[3] of ages 11,12,...,20 | 10F5.3/ | 0.0 - 1.0 |
| 3 | 1-5 | Registration distribution fractions[2] for LDGVs[3] of ages 21,22,...,25+ | 5F5.3/ | 0.0 - 1.0 |
| 4 | 1-10 | Registration distribution fractions[2] for LDGTs[3] of ages 1,2, ..., 10 | 10F5.3/ | 0.0 - 1.0 |
| 5 | 1-10 | Registration distribution fractions[2] for LDGTs[3] of ages 11,12, ..., 20 | 10F5.3/ | 0.0 - 1.0 |
| 6 | 1-5 | Registration distribution fractions[2] for LDGTs[3] of ages 21,22, ..., 205+ | 5F5.3/ | 0.0 - 1.0 |
| 7-9[4] | | Registration distribution fractions[2] for LDGT2s | | |
| 10-12[4] | | Registration distribution fractions[2] for HDGVs | | |
| 13-15[4] | | Registration distribution fractions[2] for LDDVs[3] | | |
| 16-18[4] | | Registration distribution fractions[2] for LDDTs[3] | | |
| 19-21[4] | | Registration distribution fractions[2] for HDDVs3 | | |
| 22-24[4 5] | | Registration distribution fractions[2] for MCs | | |

Source: "MOBILE5 User's Guide"

1 If both annual mileage accumulation rates and registration distributions by age are being input (MYMRFG=4), the two sets of values must be internally consistent (see section 2.2.3.4).
2 Values must sum to 1.0 for each vehicle type. The registration distribution entered as data for MOBILE5 should be based on July 1; MOBILE5 will convert them to a January 1 distribution if emission factors for January 1 are requested.
3 The same set of registration distribution fractions must be entered for LDGVs and LDDVs, and the same set of LDGT1s and LDDTs (see section 2.2.3.4).
4 Record continue in sets of three per vehicle type, following the structure shown above for LDGVs and LDGT1s.
5 For motorcycles only, values of .000 should be used for ages 13 through 25+ (see section 2.2.3.4).

**Table 2-2**
**Summary of annual mileage accumulation rates Records**
**(required if MYMRFG = 2 or 4[1])**

| Record | Field | Content and Description | Format | Allowable Value |
|---|---|---|---|---|
| 1 | 1-10 | Average Annual mileage accumulation [2] for LDGVs of ages 1,2, ..., 10 | 10F7.5/ | ≥0.0 |
| 2 | 1- | Average Annual mileage accumulation[2] for LDGVs of ages 11,12,..., 20 | 10F7.5/ | ≥0.0 |
| 3 | 1-5 | Average Annual mileage accumulation[2] for LDGVs of ages 21,22,..., 25+ | 5F5.3/ | ≥0.0 |
| 4 | 1-10 | Average Annual mileage accumulation[2] for LDGT1s of ages 1,2,..., 10 | 10F7.5/ | ≥0.0 |
| 5 | 1-10 | Average Annual mileage accumulation[2] for LDGT1s of ages 11,12,..., 20 | 10F7.5/ | ≥0.0 |
| 6 | 1-5 | Average Annual mileage accumulation[2] for LDGT1s of ages 21,22,..., 25+ | 5F7.5/ | ≥0.0 |
| 7-9[3] | | Average annual mileage accumulation[2] for LDGT2s | | |
| 10-12[3] | | Average annual mileage accumulation[2] for HDGVs | | |
| 13-15[3] | | Average annual mileage accumulation[2] for LDDVs | | |
| 16-18[3] | | Average annual mileage accumulation[2] for LDDTs | | |
| 19-21[3] | | Average annual mileage accumulation[2] for HDDVs | | |
| 22-24[3,4] | | Average annual mileage accumulation[2] for MCs | | |

Source: "MOBILE5 User's Guide"

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1 If both annual mileage accumulation rates and registration distributions by age are being input (MYMRFG=4), the two sets of values must be internally consistent (see section 2.2.3.4).
2 Values as input as miles/100,000 (e.g.,24,358 miles in input as .23458
3 Record continue in sets of three per vehicle type, following the structure shown above for LDGVs and LDGT1s.
4 For motorcycles only, values of .00000 should be used for ages 13 through 25+ (see section 2.2.3.3).

**Table 2-3**
**MOBILE5 default mileage accumulation rates per vehicle by vehicle class**

| Age | LDGV | LDGT1 | LDGT2 | HDGV | LDDV | LDDT | MC |
|---|---|---|---|---|---|---|---|
| 1 | .14390 | .15442 | .14779 | .17251 | .17825 | .21004 | .04786 |
| 2 | .13612 | .14508 | .14259 | .16185 | .16478 | .19125 | .04475 |
| 3 | .12875 | .13631 | .13758 | .15185 | .15233 | .17415 | .04164 |
| 4 | .12180 | .12807 | .13275 | .14246 | .14081 | .15858 | .03853 |
| 5 | .11522 | .12032 | .12809 | .13365 | .13017 | .14440 | .03543 |
| 6 | .10899 | .11305 | .12359 | .12539 | .12033 | .13149 | .03232 |
| 7 | .10310 | .10621 | .11924 | .11764 | .11124 | .11973 | .02921 |
| 8 | .09751 | .09979 | .11505 | .11037 | .10283 | .10902 | .02611 |
| 9 | .09225 | .09376 | .11101 | .10355 | .09506 | .09927 | .02300 |
| 10 | .08726 | .08809 | .10711 | .09715 | .08788 | .09040 | .01989 |
| 11 | .08254 | 0.8276 | .10335 | .09114 | .08123 | .08231 | .01678 |
| 12 | .07807 | .07776 | .09972 | .08551 | .07509 | .07495 | .01368 |
| 13 | .07386 | .07306 | .09621 | .08022 | .06942 | .06825 | .00000 |
| 14 | .06987 | .06864 | .09283 | .07526 | .06417 | .06215 | .00000 |
| 15 | .06608 | .06449 | .08957 | .07061 | .05932 | .05659 | .00000 |
| 16 | .06251 | .06059 | .08642 | .06625 | .05484 | .05153 | .00000 |
| 17 | .05913 | .05693 | .08339 | .06215 | .05069 | .04692 | .00000 |
| 18 | .05594 | .05348 | .08046 | .05831 | .04686 | .04272 | .00000 |
| 19 | .05291 | .05025 | .07763 | .05471 | .04332 | .03890 | .00000 |
| 20 | .05005 | .04721 | .07490 | .05132 | .04005 | .03543 | .00000 |
| 21 | .04735 | .04436 | .07227 | .04815 | .03702 | .03226 | .00000 |
| 22 | .04478 | .04168 | .06973 | .04517 | .03422 | .02937 | .00000 |
| 23 | .04237 | .03916 | .06728 | .04238 | .03163 | .02675 | .00000 |
| 24 | .04007 | .03679 | .06492 | .03976 | .02924 | .02435 | .00000 |
| 25+ | .03790 | .03456 | .06264 | .03730 | .02703 | .02218 | .00000 |

**Table 2-4**
**Mileage accumulation rates calculated in California using I/M and DMVdata**

| | | Mileage Accumulation | | |
|---|---|---|---|---|
| Age | Year | Autos | LDTs | MDVs |
| 0 | 92 | 13002 | 14348 | 9602 |
| 1 | 92 | 15772 | 14954 | 13582 |
| 2 | 91 | 13826 | 15448 | 20083 |
| 3 | 90 | 13872 | 15999 | 16859 |
| 4 | 89 | 13447 | 15387 | 15534 |
| 5 | 88 | 12942 | 14550 | 15259 |
| 6 | 87 | 12300 | 13635 | 13911 |
| 7 | 86 | 11634 | 12921 | 12314 |
| 8 | 85 | 11046 | 12072 | 12264 |
| 9 | 84 | 10551 | 11362 | 11722 |
| 10 | 83 | 10189 | 10724 | 11497 |
| 11 | 82 | 9906 | 10592 | 10318 |
| 12 | 81 | 9771 | 10330 | 9438 |
| 13 | 80 | 9804 | 10097 | 10407 |
| 14 | 79 | 9187 | 9729 | 9771 |
| 15 | 78 | 8912 | 9516 | 10552 |
| 16 | 77 | 8586 | 9323 | 10147 |
| 17 | 76 | 8322 | 9276 | 8644 |
| 18 | 75 | 8057 | 9400 | 8819 |
| 19 | 74 | 8221 | 9160 | 9535 |
| 20 | 73 | 7770 | 8859 | 8593 |
| 21 | 72 | 7654 | 8646 | 9060 |
| 22 | 71 | 7875 | 8322 | 10373 |
| 23 | 70 | 7803 | 8159 | 8680 |
| 24 | 69 | 7720 | 8207 | 7542 |
| 25 | 68 | 7516 | 7994 | 5462 |

**Table 2-5**
**Summary of decision criteria used in development of mileage accumulation rates from I/M data**

| Study | Vehicle Matching | **Low mileage cut-off (miles per year)** | **High Mileage Cut-off (miles per year)** | **Minimum Time Between Tests** |
|---|---|---|---|---|
| BAR, 1994 | License plate | None | 60,000 for vehicles < 2 years old; 50,000 for vehicles 2 years old and 40,000 for vehicles > 2 years old | 300 days |
| EEA, 1985 | VIN number or combination of license, make and model year | 500 | 40,000 | none |
| VRC, 1994 | VIN number | 0 | 100,000 | 6 months |
| ARB, 1993 | License Plate | 0 | 30,000 | Not discussed |

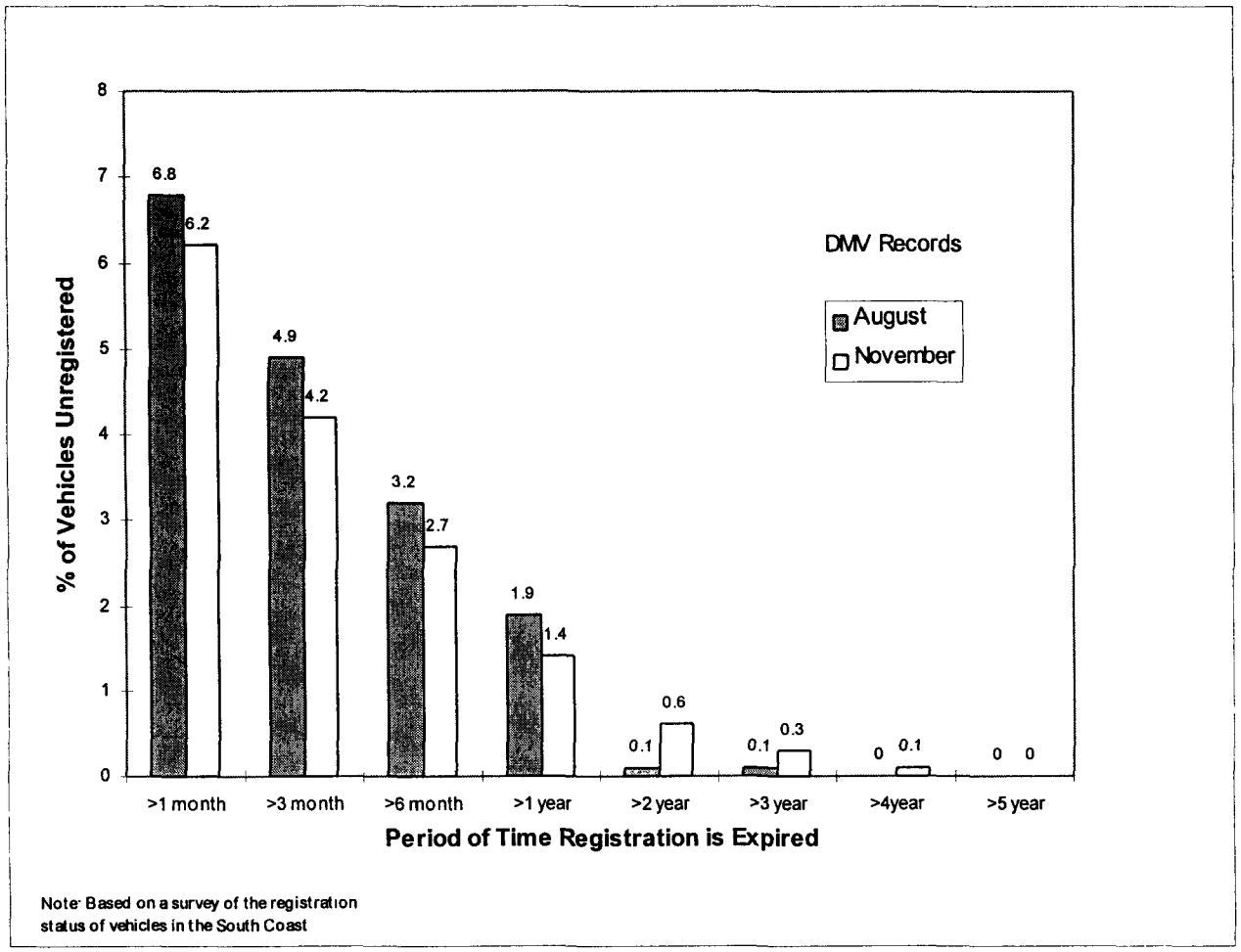


**Figure 2-1**
**Relationship between registration status of California vehicles and period of time with expired registrations. Source: "Status Report - Unregistered Vehicle Survey," ARB, July 25, 1990**

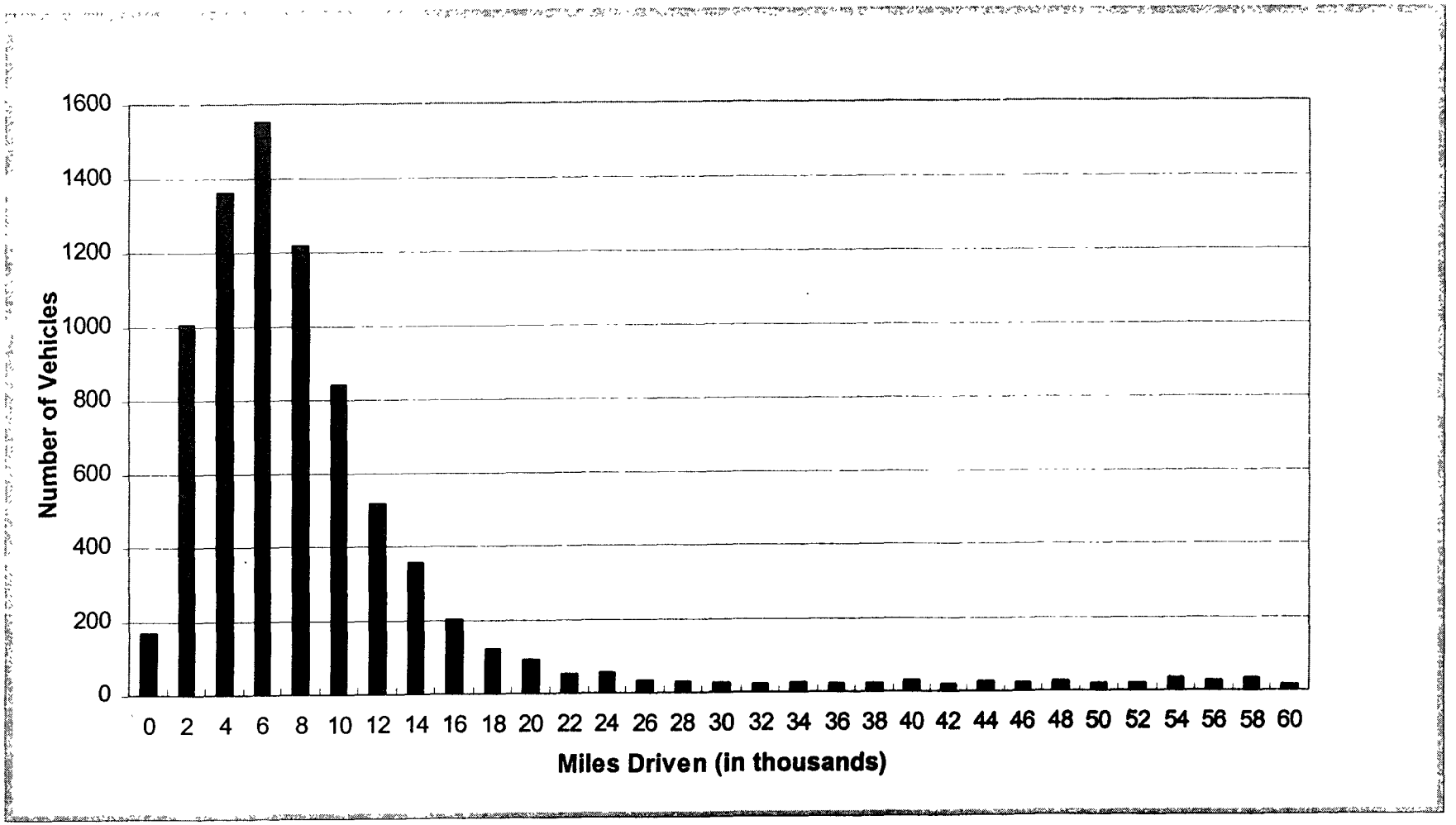


**Figure 2-2**
**Example mileage accumulation distribution**

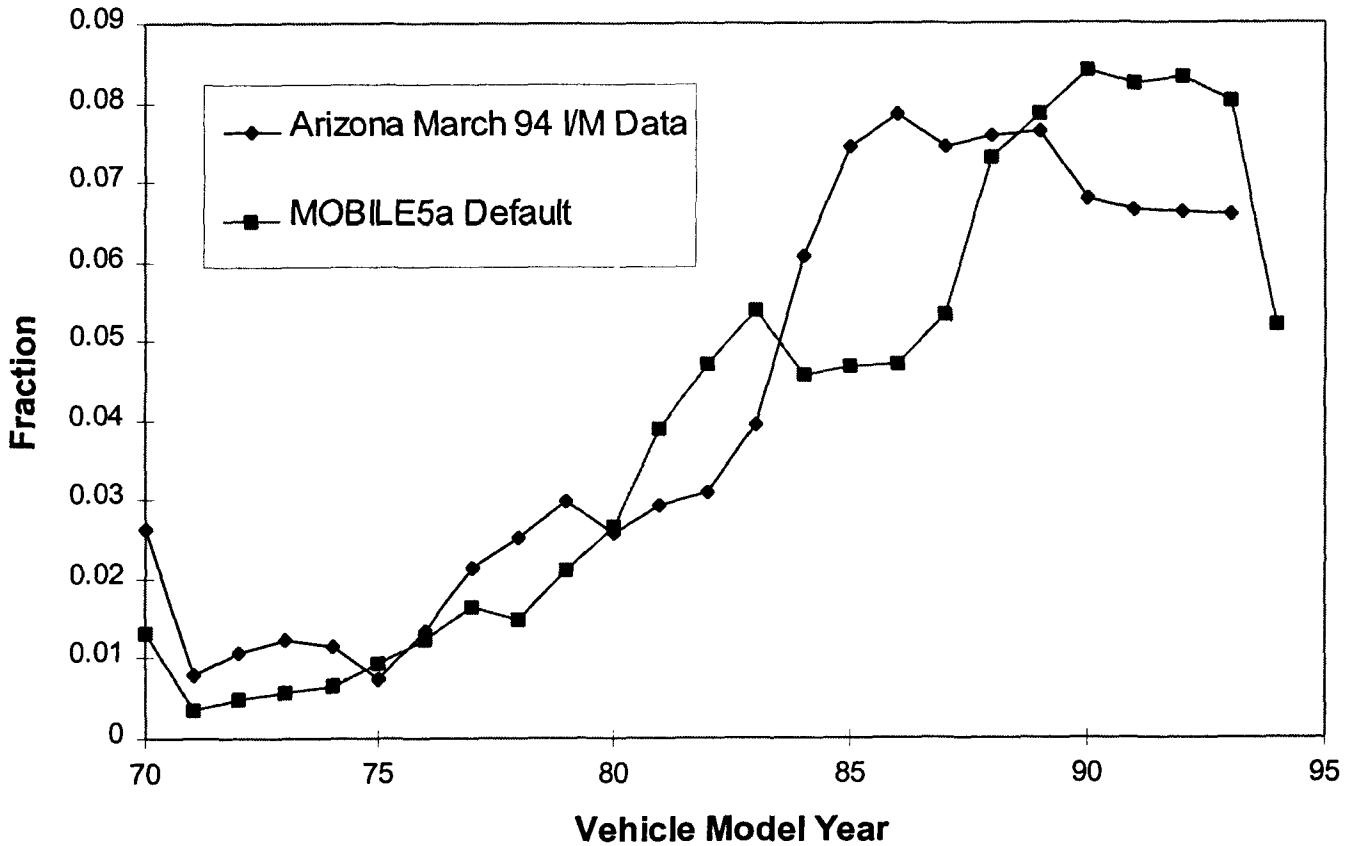


**Figure 2-3**
**Comparison of MOBILE5 and ArizonaI/M data base registration distributions for all light duty vehicles**

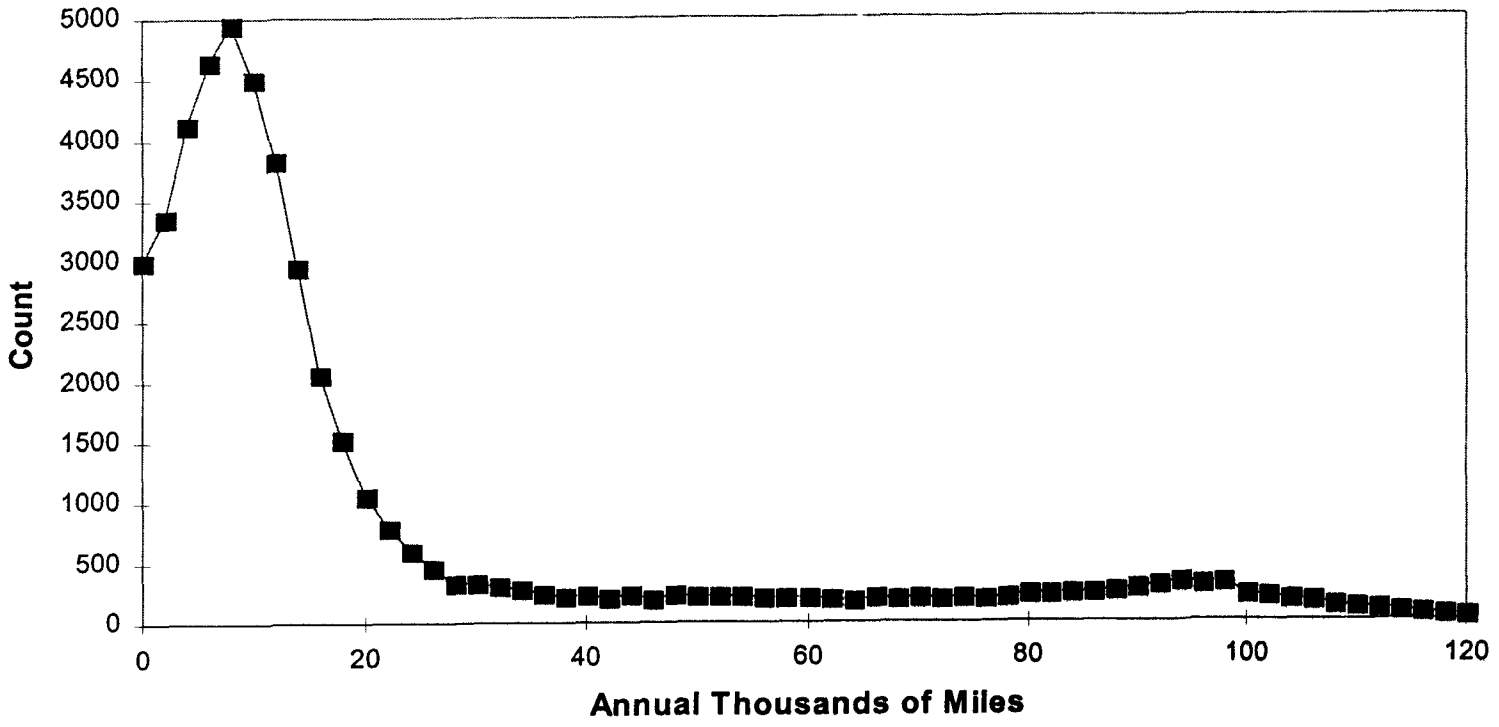


**Figure 2-4**
**Arizona I/M mileage distribution across all vehicle ages**

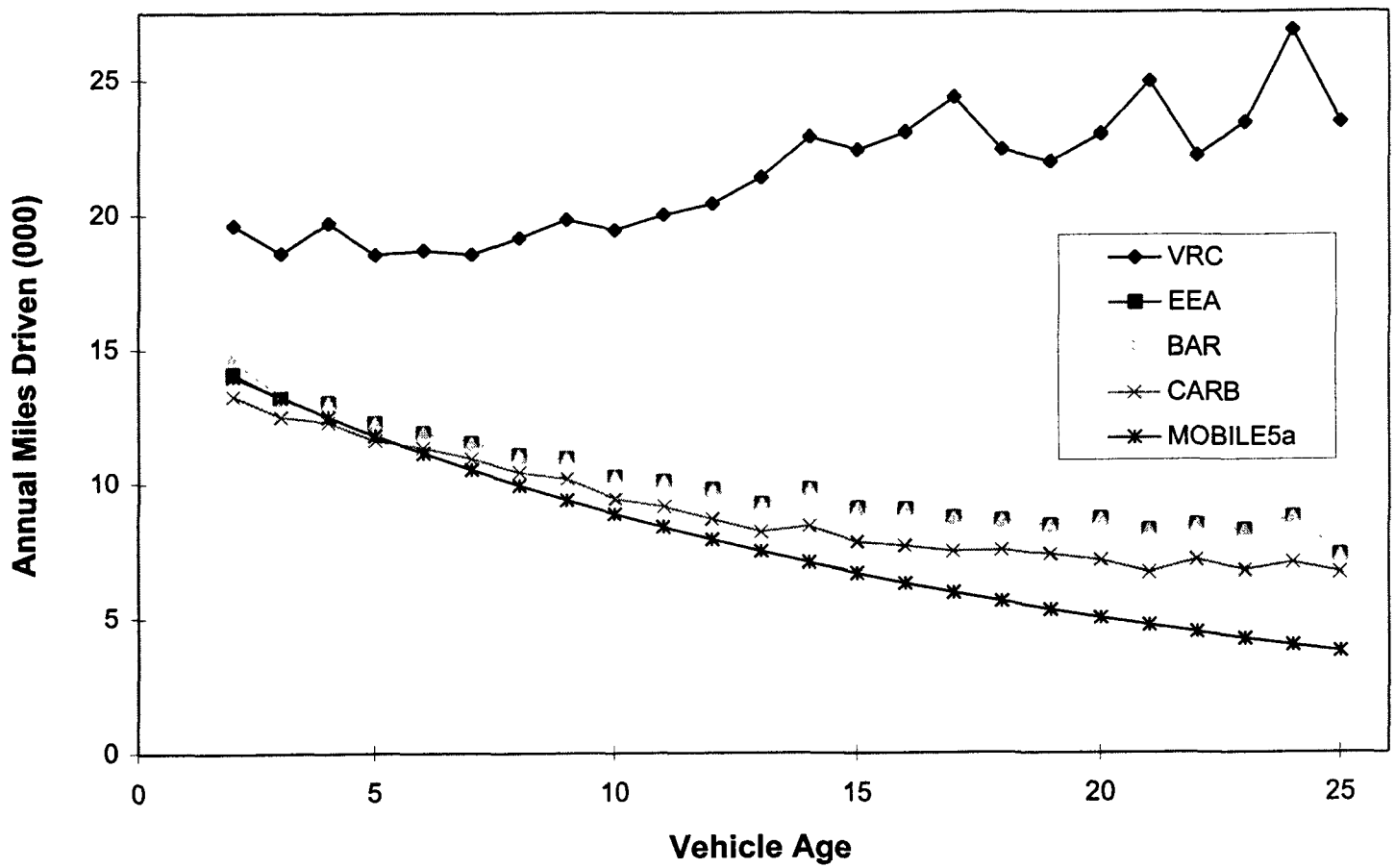


**Figure 2-5**
**Comparison of Arizona I/M mileage accumulation distributions under different truncation schemes**

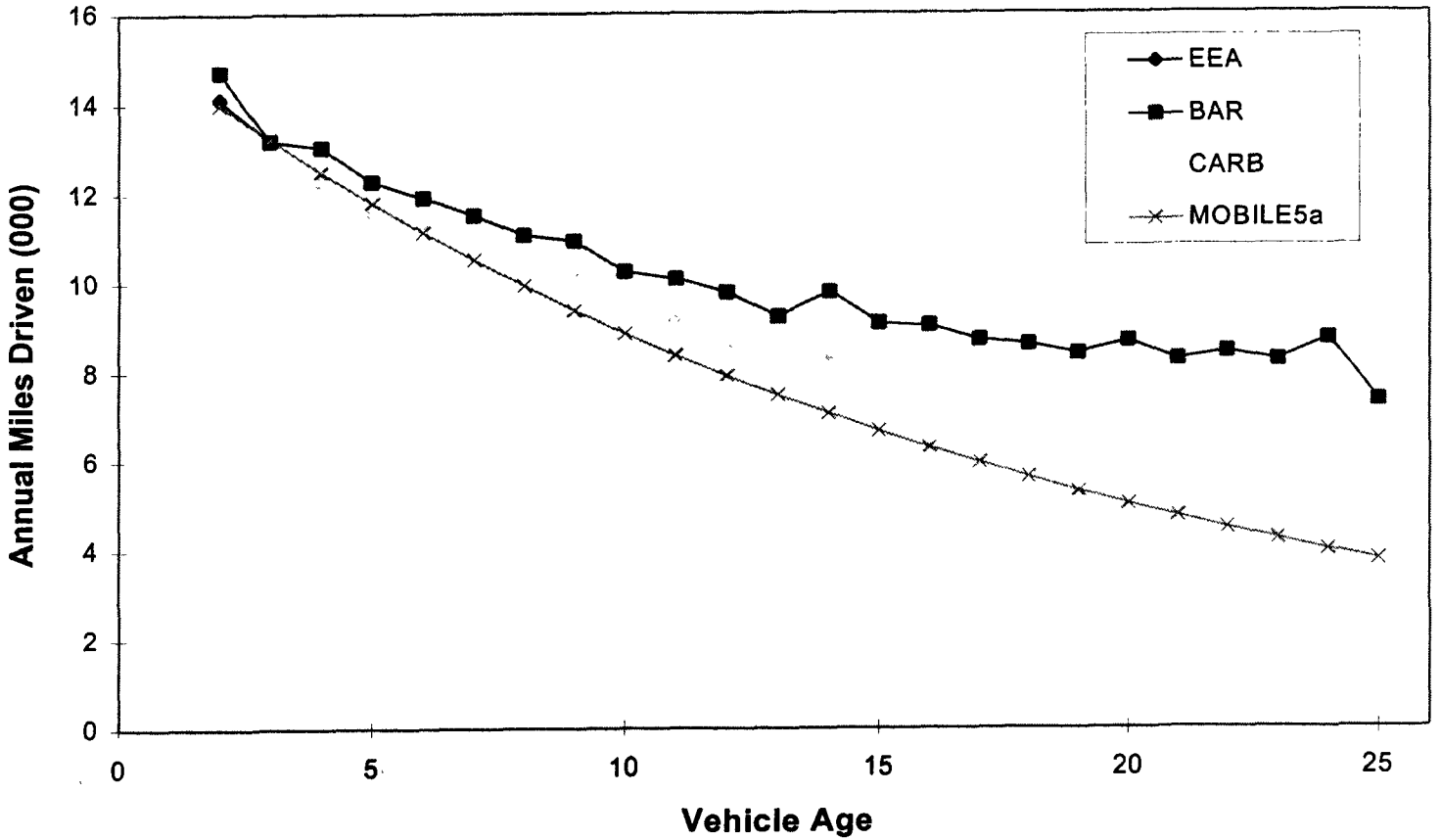


**Figure 2-6**
**Comparison of mileage accumulation distributions under three different truncation schemes**

# 3
# USE OF REMOTE SENSING DATA TO GENERATE VEHICLE ACTIVITY CHARACTERISTICS

Data from large-scale remote sensing programs can be used to generate regional fleet characteristic data for input into to mobile source emission inventory development and the MOBILE emission factor model. This section describes how the following vehicle activity characteristics can be derived or approximated from remote sensing data for use in emission inventory development:

- registration distributions,
- VMT mix,
- diurnal travel distributions,
- diesel sales fractions,
- evaluation of unregistered vehicles, and
- evaluation of vehicle county/state of origin to determine vehicle I/M status.

The remote sensing data can provide information at a regional level which can be significantly different from default data currently used to generate many mobile source emission inventories. In addition, if sufficient data are available, it may be possible to evaluate data at the facility class level (i.e., roadway classification) or the transportation model zonal level allowing for additional refinement of emissions estimates. Note that for such uses, the scale of the remote sensing program needs to be large enough to capture a significant portion of the vehicle fleet, such as the one completed as part of the California Pilot I/M program.

Although the primary focus of most remote sensing programs is to collect emissions information, fleet characteristics can be derived from license plate data typically recorded during a remote sensing program. The license plate data, cross checked with state motor vehicle records, can yield valuable information on the characteristics of the local fleet. These local data can offer an improvement over generally used national default or state-level fleet characteristics data.

The remainder of this section covers (1) an overview of fleet data from remote sensing programs useful in understanding how these data are used, (2) a literature review of previous studies using remote sensing to develop fleet data, (3) the methodology for estimating fleet characteristics from remote sensing data, and (4) example applications of this methodology.

# OVERVIEW OF FLEET DATA FROM REMOTE SENSING PROGRAMS

The methodologies described in this document summarize how fleet characteristics and activity data can be distilled from the vehicle data of remote sensing programs (note that the emissions data of these programs are not used). For example, vehicle counts, roadway type, and time of day data can yield information on hourly variation of travel by roadway classification. Moreover, when remote sensing data are combined with license plate data that are cross-checked with state motor vehicle records, they can provide valuable information on the age and vehicle class make up of the fleet.

In brief, the remote sensor apparatus is triggered when a vehicle blocks the path of an infra-red beam set across a lane of traffic. Once the vehicle clears the path, the sensor takes a measurement of the exhaust plume. In general, the light-duty cars and trucks are the vehicle group of interest, thus the sensor is located about ten to twelve inches off the ground. A video camera is used to record the license plate of the passing vehicle. License plates are determined either through manual review of video recordings or through electronic license plate readers. License plate data are matched with state records to produce the data needed for the evaluation of fleet characteristics.

The data generally collected that are useful for the evaluation of activity and characteristics of the fleet include the following:

- site description and location,
- time of day,
- date of measurement, and
- vehicle licence plate.

From the license plate data, the following can be determined from state registration records:

- vehicle identification number (VIN)
- vehicle model year,
- vehicle class,
- vehicle fuel type,
- county and/or state of registration, and
- registration expiration date.

Except for the vehicle identification number (VIN), not all states keep each of these on record. If this is the case, these items can be determined from the VIN that is unique to each vehicle. VIN

decoding can be through VIN decoding software supplemented with manual decoding using VIN decoding books where needed.

Noteworthy considerations in the evaluation of fleet and activity data from remote sensor data include (1) regional variation and fleet coverage, (2) facility (roadway) class limitations, (3) vehicle class biases, (4) VIN decoding considerations, and (5) using vehicle counts to estimate travel, population and sales. These are discussed individually below.

### REGIONAL VARIATION AND FLEET COVERAGE

Variation of socioeconomic conditions and land-use categories (e.g., commercial, industrial, and residential) result in variation in fleet characteristics. In order to accurately evaluate the vehicle fleet as a whole, it is important that remote sensing be completed at several locations to ensure fleet coverage. As a benchmark, the Enhanced I/M Final Rule includes requirements that on-road testing of 0.5 percent of the fleet through remote sensing be completed. It is programs of this magnitude that can utilize remote sensing data for the evaluation of fleet characteristics. If a program is sufficiently large, such as the California Pilot I/M Program where 47 percent of the eligible fleet was measured at over three hundred locations (Radian, 1995), subregional analyses can be completed. Subregional information can be used to evaluate data by zone for use with travel demand models or by roadway facility class.

### FACILITY CLASS LIMITATIONS

Classification by facility class can be made provided that individual sites are identifiable within the vehicle database and that each sites is assigned a roadway classification. This is generally the case for most programs. Remote sensor technology is currently limited to use on single-lane roadways. Some initial work has been done using remote sensing on two traffic lanes and has been generally successful as long as travel densities are low (two seconds between passing vehicles) (Bishop et. al., 1994). Commonly used remote sensor sites include single-lane roads, multi-lane roads where travel is restricted to one lane, expressway on and off ramps, and single-lane expressway interchanges. Because of the restriction on roadway types, the remote sensing sample may not accurately reflect the distribution of travel on each facility class. It is reasonable to expect that the characteristics of limited-access roadways (e.g., expressways and freeways) may be different from surface streets. For example, limited-access roadways may have more out-of-state vehicles or heavy-duty vehicles. For this reason, it may be desired to evaluate the characteristics of limited-access roadways separately from surface streets. The data for surface streets and limited-access roadways can be combined into an overall value according the relative VMT proportion of each roadway from the Highway Performance Monitoring System (HPMS) VMT data.

## VEHICLE CLASS BIASES

Remote sensing is generally used to evaluate the light-duty fleet. The larger the vehicle, the less likely the apparatus will obtain a valid measurement. For example, the wheels or the cab of large trucks can trigger the remote sensor device resulting in an invalid emissions and license plate reading. For the purposes of evaluating fleet characteristics, retaining the records of license plates even if valid emissions data are not recorded will enhance the representativeness of larger vehicle classes in the database. It is therefore recommended that the evaluation of fleet characteristics from remote sensing data be restricted to the light-duty vehicle classes[1] unless review of license plate data show that heavier vehicles are captured regularly (e.g., manual review of license plate data may capture the heavier vehicle classes).

## VIN DECODER LIMITATIONS

Vehicle identification number (VIN) decoding may be required if state records do not include vehicle class, vehicle model year, and/or vehicle fuel type data. The VIN is a 12 to 17 digit alpha-numeric field which, by law, is unique to each vehicle. Since the 1981 model year vehicle, the format of the VIN has been standardized. Most states maintain VIN decoders in some form. VIN decoding to obtain vehicle data can be done manually although this is not recommended especially for pre-1981 vehicles. VIN decoding software can be obtained from various sources (e.g., the Highway Loss Data Institute, R. L. Polk, and Radian Corporation) that includes the complex algorithms required to evaluate older model year vehicles. There are some limitations to VIN decoding even when utilizing decoding software. For example, for older model years, a VIN may only indicate a range of model years instead of a specific value. For increased accuracy, vehicle data can be obtained through VIN decoding in combination with state records. A previous example of how this was completed is included in an EEA study of I/M data for the EPA (EEA, 1985).

## USING VEHICLE COUNTS TO ESTIMATE THE FRACTION OF TRAVEL, POPULATION AND SALES

Each record of the remote sensing database represents a single vehicle. Classifying each record, for example, by time of day or age allows for estimating counts by each classification. The fraction of a particular activity, such as vehicle travel, is determined by the total count by each classification divided by the total count of the database. In completing this calculation, however,

[1] There are five light duty classes defined by MOBILE5a, light-duty gasoline vehicles (LDGV), light-duty gasoline trucks less than 6,000 pounds gross vehicle weight (LDGT1), light-duty gasoline trucks more than 6,000 pounds gross vehicle weight (LDGT2), light-duty diesel vehicles (LDDV), and light-duty diesel trucks (LDDT).

it is important to understand the distinction between different types of activity (vehicle miles traveled, vehicle population, and vehicle sales) that are discussed in this section.

Vehicle miles traveled (VMT) represents the distance traveled by each vehicle. In this document, it assumed that VMT is proportional to the vehicle counts of the remote sensing database. In other words, the more a vehicle travels, the greater the chance it will pass by and be measured by a remote sensor. The fraction of VMT used to determine VMT mixes and diurnal travel distributions (discussed in the methodology portion of this section) can be determined from the fraction of vehicle counts from the remote sensor database assuming that travel is proportional to the vehicle counts.

Vehicle population or sales represent the number of vehicles in the fleet independent of how much each vehicle is driven. For the purpose of evaluating vehicle population or sales from the remote sensing database, one should remove duplicate vehicle records (i.e., vehicles that appear more than once). This is because for population and sales, it is the count of unique vehicles which best represents these activities and because the probability of multiple measurements is proportional to how much a vehicle is driven.[2] The fraction of population or sales (used to define registration distributions and diesel sales fractions) is then determined from the fraction of vehicle counts after duplicate vehicle records have been removed.

Remote sensing should be used with great caution to estimate travel fractions, population, and sales distributions. As mentioned above, fleet characteristics can vary greatly with neighborhood socioeconomic status and landuse (e.g., residential vs. Industrial). Accurate portrayal of fleet characteristics would require a well-designed mix of remote sensing locations.

# LITERATURE REVIEW

The literature review summarized below is separated into two sections covering: (1) a document review of key references; and (2) verbal communications with regulators and scientists experienced in the evaluation of remote sensing data. The review focuses on methods of identifying fleet characteristics data such as vehicle class and model year in the remote sensing databases, as well as example calculations of fleet characteristics data, and description of potential biases of remote sensing databases and methods of adjusting for these biases.

[2] Note that it is common to have multiple measurements of vehicles in the remote sensing database, because measurements are often taken at the same or nearby sites on different days. In the example applications included in this section, 56 percent of the vehicles in the database were measured more than once.

## DOCUMENT REVIEW

The documents covered in this review are:

1. *Evaluation of the California Pilot I/M Program* (Radian, 1995),

2. *Analysis of Data from the California Enhanced I/M Program* (Sierra, 1995),

3. *Comparison of Remote Sensing Data and Emission Factor Models: The Proportion of Emissions From High Emitting Vehicles* (Pollack et. al., 1992),

4. *Estimation of Mileage Accumulation Rates and I/M Failure Rates from I/M Program Data* (EEA, 1985), and

5. *On-Road Motor Vehicle Activity Data, Volume II: Vehicle Age Distribution and Mileage Accumulation Rate by County* (Valley Research, 1994).

The following documents were also reviewed but did not offer sufficient information relative to use of remote sensing data to generate vehicle activity inputs:

1. *Evaluation of a Remote Sensing Device at a Centralized I/M Lane* (EPA, 1992b),

2. *Identifying Excess Emitters with a Remote Sensing Device: a Preliminary Analysis* (EPA, 1991), and

3. *Methodology for Estimating Emissions From On-Road Motor Vehicles, Volume II: Weight (E7FWT)* (ARB, 1993).

***Evaluation of the California Pilot I/M Program (Radian, 1995)***

This report, completed for the State of California, describes the California Pilot I/M Program and presents the results of an initial evaluation of the data collected. A portion of the pilot program was a large-scale remote sensing program conducted in the Sacramento region in the summer of 1994. In this program, remote sensors were placed at more than three hundred locations resulting in more than two million measurements covering 47 percent of the registered Sacramento fleet.

Detailed information is provided describing the fleet coverage of the remote sensing program and how to optimize coverage. Also, a detailed model year analysis is presented examining the differences between the model year distribution of the state registration data for Sacramento and the model year distribution of the fleet detected by the remote sensor. Notably, the Radian report

adjusted state registration data to reflect the model year variation in annual travel (i.e., new vehicles are driven more than older vehicles) for a more equitable comparison to the remote sensing data. This adjustment consisted of:

$$MYDist_{i,\ adjusted} = MYDist_{i,\ unadjusted} * \frac{MAR_i}{MAR_{fleet\ average}}$$

where:

*MYDist* is the model year registration distribution,
*MAR* is the mileage accumulation rate,
the subscript *i* indicates each model year, and
the subscript *fleet average* is the average over all model years.

In this adjustment, the mileage accumulation rate (MAR) data were taken from the California Air Resources Board (ARB) EMFAC7F emission factor model. For light-duty automobiles, these MAR data are based on analysis of California I/M Program odometer data.

It should be noted that the Radian equation above can be used more generally to adjust for any model year bias as long as the variation of each model year versus the fleet average is known. This section discusses adjusting the remote sensing data to more accurately reflect vehicle registration which is the opposite of the Radian adjustment. Therefore the inverse of the adjustment ratio shown above will be used.

It should also be noted than even after the Radian adjustment of the model year variation in mileage accumulation rates was completed, the remote sensing data still appear to underrepresent older model years (1979 and earlier). This may be due to a combination of two effects: (1) the mileage accumulation rates used in the adjustment noted above may not reflect local conditions, and/or (2) additional biases may be present, e.g., older license plates may be more difficult to read. Radian, however, reports the differences in the model year distributions of the registration data and the remote sensing data to be statistically insignificant.

***Analysis of Data from the California Enhanced I/M Program (Sierra, 1995)***

This report, completed for the U.S. EPA, reviews and evaluates the data of California Pilot I/M Program. Of importance to this work assignment is the discussion of the coverage of the remote sensing program. Sierra reports that the remote sensing program coverage of the registered fleet varies significantly by model year as summarized by the following capture percents of four model year groups.

| | |
|---|---|
| 1983-and-later | 48% |
| 1981-1982 | 35% |
| 1975-1980 | 27% |
| pre-1975 | 19% |

Sierra reports that this model year variation is likely due to lower mileage accumulation rates of the older vehicles, different driving patters of the older fleet, and/or representativeness of the remote sensing sites. Sierra did not attempt to correct for these biases as was done in the Radian report.

Note that there is an apparent discrepancy between the 47 percent coverage reported by Radian and the model year coverage reported by Sierra (i.e., if all of the Sierra-reported model year groups were combined, they would not yield 47 percent). This may be due to an examination of a subset of data, for example, only light-duty automobiles.

***Comparison of Remote Sensing Data and Emission Factor Models: The Proportion of Emissions From High Emitting Vehicles (Pollack et. al., 1992)***

This paper, presented and the 85th Annual Air and Waste Management Association Meeting, examines the emissions distribution of remote sensing data versus that of the EMFAC and MOBILE emission factor models. Registration distributions (weighted for model year differences in annual miles traveled) from remote sensing data were used with the emissions factor models for comparative purposes. The paper also describes why distributions are adjusted for model year differences in annual miles traveled.

***Estimation of Mileage Accumulation Rates and I/M Failure Rates from I/M Program Data (EEA, 1985)***

This report summarized work completed by EEA for the U.S. EPA in 1985. Of particular interest is a detailed discussion of the method used to match motor vehicle data records. The report describes how the VIN was used to verify state I/M data for vehicle class and model year. EEA utilized VIN decoding software called VINDICATOR produced by the Highway Loss Data Institute and supplemented VINDICATOR with additional decoding data on imported light-duty trucks. There are some noted deficiencies in the VIN decoding for older vehicles (pre-1980 model years) because of lack of industry agreement on codes until the 1980 model year. For example, VIN decoding can only identify a range of model years (instead of a specific model year) in some cases. For 1981 and later model years, VINs were standardized making VIN decoding much more reliable.

The information in this report would be of use to states that do not maintain model year or vehicle class information in the state records. In this case, VIN decoding would be required to get the information required to estimate fleet characteristics data.

***On-Road Motor Vehicle Activity Data, Volume II: Vehicle Age Distribution and Mileage Accumulation Rate by County (Valley Research, 1994)***

This report, completed by Valley Research Corporation for the ARB, evaluated county-specific fleet characteristics data from the state department of motor vehicles (DMV) data and state I/M data. The relevance of this report is that the state DMV data provide an example of how DMV data could be used to identify vehicle coverage of a remote sensing program. Notable aspects of this study for the the issues at hand are:

- Valley Research utilized an electronic VIN decoder, called VINA (developed by R. L. Polk and used by the State of California), to determine a vehicle's model year instead of relying of the model year data included in the records of the California Department of Motor Vehicles (DMV). The VIN-decoded model year was considered more reliable than that input into the DMV database.

- Wide variation was found in model year distributions by county. For example, the mean age of automobiles ranges from 5.1 years to 13.1 years. This indicates the importance of using region-specific data in place of statewide averages where possible.

## VERBAL COMMUNICATIONS

Personal contacts were made with individuals experienced in processing remote sensing data. The agencies contacted included the California Bureau of Automotive Repair (BAR), the Arizona Department of Environmental Quality (ADEQ), the Department of Chemistry of the University of Denver, and the U.S. EPA Motor Vehicle Emission Laboratory.

### *California BAR*

The California Pilot I/M program was discussed with the Bureau of Automotive Repair. They noted that there are obvious limitations in measuring the vehicle fleet accurately. For example, the remote sensing apparatus has the potential to measure all vehicles; however, in general, the setup is designed to measure the light-duty fleet thereby missing the license plate information of the majority of buses, articulated trucks and motorcycles. With respect to model year or age biases of remote sensing programs, it was noted that the plate recorder had a higher success rate on the newer California licence plates, which have a reflective coating added to the plate. There are no data on how this affected the results.

*Arizona DEQ*

The specifics of the current Arizona program were discussed, as well as potential biases of the license plate recording apparatus with DEQ staff. The automatic recorder used by Arizona decodes the information based on the font shape and spacing to distinguish an Arizona plate from other states. In a couple of instances a Michigan plate has been misread as an Arizona plate.

The sensor apparatus and plate reader are located about 12 inches off the ground. There is a problem measuring jacked-up pickups, but in general most light-duty vehicles are measured. The plate recorder has about a 75 percent success rate; this can go up to about 90 percent if the remote sensing operator reviews the recorded images and fills in missing plate data. In the Arizona program, this back filling of missing data is completed.

*University of Denver, Department of Chemistry*

Issues related to obtaining vehicle information from state DMVs were discussed. It was noted that DMV VIN transcription errors are typically one to two percent. However, these errors are generally slight and do not statistically alter the results. It was also noted that VINs are very unreliable prior to the 1981 model year. They use several older VIN decoder books to assist in looking at older model years. The University has had some difficulty in the past with some states in cross referencing remote sensing data with state records; however, most states have the capabilities and are responsive to their requests.

# METHODOLOGY

This subsection summarizes the methodology for using remote sensing data to develop the following mobile source emission inventory modeling inputs:

- registration distributions,
- VMT mix,
- diurnal travel distributions,
- diesel sales fractions,
- evaluation of unregistered vehicles, and
- evaluation of vehicle county/state of origin to determine vehicle I/M status.

Each of these items is discussed in detail in the following.

## EVALUATION OF VEHICLE REGISTRATION DISTRIBUTIONS

Vehicle registration distributions are the fractional distribution of vehicle class population by model year. The registration distribution accounts for the age of the fleet and has a significant impact on emissions calculations. For each model year of a vehicle class, the registration distribution is determined by the population of the model year divided by the population of the entire vehicle class. For MOBILE5a, a twenty-five year distribution is used where the 25th year represents all model years of 25 years and older.

The steps required for the evaluation vehicle registration distributions in the format required by MOBILE5a are:

1. Separate the data by vehicle class and remove duplicate vehicle records.
2. Calculate the unadjusted distribution.
3. Adjust the data for age-dependent mileage.
4. Adjust the data for other biases.
5. Adjust the data to represent July 1st of the calendar year.

Each of these steps is discussed here.

### *Separate the Data by Vehicle Class and Remove Duplicate Records*

Registration distributions are input into MOBILE5a for each vehicle class requiring the separation of data by vehicle classes. Note that for light-duty vehicles and trucks, MOBILE5a requires a single registration distribution that includes both diesel- and gasoline-powered vehicles (i.e., one distribution for LDGV and LDDV combined and one distribution for LDGT1 and LDDT combined); the model will not run unless the distributions of these classes are equivalent. In general, remote sensing data will only capture the light-duty fleet accurately (see Section 2.2.3 of the MOBILE5a User's Guide). Thus for the heavier vehicles, other data sources or the model default values should be used.

### *Calculate the Unadjusted Distribution*

The unadjusted distribution is calculated as the sum of population of each model year divided by the sum of population of all model years of the vehicle class. This is shown by the following equation.

$$MYDist_{i,\ unadjusted} = \frac{\sum POP_i}{\sum POP} \tag{3-1}$$

where:
*MYDist* is the model year registration distribution,
*POP* is the vehicle population, and
the subscript *i* indicates each model year.

For consistency with MOBILE5a format requirements, the 25th model year includes all vehicles 25 years old and older.

***Adjust the Data for Age-dependent Mileage***

The unadjusted registration distribution should be adjusted to account for age-dependent mileage accumulation. Because older vehicles travel less than newer vehicles, older vehicles are less likely to have been included in the remote sensing database and the population of older vehicles in the unadjusted data are likely underrepresented. This adjustment for age-dependent mileage is shown by the following equation.

$$MYDist_{i,\ adjusted} = MYDist_{i,\ unadjusted} * \frac{MAR_{fleet\ average}}{MAR_i} \tag{3-2}$$

where:
*MYDist* is the model year registration distribution,
*MAR* is the mileage accumulation rate,
the subscript *i* indicates each model year, and
the subscript *fleet average* is the average over all model years.

Ideally, MAR data used in this adjustment should be representative of the local fleet. In the absence of data, the default mileage accumulation rates from MOBILE can be used. After applying this equation, the adjusted model year distribution should be renormalized to sum to one. From the equation above, the adjustment is inversely proportional to the model year MAR thus adjusting the data downwards for newer model years with a MAR greater than the fleet average and adjusting the data upwards for older model years with a MAR less than the fleet average. Note that this equation is the inverse of the adjustment used by Radian (Radian, 1995). It is the inverse because in the Radian report, the registration data were adjusted to more accurately reflect the remote sensing data whereas in this analysis, the remote sensing data are adjusted to more accurately reflect the registration data.

### *Adjust the Data for Other Biases*

The equation shown above to adjust for age-dependent mileage can also be applied more generally to account for any model year bias in the database as long as the variation of each model year versus the fleet average is known. For example, the California BAR noted that the accuracy of the automatic license plate reader to interpret different types of license plates varied. Newer license plates have a reflector coating aiding in the ability of the reader to evaluate the plate. However, the effect of varying license plate types was not quantified in the California Pilot I/M Program.

### *Adjust the Data to Represent July 1 of the Calendar Year*

The MOBILE5a registration distribution data represent July 1 of the calendar year of evaluation. For input into the MOBILE5a model, the data need to be adjusted to represent July 1. MOBILE5a assumes that light-duty vehicle sales begin on October 1 of the year prior to the model year (i.e., 1995 model year vehicles begin selling on October 1, 1994). For other vehicle classes, the model assumes that sales begin on January 1 of the model year. MOBILE5a also assumes that sales are uniform throughout a year.

The process to adjust light-duty vehicles to represent July 1 can be separated into two cases:

1. For remote sensing data collected after July 1 and before October 1, too many current model year vehicles are included in the database. The excess percent of current model year vehicles is the number of days past July 1 divided by 365. For example, if the remote sensing data were collected on September 1, the current model year is 16.7 percent (61 days divided by 365 days) too large. Excess percent of the current model year are removed from the distribution. The registration distribution is then renormalized to sum to one.

2. For remote sensing data collected before July 1 and after October 1, too few current model year vehicles are included in the database. The percent missing current model year vehicles is the number of days prior July 1 divided by 365. The current model year distribution is adjusted upward by the percent of vehicles missing. The registration distribution is then renormalized to sum to one.

## EVALUATION OF DIURNAL TRAVEL DISTRIBUTIONS

Diurnal travel distributions are the hourly variation of vehicle traffic. The diurnal distribution of travel is important in air quality modeling because it affects the time of day emissions are

predicted to be released. Remote sensing data can provide data on diurnal travel patterns during the period the sensor is operating. Emissions modeling generally employs the use of separate diurnal distributions for weekday and weekend travel. Generally, diurnal distributions are not developed for individual vehicle classes. Since identification of vehicle classes is not required, the remote sensing data do not need to be matched with state records. The following are the steps required to evaluate diurnal travel distributions from remote sensing data:

1. Separate the data by hour of day and day of week.
2. Evaluate the representation of directions of travel.
3. Evaluate the diurnal distribution of the portion of the day not covered by remote sensing.

Each of these steps is discussed below. Note that diurnal distribution data for the hours not covered by the remote sensing program will be required to complete the evaluation of a 24-hour diurnal distribution.

***Separate the Data by Hour of Day and Day of Week***

Diurnal travel patterns vary by each day of the week. In general, weekday travel is similar enough so that one distribution can be used to represent all five weekdays. Sunday and Saturday diurnal distributions can be determined separately or together depending on how much variation between days is observed. The general equation for determining the diurnal distribution is the sum of travel for each hour divided by the sum over all hours:

$$Diurnal = \frac{\sum Travel_i}{\sum Travel} \tag{3-3}$$

where:
*Diurnal* is the diurnal distribution,
*Travel* is the vehicle count, and
the subscript *i* indicates each hour.

***Evaluate the Representation of Directions of Travel***

It is important when using remote sensing data to make sure travel in both directions of roadways are included to capture commute travel patterns. In the California Pilot I/M Program, remote sensing was generally performed for both directions of traffic for each roadway site in the database, so the representation of travel should be accurate. To illustrate this point, two sites (Site 93 and Site 34) representing Highway 50 in opposite directions of travel are shown in Figure 3-1. Site 93 is dominated by the afternoon commute traffic; Site 34 is dominated by the

morning commute traffic. Thus, it is essential that equal representation of directions of travel be present when determining the diurnal distribution from remote sensing data.

### *Evaluate Diurnal Distribution of the Portion of the Day Not Covered by Remote Sensing*

Remote sensing is generally not performed across all 24 hours of a day. A second source of diurnal distribution data, such as that used in EPS2 (EPA, 1992a) or locally available data, is required to complete the 24-hour diurnal distribution. The steps to do this are (1) calculate the fraction of travel covered by the remote sensing program from the secondary data source, (2) multiply each hour of the diurnal distribution calculated from the remote sensing program data by this fraction, and (3) use the diurnal data from (2) for the hours covered by the remote sensing program and use the diurnal data from the secondary source for the remaining hours.

## EVALUATION OF VMT MIX

VMT mix is the fraction of travel among the individual vehicle classes. The MOBILE model uses VMT mix to estimate a fleet average emission factor. VMT mix can vary by roadway classification, thus vehicle class data derived from a remote sensing program can offer a method for estimated VMT mix on various roadways. The following are the steps required to evaluate the VMT mix from remote sensing data.

1. Separate the data by vehicle class.
2. Combine with data for vehicle classes not captured by the remote sensing apparatus.

These two steps are discussed below.

### *Separate the Data by Vehicle Class*

VMT mix is calculated by separating the DMV-matched database into individual vehicle classes. The mix is calculated from the sum of each vehicle over the total records in the database:

$$VMT\ Mix = \frac{\sum Travel_i}{\sum Travel} \tag{3-4}$$

where:

*VMT Mix* is the calculated VMT mix,
*Travel* is the vehicle count, and
the subscript *i* indicates each vehicle class.

If sufficient data are available, VMT mix by facility class (i.e., roadway classification) can be estimated. In this case, the data would be separated into facility classes as well as vehicle classes prior to calculating the VMT mix.

***Combine with Data for Vehicle Classes Not Captured by the Remote Sensing Apparatus***

As was noted above, the remote sensing apparatus is less likely to accurately capture the heavier vehicles. MOBILE5a requires that all vehicle classes be included in a user-supplied VMT mix. An alternate source of VMT mix data from the MOBILE model or from local sources should be used to fill in the remaining vehicle classes not captured by the remote sensing program. The steps to complete this are (1) calculate the fraction of VMT covered by the vehicle classes of the remote sensing program, (2) multiply the VMT mix of each vehicle class by this fraction, and (3) combine the revised VMT mix from (2) with the remaining vehicle classes of the alternative source to complete the VMT mix. An example of these steps follows.

Let's assume that the remote sensing program accurately identifies the LDGV, LDGT1, and LDGT2 vehicle classes. It is determined from the existing inventory data that 75 percent of the VMT is covered by these vehicle classes (step 1). From the remote sensing data, the VMT mix for each of these vehicle classes is determined to be:

| LDGV | LDGT1 | LDGT2 |
|---|---|---|
| 0.650 | 0.250 | 0.100 |

In order to combine these values with those not covered by the remote sensing program, multiply the values above by the total contribution of these vehicle classes (0.75 or 75 percent) to yield:

| LDGV | LDGT1 | LDGT2 |
|---|---|---|
| 0.488 | 0.187 | 0.075 |

These values can then be combined with those of the remaining vehicle classes so that the total over all vehicle classes sums to one.

## EVALUATION OF DIESEL SALES FRACTIONS

Diesel sales fractions are the fraction of each model year vehicles which are diesel powered. Diesel sales fractions are used in MOBILE for the light-duty vehicles to calculate the diesel travel fraction of light-duty diesel vehicles and trucks (LDDVs and LDDTs). These vehicle classes differ from their gasoline counterparts in the chemical speciation of exhaust VOC emissions (diesel exhaust VOC is generally more reactive than gasoline exhaust VOC), the quantity of evaporative emissions (diesel vehicles have little or no evaporative emissions), the

quantity of particulate emissions (diesels generally emit more particulate emissions). The steps required to estimate diesel sales fractions are as follows.

1. Separate the data by vehicle class/model year and remove duplicate vehicle records.
2. Calculate the diesel sales fraction.

Duplicate vehicles are removed from the calculation since vehicle population is to be estimated. The procedure to calculate diesel sales fractions is to sum the population of diesel vehicles over the population of all vehicles for a given model year and light-duty vehicle class as shown below.

$$Diesel\ Sales = \frac{\sum Pop_{Diesel}}{\sum Pop_{Total}} \tag{3-5}$$

where:

*Diesel Sales* is the calculated diesel sales fraction for each model year, and
*Pop* is the model year population for diesel and total vehicles.

This calculation is repeated for each model year and for the two vehicle classes LDDV and LDDT.

## EVALUATION OF UNREGISTERED VEHICLES

Data from remote sensing programs can be used to evaluate the characteristics of the unregistered fleet. In this discussion, we use "unregistered" to refer to vehicles with in-state license plates that have expired registrations[3]. The license plate data, cross checked with state motor vehicle records, can provide valuable information on the fraction of fleet unregistered and the length of period the vehicle is unregistered. Unregistered vehicles are not generally accounted for in mobile source modeling and it may be worthwhile to examine the remote sensing database to determine the pervasiveness of unregistered vehicles. One benefit of using remote sensing data to estimate fleet characteristics is that unregistered vehicles are included in the remote sensing data base. The steps required to estimate the unregistered vehicle fraction are as follows.

1. Remove duplicate vehicle records from the DMV-matched database.
2. Calculate the unregistered vehicle fraction.

[3]Evaluating vehicles registered out-of-state or out-of-country is discussed later in this section.

Duplicate vehicle records are removed from the data base to obtain the unique vehicle population. To evaluate the fraction of unregistered vehicles in the remote sensing database, the sum of the population of unregistered vehicles are divided by the total population of vehicles as shown below.

$$Unregistered = \frac{\sum Pop_{Unregistered}}{\sum Pop_{Total}} \tag{3-6}$$

where:

*Unregistered* is the fraction of unregistered vehicles, and
*Pop* is the population of unique vehicles.

This calculation can be completed by vehicle class or for the fleet total. Note that the date by which active vehicle registration should be determined is the date that the DMV data were obtained. For example, if the DMV data were obtained on March 1, active registration should be determined relative to March 1.

It is also worthwhile to examine the length of period unregistered. Most unregistered vehicles may be late in registering and will renew registration within a few months, as described in Section 2. Thus it would be worthwhile to note the fraction of unregistered vehicles by the length of period unregistered to determine the fraction of vehicles that have been unregistered for a considerable period. If it is determined that a significant portion of the fleet are unregistered for a long period, it would be informative to examine the differences between the registered and unregistered fleet (e.g., model year distribution or average vehicle age).

## EVALUATION OF VEHICLE COUNTY/STATE OF ORIGIN TO DETERMINE VEHICLE I/M STATUS

Data from a remote sensing program can be used to evaluate the origin of travel within the region covered by the program. For example, the fraction of the local travel which is out-of-state can be determined from review of license plate data[4]. Moreover, from the DMV data of in-state vehicles, the county of registration can be determined to evaluate whether a vehicle is subject to an I/M program or not. This information would be useful in determining the fraction of local travel by vehicles not subject to an I/M program. It is common in mobile source modeling

[4]This methodology can be applied to determine the fraction of travel by vehicles registered out-of-state or out-of-country in case special consideration of these vehicles is desired in the emission inventory development.

practices to assume that all local travel is subject to the local I/M program, which can lead to an overestimate of the benefits of an I/M program.

Calculating the fraction of vehicles not subject to an I/M program can be done in three steps:

1. Separate out vehicles classes covered by the I/M program.
2. Separate vehicles by whether or not the vehicle is subject to an I/M program.
3. Calculate the fraction not subject to the I/M program.

The equation to calculate the fraction of vehicles not subject to an I/M program is the sum of vehicles not subject divided by the total number of vehicles.

$$Fraction_{no-I/M} = \frac{\sum Travel_{no-I/M}}{\sum Travel_{Total}} \tag{3-7}$$

where:

$Fraction_{no-I/M}$ is the calculated fraction of vehicles not subject to an I/M program, and
*Travel* is the vehicle count (including duplicate vehicle records).

# EXAMPLE APPLICATIONS

This subsection provides example applications of the methods described above using the California Pilot I/M Program remote sensing database. The California Pilot I/M Program data base is first described, and is followed by example calculations of:

- registration distributions,
- diurnal travel distributions,
- VMT mix,
- unregistered vehicles, and
- vehicle county of origin (to determine I/M status).

Because diesel vehicles were removed from the California Pilot I/M Program remote sensing database, an estimate of diesel sales fractions was not completed.

## DESCRIPTION OF THE CALIFORNIA PILOT I/M PROGRAM DATA USED IN THE EXAMPLES

The California Bureau of Automotive Repair (BAR) sponsored the California Pilot I/M Program, which included a large-scale remote sensing program in the city of Sacramento in the summer of 1994. During the months of July, August and September, remote sensing was performed at 337 sites and approximately two million valid remote sensing readings were obtained. The evaluation of the remote sensing data was completed by Radian Corporation for the California BAR. According to Radian, the program produced 1,329,694 remote sensing records with matched DMV records, covering 47 percent of the eligible Sacramento vehicle population (Radian, 1995).

The remote sensing data are available to the public through the California BAR. The data base includes two subsets consisting of 1,969,044 valid remote sensing readings and 1,113,939 remote sensing readings with matched DMV data. The differences between the Radian DMV-matched databases (1.3 million records) and the publicly available DMV-matched data (1.1 million records) are not documented. The DMV-matched data include model year data, fuel type data (although diesel-powered vehicles were removed from the databases), vehicle weight data (not complete), and vehicle model description (e.g., sedan, pick-up). From the model description, vehicle weight data and information received from the BAR, vehicle classes were identified.

Of the 1,113,939 records in the DMV-matched database, more than 95 percent – 1,062,073 records representing 503,838 unique vehicles – were used in the examples summarized in this section. Records were removed from the database for two reasons. First, because model descriptions were not standardized (more than a thousand variations), not all vehicles could be assigned to a vehicle class and were dropped from this evaluation resulting in a loss of about 3 percent of the total records. In addition, the number of trucks over 6,000 pounds gross vehicle weight (classified as LDGT2 in MOBILE5a) did not appear to be completely represented in the database, and the records for these vehicles were dropped (of the trucks with valid vehicle weight data, less than one percent were classified as over 6,000 lbs gross vehicle weight). Records for buses and motor homes were also dropped as their representativeness in a remote sensing database are questionable. Total records dropped due to vehicle class considerations were 50,509. Second, an additional 1,357 records were eliminated due to missing or undecipherable data.

## ESTIMATION OF REGISTRATION DISTRIBUTIONS

The following presents the example estimation of registration distributions from the remote sensing data of the California Pilot I/M Program; a comparison of estimated distributions with those of the emissions factor models (MOBILE5a and EMFAC7F) and an example of site-by-site variation of the California Pilot I/M Program data are then presented.

Duplicate records are removed from the database (as the registration distribution represents the population of unique vehicles by model year) and the registration distributions were calculated for the LDGV and LDGT1 vehicle classes. In the examples that follow, 399,309 and 104,529 unique LDGVs and LDGT1s were used in the calculations. The unadjusted registration distribution calculated from the California Pilot I/M database are shown in Tables 3-1a and 3-1b for LDGVs and LDGT1s, respectively.

The California Pilot I/M Program data were adjusted for age-dependent mileage accumulation using mileage accumulation rate (MAR) data from the California ARB EMFAC7F emission factor model. For LDGVs, these MAR data are based on analysis of California I/M Program odometer data; for LDGT1s, these MAR data are based on the MOBILE4 emission factor model (ARB, 1993). The mileage-adjusted data for LDGVs and LDGT1s are also shown in Tables 3-1a and 3-1b, respectively.

For the purposes of this evaluation, no further adjustments to the registration distributions determined from the California Pilot I/M Program were made other than to adjust the data to July 1. In the California Pilot I/M Program the mean date of the remote sensing test data was July 26, 1994. Thus to adjust the data to represent July 1, the current model year vehicles were reduced by 7.1 percent (25 divided by 365) and the distributions were renormalized. The resulting LDGV and LDGT1 registration distributions adjusted to July 1 are also shown in Tables 3-1a and 3-1b, respectively. These distributions are now in the format required by the MOBILE model.

***Comparison of the California Pilot I/M Program Registration***

The registration distribution of the California Pilot I/M Program along with the 1994 default distributions of MOBILE5a and EMFAC7f are shown in Figures 3-2a and 3-2b for LDGVs and LDGT1s, respectively. For MOBILE5a, the registration data are national average 1990 values determined from R. L. Polk data. For EMFAC7F, the LDGV distribution is 1994 data determined from California DMV data; the LDGT1 data are the averages of 1976 through 1983 calendar years of R. L. Polk data for the State of California (ARB, 1993). Clearly, there are significant differences between these and the distribution calculated from the remote sensing data. The average fleet age can be used to quantify the differences between these distributions and are presented in Table 3-2 for each of the distributions. Table 3-2 shows that the age of the fleet in Sacramento is, on average, more than one year older than the fleet represented in the emission factor models for 1994. This is significant considering that a year of fleet turnover can lower emission rates by more than 10 percent (the degree to which fleet turnover affects emissions depends on the fleet makeup and the calendar year of evaluation).

***Site-by-site Variation of the California Pilot I/M Program Data***

Significant site-by-site variation of registration distributions can be expected as the fleet characteristics of various neighborhoods are different. This illustrates the problem with using only one or two remote sensing sites to characterize the whole fleet. However, when several hundred sites are measured as was done in the California Pilot I/M Program, sites can be grouped into subregions for the purposes of calculating fleet characteristics at the subregion level. For illustrative purposes, we evaluated twelve random sites (chosen by every thirtieth location in order of appearance in the DMV-matched database). The variation of fleet age for each site was determined by the population-weighted average age for each vehicle class. The results of this evaluation are shown in Table 3-3. Average age can vary by more than two years showing considerable variation within Sacramento region.

## ESTIMATION OF DIURNAL TRAVEL DISTRIBUTIONS

Diurnal travel distributions were determined from the remote sensing database prior to matching with DMV records. DMV matched data were not required because vehicle information such as vehicle class was not needed to estimate diurnal travel distributions. In order to maximize the number of hours included in this evaluation, the diurnal distributions from the California I/M Pilot Program remote sensing data were determined using sites which began operation before 7 am and finished after 6 pm. This resulted in 101 sites (271,886 records) used to determined the weekday distribution and 10 sites (41,359 records) used to determine the Saturday diurnal distribution; no measurements were taken on Sundays. Note that for the purposes of comparison and for filling in hours not covered by the remote sensing program, the default diurnal distribution of the EPA's Emission Preprocessor System Version 2.0 (EPS2) was used (EPA, 1992a).

Figures 3-3a and 3b show the diurnal distribution determined from the California Pilot I/M Program data for weekdays and Saturdays, respectively. Included in the weekday profile is the default distribution for the same period from EPS2. Figure 3-3a shows that the diurnal distribution from the California Pilot I/M Program has significantly less travel during the weekday morning and afternoon peak periods relative to the mid-day travel than the EPS2 distribution. Comparing Figures 3-3a and 3-3b reveals considerable differences between the distribution of travel on weekdays and on Saturdays.

From the EPS2 distribution, 73.9 percent of the travel is included in the hours evaluated from the California Pilot remote sensing program (hours ending 8 through 18). In order to get the 24-hour distribution, each hour of the fractional travel from the remote sensing data are multiplied by 73.9 percent, and the remaining hours are taken from the EPS2 distribution. The results of this evaluation are shown in Table 3-4 and in Figure 3-4. Again, the diurnal distribution from the

California Pilot I/M Program has significantly less travel during the weekday morning and afternoon peak periods relative to the mid-day travel than the EPS2 distribution.

### ESTIMATION OF VMT MIX

VMT mix from the remote sensing data of the California Pilot I/M program is only calculated for two vehicle classes (LDGVs and LDGT1s) because heavier vehicles were not accurately represented and all diesel-powered vehicles were removed from the data base. VMT mix for the entire database (1,062,073 total records) and for twelve randomly selected sites are shown in Table 3-5 for these two vehicle classes. The data shown in Table 3-5 illustrate that VMT mix can vary widely resulting in regional differences in estimated emissions.

The MOBILE5a 1994 VMT mix was used to fill in the VMT mix of the remaining vehicle classes. From the MOBILE5a data, the LDGVs and LDGT1s account for 81.3 percent of the fleet total VMT. Using 81.3 percent to weight the values for LDGVs and LDGT1s calculated from the California Pilot I/M Program, the overall VMT mix is shown in Table 3-6 for the entire database along with the MOBILE5a default VMT mix. Table 3-6 shows that LDGVs are present in a larger proportion to LDGT1s in the California Pilot I/M Program database than is assumed in MOBILE5a.

### ESTIMATION OF UNREGISTERED VEHICLES

The fraction of the fleet with lapsed registration was determined from the California Pilot I/M program database since the database contained the expiration date of each matched vehicle. Unfortunately, the California BAR was uncertain as to the exact date of the acquisition of the DMV registration data, but the BAR indicated that the data were obtained at the initiation of the project. For the purposes of this example, an acquisition date of July 1, 1994 was assumed. After the removal of duplicate vehicle records, 399,309 and 104,529 unique LDGVs and LDGT1s were used resulting in a lapsed registered vehicle population of 12.5 percent and 10.9 percent for LDGVs and LDGT1s, respectively. However, if one examined the population of vehicles more than one year unregistered, the populations fell to 1.5 percent and 1.4 percent for LDGVs and LDGT1s, respectively. This indicates that the vast majority of unregistered vehicles are eventually registered within a year.

### ESTIMATION OF VEHICLE COUNTY OF ORIGIN (TO DETERMINE I/M STATUS)

The county of registration was examined to determine the type of I/M program the fleet of the California Pilot I/M Program was subject to. No data were provided on the fraction of travel by out-of-state vehicles in the database. In 1996, the enhanced I/M program will be initiated in California, and this evaluation determined the fraction of the fleet which would be subject to the enhanced I/M program based on county of registration. Of the 1,062,073 records of the DMV-

matched database, 78.2 percent of the travel was by vehicles registered in Sacramento County. This shows that the majority of travel was made by the local fleet. When including all of the counties to be incorporated into the California enhanced I/M program, 81.3 percent of the travel was made by vehicles subject to the enhanced I/M program. This illustrates that about one-fifth of the travel (for these two vehicle classes) will be made by vehicles subject to the existing California I/M program.

**Table 3-1a**
**Unadjusted and adjusted LDGV registration distribution data from the California Pilot I/M Program**

| Model Year by Age (1994 = 0) | Unadjusted Model Year Distribution | Distribution Adjusted for Age-dependent Mileage | Distribution Adjusted to July 1st |
|---|---|---|---|
| 0 | 0.059 | 0.040 | 0.037 |
| 1 | 0.075 | 0.052 | 0.053 |
| 2 | 0.069 | 0.051 | 0.051 |
| 3 | 0.083 | 0.064 | 0.064 |
| 4 | 0.081 | 0.065 | 0.066 |
| 5 | 0.086 | 0.073 | 0.073 |
| 6 | 0.080 | 0.072 | 0.072 |
| 7 | 0.080 | 0.077 | 0.077 |
| 8 | 0.071 | 0.072 | 0.072 |
| 9 | 0.063 | 0.069 | 0.069 |
| 10 | 0.053 | 0.062 | 0.062 |
| 11 | 0.035 | 0.044 | 0.044 |
| 12 | 0.027 | 0.036 | 0.036 |
| 13 | 0.024 | 0.034 | 0.034 |
| 14 | 0.021 | 0.031 | 0.031 |
| 15 | 0.022 | 0.033 | 0.033 |
| 16 | 0.018 | 0.029 | 0.029 |
| 17 | 0.012 | 0.019 | 0.020 |
| 18 | 0.007 | 0.012 | 0.012 |
| 19 | 0.004 | 0.006 | 0.006 |
| 20 | 0.004 | 0.007 | 0.007 |
| 21 | 0.004 | 0.008 | 0.008 |
| 22 | 0.004 | 0.007 | 0.007 |
| 23 | 0.003 | 0.005 | 0.005 |
| 24 | 0.017 | 0.032 | 0.032 |

**Table 3-1b**
**Unadjusted and adjusted LDGT1 registration distribution data from the California Pilot I/M Program**

| Model Year by Age (1994 = 0) | Unadjusted Model Year Distribution | Distribution Adjusted for Age-dependent Mileage | Distribution Adjusted to July 1st |
|---|---|---|---|
| 0 | 0.068 | 0.039 | 0.037 |
| 1 | 0.092 | 0.057 | 0.057 |
| 2 | 0.081 | 0.054 | 0.054 |
| 3 | 0.093 | 0.067 | 0.067 |
| 4 | 0.072 | 0.055 | 0.055 |
| 5 | 0.083 | 0.068 | 0.068 |
| 6 | 0.070 | 0.062 | 0.062 |
| 7 | 0.073 | 0.069 | 0.069 |
| 8 | 0.078 | 0.079 | 0.079 |
| 9 | 0.052 | 0.056 | 0.057 |
| 10 | 0.042 | 0.049 | 0.049 |
| 11 | 0.023 | 0.028 | 0.029 |
| 12 | 0.019 | 0.026 | 0.026 |
| 13 | 0.015 | 0.022 | 0.022 |
| 14 | 0.015 | 0.023 | 0.023 |
| 15 | 0.021 | 0.035 | 0.035 |
| 16 | 0.018 | 0.032 | 0.032 |
| 17 | 0.016 | 0.030 | 0.030 |
| 18 | 0.010 | 0.021 | 0.021 |
| 19 | 0.007 | 0.016 | 0.016 |
| 20 | 0.007 | 0.016 | 0.016 |
| 21 | 0.008 | 0.018 | 0.018 |
| 22 | 0.007 | 0.015 | 0.016 |
| 23 | 0.005 | 0.011 | 0.011 |
| 24 | 0.024 | 0.051 | 0.052 |

**Table 3-2**
**Population-weighted average fleet ages based on registration distribution data. The age of current model years is assumed to be 0; the age of vehicles 24 years old and older is assumed to be 24**

| Vehicle Class | Population-weighted Average Vehicle Age (years) by Source of Registration Distribution Data | | |
|---|---|---|---|
| | California Pilot I/M Program | EMFAC7f | MOBILE5a |
| LDGV | 8.5 | 7.3 | 7.2 |
| LDGT1 | 9.4 | 7.6 | 7.8 |

**Table 3-3**
**Population-weighted fleet average ages for twelve randomly selected sites of the California Pilot I/M Program database. The age of current model years is assumed to be 0; the age of vehicles 24 years old and older is assumed to be 24**

| Site ID | Site Type | LDGV Average Age (years) | LDGT1 Average Age (years) |
|---|---|---|---|
| 514 | Limited Access | 8.1 | 9.2 |
| 12 | Limited Access | 7.8 | 8.2 |
| 66 | Limited Access | 8.0 | 8.7 |
| 223 | Limited Access | 8.2 | 8.2 |
| 151 | Surface Street | 8.5 | 9.3 |
| 586 | Surface Street | 8.0 | 8.6 |
| 606 | n/a | 7.9 | 8.6 |
| B521 | Surface Street | 10.1 | 10.6 |
| B129 | Surface Street | 7.5 | 8.3 |
| B57 | n/a | 8.1 | 8.8 |
| 557 | Limited Access | 7.6 | 7.8 |
| 190 | n/a | 8.5 | 9.9 |

n/a = site description not included in BAR-released data.

**Table 3-4**
**24-hour weekday diurnal distributions from EPS2 (EPA, 1992) and from the remote sensing data of the California Pilot I/M Program**

| Hour Ending | EPS2 Diurnal Distribution (EPA, 1992b) | CA Pilot I/M Program Diurnal Distribution |
|---|---|---|
| 0 | 0.010 | 0.010 |
| 1 | 0.010 | 0.010 |
| 2 | 0.010 | 0.010 |
| 4 | 0.010 | 0.010 |
| 5 | 0.010 | 0.010 |
| 6 | 0.010 | 0.010 |
| 7 | 0.063 | 0.063 |
| 8 | 0.104 | 0.062 |
| 9 | 0.063 | 0.058 |
| 10 | 0.052 | 0.052 |
| 11 | 0.052 | 0.055 |
| 12 | 0.052 | 0.061 |
| 13 | 0.052 | 0.066 |
| 14 | 0.052 | 0.066 |
| 15 | 0.052 | 0.068 |
| 16 | 0.063 | 0.075 |
| 17 | 0.104 | 0.083 |
| 18 | 0.083 | 0.086 |
| 19 | 0.063 | 0.063 |
| 20 | 0.042 | 0.042 |
| 21 | 0.010 | 0.010 |
| 22 | 0.010 | 0.010 |
| 23 | 0.010 | 0.010 |
| 24 | 0.010 | 0.010 |

**Table 3-5**
**VMT Mix data for the sum of all sites and for twelve randomly selected sites of the California Pilot I/M Program Database**

| Site ID | Site Type | LDGV VMT Mix | LDGT1 VMT Mix |
|---|---|---|---|
| All Sites | | 0.804 | 0.196 |
| 514 | Limited Access | 0.747 | 0.253 |
| 12 | Limited Access | 0.855 | 0.145 |
| 66 | Limited Access | 0.677 | 0.323 |
| 223 | Limited Access | 0.852 | 0.148 |
| 151 | Surface Street | 0.794 | 0.206 |
| 586 | Surface Street | 0.823 | 0.177 |
| 606 | n/a | 0.810 | 0.190 |
| B521 | Surface Street | 0.834 | 0.166 |
| B129 | Surface Street | 0.721 | 0.279 |
| B57 | n/a | 0.780 | 0.220 |
| 557 | Limited Access | 0.725 | 0.275 |
| 190 | n/a | 0.824 | 0.176 |

n/a = site description not included in BAR-released data.

**Table 3-6**
**MOBILE5a 1994 default VMT mix data and VMT mix data calculated from the California Pilot I/M Program database. Only LDGVs and LDGT1s are included**

| Vehicle Class | MOBILE5a 1994 Default | California Pilot I/M Program |
|---|---|---|
| LDGV | 0.636 | 0.654 |
| LDGT1 | 0.177 | 0.159 |
| LDGT2 | 0.083 | 0.083 |
| HDGV | 0.031 | 0.031 |
| LDDV | 0.004 | 0.004 |
| LDDT | 0.002 | 0.002 |
| HDDV | 0.059 | 0.059 |
| MC | 0.007 | 0.007 |

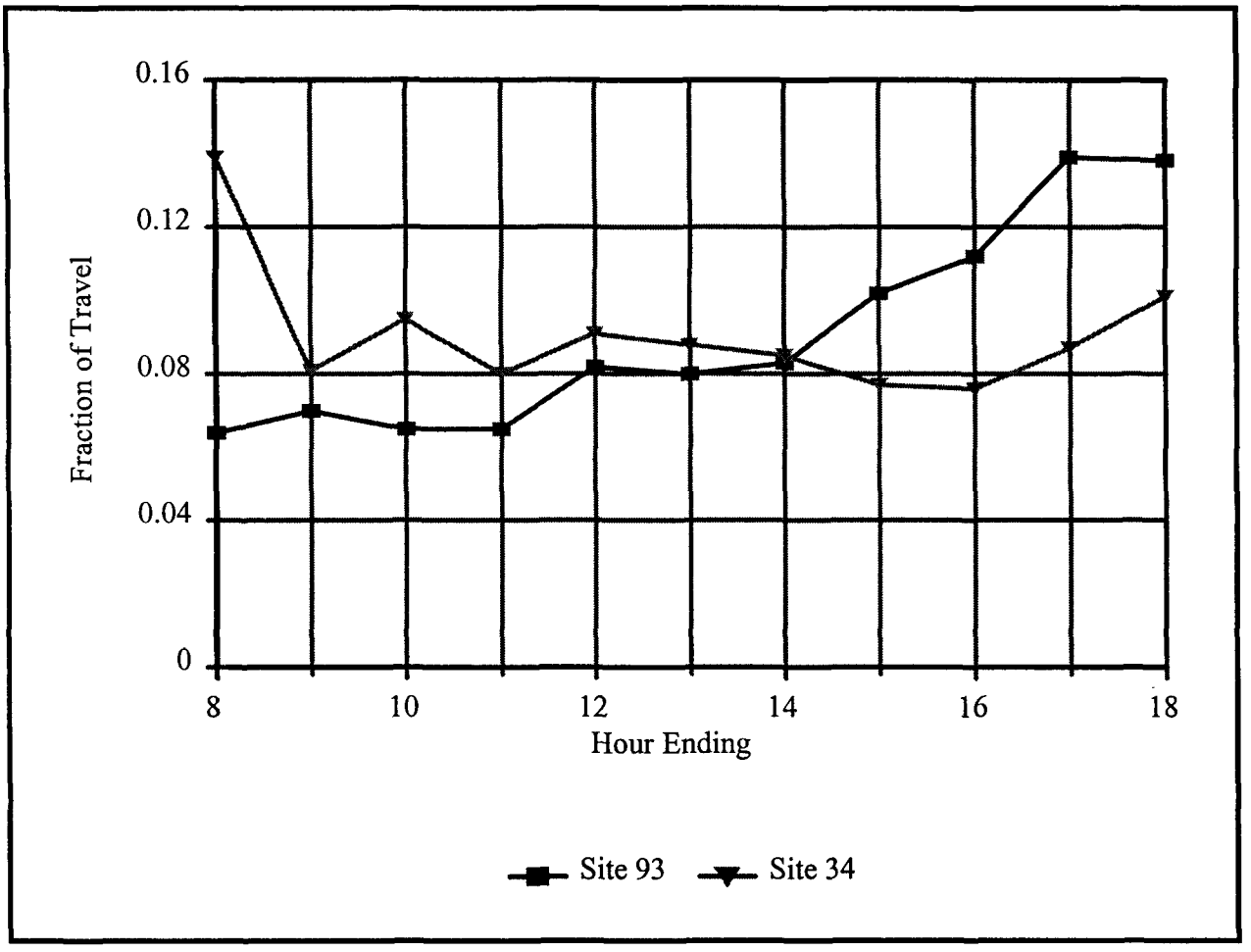


**Figure 3-1**
**Two sites on opposing directions of Highway 50 in Sacramento showing weekday morning and afternoon commute patterns**

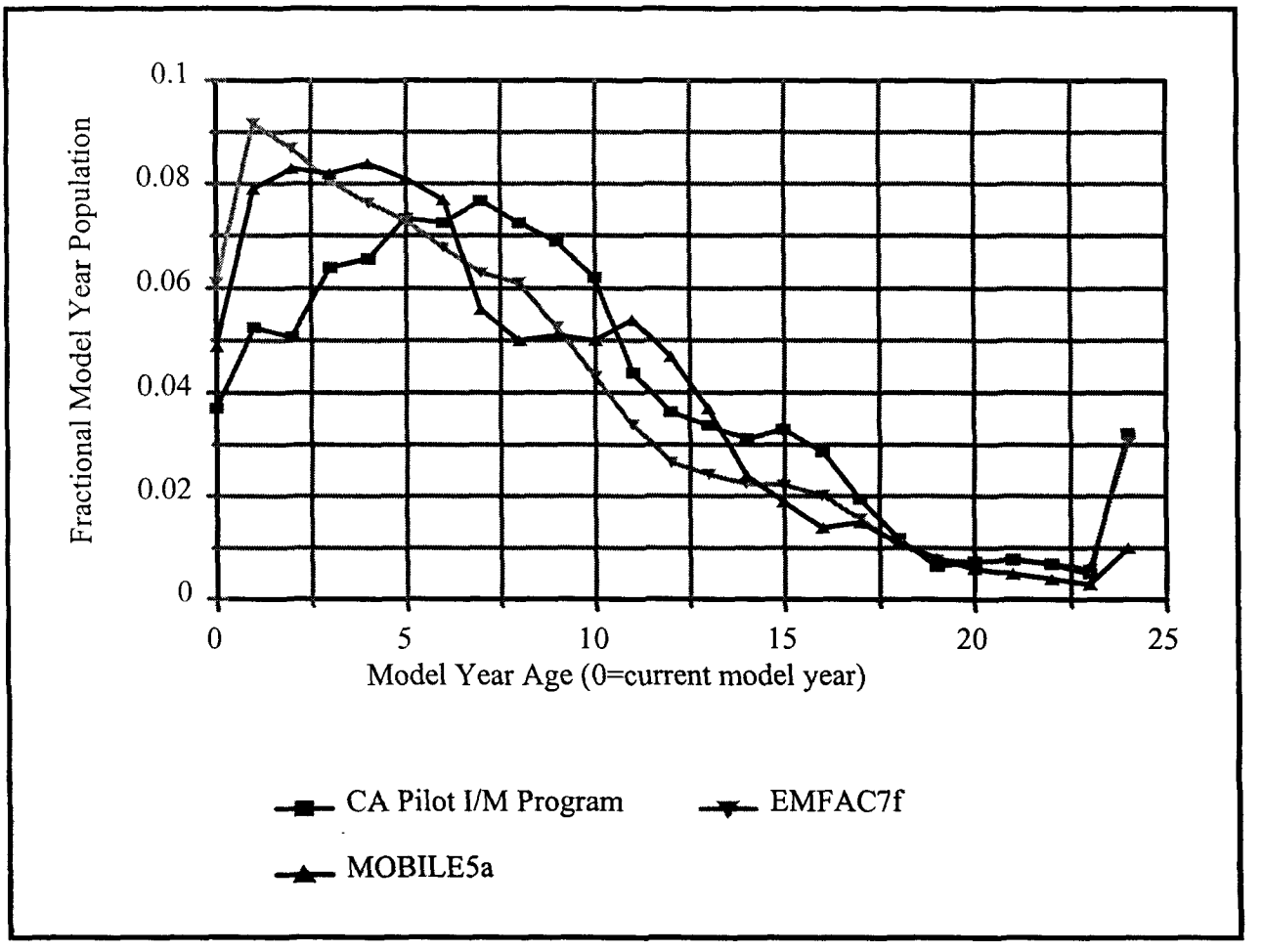


**Figure 3-2a**
**LDGT1 registration distribution data determined from the California Pilot I/M Program remote sensing data and the emission factor models, MOBILE5a and EMFAC7F**

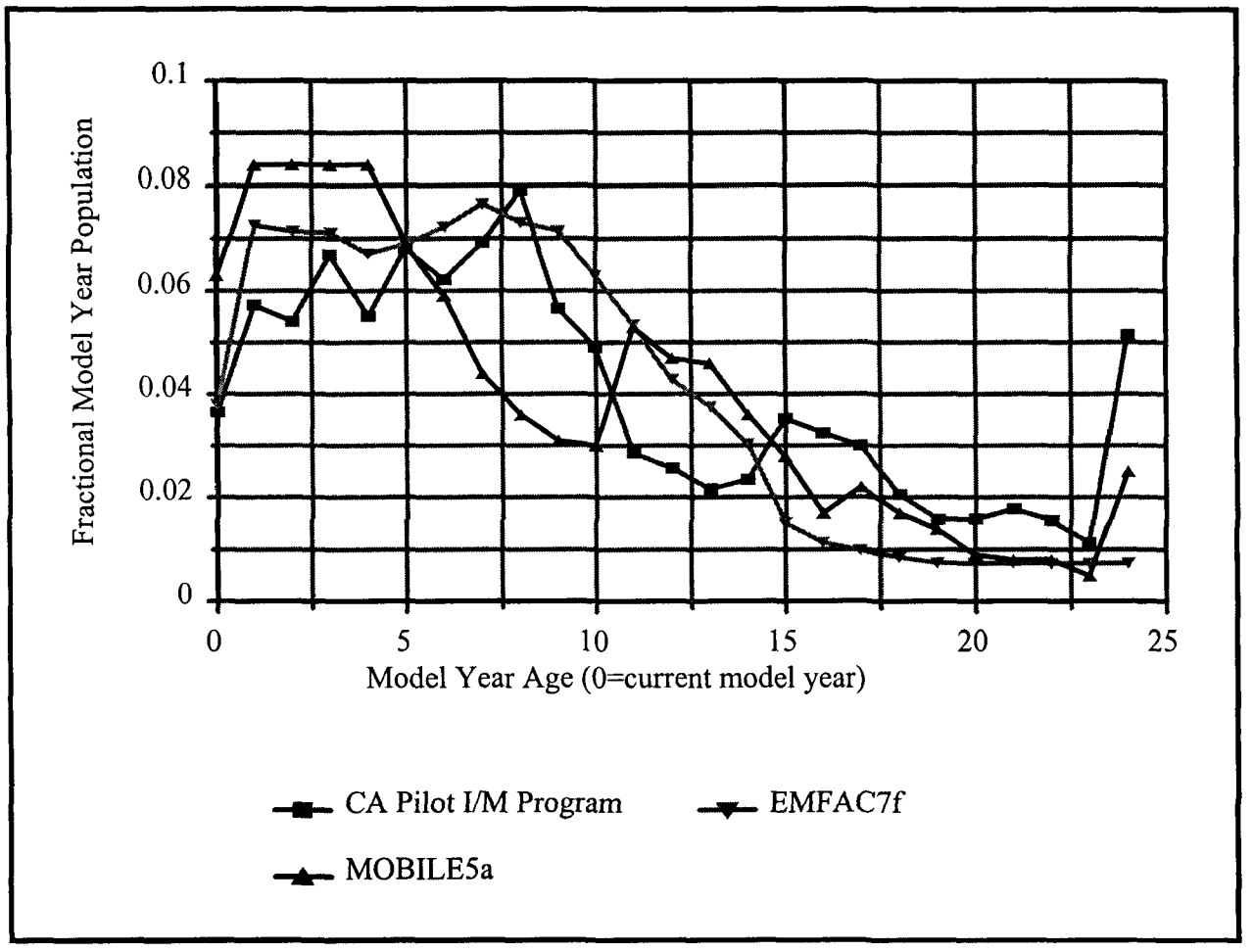


**Figure 3-2b**
**LDGV registration distribution data determined from the California Pilot I/M Program remote sensing data and the emission factor models, MOBILE5a and EMFAC7F**

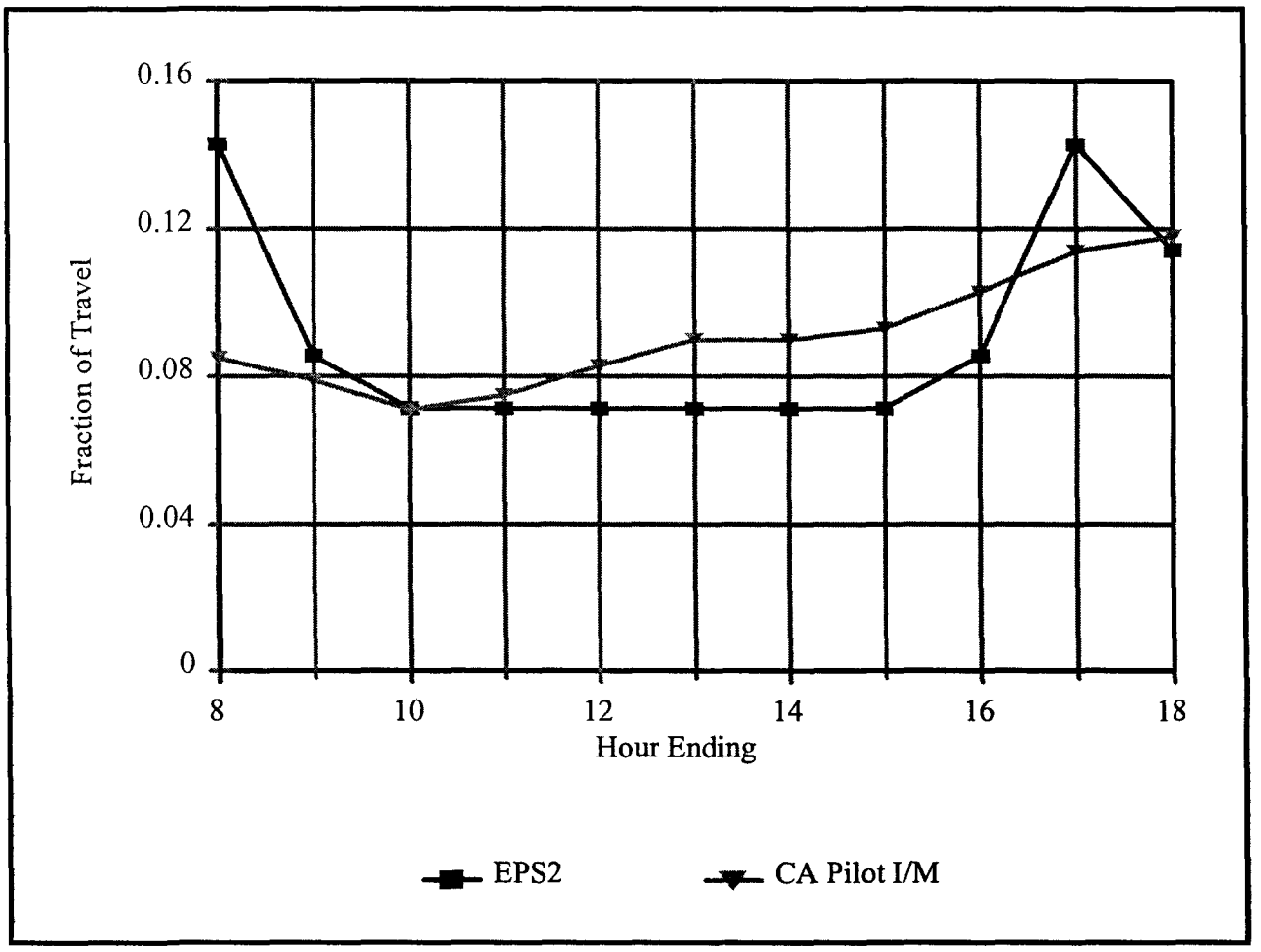


**Figure 3-3a**
**Weekday diurnal travel distributions from EPS2 (EPA, 1992) and from the remote sensing data of the California Pilot I/M Program**

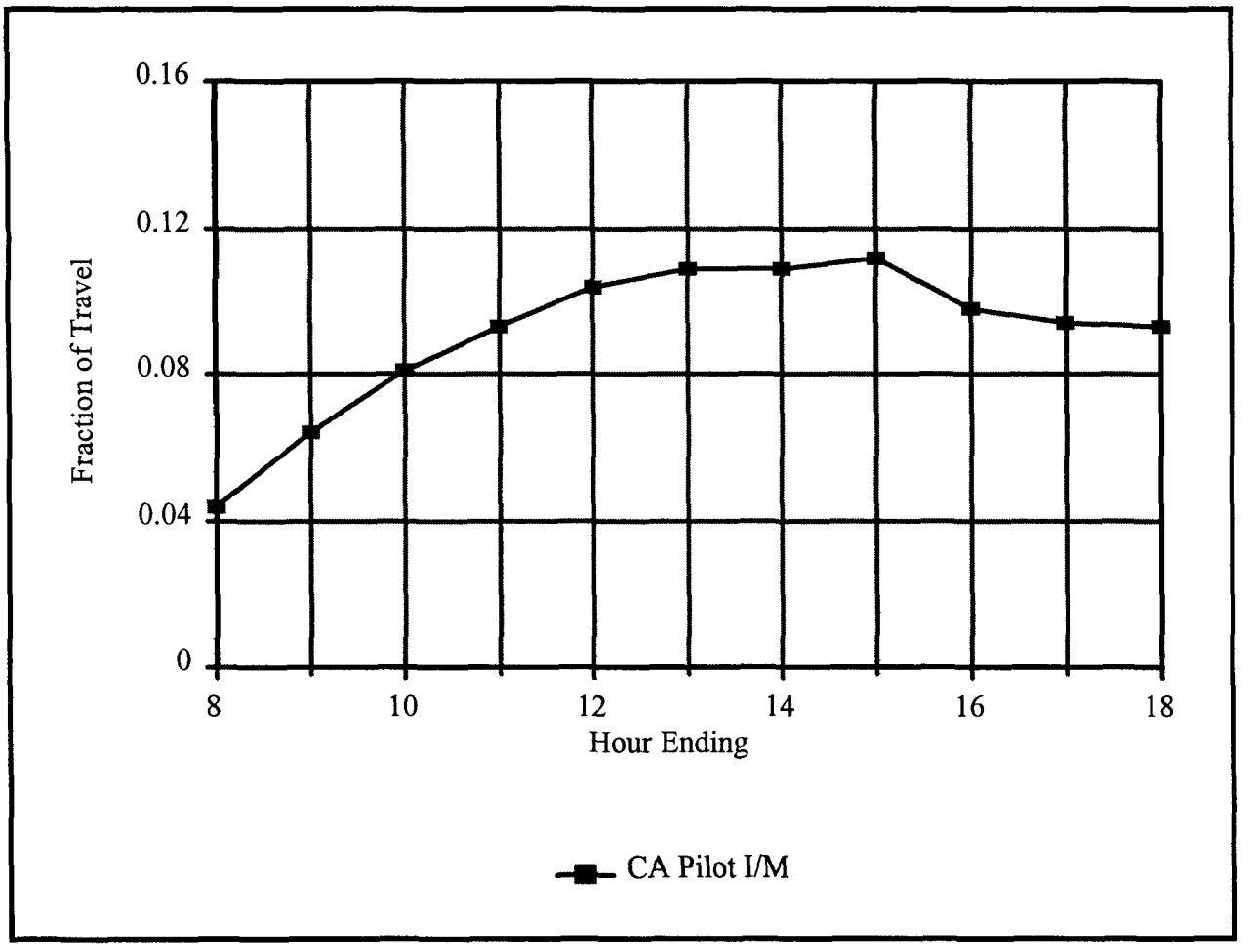


**Figure 3-3b**
**Saturday diurnal travel distribution calculated from the remote sensing data of the California Pilot I/M Program**

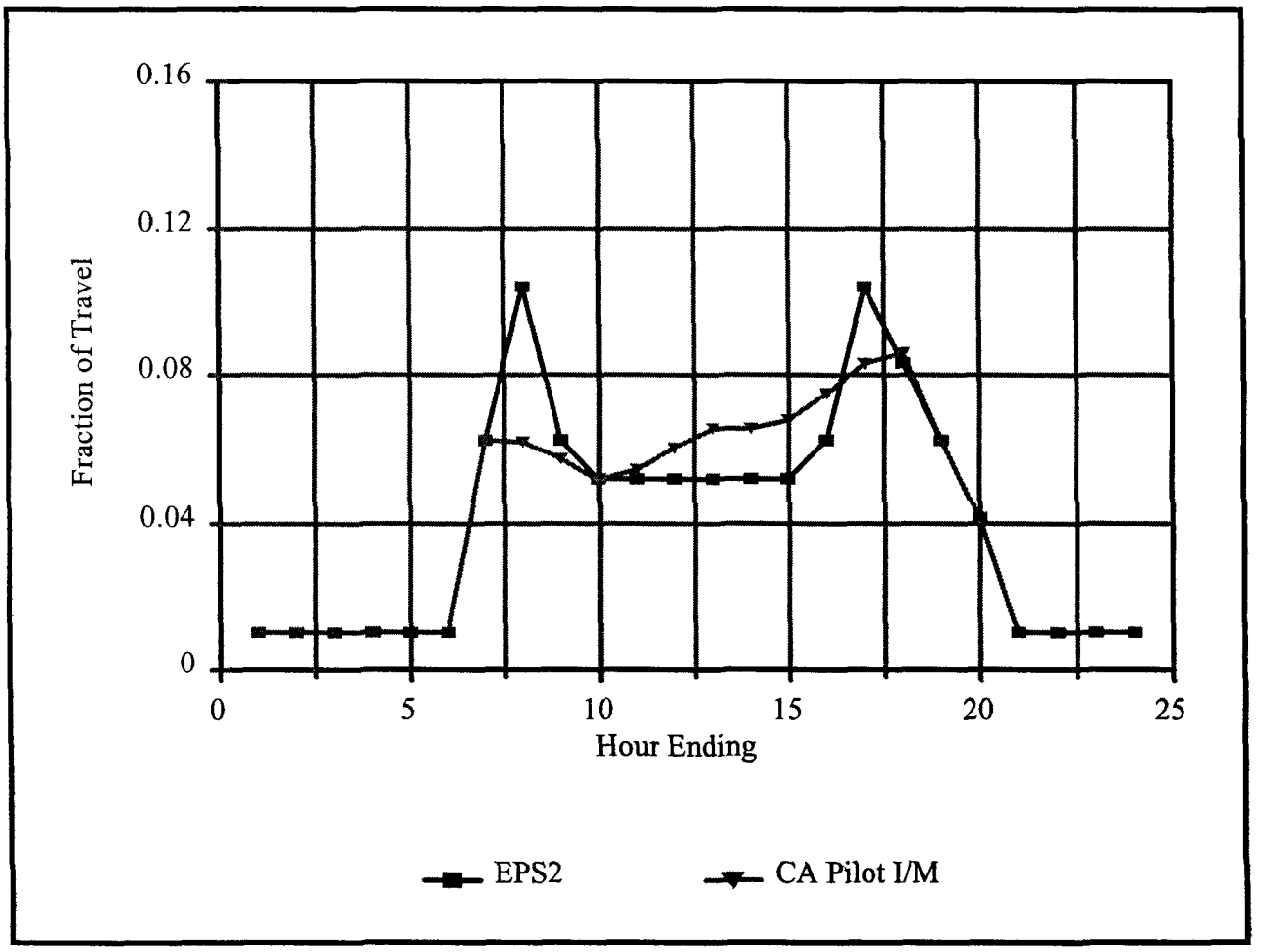


**Figure 3-4**
**24-hour weekday diurnal travel distributions from EPS2 (EPA, 1992) and from the remote sensing data of the California Pilot I/M Program**

# 4

# ESTIMATION OF MOBILE SOURCE FUEL CONSUMPTION AND AREA VMT

## INTRODUCTION

This section presents the methodology for the estimation of mobile source fuel consumption and vehicle miles traveled (VMT) from tax revenue and other data sources. VMT estimates are usually based upon data compiled for transportation network planning purposes. This section presents an alternate methodology to independently estimate VMT and compare this estimate to others calculated by traditional methods. The methodology calculates VMT from estimates of area fuel consumption, fleet fuel economy and refueling loss rates. It is suggested that if the two VMT estimates differ substantially, further investigation may be warranted. This section begins with a literature review of relevant studies, then provides details of the methodology to estimate VMT. Example calculations are then provided for Sacramento County, CA and for Maricopa County, AZ.

## LITERATURE REVIEW

This literature review summarizes previous work or related studies on how to estimate mobile source fuel consumption in a nonattainment area. Each of these documents discusses issues that should be considered in calculations of VMT from fuel consumption estimates. The following documents are reviewed in this section.

- *A Determination of Motor Vehicle Activity Factors for Atlanta, Georgia through Fuel Consumption Analysis* (Hayes, 1993).
- *The Mobile4 Fuel Consumption Model* (EPA, 1991).
- *Procedures for Emission Inventory Preparation - Volume IV: Mobile Sources* (EPA, 1992).
- *User's Guide to MOBILE5 (Mobile Source Emission Factor Model)* (EPA, 1994).
- *Emission Inventory Procedural Manual - Volume III: Methods for Assessing Area Source Emissions* (ARB, 1995).

In addition to the document review, several contacts with state agencies have provided useful information regarding estimates of fuel sales or consumption. Two that were of particular importance are also summarized below.

***A Determination of Motor Vehicle Activity Factors for Atlanta, Georgia through Fuel Consumption Analysis (Hayes, 1993).***

Adam Hayes completed this master's thesis under the direction of Professor Michael O. Rodgers at the Georgia Institute of Technology. Hayes' objective was to develop alternate means to calculate VMT in Atlanta, Georgia. He discussed traditional VMT estimation methods and two alternative methods based on estimates of fuel consumption and fuel economy. Hayes also discussed the limitations of the various approaches.

Traditional VMT estimation methods utilize traffic count data, random sampling, historical data, and statistical extrapolation. Transportation modelers developed these methods in order to evaluate the performance of the transportation network rather than to provide an accurate estimate of vehicle emissions. Hayes identified a number of biases (listed below) that may associated with these traditional techniques.

- The Department of Transportation and travel demand modelers use road classifications in order to extrapolate traffic flows. Road sections may need to be re-classified more frequently than current practices allow (e.g. urban vs. rural), especially during periods of rapid growth.

- Traffic count data are incomplete because (1) many roadways are sampled only once in several years, and (2) sample locations are often sited to target traffic flow problems of local concern.

- Traffic counts usually last only 24-48 hours. At this time scale, many short-term factors may confound results (e.g., weather, traffic accidents, traffic congestion).

- Seasonal variations in traffic flow at the sample site must be accounted for properly.

- Many data collection efforts are costly, therefore, outdated information is frequently used. For example, origin-destination roadside questionnaires provide extremely valuable data, but are expensive to administer. The Census Bureau's Journey to Work data are often used, however, these are only updated every 10 years.

- Analysts adjust transportation demand models until the model results match traffic count data. Some analysts use arbitrary adjustment techniques that do not provide an accurate representation of VMT, particularly if VMT counts are not the analysts' primary focus.

- Transportation demand models require large quantities of descriptive data regarding the transportation network. Human coding errors sometimes occur as a result.

In order to circumvent these biases, Mr. Hayes proposed two alternative methods to estimate fuel consumption and calculate VMT. The first method utilized fuel shipment records, and the second method applied fuel tax revenue data.

Data representing the total fuel shipped to Atlanta, Georgia in 1986 were gathered from two pipeline companies. These data were treated as an upper limit estimate of fuel consumed on-road in Atlanta. Error may be introduced in this estimate if significant amounts of fuel were (a) transported overland for use in other communities following dispersal from the pipelines, (b) transported from other communities for use in Atlanta, (c) used for off-road purposes, or (d) lost due to volatilization. Fuel shipments to Atlanta are limited to two pipeline carriers, thus data acquisition is relatively simple. Mr. Hayes points out that this method is difficult to apply to other U.S. cities because numerous overland or waterway shipment routes are difficult to track and quantify. Furthermore, recent data are very difficult to obtain because shippers lack incentive to share information.

A second estimate of fuel consumption was based upon fuel tax revenue information. Tax revenue figures are available only at the state level. Mr. Hayes disaggregated the state tax revenue figure according to the proportion of VMT that occurred in Atlanta during 1986 (estimated by the Georgia Department of Transportation).

Mr. Hayes then calculated VMT from these estimates of fuel consumption. He demonstrated sensitivity to fleet fuel economy, off-road fuel use, and out-of-area fuel use. Assuming 1986 fleet fuel economy between 14 and 16.7 mpg and more than 75 percent on-road fuel use in the area, Mr. Hayes' estimates of VMT differed from those made by the Georgia DOT and HPMS by less than 30 percent.

***Procedures for Emission Inventory Preparation - Volume IV: Mobile Sources* (EPA, 1992), and the *User's Guide to MOBILE5 (Mobile Source Emission Factor Model)* (EPA, 1994).**

These two documents are complementary and are discussed here jointly. They describe current EPA procedures for completing the mobile source emissions inventory and provide a context for the calculation of VMT. A detailed method to estimate VMT from fleet characteristics is fully described. Additionally, methods to quantify resting losses and emissions from non-road sources are described. These documents provide helpful guidance for segregating on-highway fuel consumption from total fuel consumption.

***The Mobile4 Fuel Consumption Model* (EPA, 1991).**

The purpose of the MOBILE4 Fuel Consumption Model (M4FC) is to calculate fuel consumption using fleet VMT and fleet fuel economy. Note that this is the reverse of the methodology presented in this document (i.e., calculating VMT from fuel economy and fuel consumption). The M4FC guide demonstrates that these calculations are sensitive to fuel economy, fleet distribution, and mileage accumulation rates.

***Emission Inventory Procedural Manual - Volume III: Methods for Assessing Area Source Emissions* (ARB, 1995).**

This document presents the California ARB's methods for calculating vaporization losses associated with refueling stations. Emission factors as a function of fuel sales are given for underground storage tank working and breathing losses, and for refueling losses due to vapor displacement and spillage. These types of losses should be considered during calculations of on-highway fuel consumption.

### CALIFORNIA DEPARTMENT OF TRANSPORTATION, ECONOMICS ANALYSIS UNIT

The Economics Analysis Unit of the California Department of Transportation (CalTrans) has performed a regression analysis to verify correlations of several factors with historical state fuel consumption. These factors include the total number of driver's licenses, total number of registered vehicles, total sales, service station sales, and sales of eating and drinking establishments. The relationship of retail sales to fuel consumption is not intuitive. However, the rationale was that sales are inflated when a heavy tourist population exists, and so too, fuel consumption must increase.

In order to calculate fuel consumption in California localities, CalTrans extrapolates the above regression to the county level. The statewide fuel consumption figure, which is known, is disaggregated according to each county's proportion of the above factors.

### CALIFORNIA BOARD OF EQUALIZATION, FUEL TAXES DIVISION

The Fuel Taxes Division of the California Board of Equalization also estimates fuel consumption at the county level. The statewide fuel consumption figure is disaggregated according to the proportion of service station taxable sales in each county. Agency employees estimate that 80 to 95 percent of service station sales are attributable to fuel.

# METHODOLOGY FOR ESTIMATING VMT

Emissions associated with on-road motor vehicle use are an important element of any emission inventory. The USEPA provides a mobile source emission factor model (MOBILE) that estimates vehicle emission factors. These emission factors are combined with locale-specific estimates of vehicle miles traveled (VMT) to estimate mobile source emissions. VMT estimates are available from state departments of transportation (DOT) or county planning agencies, such as metropolitan transportation planning organizations (MPO). While readily available at the resolution needed for air quality planning purposes (e.g., county or even sub-county levels), these VMT estimates are usually compiled for transportation network planning purposes, not for air quality planning. The adequacy of these estimates for air quality planning purposes can vary depending upon the area and the VMT estimation methods used.

This subsection presents a method to independently derive VMT for comparison with transportation planners' estimates of VMT. Specifically, this section presents a means to estimate VMT from fuel consumption and fleet fuel economy. Locale-specific or national average data may be used, depending upon availability. If the results of this fuels-based method differ substantially from transportation planners' estimates, further investigation may be warranted.

In order to allow a valid comparison of results, the fuels-based method must be based upon data that are independent of transportation planners' estimates of VMT. Tax revenue data and demographic statistics are used to disaggregate statewide figures of on-road fuel consumption provided by the Federal Highway Administration (FHWA). On-road fuel consumption is also corrected for refueling losses. Locally determined fleet fuel economy is suggested for use, although national average fuel economy may be used if no other data are available.

## OVERVIEW OF CALCULATION PROCEDURES

The basis of this methodology is a five-step procedure to estimate VMT. Before proceeding, the following data must be obtained:

- Statewide gasoline and special fuels consumption data which are published annually in *Highway Statistics* by the Federal Highway Administration.

- Information regarding the extent of Stage I and Stage II refueling control measures in the area of interest; these are available from state agencies or the EPA.

- Registration distributions and mileage accumulation rates should be used to determine local fuel economy if possible; otherwise, national averages contained in the MOBILE model can be used.

- Economic and population statistics which are maintained by state and federal agencies for the U.S., state, and counties of interest (see List of Contacts, Appendix A).

The five steps in the methodology, described in detail below, are as follows:

Step 1: Adjust statewide gasoline and special fuels distributions to account for off-road use.

Step 2: Geographically disaggregate fuel distribution from Step 1 and assign fuel volumes to the counties of interest according to each county's share of economic and population indicators.

Step 3: Adjust the fuel distributions obtained in Step 2 for refueling losses. The result represents the counties' on-road fuel consumption.

Step 4: Calculate diesel- and gasoline-powered fleet fuel economies. This is achieved by weighting on-road fuel economies according to vehicle stock (numbers of vehicles) and mileage accumulation rates. If possible, local data should be used. However, a method to use national averages extracted from MOBILE 5 is described for cases where no other data are available.

Step 5: Multiply on-road fuel consumption by fleet fuel economies to calculate VMT.

## DESCRIPTION OF CALCULATION PROCEDURES

### *Step 1: Estimate On-Road Fuel Consumption*

On-road gasoline consumed in a state ($G_{state}$) includes all gasoline and gasohol used on state roads, taxed and untaxed. $G_{state}$ can be calculated for the 50 states and the District of Columbia from data that are published annually by the Federal Highway Administration (FHWA) in *Highway Statistics.* In order to calculate $G_{state}$, total gasoline consumption must be corrected for refueling facility losses, and for the following non-road uses: agriculture, aviation, industry, construction, and marine. Table 4-1 shows 1994 data corrected for non-road use for selected states and the nation as a whole.

The FHWA also tabulates on-road private and commercial use of special fuels ($D_{state}$) (Table 4-2). Special fuels consist principally of diesel fuel with minor amounts of liquefied

petroleum gases and other fuels. In this analysis, special fuels are treated as a surrogate for diesel.

**Table 4-1**
**Gasoline distributed in selected states for 1994 (FHWA, 1994)**

| State | Total Gasoline ($10^6$ gallons) | Non-Highway Gasoline[1] ($10^6$ gallons) | Highway Gasoline[1] ($10^6$ gallons) |
|---|---|---|---|
| Arizona | 1935 | 35 | 1900 |
| California | 13162 | 229 | 12933 |
| Connecticut | 1403 | 67 | 1336 |
| New York | 5543 | 111 | 5433 |
| United States | 118531 | 2955 | 115576 |

Not yet corrected for volatilization and handling losses. In *Highway Statistics*, FHWA subtracts losses reported by states due to handling and volatilization. The methods used by states are not uniform, therefore, a different method to calculate these losses is used later in this analysis. Values in the table do not perfectly match those in the FHWA publication because FHWA-reported losses were re-distributed on a percent basis to highway and non-highway data.

**Table 4-2**
**On-road special fuels consumption in selected states for 1994 (FHWA, 1994)**

| State | Special Fuels On-Road Use ($10^6$ gallons) |
|---|---|
| Arizona | 463.5 |
| California | 2,035.6 |
| Connecticut | 186.5 |
| New York | 917.0 |
| UnitedStates | 25,123.6 |

Special fuels consist principally of diesel fuel with minor amounts of liquefied petroleum gases and other fuels. In this analysis, special fuels are treated as a surrogate for diesel.

### *Step 2: Disaggregate to Counties*

Economic and population statistics can be used to proportionally disaggregate statewide on-road fuel consumption ($F_{state}$) to counties. (Note that $F_{state}$ is used here interchangeably with $D_{state}$ or $G_{state}$.) These statistics include:

- service station taxable sales (ss),
- number of registered vehicles (rv),
- number of valid driver's licenses (dl),
- total taxable sales (ts), and
- population (pop).

Records of these statistics are maintained by state agencies (see Appendix A for an example list of agencies including those contacted in this study).

County proportions (p) are calculated for each of the five statistics. For example, the proportion of statewide service station sales for a county, $p_{ss}$, is calculated as

$$p_{ss} = ss_{county} / ss_{state} \tag{4-1}$$

The average proportion is calculated as

$$p_{avg} = (p_{ss} + p_{rv} + p_{dl} + p_{ts} + p_{pop}) / 5 \tag{4-2}$$

It is expected that the five proportions should be very similar. If the five proportions are approximately equal, then the average proportion may be used to calculate $F_{county}$. If any one of the proportions above differs substantially from $p_{avg}$, say by more than 10 percent, a simple regression on historical state/country proportions can be used to determine weighting factors for the five proportions. In such a case, state and U.S. data for at least 20 time periods should be used (e.g. 20 years, 20 months, etc.). This approach assumes that state/U.S. correlations reflect county/state correlations reasonably well. Details of estimating county fuel consumption (diesel or gasoline) using weighted averages of the five proportions are provided in Appendix D.

$$F_{county} = F_{state} \times p_{avg} \tag{4-3}$$

### *Step 3: Adjust for Refueling Emissions*

The California ARB and the U.S. EPA have developed spillage and volatilization emission factors for gasoline dispensing facilities (see Table 4-3). These factors depend on the use of evaporative control systems, and are expressed in lb/1000 gallons throughput. Loss rates expressed in gallons lost/gallons throughput are needed to adjust fuel consumption figures for refueling losses. The liquid density of gasoline is approximately 7.5 lb/gallon. Division of the emission factors listed in Table 4-3 by this density yields the required loss rates, as shown in Table 4-4. Note that although it is theoretically correct to subtract the amount of fuel loss due to refueling, the quantity of fuel lost is generally a very small fraction of the total fuel consumption, and this step can be skipped without affecting the resulting calculations. This point is demonstrated in the example calculations that follow.

Diesel fuel is relatively non-volatile, therefore, its volatilization losses are neglected here. The refueling spillage rate for diesel is assumed to be equal to that for gasoline.

**Table 4-3**
**Emission factors for gasoline dispensing facilities (lb/1000 gallons throughput).**
**Source: ARB (1995)**

| Source of Loss | Without Stage I/Stage II Control | With Stage I/Stage II Control |
|---|---|---|
| Underground Storage Tanks | | |
| Working Losses | 9.5 | 0.475 |
| Breathing Losses | 1.0* | 0.1* |
| Refueling: | | |
| Vapor Displacement | 10.0 | 0.5 |
| Spillage | 0.7 | 0.7 |

* 1.0 if no control or only Stage I control; 0.1 if both Stage I and Stage II controls.

**Table 4-4.**
**Loss rates for gasoline dispensing Facilities**
**(gallons lost/1000 gallons throughput).**

| Source of Loss | Without Stage I/Stage II Control | With Stage I/Stage II Control |
|---|---|---|
| Underground Storage Tanks: | | |
| Working Losses | 1.27 | 0.06 |
| Breathing Losses | 0.13* | 0.01* |
| Refueling: | | |
| Vapor Displacement | 1.33 | 0.07 |
| Spillage | 0.09 | 0.09 |

* 0.13 if no control or only Stage I control; 0.01 if both Stage I and Stage II controls (derived from Table 3-3).

### *Step 4: Calculate Fleet Fuel Economy*

Fleet fuel economy ($mpg_f$) is averaged across vehicle classes and ages, weighted by mileage accumulation rate (ma) and vehicle stock (vs). There are eight vehicle classes used in MOBILE5a, defined by EPA (1992) as:

| Class | Description |
|---|---|
| LDGV | Light duty gasoline-powered vehicles |
| LDGT1 | Light duty gasoline-powered trucks (up to 6000 lb. GVW) |
| LDGT2 | Light duty gasoline-powered trucks (6001 - 8500 lb. GVW) |
| HDGV. | Heavy duty gasoline-powered vehicles |
| LDDV | Light duty diesel-powered vehicles |
| LDDT | Light duty diesel-powered trucks |
| HDDV | Heavy duty diesel-powered trucks |
| MC | Motorcycles |

In the MOBILE5 model and the ARB mobile source emissions factor model (EMFAC7F), estimates of on-road fuel economies are provided for these eight categories (or their equivalents) according to vehicle model year (EPA, 1994; ARB, 1993). These values are tabulated in Appendix B.

If available, local mileage accumulation data and registration distributions can be used to calculate fleet fuel economy ($mpg_f$) according to the following equation.

$$Fleet\ Fuel\ Economy = mpg_f = \frac{\sum mpg_{ij} \times ma_{ij} \times vs_{ij}}{\sum ma_{ij} \times vs_{ij}} \qquad (4\text{-}4)$$

Where

- Vehicle stock (vs) is the total number of vehicles for class *i* and age *j*,
- mileage accumulation rate (ma) is the average number of miles per year traveled by a vehicle for class *i* and age *j*

Separate fuel economies should be calculated for the diesel- and gasoline-powered fleets ($mpg_{fd}$ and $mpg_{fg}$).

If local mileage and registration data are unavailable, national average fleet fuel economy may be used. Equation 4-4 is equivalent to:

$$mpg_f = \sum \frac{vmt_{ij}}{VMT} \times mpg_{ij} \qquad (4\text{-}5)$$

Where

$vmt_{ij}$ = annual average vehicle miles traveled for cars of class *i* and age *j*.
$VMT$ = annual total vehicle miles traveled for all classes
$mpg_{ij}$ represents the fuel economy of a vehicle of class *i* and age *j*

The ratio, vmt/VMT, is defined as the VMT mix in MOBILE. MOBILE5a includes national average VMT mixes as default values based on historical mileage accumulation rates and national registration distribution data (EPA, 1994). The 1994 predicted VMT mix by class ($vmt_i$/VMT) using MOBILE5a default settings is shown in Table 4-5.

**Table 4-5.**
**1994 VMT Mix by class predicted by MOBILE5a.**

| Fleet | Vehicle Class | $vmt_i/VMT$ | $vmt_i/VMT$ Normalized to gas and diesel fleets |
|---|---|---|---|
| Gasoline | LDGV | 0.636 | 0.681 |
| | LDGT1 | 0.177 | 0.190 |
| | LDGT2 | 0.083 | 0.090 |
| | HDGV | 0.031 | 0.033 |
| | MC | 0.007 | 0.008 |
| | | | SUM=1.0 |
| Diesel | LDDV | 0.004 | 0.062 |
| | LDDT | 0.002 | 0.031 |
| | HDDV | 0.059 | 0.908 |
| | | | SUM=1.0 |

However, for input to Equation 4-5, the travel mix must be further broken down by vehicle age. The travel fraction (tf) is defined as the average proportion of VMT within a vehicle class traveled by vehicles of a given age. MOBILE5a contains travel fractions estimated from national average historical data. The necessary travel fractions may be extracted from the MOBILE5 source code as described in Appendix E. Using these travel fractions, the VMT mix shown in Table 4-5 may be further broken down by vehicle age as follows:

$$vmt_{ij}/VMT = tf_{ij} \times vmt_i/VMT \qquad (4\text{-}6)$$

The national average VMT mix by age and class is calculated for 1994 in Appendix C. Note that in Section 3 of this report, example California data showed a VMT mix that differs from national defaults. It is recommended that local VMT mix data be used whenever possible.

***Step 5: Calculate Area VMT***

After the previous calculations are carried out, county-wide annual VMT may be estimated.

$$Diesel\ fleet\ VMT = D_{county} \times mpg_{fd} \tag{4-7}$$

$$Gasoline\ fleet\ VMT = G_{county} \times mpg_{fg} \tag{4-8}$$

$D_{county}$ and $G_{county}$ represent the estimated on-road diesel and gasoline consumption in a county (from Equation 4-3). The variables $mpg_{fd}$ and $mpg_{fg}$ represent the diesel- and gasoline-powered fleet fuel economies (from Equations 4-4 or 4-5).

If monthly VMT is desired, yearly VMT may be scaled and distributed throughout the year according to the monthly distributions of fuel usage reported in the *Highway Statistics*, and/or periodic sales patterns reported by state agencies. The Federal Highway Administration utilizes monthly adjustment factors to seasonally allocate VMT (US Department of Transportation, 1981).

# EXAMPLE APPLICATIONS

In this subsection the methodology described above is applied to Sacramento County, California and Maricopa County, Arizona using 1994 data to estimate 1994 VMT.

## SACRAMENTO COUNTY, CALIFORNIA

Table 4-6 lists data that were obtained from the FHWA report, *Highway Statistics-1994*, and from various California state agencies (listed in Appendix A).

**Table 4-6**
**Sacramento County and California 1994 relevant statistics**

| | Sacramento | California | units |
|---|---|---|---|
| Total Gasoline Consumption | | 13.16 | billion gallons |
| Total Special Fuels (i.e. Diesel) | | 2.04 | billion gallons |
| Active Drivers Licenses | 727 | 20156 | thousand |
| Registered Vehicles | 779 | 22339 | thousand |
| Population | 1.130 | 31.95 | million |
| Total Taxable Sales | 10.97 | 285.98 | billion $ |
| Service Station Taxable Sales | 0.5470 | 16.61 | billion $ |

***Step 1. Adjust fuel consumption for off-road use.***

FHWA reports that 0.229 billion gallons of gasoline were used off-road in California in 1994, and that the state did not account for handling losses. For states that track handling losses, these losses should be redistributed to on- and off-road FHWA consumption figures on a percent basis before continuing with this procedure. These losses are inconsistently calculated for the FHWA report, and an alternate means to account for these losses is included in Step 3. Special fuels consumption was reported as on-highway use, therefore, no adjustment is necessary. Adjusted gasoline consumption is simply calculated as total gasoline consumption (13.16 billion gallons) minus off-road gasoline consumption (0.229 billion gallons), or 12.93 billion gallons.

***Step 2. Geographically disaggregate fuel consumption from Step 1.***

Calculate county/state proportions (p) for numbers of drivers licenses (dl), numbers of registered vehicles (rv), population (pop), total taxable sales (ts), and service station taxable sales (ss). Also calculate the average proportion ($p_{avg}$) and percent differences from the average (see Table 4-7).

For instance, the county/state proportion for the number of drivers' licenses is calculated as follows: $p_{dl} = dl_{county}/dl_{state} = 727 / 20156 = 0.0361$.

**Table 4-7**
**Sacramento County/state proportions for various factors**

| Proportion | Value | % Difference from $p_{avg}$ |
|---|---|---|
| $p_{dl}$ | 0.0361 | +2% |
| $p_{rv}$ | 0.0341 | -4% |
| $p_{pop}$ | 0.0354 | +0% |
| $p_{ts}$ | 0.0384 | +8% |
| $p_{ss}$ | 0.0329 | -7% |
| $p_{avg}$ | 0.0354 | na |

Since the proportions are roughly equal (none differs from the average by more than 10 percent), $p_{avg}$ may be used to geographically disaggregate fuel consumption.

Disaggregate fuel consumption, and assign volumes to the counties of interest:

Gasoline volume disaggregated for Sacramento = State gasoline volume × $p_{avg}$
= 12.93 × 0.0354 = 0.458 billion gallons = 458 million gallons

Diesel volume disaggregated for Sacramento = State special fuels volume × $p_{avg}$
= 2.035 × 0.0354 = 0.072 billion gallons = 72 million gallons

***Step 3. Adjust for refueling losses.***

Sacramento county has implemented both Stage I and Stage II refueling losses controls. From Table 4-4, the loss rate for gasoline = 0.06 + 0.01 + 0.07 + 0.09 gallons lost per 1000 gallons throughput = 0.23 gallons/1000 gallons. The loss rate for diesel is simply due to spillage, 0.09 gallons/1000 gallons. Therefore,

Adjustment for gasoline = -458 million × 0.23/1000 = -105 thousand gallons

Adjustment for diesel = -72 million × 0.09/1000 = -6.5 thousand gallons

On-road gasoline use in Sacramento County, $G_{county}$ = 458 million - 105 thousand
≅ 458 million gallons

On-road diesel use in Sacramento County, $D_{county}$ = 72 million - 6.5 thousand
≅ 72 million gallons

These loss rates generally do not significantly affect the results of these calculations. However, if loss rates are improved and revised in the future, or if there is a substantial future increase in automobile fuel economies, it is possible that this fraction of total fuel consumption may become more important.

***Step 4. Calculate diesel- and gasoline-powered fleet fuel economies ($mpg_{fd}$ and $mpg_{fg}$).***

Local data could not be obtained, therefore, estimates based on national averages were used. Values of $vmt_{ij}/VMT \times mpg_{ij}$ (see Equation 4-5) are tabulated in Table 4-10 (at the end of this section). Summing over vehicle class *i* and vehicle age j, the following estimates for fleet fuel economies were calculated.

$mpg_{fd}$ = 7.5 miles/gallon (for the diesel fleet)
$mpg_{fg}$ = 20.7 miles/gallon (for the gasoline fleet)

The low fuel economy for the diesel fleet reflects the large proportion of vehicle miles traveled by heavy duty diesel vehicles (approximately 91% from Table 4-5).

***Step 5. Calculate area annual VMT for the diesel- and gasoline- powered fleets.***

VMT-gas = 458 million gallons × 20.7 miles/gallon = 9.48 billion miles

VMT-diesel = 72 million gallons × 7.5 miles/gallon = 0.54 billion miles

These calculated values compare well to data obtained from the FHWA's Highway Performance Monitoring System (HPMS) database, and from BURDEN7F model output:

| | HPMS | BURDEN7F | Units |
|---|---|---|---|
| VMT-gas | 8.25 | 8.89 | billion miles |
| VMT-diesel | 0.65 | 0.49 | billion miles |

However, they compare poorly to the California Department of Transportation total VMT estimate for Sacramento County, 4.11 billion miles (California Department of Transportation, 1994).

## MARICOPA COUNTY, ARIZONA

Table 4-8 lists data that were obtained from the FHWA report, *Highway Statistics-1994*, and from various Arizona state agencies (listed in Appendix A). Service station taxable sales for the state could not be calculated. Confidentiality restrictions have been placed on this data for several Arizona counties. However, this figure is at least 0.198 billion dollars, the sum of taxable service station sales in the unrestricted counties. Judging by the impact the restricted counties have on the state economy, this figure probably lies between 0.20 and 0.24 billion dollars.

**Table 4-8**
**Maricopa County data obtained for 1994**

| | Maricopa County | Arizona | Units |
|---|---|---|---|
| Total Gasoline Consumption | | 1.935 | billion gallons |
| Total Special Fuels Consumption (On-Highway) | | 0.463 | billion gallons |
| Active Drivers Licenses | 1514 | 2631 | thousand |
| Registered Vehicles | 1532 | 2762 | thousand |
| Population | 2.36 | 4.08 | million |
| Total Taxable Sales | 31.9 | 49.3 | billion $ |
| Service Station Taxable Sales | 0.149 | 0.20-0.24 | billion $ |

***Step 1. Adjust fuel consumption for off-road use.***

FHWA reports that 0.035 billion gallons of gasoline were used off-road in Arizona in 1994, and that the state did not account for handling losses. For states that track handling losses, these losses should be redistributed to on- and off-road FHWA consumption figures on a percent basis before continuing with this procedure. These losses are inconsistently calculated for the FHWA report, and an alternate means to account for these losses is included in step 3. Special fuels consumption was reported for on-highway use, therefore, no adjustment is necessary.

Adjusted gasoline consumption = 1.935 - 0.035 = 1.90 billion gallons.

***Step 2. Geographically disaggregate fuel consumption.***

Calculate county-state proportions (p) for numbers of drivers licenses (dl), numbers of registered vehicles (rv), population (pop), total taxable sales (ts), and service station taxable sales (ss). Also calculate the average proportion ($p_{avg}$) and percent differences from the average. For instance, the county-state proportion for the number of drivers licenses is calculated as follows: $p_{dl} = dl_{county}/dl_{state} = 727 / 20156 = 0.0361$. The five proportions and the average proportion are shown in Table 4-9. Due to uncertainty in $p_{ss}$, it was excluded from the calculation of the average in this case.

**Table 4-9**
**Maricopa county/state proportions for various factors**

| Proportion | Value | % Difference from $p_{avg}$ |
|---|---|---|
| $p_{dl}$ | 0.575 | -7% |
| $p_{rv}$ | 0.555 | -10% |
| $p_{pop}$ | 0.578 | -6% |
| $p_{ts}$ | 0.647 | +5% |
| $p_{ss}$ | 0.62 to 0.75 | +1% to +20% |
| $p_{avg}$ | 0.617 | na |

Since the proportions are roughly equal (none differs from the average by more than 10 percent, with the possible exception of $p_{ss}$ ) $p_{avg}$ may be used to geographically disaggregate fuel consumption:

Gasoline volume desaggregated for Maricopa = State gasoline volume × $p_{avg}$
= 1.90 × 0.617 = 1.17 billion gallons

Diesel volume disaggregated for Maricopa = State special fuels volume × $p_{avg}$
= 0.463 × 0.617 = 0.286 billion gallons

***Step 3. Adjust for refueling losses.***

Maricopa county has implemented both Stage I and Stage II refueling losses controls. From Table 4-4, the loss rate for gasoline = 0.06 + 0.01 + 0.07 + 0.09 gallons lost per 1000 gallons throughput = 0.23 gallons/1000 gallons. The loss rate for diesel is simply due to spillage, 0.09 gallons/1000 gallons.

Adjustment for gasoline = -1.17 billion × 0.23/1000 = -270 thousand gallons

Adjustment for diesel = -0.286 billion × 0.09/1000 = -26 thousand gallons

On-road gasoline use in Maricopa County, $G_{county}$ = 1.17 billion - 270 thousand
≅ 1.17 billion gallons

On-road diesel use in Maricopa County, $D_{county}$ = 0.286 billion - 26 thousand
≅ 0.286 billion gallons

***Step 4. Calculate diesel- and gasoline-powered fleet fuel economies ($mpg_{fd}$ and $mpg_{fg}$).***

Local mileage accumulation and registration data could not be obtained, therefore, fleet fuel economy estimates based on national averages were used. The results are the same as calculated above for Sacramento county:

$mpg_{fd}$ = 7.5 miles/gallon (i.e., 7.5 mpg for all diesel vehicles)
$mpg_{fg}$ = 20.7 miles/gallon (i.e., 20.7 mpg for all light and heavy duty trucks and cars).

***Step 5. Calculate area annual VMT for the diesel- and gasoline- powered fleets.***

VMT-gas = 1.17 billion gallons × 20.7 miles/gallon = 24.2 billion miles
VMT-diesel = 0.286 billion gallons × 7.5 miles/gallon = 2.15 billion miles

These figures were compared to the 1994 HPMS database, and were more than an order of magnitude larger. However, this appears to be due to a typographical error in the HPMS database. This example highlights the value of performing a double-check on VMT estimates. Other sources of information estimate that total VMT in Maricopa County was approximately equal to 20 billion miles in 1993. This figure represents VMT by both gas- and diesel-powered vehicles. The 1994 estimate calculated above is 30 percent greater, while an annual growth rate of only five to seven percent is expected. This suggests that it may be useful to reevaluate Maricopa County VMT estimates calculated by more traditional means.

**Table 4-10**
**Calculation of national average fleet fuel economies from MOBILE5a Defaults**

| Class | vmtij/VMT*mpgij by vehicle class and model year 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 | 1981 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Gas-powered fleet | | | | | | | | | | | |
| LDGV | 0.033 | 0.011 | 0.015 | 0.021 | 0.030 | 0.044 | 0.069 | 0.100 | 0.112 | 0.168 | 0.230 |
| LDGT1 | 0.019 | 0.004 | 0.007 | 0.007 | 0.009 | 0.016 | 0.023 | 0.030 | 0.024 | 0.050 | 0.073 |
| LDGT2 | 0.015 | 0.004 | 0.005 | 0.005 | 0.006 | 0.011 | 0.015 | 0.020 | 0.015 | 0.032 | 0.046 |
| HDGV | 0.014 | 0.002 | 0.003 | 0.003 | 0.003 | 0.005 | 0.007 | 0.008 | 0.010 | 0.010 | 0.014 |
| MC | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | **Sum =** | **20.66** | **=mpg-f** | | | | | | | | |
| Diesel-powered fleet | | | | | | | | | | | |
| LDDV | 0.001 | 0.000 | 0.001 | 0.001 | 0.001 | 0.003 | 0.007 | 0.018 | 0.046 | 0.142 | 0.263 |
| LDDT | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.005 | 0.008 | 0.033 | 0.077 |
| HDDV | 0.033 | 0.011 | 0.016 | 0.022 | 0.028 | 0.044 | 0.069 | 0.085 | 0.074 | 0.065 | 0.162 |
| | **Sum =** | **7.54** | **=mpg-f** | | | | | | | | |

$vmt_{ij}$ = annual average vehicle miles traveled for cars of class $i$ and age $j$.
$VMT$ = annual total vehicle miles traveled for all classes
$mpg_{ij}$ represents the fuel economy of a vehicle of class $i$ and age $j$

**Table 4-10. Continued.**

| Class | vmtij/VMT*mpgij by vehicle class and model year 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 |
|---|---|---|---|---|---|---|---|---|---|---|
| Gas-powered fleet | | | | | | | | | | |
| LDGV | 0.380 | 0.531 | 0.667 | 0.680 | 0.745 | 0.782 | 0.911 | 1.309 | 1.436 | 1.573 |
| LDGT1 | 0.097 | 0.114 | 0.138 | 0.085 | 0.098 | 0.122 | 0.155 | 0.217 | 0.271 | 0.347 |
| LDGT2 | 0.058 | 0.112 | 0.112 | 0.042 | 0.050 | 0.091 | 0.058 | 0.087 | 0.093 | 0.132 |
| HDGV | 0.017 | 0.017 | 0.022 | 0.012 | 0.011 | 0.011 | 0.009 | 0.016 | 0.019 | 0.026 |
| MC | 0.000 | 0.000 | 0.019 | 0.005 | 0.008 | 0.011 | 0.016 | 0.022 | 0.030 | 0.041 |
| Diesel-powered fleet | | | | | | | | | | |
| LDDV | 0.347 | 0.214 | 0.220 | 0.120 | 0.045 | 0.048 | 0.000 | 0.000 | 0.000 | 0.035 |
| LDDT | 0.182 | 0.106 | 0.063 | 0.019 | 0.014 | 0.008 | 0.007 | 0.010 | 0.013 | 0.017 |
| HDDV | 0.218 | 0.223 | 0.283 | 0.241 | 0.248 | 0.214 | 0.224 | 0.366 | 0.471 | 0.465 |

$vmt_{ij}$ = annual average vehicle miles traveled for cars of class $i$ and age $j$.
$VMT$ = annual total vehicle miles traveled for all classes
$mpg_{ij}$ represents the fuel economy of a vehicle of class $i$ and age $j$

**Table 4-10. Concluded**

| Class | vmtij/VMT*mpgij by vehicle class and model year 1993 | 1994 | 1995 |
|---|---|---|---|
| Gas-powered fleet | | | |
| LDGV | 1.733 | 1.742 | 0.365 |
| LDGT1 | 0.391 | 0.415 | 0.105 |
| LDGT2 | 0.140 | 0.145 | 0.036 |
| HDGV | 0.030 | 0.032 | 0.000 |
| MC | 0.072 | 0.096 | 0.000 |
| | | | |
| Diesel-powered fleet | | | |
| LDDV | 0.041 | 0.042 | 0.089 |
| LDDT | 0.020 | 0.022 | 0.006 |
| HDDV | 0.542 | 0.588 | 0.000 |

$vmt_{ij}$ = annual average vehicle miles traveled for cars of class $i$ and age $j$.
$VMT$ = annual total vehicle miles traveled for all classes
$mpg_{ij}$ represents the fuel economy of a vehicle of class $i$ and age $j$

# APPENDIX A

# LIST OF CONTACTS IN FEDERAL AND STATE AGENCIES

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All States

Office of Highway Information Management, Federal Highway Administration, Washington, D.C.

California

For taxable sales:
(Robert Rossi) Statistics Section, Agency Planning and Research Division, State Board of Equalization, 450 N. Street, Sacramento, California 95814.

For statewide fuel sales, drivers' license, vehicle registration, and population:
*Travel and Related Factors in California.* published annually by the Transportation System Information Program, California Department of Transportation, Sacramento, California.

Arizona

For taxable sales:
(Karen Walker) Econometrics, Arizona Department of Revenue, 1600 W. Monroe, Phoenix, Arizona 85007.

For drivers' license, vehicle registrations:
(Marv Dobson) Motor Vehicle Division, Arizona Department of Transportation, 1801 West Jefferson Street, Phoenix, Arizona.

For population:
Arizona Department of Economic Security, Phoenix, Arizona.

New York

For taxable sales:
(Steven Zych) Revenue Analysis and Data Bureau, Office of Tax Policy Analysis, Department of Taxation and Finance, W.A. Harriman Campus, Albany, New York 12227.

For drivers' license, vehicle registrations:
(Brian Ginett) Department of Motor Vehicles, Albany, New York 12228.

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# APPENDIX B

# ESTIMATED VEHICLE FUEL ECONOMIES BY VEHICLE CLASS AND MODEL YEAR

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## Fuel Economies from Emissions Models Defaults

| Class | Fuel Economies by Vehicle Class and Model Year (mpg) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1941-1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 |
| Gas-powered fleet | | | | | | | | | | | |
| LDGV* | 12.46 | 12.46 | 12.06 | 12.15 | 11.95 | 13.20 | 14.58 | 15.32 | 16.55 | 16.83 | 19.42 |
| LDGT1* | 10.64 | 10.64 | 10.64 | 10.64 | 10.45 | 10.45 | 11.45 | 12.05 | 13.09 | 12.78 | 12.31 |
| LDGT2* | 10.65 | 10.65 | 10.65 | 10.65 | 10.46 | 10.46 | 11.45 | 12.06 | 13.10 | 12.78 | 12.34 |
| HDGV* | 7.76 | 7.88 | 7.88 | 7.88 | 7.90 | 8.06 | 8.22 | 8.46 | 8.68 | 8.87 | 9.01 |
| MC*** | 50.00 | 50.00 | 50.00 | 50.00 | 50.00 | 50.00 | 50.00 | 50.00 | 50.00 | 50.00 | 50.00 |
| Diesel-powered fleet | | | | | | | | | | | |
| LDDV** | 21.56 | 21.56 | 20.86 | 21.02 | 20.64 | 22.84 | 25.22 | 24.82 | 24.99 | 23.90 | 26.22 |
| LDDT** | 18.42 | 18.42 | 18.42 | 18.42 | 18.09 | 18.09 | 19.81 | 19.53 | 19.77 | 18.15 | 16.64 |
| HDDV*** | 5.50 | 5.50 | 5.50 | 5.50 | 5.50 | 5.50 | 5.50 | 5.50 | 5.50 | 5.50 | 5.50 |

*From Mobile5a
*From diesel advantage factors given in the Mobile4 Fuel Consumption model.
Fuel econ (diesel) = adv factor x Fuel econ (gas)
***From EMFAC7F

## Fuel Economies from Emissions Models Defaults

| Class | Fuel Economies By Vehicle Class and Model Year (mpg) | | | | |
|---|---|---|---|---|---|
| | 1991 | 1992 | 1993 | 1994 | 1995 |
| Gas-powered fleet | | | | | |
| LDGV* | 22.71 | 22.68 | 22.66 | 22.64 | 22.64 |
| LDGT1* | 17.10 | 17.05 | 16.99 | 16.93 | 16.87 |
| LDGT2* | 16.95 | 16.86 | 16.77 | 16.68 | 16.58 |
| HDGV* | 10.48 | 10.49 | 10.50 | 10.51 | 10.52 |
| MC*** | 50.00 | 50.00 | 50.00 | 50.00 | 50.00 |
| Diesel-powered fleet | | | | | |
| LDDV** | 27.25 | 27.22 | 27.19 | 27.17 | 27.17 |
| LDDT** | 20.43 | 20.35 | 20.26 | 20.17 | 20.07 |
| HDDV*** | 5.81 | 5.86 | 5.96 | 6.07 | 6.17 |

*From Mobile5a

**From diesel advantage factors given in the Mobile4 Fuel Consumption model.

Fuel econ (diesel) = adv factor x Fuel econ (gas)

***From EMFAC7F

# APPENDIX C

# ESTIMATED NATIONAL AVERAGE VMT MIX FOR 1994

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## Vehicle Mix for 1994 - Estimated Using Mobile5 Defaults

| | Vehicle Mix by Class | Vehicle Mix by Class and Model Year | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Class | vmti/VMT | 1941-1971* | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 |
| Gas-powered | | | | | | | | | | | |
| LDGV | 0.681 | 0.00272 | 0.00089 | 0.00123 | 0.00157 | 0.00204 | 0.00286 | 0.00415 | 0.00592 | 0.00579 | 0.00810 |
| LDGT1 | 0.190 | 0.00174 | 0.00038 | 0.00063 | 0.00066 | 0.00080 | 0.00133 | 0.00172 | 0.00235 | 0.00191 | 0.00330 |
| LDGT2 | 0.089 | 0.00138 | 0.00033 | 0.00052 | 0.00047 | 0.00055 | 0.00095 | 0.00118 | 0.00156 | 0.00124 | 0.00211 |
| HDGV | 0.033 | 0.00173 | 0.00022 | 0.00037 | 0.00039 | 0.00040 | 0.00059 | 0.00076 | 0.00095 | 0.00106 | 0.00100 |
| MC | 0.007 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| Diesel-powered | | | | | | | | | | | |
| LDDV | 0.062 | 0.00003 | 0.00002 | 0.00003 | 0.00006 | 0.00006 | 0.00011 | 0.00028 | 0.00075 | 0.00176 | 0.00542 |
| LDDT | 0.031 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00025 | 0.00048 | 0.00170 |
| HDDV | 0.908 | 0.00608 | 0.00200 | 0.00300 | 0.00399 | 0.00517 | 0.00799 | 0.01262 | 0.01552 | 0.01343 | 0.01180 |

*approximated

## Vehicle Mix for 1994 - Estimated Using Mobile5 Defaults

| | Vehicle Mix by Class | Vehicle Mix by Class and Model Year | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Class | vmti/VMT | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 |
| Gas-powered | 0.681 | 0.01069 | 0.01764 | 0.02431 | 0.02969 | 0.02928 | 0.03180 | 0.03296 | 0.03909 | 0.05686 | 0.06319 |
| LDGV | 0.190 | 0.00442 | 0.00576 | 0.00658 | 0.00811 | 0.00495 | 0.00546 | 0.00677 | 0.00881 | 0.01258 | 0.01567 |
| LDGT1 | 0.089 | 0.00279 | 0.00349 | 0.00652 | 0.00660 | 0.00243 | 0.00279 | 0.00506 | 0.00331 | 0.00504 | 0.00543 |
| LDGT2 | 0.089 | 0.00279 | 0.00349 | 0.00652 | 0.00660 | 0.00243 | 0.00279 | 0.00506 | 0.00331 | 0.00504 | 0.00543 |
| HDGV | 0.033 | 0.00142 | 0.00173 | 0.00171 | 0.00216 | 0.00122 | 0.00112 | 0.00107 | 0.00092 | 0.00154 | 0.00189 |
| MC | 0.007 | 0.00000 | 0.00000 | 0.00000 | 0.00039 | 0.00011 | 0.00016 | 0.00022 | 0.00031 | 0.00043 | 0.00059 |
| Diesel-powered | | | | | | | | | | | |
| LDDV | 0.062 | 0.00994 | 0.01320 | 0.00810 | 0.00815 | 0.00433 | 0.00159 | 0.00169 | 0.00000 | 0.00000 | 0.00000 |
| LDDT | 0.031 | 0.00384 | 0.00895 | 0.00507 | 0.00307 | 0.00091 | 0.00066 | 0.00036 | 0.00032 | 0.00048 | 0.00061 |
| HDDV | 0.908 | 0.02950 | 0.03958 | 0.04048 | 0.05147 | 0.04384 | 0.04475 | 0.03821 | 0.03958 | 0.06417 | 0.08178 |

## Vehicle Mix for 1994 - Estimated Mobile5 Defaults

| | Vehicle Mix by Class | Vehicle Mix by Class and Model Year | | | | |
|---|---|---|---|---|---|---|
| Class | vmti/VMT | 1991 | 1992 | 1993 | 1994 | 1995 |
| Gas-powered | | | | | | |
| LDGV | 0.681 | 0.06925 | 0.07143 | 0.07647 | 0.07695 | 0.01614 |
| LDGT1 | 0.190 | 0.02030 | 0.02160 | 0.02299 | 0.02448 | 0.00622 |
| LDGT2 | 0.089 | 0.00779 | 0.00808 | 0.00837 | 0.00867 | 0.00219 |
| HDGV | 0.033 | 0.00249 | 0.00265 | 0.00282 | 0.00304 | 0.00000 |
| MC | 0.007 | 0.00081 | 0.00109 | 0.00145 | 0.00192 | 0.00000 |
| Diesel-powered | | | | | | |
| LDDV | 0.062 | 0.00129 | 0.00137 | 0.00150 | 0.00154 | 0.00326 |
| LDDT | 0.031 | 0.00082 | 0.00090 | 0.00098 | 0.00108 | 0.00028 |
| HDDV | 0.908 | 0.07997 | 0.08514 | 0.09086 | 0.09694 | 0.00000 |

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# APPENDIX D

# MULTIVARIATE LINEAR REGRESSION PROCEDURE

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## INTRODUCTION

This appendix describes how to use standard statistical regression analysis to determine weighting factors for calculating county fuel consumption from related variables as discussed in Section 4. We also describe here how to test whether particular variables are useful for predicting a dependent variable. The following state and U.S. variables that are correlated with fuel consumption are used:

On-road fuel consumption
Population
Number of registered vehicles
Number of active drivers licenses
Total taxable sales (dollar amount)
Total service station sales (dollar amount)

These state and national figures should be obtained for 20 time periods (e.g. 20 years, 20 months, 20 quarters, etc.).

Procedure Steps

1. Calculate state/U.S. proportions of the above quantities.
2. Perform a linear least-squares regression analysis using a spreadsheet or statistical software.
3. Perform a standard error analysis to determine which of the proportions are useful for predicting state fuel consumption.
4. Eliminate those proportions that are not useful.
5. Repeat Step 2, with useful proportions only.

The linear model to predict county fuel consumption ($F_{county}$) is

$$F_{county}/F_{state} = a \times p_{ss} + b \times p_{ts} + c \times p_{pop} + d \times p_{rv} + e \times p_{dl} \qquad \text{D-1}$$

In Equation D1, $F_{county}/F_{state}$ is termed the dependent variable, the five proportions are the independent variables, and a though e are regression coefficients. For equation D1, it is assumed that the y-intercept is equal to 0, although this is not absolutely necessary. If prediction of $F_{county}/F_{state}$ is improved by allowing a non-zero y-intercept, then equation D1 should be written as follows, where f represents the y-intercept.

$$F_{county}/F_{state} = a \times p_{ss} + b \times p_{ts} + c \times p_{pop} + d \times p_{rv} + e \times p_{dl} + f \qquad \text{D-2}$$

Ideally, a regression analysis would be performed using Equation D1 or D2 as the linear model. However, fuel consumption statistics are only known at the statewide and nationwide levels.

Therefore, historical state and U.S. data must be used to estimate the regression coefficients. Equation D3 is the linear model that will be used for this approach, where the proportions are calculated on a state/U.S. basis, rather than a county/state basis.

$$F_{state}/F_{U.S.} = a \times p_{ss} + b \times p_{ts} + c \times p_{pop} + d \times p_{rv} + e \times p_{dl} + f \qquad \text{D-3}$$

This approach assumes that state/U.S. fuel consumption patterns accurately reflect county/state patterns. Historical data for at least 20 time periods should be used to calculate the proportions in order to obtain a statistically robust sample size.

**PROCEDURE**

Step 1. Calculate state/U.S. proportions for population (pop), number of registered vehicles (rv), number of active drivers licenses (dl), total taxable sales (ts), total service station sales (ss), and on-road fuel consumption (F) for 20 time periods. For example, the state/U.S. proportion of service station sales, $p_{ss}$, would be calculated as

$$p_{ss} = ss_{state}/ss_{U.S.} \qquad \text{D-4}$$

Similarly, calculate $p_{pop}$, $p_{rv}$, $p_{dl}$, $p_{ts}$, and $F_{state}/F_{U.S.}$

Step 2. Perform a linear least-squares regression analysis on the values obtained in Step 1. A spreadsheet computer program (such as Quattro Pro, Excel, or another) or a simple statistical program (such as Minitab or StatMost) is needed. $F_{state}/F_{U.S.}$ should be treated as the dependent variable, and the other proportions should be treated as five independent variables. Output will include the regression coefficients (a though e) and their standard errors ($SE_a$ though $SE_e$), the y-intercept (f) and its standard error ($SE_f$), and a correlation coefficient (R-squared).

Step 3. Perform a standard error analysis to determine which of the five proportions are useful for predicting state fuel consumption. This analysis is based on the Student's t-Distribution. See Woolon (1987), Mendenhall et. al. (1986), or another statistics text for a complete discussion of the t-Distribution. A statistical level of significance ($\alpha$) must be selected as a decision criteria, which defines the probability that this analysis will be in error. Frequently used levels of significance are 0.01, 0.05, or 0.10.

t-Statistics are then calculated for the intercept, f, and the correlation coefficients a though e. For example, the t-statistic for coefficient b is calculated as

$$t\text{-}statistic_b = b / Se_b \qquad \text{D-5}$$

Each value of the t-statistic corresponds to a probability (p-value), tabulated in tables of the student's t-distribution (available in most statistics texts). If the p-value for a coefficient is greater than $\alpha$, its corresponding proportion is considered to be not useful for predicting fuel consumption, and it may be eliminated from the linear model. If the p-value for the intercept is greater than $\alpha$, the regression may be forced through zero ($f = 0$).

Step 4. Eliminate the proportions that are not useful, and repeat Step 2 with useful proportions only.

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# APPENDIX E

# TECHNIQUE TO EXTRACT NATIONAL AVERAGE TRAVEL FRACTIONS AND FUEL ECONOMICS FROM THE MOBILE5a SOURCE CODE

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In order to estimate VMT, travel fractions must be defined by vehicle type and age. National average values may be extracted from the source code of MOBILE5, the EPA-approved model for calculating emission factors. The following information is provided because the methods to extract these data are not readily apparent in the MOBILE documentation.

Travel fractions may be obtained by generating a certain output file. This file is generated by setting the OUTFMT flag (*) to 5 and including the shown set of flags int he "One-Time Data" section of the MOBILE5 input file (**). The One-Time Data" record flags shown below reference the various motor vehicle categories included in the MOBILE model. For more detailed information regarding user inputs, the user's guide to MOBILE should be consulted (USEPA, 1994). The following example input file:

```
  1      PROMPT  -  No prompting.
  Project ID:  User-Defined Text
  1      TAMFLG  -  Use MOBILE5 default tampering rates.
  1      SPDFLG  -  User supplies one value of average speed for all vehicle
                    types.
  1      VMFLAG  -  Use MOBILE5 VMT mix.
  1      MYMRFG  -  Use default mileage accumulation rates and registration
                    data.
  1      NEWFLG  -  MOBILE5 basic exhaust emissions rates are used.
  1      IMFLAG  -  No I/M program.
  1      ALHFLG  -  Do not apply additional correction factors.
  1      ATPFLG  -  No ATP program.
  1      RLFFLAG -  Use uncontrolled refueling emission rates.
*  2     LOCFLG  -  LAP record will appear once, in one-time data section.
  1      TEMFLG  -  Min/Max temperatures will be used.
  5      OUTFMT  -  By model year, 112-column descriptive format.
  4      PRTFLG  -  Print exhaust HC, CO, and NOx results.
  1      IDLFLG  -  No idle emission factors calculated.
  3      NMHFLG  -  Calculate emissions for volatile organic hydrocarbons.
  3      HCFLAG  -  Print sum and component emissions.
**User-Defined. C 72. 92. 11.5 08.7 92 1 1 2     Local Area Parameter record
  22222222 1                                     By-Model Year Vector
  1 95 19.6 75.0 20.6 27.3 20.6 01               Scenario description record
```

The output file produced by running MOBILE5 with the above inputs would provide the travel fractions by model type and age.

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VOLUME IV: CHAPTER 3

# USE OF LOCALITY-SPECIFIC TRANSPORTATION DATA FOR THE DEVELOPMENT OF MOBILE SOURCE EMISSION INVENTORIES

September 1996

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Prepared for:
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Emission Inventory Improvement Program

## DISCLAIMER

This document was furnished to the Emission Inventory Improvement Program and the U.S. Environmental Protection Agency by Cambridge Systematics, Inc., Oakland, California, and Eastern Research Group, Inc., Morrisville, North Carolina. This report is intended to be a final document and has been reviewed and approved for publication. The opinions, findings, and conclusions expressed represent a consensus of the members of the Mobile Sources Committee of the Emission Inventory Improvement Program. Any mention of company or product names does not constitute an endorsement by the U.S. Environmental Protection Agency.

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# 1

# INTRODUCTION

The Clean Air Act Amendments (CAAA) of 1990 require that state and local agencies develop better, complete, and accurate emission inventories as an integral part of their air quality management and transportation planning responsibilities. Based on the EPA's 1990 Base Year Inventory development experience, it is essential to develop better methods for helping responsible state and local agencies accomplish this task in a timely and economical manner. Although the results of current emission inventories are used at the national and regional level, the inventories themselves are developed and compiled locally by State Departments of Transportation (State DOTs), State Air Pollution Control Districts (State APCDs), Metropolitan Planning Organizations (MPOs), and Regional Air Quality Councils (RAQCs).

Deficiencies and inconsistencies of the current emission inventory development process accentuate the need for developing and implementing more systematic and comprehensive methods for the collection, interpretation, and reporting of data. Current flexibility in selecting methods, while allowing state and local agencies to generate emission inventories using locally available and acceptable analytical techniques, typically results in the development of datasets of unknown quality and varying degrees of completeness. Equally important, an examination of existing mobile source emission inventory practices demonstrates that states and local agencies are not taking advantage of the full range of potential locality-specific data sources. A variety of sources of local data can be used to both improve and confirm the accuracy of various travel-related parameters, and thereby reducing the reliance that needs to be placed on national default assumptions. In summary, state and local decision makers too often are currently dependent on using inconsistent and incomplete analytical tools in order to meet their particular transportation, congestion management, air quality, and capital improvement needs.

The U.S. EPA, in conjunction with State and Territorial Air Pollution Control Officials (STAPPA/ALAPCO), has launched the Emission Inventory Improvement Program (EIIP) in order to address the deficiencies in the current emission inventory compilation process and to meet the requirements set forth in the CAAA. Working groups of state, local, EPA, and industry representatives are currently addressing various requirements of this emission inventory process and developing standard procedures to meet data needs. This effort is resulting in the production of a series of documents describing all phases of the emission inventory data collection and reporting process.

The purpose of this particular report is to provide guidance for state and local agencies for use in developing motor vehicle emission inventories using Highway Performance Monitoring System (HPMS) datasets and Travel Demand Model (TDM) outputs. Guidance is provided for the following topics:

- **Section 2.0: Developing Locality-Specific Inputs from HPMS Data.** This section describes enhanced guidance to convert HPMS vehicle miles of travel (VMT) data to the vehicle classes contained in the EPA MOBILE5A emission factor model.

- **Section 3.0: Developing Locality-Specific Inputs from TDMs.** This section presents guidance and improved procedures designed to improve the outputs generated from the TDM process for subsequent input in the compilation of emission inventories.

- **Section 4.0: Use of Local Data for VMT Projections.** This section presents guidance for identifying non-TDM and TDM procedures designed to more accurately predict future VMT of passenger and commercial vehicles.

Basic guidance for many of the elements contained within each of the topic areas above has already been developed by EPA. In these cases, the guidance was evaluated and refined in order to reflect the best use of HPMS datasets and TDM outputs. The updated guidance and refined analytical methods outlined herein accomplish the following objectives:

- Provide guidance on recommended current practices for obtaining locality-specific data outputs from the TDM process;

- Identify the documentation sources for available methods and provide new documentation for refined methods;

- Prepare documentation for the refined methods that is suitable for education and training of emission inventory preparers; and

- Provide example applications of selected recommended methods for training and illustrative purposes.

The refined methods and guidance documented in this report are not intended to suggest that other data sources, analytical methods, and procedures cannot be used to compile mobile source emission inventories. The material contained herein is, however, intended to provide state and local emission inventory preparers with updated guidance on how to implement state-of-the-practice TDM techniques in order to better and more

accurately compile emission inventories. Summaries of the sections contained in this report are provided below.

## DEVELOPING LOCALITY-SPECIFIC INPUTS FROM HIGHWAY PERFORMANCE MONITORING SYSTEM (HPMS) DATA

Section 2.0 of this report presents the updated guidance recommended for mapping HPMS vehicle miles of travel (VMT) by vehicle class for input into MOBILE5A. The analytical methods, step-by-step procedures, and example computations for implementing the updated guidance are described in detail in this section. This task was implemented in order to revise the EPA Guidance for the following vehicle types:

- Vehicle Type 3 - Other 2-Axle, 4-Tire Vehicles by fuel type;
- Vehicle Type 5 - Single Unit Trucks 2-Axles, 6-Tire Vehicles by fuel type;
- Vehicle Type 6 - Single Unit Trucks 3-Axles by fuel type; and
- Vehicle Type 7 - Single Unit Trucks 4 or More Axles by fuel type.

The analytical procedures were developed for application using the urban roadway segment file contained in the HPMS dataset (i.e., rural roadway segment file is not included in the analysis). An example calculation is also included in this section, which implements and tests the EPA Guidance and the revised EPA Guidance for the urban area segments of the Colorado and Washington statewide HPMS datasets. Sources for updating the EPA Guidance included the Census Truck Inventory and Use Survey (TIUS) dataset.

## DEVELOPING LOCALITY-SPECIFIC INPUTS FROM TRAVEL DEMAND MODELS (TDMS)

Section 3.0 of this report presents state-of-the-practice methods, step-by-step procedures, and selected example calculations for developing locality-specific on-road motor vehicle emission inventory inputs based on data generated as part of an urban area's transportation demand modeling and forecasting process. Methods are described for the following parameters:

- VMT reconciliation with HPMS;
- VMT and trip distribution;

- Speed estimation methods;
- Percent non-FTP driving;
- Hot/cold/hot stabilized weighting factors; and
- Trip duration.

Outlines of the applicable methods and procedures of the state-of-the-practice for each parameter are presented in this section. The modeling and forecasting process referred to above considers the use of travel demand models (TDMs) supplemented by enhanced TDM modules, post-TDM processors, and observed travel survey data. Recommended methods for guidance, or in some cases instructions for application, are provided for each parameter. The application instructions provide detailed information about how to implement the prescribed techniques. The number of applicable methods and instructions presented for each parameter vary depending on the level of existing research and information available in the state-of-the-practice.
The methods recommended for implementation by local and state agencies in Section 3.0 consider a wide variety of TDM applications. Depending on the specific parameter, these applications may include revising TDM highway network coding schemes, implementing analytical procedures now available with recent versions of TDM software (e.g., MINUTP), introducing household travel survey data in new ways to refine TDM outputs, and using available and developing new post-TDM processors.

## USE OF LOCAL DATA FOR VMT PROJECTIONS

Section 4.0 presents guidance for gathering and using local data to develop forecasts of vehicle miles of travel (VMT) for use in emissions modeling. Traditionally, states and local agencies have used the following methods to forecast future VMT:

- Socioeconomic Forecasts and Economic Growth Factors;
- Traffic Growth Trends; and
- Travel Demand Models (TDMs).

This section contains summaries of the state-of-the-practice analytical models, datasets, and procedures available to generate locality-specific future VMT forecasts for metropolitan areas and states with and without TDMs. It is recommended that those areas without TDMs should rely upon socioeconomic and traffic trend growth factor forecasting methods while those areas with TDMs should focus on using TDMs to generate future forecasts.

Several non-TDM analytical procedures are available for state and local agencies to develop base year and future forecasts of VMT. These techniques tend to focus on developing VMT forecasts by using socioeconomic growth factors, traffic trends, and economic trends. In some cases, combinations of these techniques can be used to generate VMT forecasts having a higher level of confidence than a forecast that is based on a single technique or indicator.

Various TDM analytical procedures are available for state and local agencies to develop base and future year forecasts of VMT. The majority of these techniques focus on predicting future forecasts of passenger or automobile VMT. Historically, state and local agencies have forecasted future commercial or truck VMT using commercial vehicle factors that are generated from observed vehicle classification data that are applied to TDM generated outputs for passenger vehicles. Because emissions generated by truck and passenger vehicles are very different, the methods presented in this section consider techniques designed to disaggregate total estimated VMT by passenger and commercial vehicles. The methods also consider techniques to reconcile the potential differences between TDM VMT outputs with those contained in the HPMS dataset.

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# 2

# DEVELOPING LOCALITY-SPECIFIC INPUTS FROM HIGHWAY PERFORMANCE MONITORING SYSTEM DATA

This section presents methods and example calculations for mapping Highway Performance Monitoring System (HPMS) vehicle miles of travel (VMT) by vehicle class for input into MOBILE5A. The recommended method includes procedures to revise the EPA Guidance for the following vehicle types:

Vehicle Type 3 - Other 2-Axle, 4-Tire Vehicles by fuel type;

Vehicle Type 5 - Single Unit Trucks 2-Axles, 6-Tire Vehicles by fuel type;

Vehicle Type 6 - Single Unit Trucks 3-Axles by fuel type; and

Vehicle Type 7 - Single Unit Trucks 4 or More Axles by fuel type.

These procedures were developed for application on the urban roadway segment file contained in the HPMS datasets. The example calculation implements and tests both the EPA Guidance and the revised EPA Guidance for the urban area segments of the Colorado and Washington statewide HPMS datasets. The specific methods and example calculations are presented below.

## METHODS

This section presents two approaches for mapping Highway Performance Monitoring System (HPMS) vehicle miles of travel (VMT) by vehicle class for input into MOBILE5A. The first method uses the EPA Guidance mapping developed by the Office of Mobile Sources and the second involves updating the EPA Guidance mapping using Census Truck Inventory and Use Survey (TIUS) data. This section describes the application of each method.

### *Method 1: Use Existing EPA Guidance Mapping*

EPA's Office of Mobile Sources (OMS) developed a matching scheme for states to use to apportion the VMT as reported in the HPMS vehicle class categories to the eight MOBILE model vehicle class categories. Table 2-1 contains the mapping scheme which was developed by OMS for state and local agencies to use to translate a locally developed VMT mix derived from HPMS data into MOBILE vehicle class categories. Default MOBILE5A VMT fractions and recent American Automobile Manufactures Association data on diesel/gasoline splits in annual sales of some vehicle classes were used to determine the apportionment percentages.

**TABLE 2-1**
**SUMMARY OF EPA GUIDANCE MAPPING**

| HPMS Category | MOBILE5A Category |
|---|---|
| Motorcycle | MC |
| Passenger Car | 98.64% LDGV<br>1.36% LDDV |
| Other 2-Axle, 4-Tire Vehicles | 65.71% LDGT1<br>33.47% LDGT2<br>0.82% LDDT |
| Buses | 10.28% HDGV<br>89.72% HDDV |
| Single Unit Trucks (1) | |
| 2-Axle, 6-Tire | 87.90% HDGV<br>12.10% HDDV |
| 3-Axle | 50.00% HDGV<br>50.00% HDDV |

**TABLE 2-1**
**(CONTINUED)**

| HPMS Category | MOBILE5A Category |
|---|---|
| 4 or More Axle | 50.00% HDGV<br>50.00% HDDV |
| Single Trailer Trucks | |
| 4 or Fewer Axle | HDDV |
| 5-Axle | HDDV |
| 6 or More Axle | HDDV |
| Multi Trailer Trucks | |
| 5 or Fewer Axle | HDDV |
| 6-Axle | HDDV |
| 7 or More Axle | HDDV |

*Source: Office of Mobile Sources.*

***Method 2: Use Updated EPA Guidance Mapping***

This method is the recommended approach and involves three steps.

- Step 1 - Update the EPA Guidance mapping from HPMS vehicle types to MOBILE5A using the Census Truck Inventory and Use Survey (TIUS) data source for:
  - Vehicle Type 3 - Other 2-Axle, 4-Tire Vehicles by fuel type;
  - Vehicle Type 5 - Single Unit Trucks 2-Axles, 6-Tire Vehicles by fuel type;

- Vehicle Type 6 - Single Unit Trucks 3-Axles by fuel type; and
- Vehicle Type 7 - Single Unit Trucks 4 or More Axles by fuel type.

Vehicle Type 3 percentages should be redefined using engine type and size data contained in TIUS Table 2a titled "Trucks, Truck Miles, and Average Annual Miles". Engine type and size data contained in TIUS Table 13 titled "Truck Miles by Truck Type and Axle Arrangement" should be used to redefine percentages for Vehicle Types 5, 6, and 7. The calculation for gasoline vehicles should include the categories for gasoline, liquefied gas or other, and not reported vehicles.

For Vehicle Type 3, the percentages should be calculated using engine type and size data from TIUS Table 2a. To obtain the miles of other 2-axle, 4-tire vehicles, the "Trucks, excluding pickups, panels, minivans, utilities, and station wagons" values must be subtracted from the "All trucks" values. The EPA Guidance percentages are used to distribute remaining gasoline truck percentages into the light duty gasoline trucks (LDGT) categories LDGT1 and LDGT2.

The following equations represent the computations required to implement this step.

Disel Percentage = (2-1)

$$\frac{\text{(All Trucks Diesel 1992 Trucks Miles)} - \text{(Trucks, Excluding Pickups...Diesel 1992 Trucks Miles)}}{\text{(All Trucks Engine 1992 Trucks Miles)} - \text{(Trucks, Excluding Pickups...Engine 1992 Trucks Miles)}} \times 100$$

$$\text{Gasoline Percentage} = 100 - \text{Diesel Percentage}$$

(2-2)

$$\text{LDGT1 Percentage} = \frac{65.71}{65.71 + 33.47} \times \text{Diesel Percentage}$$

(2-3)

$$\text{LDGT2 Percentage} = \text{Gasoline Percentage} - \text{LDGT1 Percentage}$$

(2-4)

As an example, for Vehicle Type 5 the percentages for 2-axle, 6-tire single unit trucks is calculated using the engine type and size data from TIUS Table 13.

$$\text{Disel Percentage} = \frac{\text{2 - Axle Diesel Miles}}{\text{Total Engine Miles}} \times 100 \tag{2-5}$$

$$\text{Gasoline Percentage} = 100 - \text{Diesel Percentage} \tag{2-6}$$

- **Step 2** – Obtain mapping from the Federal Highway Administration (FHWA) for converting the vehicle type groups for 4-tire, single unit commercial vehicles (SUCVs), and combinations into the thirteen vehicle types. Conduct mapping separately by state and roadway functional system using Highway Statistics summary tables and files from the FHWA Electronic Bulletin Board System (FEBBS). FEBBS can be contacted on-line at 1-800-337-FHWA (3492) using any communications software. If you have any questions about FEBBS, contact the FHWA Computer Help Desk at 202-366-1120.

- **Step 3** – On a statewide basis, obtain the ratio of local urban vehicle miles of travel (VMT) to VMT on the non-local urban functional systems using Highway Statistics data from FHWA. The table from Highway Statistics is titled "Annual Vehicle-Miles of Travel by Functional System".

The following equation represents the computations required to implement this step.

$$\text{Ratio of Local Urban VMT to Non-Local} = \frac{\text{VMT for Urban Local}}{\text{VMT for Urban Total}} \tag{2-7}$$

The computational steps for this approach to update EPA Guidance mapping for each sample section in a given nonattainment area are shown below:

(A) **Expanded VMT calculation using HPMS data.** The inputs for computing the expanded VMT include average annual daily traffic (AADT) (HPMS

item #28), the length of the segment (HPMS item #25), and the expansion factor (HPMS item #41 or #42 - use item #41 if both #41 and #42 are nonzero). The expanded VMT calculation takes the form:

Expanded VMT = (AADT) x (Length of Segment) x (Expansion Factor) (2-8)

(B) **Calculate Local Urban VMT.** The Local Urban VMT is computed using the expanded VMT generated in (A) and the ratio of local to non-local urban VMT developed in Step 3 (Equation 2-7).

Local Urban VMT =
(Expanded VMT) x (Ratio of Local Urban VMT to Non-Local) (2-9)

(C) **Calculate VMT for Single Unit Combined Vehicles (SUCVs), Combinations, and 4-Tire Vehicle Types.** These values are calculated using the expanded VMT computed above and the average percentage of SUCVs, Combination Trucks, and 4-Tire Vehicle Types obtained from HPMS data. The average percentage data from HPMS that should be used include items #65A2 and #65B2 for the average percentage of SUCVs and Combinations, respectively. The equations for these three vehicle types are shown below:

VMT SUCVs = (Expanded VMT) x (Average Percentage of SUCVs) (2-10)

(2-11)
VMT Combinations = (Expanded VMT) x (Average Percentage of Combinations)

VMT 4-Tire Vehicles = (2-12)
(Expanded VMT) - (VMT SUCVs + VMT Combinations + VMT Local)

(D) **Distribute calculated VMT values across vehicle types.** Use the mapping developed in Step 2 to distribute VMT 4-Tire Vehicles across Vehicle Types 2 and 3; Local Urban VMT across Vehicle Types 2 and 3; and VMT SUCVs across Vehicle Types 5 through 7. The VMT for 4-Tire Vehicles and Local Urban are summed to get the total VMT for Vehicle Types 2 and 3.

VMT by Vehicle Type = (2-13)
(VMT Computed in (C)) x (Appropriate Mapping Percentage from Step 2)

(E) **Convert VMT by MOBILE5A category.** Use the mapping identified and calculated in Step 1 to convert the VMT by MOBILE5A category. Use the

EPA Guidance contained in Table 2-1 or the Revised EPA Guidance if calculated in Step 1. The recommended approach is to compute Revised EPA Guidance through Step 1.

VMT by MOBILE5A Category by Fuel Type = (2-14)
VMT Computed in (D) x (EPA Guidance (or revised) Percentage by Fuel Type)

(F) **Add across all sections in the nonattainment area to obtain the VMT by MOBILE5A category.**

## EXAMPLE CALCULATIONS

The example calculation implements and tests both the existing EPA Guidance and the revised EPA Guidance for the urban area segments of the Colorado and Washington statewide HPMS datasets using the methods described above.

- Step 1 – Update the EPA Guidance mapping from HPMS vehicle types to Mobile 5A using the TIUS data. Tables 2-2 and 2-3 present the relevant information from TIUS Tables 2a and 13, respectively.

**TABLE 2-2**
**DATA FROM TIUS TABLE 2A**
**(TRUCKS, TRUCK MILES, AND AVERAGE ANNUAL MILES: 1992 AND 1987)**

| Engine Type and Size | 1992 Trucks miles (millions) | |
|---|---|---|
| | All trucks | Trucks, excluding pickups, panels, minivans, utilities, and station wagons |
| Engine | 786,273.8 | 116,579.6 |
| Gasoline | 667,992.9 | 20,361.4 |
| Diesel | 113,593.6 | 94,719.3 |
| Liquefied Gas or Other | 3,386.5 | 782.2 |
| Not Required | 1,300.9 | 716.7 |

*Source: Transportation-Truck Inventory and Use Survey, Table 2a.*

**TABLE 2-3**
**DATA FROM TIUS TABLE 13**
**(TRUCKS MILES BY TRUCK TYPE AND AXLE ARRANGEMENT: 1992)**

| Engine Type and Size | Single-unit trucks | | |
|---|---|---|---|
| | 2 axles | 3 axles | 4 axles or more |
| Engine | 696,329.8 | 5,763.5 | 1855.6 |
| Gasoline | 659,275.6 | 496.7 | (S) |
| Diesel | 32,593.5 | 5,236.9 | 1806.90 |
| Liquefied Gas or Other | 3,233.5 | 23.1 | (S) |
| Not Required | 1227.2 | 6.8 | (Z) |

*Source: Transportation-Truck Inventory and Use Survey, Table 2a.*

For Vehicle Type 3, the percentages are calculated using Equations 2-1 through 2-4. The data is contained in Table 2-2.

$$\text{Disel Percentage} = \frac{113{,}593.6 - 94{,}719.3}{786{,}273.8 - 116{,}579.6} \times 100 = 2.82\%$$

$$\text{Gasoline Percentage} = 100 - 2.82 = 97.18\%$$

$$\text{LDGT1 Percentage} = \frac{65.71}{65.71 + 33.47} \times 97.18 = 64.39\%$$

$$\text{LDGT2 Percentage} = 97.18 - 64.39 = 32.79\%$$

For Vehicle Type 5, the percentages for 2-axle, 6-tire single unit trucks is calculated using the data from Table 2-3 in Equations 2-5 and 2-6.

$$\text{Disel Percentage} = \frac{35{,}593.5}{696{,}329.8} \times 100 = 4.68\%$$

$$\text{Gasoline Percentage} = 100 - 4.68 = 95.32\%$$

For Vehicle Type 6 the percentages for 3-axle single unit trucks is calculated using the data from Table 2-3.

$$\text{Disel Percentage} = \frac{5{,}236.9}{5{,}763.5} \times 100 = 90.86\%$$

$$\text{Gasoline Percentage} = 100 - 90.86 = 9.14\%$$

For Vehicle Type 7 the percentages for 4 or more axle single unit trucks is calculated using the data from Table 2-3.

$$\text{Disel Percentage} = \frac{1{,}806.9}{1{,}855.6} \times 100 = 97.37\%$$

$$\text{Gasoline Percentage} = 100 - 97.37 = 2.63\%$$

Table 2-4 shows the summary results of both the EPA Guidance and revised EPA Guidance mapping. The mapping changes significantly for the gasoline and diesel fuel types for the SUCV 3-axles and 4 or more axle trucks (Vehicle Types 6 and 7). For example, the 50 percent gasoline and diesel splits identified in the EPA Guidance were revised to reflect an:

- 9.14 percent gasoline and 90.86 percent diesel split for SUCV 3-axle trucks; and
- 2.63 percent gasoline and 97.37 percent diesel split for SUCV 4 or more axle trucks.

**TABLE 2-4**
**SUMMARY OF EPA AND UPDATED EPA GUIDANCE MAPPING**

| HPMS Category | MOBILE5A Category | |
|---|---|---|
| | EPA Guidance | Updated EPA Guidance |
| Motorcycle | MC | same |
| Passenger Car | 98.64% LDGV | same |
| | 1.36% LDDV | same |
| Other 2-Axle, 4-Tire Vehicles | 65.71% LDGT1 | 64.39% LDGT1 |
| | 33.47% LDGT2 | 32.79% LDGT2 |
| | 0.82% LDDT | 2.82% LDDT |
| Buses | 10.28% HDGV | same |
| | 89.72% HDDV | same |
| Single Unit Trucks (1) | | |
| 2-Axle, 6-Tire | 87.90% HDGV | 95.32% HDGV |
| | 12.10% HDDV | 4.68% HDDV |
| 3-Axle | 50.00% HDGV | 9.14% HDGV |
| | 50.00% HDDV | 90.86% HDDV |
| 4 or More Axle | 50.00% HDGV | 2.63% HDGV |
| | 50.00% HDDV | 97.37% HDDV |
| Single Trailer Trucks | | |
| 4 or Fewer Axle | HDDV | same |
| 5-Axle | HDDV | same |
| 6 or More Axle | HDDV | same |

**TABLE 2-4**
**(CONTINUED)**

| HPMS Category | MOBILE5A Category | |
|---|---|---|
| | EPA Guidance | Updated EPA Guidance |
| Multi Trailer Trucks | | |
| 5 or Fewer Axle | HDDV | same |
| 6-Axle | HDDV | same |
| 7 or More Axle | HDDV | same |

*Note: (1) The revised Single Unit Truck mapping for gas vehicles include the categories for gasoline, liquefied gas or other, and not reported vehicles.*

*Source: Office of Mobile Sources and Cambridge Systematics, Inc.*

The results of applying the revised procedures to Vehicle Type 3 (Other 2-Axle, 4-Tire Vehicles) and Vehicle Type 5 (Single Unit Trucks 2-Axles, 6-Tire Vehicles) indicate similar gasoline and diesel splits for the EPA and revised EPA Guidance. For example, the diesel split for Vehicle Type 3 increases from 0.82 percent to 2.82 percent. For Vehicle Type 5, the gasoline split increases from 87.90 percent to 95.32 percent.

- **Step 2** – Table 2-5 contains the mapping obtained by state and roadway functional system for each of the vehicle types using 1993 data. Note that for Colorado, motorcycles are included with passenger cars; 2-axle, 4-tire trucks are included with passenger cars; buses are included with other single-unit trucks; and the data shown is from the previous year.

- **Step 3** – The ratio of local urban VMT to VMT on the non-local urban functional systems using Highway Statistics data from the November 1994 "Annual Vehicle-Miles of Travel by Functional System" table for each state was computed (Equation 2-7). The VMT values are in millions.

# TABLE 2-5

## MAPPING BY FUNCTIONAL CLASS AND VEHICLE TYPE FOR COLORADO AND WASHINGTON

| | Passenger Vehicles | | | | | Single-Unit Trucks | | | | | Single-Trailer Combination | | | Multi-Trailer | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| State | Passenger Cars | Motorcycles | Personal Passenger Vehicles | Buses | All Passenger Vehicles | 2-Axle 4-Tire | 2-Axle 6-Tire | 3-Axle | 4-Axle | All Single-Unit | 4-Axle | 5-Axle | 6-Axle | 5-Axle | 6-Axle | 7-Axle | All Trucks | All Motor Vehicles | AVMT |
| Rural Interstate | | | | | | | | | | | | | | | | | | | |
| Colorado | 79.3 | 0.0 | 79.3 | 0.0 | 79.3 | 0.0 | 3.5 | 1.8 | 0.0 | 5.3 | 0.9 | 12.5 | 0.2 | 1.2 | 0.4 | 0.2 | 20.7 | 100.0 | 3,881 |
| Washington | 64.6 | 0.1 | 64.7 | 0.3 | 64.9 | 21.5 | 2.5 | 0.5 | 0.1 | 24.6 | 1.4 | 5.9 | 0.5 | 0.5 | 0.7 | 1.4 | 35.1 | 100.0 | 3,759 |
| Rural Other Principal Arterial | | | | | | | | | | | | | | | | | | | |
| Colorado | 83.6 | 0.0 | 83.6 | 0.0 | 83.6 | 0.0 | 3.6 | 2.8 | 0.0 | 6.4 | 0.7 | 8.8 | 0.2 | 0.3 | 0.0 | 0.0 | 16.4 | 100.0 | 3,209 |
| Washington | 62.5 | 0.0 | 62.5 | 0.2 | 62.7 | 26.8 | 3.3 | 0.9 | 0.1 | 31.1 | 0.9 | 3.1 | 0.6 | 0.2 | 0.3 | 1.0 | 37.2 | 100.0 | 3,883 |
| Rural Minor Arterial | | | | | | | | | | | | | | | | | | | |
| Colorado | 81.8 | 0.0 | 81.8 | 0.0 | 81.8 | 0.0 | 3.6 | 4.0 | 0.0 | 7.6 | 1.1 | 8.9 | 0.5 | 0.1 | 0.0 | 0.0 | 18.2 | 100.0 | 2,269 |
| Washington | 63.5 | 0.0 | 63.6 | 0.2 | 63.5 | 27.2 | 3.2 | 1.2 | 0.1 | 31.6 | 0.8 | 2.5 | 0.4 | 0.1 | 0.2 | 0.7 | 36.3 | 100.0 | 1,945 |
| Rural Major Collector | | | | | | | | | | | | | | | | | | | |
| Colorado | 89.4 | 0.0 | 89.4 | 0.0 | 89.4 | 0.0 | 2.0 | 4.2 | 0.0 | 6.2 | 0.5 | 3.7 | 0.1 | 0.1 | 0.0 | 0.0 | 10.6 | 100.0 | 1,703 |
| Washington | 63.8 | 0.0 | 63.8 | 0.2 | 64.1 | 27.4 | 3.4 | 1.2 | 0.1 | 32.0 | 0.7 | 2.0 | 0.4 | 0.1 | 0.1 | 0.6 | 35.9 | 100.0 | 3,244 |
| Rural Minor Collector | | | | | | | | | | | | | | | | | | | |
| Colorado | 89.2 | 0.0 | 89.2 | 0.0 | 89.2 | 0.0 | 2.1 | 4.6 | 0.0 | 6.7 | 0.5 | 3.5 | 0.1 | 0.0 | 0.0 | 0.0 | 10.8 | 100.0 | 625 |
| Washington | 63.8 | 0.0 | 63.8 | 0.2 | 64.1 | 27.4 | 3.4 | 1.2 | 0.1 | 32.0 | 0.7 | 2.0 | 0.4 | 0.1 | 0.1 | 0.6 | 35.9 | 100.0 | 939 |

## TABLE 2-5

## (CONTINUED)

| | Passenger Vehicles | | | | | Single-Unit Trucks | | | | | Single-Trailer Combination | | | Multi-Trailer | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| State | Passenger Cars | Motorcycles | Personal Passenger Vehicles | Buses | All Passenger Vehicles | 2-Axle 4-Tire | 2-Axle 6-Tire | 3-Axle | 4-Axle | All Single-Unit | 4-Axle | 5-Axle | 6-Axle | 5-Axle | 6-Axle | 7-Axle | All Trucks | All Motor Vehicles | AVMT |
| Rural Local | | | | | | | | | | | | | | | | | | | |
| Colorado | 96.2 | 0.0 | 96.2 | 0.0 | 96.2 | 0.0 | 2.3 | 1.5 | 0.0 | 3.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.8 | 100.0 | 1,375 |
| Washington | 60.0 | 1.0 | 61.0 | 1.0 | 62.0 | 30.0 | 1.0 | 1.0 | 2.0 | 34.0 | 2.0 | 2.0 | 0.0 | 0.0 | 0.0 | 0.0 | 38.0 | 100.0 | 1,051 |
| Urban Interstate | | | | | | | | | | | | | | | | | | | |
| Colorado | 92.7 | 0.0 | 92.7 | 0.0 | 92.7 | 0.0 | 2.3 | 1.6 | 0.0 | 3.9 | 0.2 | 2.8 | 0.1 | 0.2 | 0.1 | 0.0 | 7.3 | 100.0 | 4,062 |
| Washington | 69.5 | 0.2 | 69.8 | 0.3 | 70.0 | 23.2 | 2.0 | 0.4 | 0.1 | 25.6 | 0.8 | 2.3 | 0.2 | 0.3 | 0.2 | 0.5 | 30.0 | 100.0 | 8,648 |
| Urban Other Freeways and Expressways | | | | | | | | | | | | | | | | | | | |
| Colorado | 96.1 | 0.0 | 96.1 | 0.0 | 96.1 | 0.0 | 1.2 | 1.4 | 0.0 | 2.6 | 0.2 | 1.1 | 0.0 | 0.0 | 0.0 | 0.0 | 3.9 | 100.0 | 2,477 |
| Washington | 65.1 | 0.1 | 65.2 | 0.1 | 65.3 | 27.9 | 2.4 | 0.7 | 0.1 | 31.1 | 0.7 | 1.8 | 0.4 | 0.0 | 0.1 | 0.6 | 34.7 | 100.0 | 3,907 |
| Urban Other Principal Arterial | | | | | | | | | | | | | | | | | | | |
| Colorado | 94.8 | 0.0 | 94.8 | 0.0 | 94.8 | 0.0 | 2.0 | 1.4 | 0.0 | 3.4 | 0.4 | 1.3 | 0.1 | 0.0 | 0.0 | 0.0 | 5.2 | 100.0 | 5,839 |
| Washington | 65.1 | 0.1 | 65.2 | 0.1 | 65.3 | 27.9 | 2.4 | 0.7 | 0.1 | 31.1 | 0.7 | 1.8 | 0.4 | 0.0 | 0.1 | 0.6 | 34.7 | 100.0 | 6,577 |
| Urban Minor Arterial | | | | | | | | | | | | | | | | | | | |
| Colorado | 92.0 | 0.0 | 92.0 | 0.0 | 92.0 | 0.0 | 3.6 | 2.6 | 0.0 | 6.2 | 0.4 | 1.3 | 0.1 | 0.0 | 0.0 | 0.0 | 8.0 | 100.0 | 3,643 |
| Washington | 65.3 | 0.0 | 65.3 | 0.2 | 65.5 | 28.0 | 3.0 | 0.8 | 0.2 | 31.9 | 1.3 | 0.9 | 0.1 | 0.0 | 0.1 | 0.2 | 34.5 | 100.0 | 6,188 |

# TABLE 2-5

## (CONTINUED)

| | Passenger Vehicles | | | | | Single-Unit Trucks | | | | | Single-Trailer Combination | | | Multi-Trailer | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| State | Passenger Cars | Motorcycles | Personal Passenger Vehicles | Buses | All Passenger Vehicles | 2-Axle 4-Tire | 2-Axle 6-Tire | 3-Axle | 4-Axle | All Single-Unit | 4-Axle | 5-Axle | 6-Axle | 5-Axle | 6-Axle | 7-Axle | All Trucks | All Motor Vehicles | AVMT |
| Urban Collector | | | | | | | | | | | | | | | | | | | |
| Colorado | 95.9 | 0.0 | 95.9 | 0.0 | 95.9 | 0.0 | 1.9 | 1.3 | 0.0 | 3.2 | 0.1 | 0.7 | 0.0 | 0.1 | 0.0 | 0.0 | 4.1 | 100.0 | 1,473 |
| Washington | 64.4 | 0.0 | 64.4 | 0.1 | 64.4 | 27.6 | 2.4 | 1.1 | 0.1 | 31.2 | 0.9 | 2.6 | 0.2 | 0.0 | 0.1 | 0.6 | 35.6 | 100.0 | 2,539 |
| Urban Local | | | | | | | | | | | | | | | | | | | |
| Colorado | 97.7 | 0.0 | 97.7 | 0.0 | 97.7 | 0.0 | 1.1 | 0.7 | 0.0 | 1.8 | 0.1 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 2.3 | 100.0 | 2,162 |
| Washington | 65.0 | 1.0 | 66.0 | 1.0 | 67.0 | 28.0 | 1.0 | 1.0 | 1.0 | 31.0 | 1.0 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 | 33.0 | 100.0 | 3,455 |

$$\text{Local Urban to Non-Urban - Urban Ratio for Colorado} = \frac{2{,}162}{19{,}656} = 0.11$$

$$\text{Local Urban to Non-Urban - Urban Ratio for Washington} = \frac{3{,}455}{31{,}314} = 0.11$$

The remaining steps for this approach to update EPA Guidance mapping for each sample section in a given nonattainment area are shown below. For the example provided, these steps were incorporated into a Statistical Analysis Software (SAS) program. Therefore, some of the specific data used for these steps have not been included in the example calculation. However, the equations and, where applicable, the specific data are summarized below:

(A) **Expanded VMT calculation using HPMS data.** The inputs for computing the expanded VMT included AADT (HPMS item #28), the length of the segment (HPMS item #25), and the expansion factor (HPMS item #41 or #42 - use item #41 if both #41 and #42 are nonzero). The expanded VMT was computed within the SAS program and uses the following equation (Equation 2-8):

Expanded VMT = (AADT) x (Length of Segment) x (Expansion Factor)

(B) **Calculate Local Urban VMT.** The Local Urban VMT was computed using the expanded VMT generated in (A) and the ratio of local to non-local urban VMT developed in Step 3 (Equation 2-7). Note that the ratio of local urban to non-local VMT was the same for both Colorado and Washington.

Local Urban VMT = (Expanded VMT) x 0.11

(C) **Calculate VMT for SUCVs, Combinations, and 4-Tire Vehicle Types.** These values were calculated using the expanded VMT computed above and the average percentage of SUCVs, Combination Trucks, and 4-Tire Vehicle Types from HPMS data. The average percentage data from HPMS included items #65A2 and #65B2 for the average percentage of SUCVs and Combinations, respectively. Again, these values were computed within the SAS program.

VMT SUCVs = (Expanded VMT) x (Average Percentage of SUCVs)

VMT Combinations = (Expanded VMT) x (Average Percentage of Combinations)

VMT 4-Tire Vehicles =
(Expanded VMT) - (VMT SUCVs + VMT Combinations + VMT Local)

(D) Distribute calculated VMT values across vehicle types. The mapping developed in Step 2 was used to distribute VMT 4-Tire Vehicles across Vehicle Types 2 and 3; Local Urban VMT across Vehicle Types 2 and 3; and VMT SUCVs across Vehicle Types 5 through 7. The VMT for 4-Tire Vehicles and Local Urban were then summed to get the total VMT for Vehicle Types 2 and 3. An example calculation for VMT for 4-Tire Vehicle Type 2 (Passenger Car) for the Urban Interstate facility type, using the results in from Step 2 (Table 2-5), would be:

VMT for Vehicle Type 2, Urban Interstate in Colorado=
(VMT for 4-Tire Vehicles) x 0.927

VMT for Vehicle Type 2, Urban Interstate in Washington=
(VMT for 4-Tire Vehicles) x 0.695

(E) Convert VMT by MOBILE5A category. The mapping identified and calculated in Step 1 was used to convert the VMT by MOBILE5A category. This example calculation includes results for both the EPA Guidance and the Revised EPA Guidance percentages contained in Table 2-4. The equation takes the form:

VMT for Vehicle Type 2, Gasoline =
(VMT for Vehicle Type 2 Computed in (D)) x 0.99

(F) Tables 2-6 and 2-7 show the urban area VMT estimates for Colorado and Washington by fuel type and selected vehicle classes for both the EPA Guidance and revised EPA Guidance methods.

**TABLE 2-6**
**SUMMARY OF COLORADO URBAN AREA VMT BY VEHICLE TYPE**

| Vehicle Type | Fuel Type | Guidance VMT (in thousands) | Revised VMT (in thousands) |
|---|---|---|---|
| 2. Passenger Car | Gasoline | 15,460,143 | 15,460,143 |
| | Diesel | 156,163 | 156,163 |
| 3. Other 2-Axle, 6-Tire Vehicles | Gasoline | 982,902 | 963,045 |
| | Diesel | 9,928 | 29,785 |
| 5. SUCV 2-Axle, 6-Tire Vehicles | Gasoline | 302,699 | 326,777 |
| | Diesel | 41,277 | 17,199 |
| 6. SUCV 3-Axle | Gasoline | 130,851 | 23,553 |
| | Diesel | 130,851 | 238,149 |
| 7. SUCV 4 or More Axle | Gasoline | 0 | 0 |
| | Diesel | 0 | 0 |
| VMT Combination | Diesel | 275,964 | 275,964 |
| Total VMT | | 17,490,778 | 17,490,778 |

*Source: Cambridge Systematics, Inc.*

**TABLE 2-7**
**SUMMARY OF WASHINGTON URBAN AREA VMT BY VEHICLE TYPE**

| Vehicle Type | Fuel Type | Guidance VMT (in thousands) | **Revised VMT (in thousands)** |
|---|---|---|---|
| 2. Passenger Car | Gasoline | 17,125,535 | 17,125,595 |
| | Diesel | 172,986 | 172,986 |
| 3. Other 2-Axle, 6-Tire Vehicles | Gasoline | 8,660,831 | 8,485,865 |
| | Diesel | 87,483 | 262,449 |
| 5. SUCV 2-Axle, 6-Tire Vehicles | Gasoline | 811,574 | 876,131 |
| | Diesel | 110,669 | 46,111 |
| 6. SUCV 3-Axle | Gasoline | 128,140 | 23,065 |
| | Diesel | 128,140 | 233,216 |
| 7. SUCV 4 or More Axle | Gasoline | 23,050 | 1,212 |
| | Diesel | 23,050 | 44,888 |
| VMT Combination | Diesel | 674,636 | 674,636 |
| Total VMT | | 27,946,154 | 27,946,154 |

*Source: Cambridge Systematics, Inc.*

# 3

# DEVELOPING LOCALITY-SPECIFIC INPUTS FROM TRAVEL DEMAND MODELS

This section presents state-of-the-practice methods and selected example calculations for developing locality-specific on-road motor vehicle emission inventory inputs from the transportation demand modeling and forecasting process. Methods are identified for the following parameters:

- VMT reconciliation with Highway Performance Monitoring System (HPMS);
- VMT and trip distribution;
- Speed estimation methods;
- Percent non-FTP driving;
- Hot/cold/hot stabilized weighting factors; and
- Trip duration.

The sections contained below present outlines of the applicable methods and procedures of the state-of-the-practice associated with each parameter. The modeling and forecasting process referred to considers the use of travel demand models (TDMs) supplemented by enhanced TDM modules, post-TDM processors, and observed travel survey data. Recommended methods for guidance or, in some cases, instructions for application are provided for each parameter. The application instructions provide detailed information about how to implement the prescribed techniques. The number of applicable methods and instructions presented for each parameter vary depending on the level of existing research and information available in the state-of-the-practice.

## 3.1 VMT RECONCILIATION WITH HPMS

Travel demand modelers for MPOs and State DOTs traditionally have had to adjust estimates of vehicle miles of travel (VMT) generated through the TDM process in order

to match HPMS estimates of VMT. These procedures are required to generate consistent VMT estimates from TDMs for roadway functional classes within HPMS for use in regional emissions and air quality analyses. Typical inconsistencies of VMT estimates include:

- Facility types coded within TDM highway networks do not directly match the functional class system within HPMS. For example, TDM highway networks incorporate several categories for highways including freeway, highway, ramp, and HOV facility types and do not distinguish between interstate and other state highways. In other words, TDM coding schemes do not match directly with the functional class system contained within HPMS for interstates, principal arterials, and minor arterials.

- TDM highway network coding schemes do not include lower level roadway functional classifications. For example, major roadway facilities have been historically coded within TDM highway networks while many arterials, collectors, and local roadways are not coded. Therefore, VMT generated by TDMs tend to be lower than if the entire highway network was modeled.

The following subsection describes two methods that can be used by MPOs and State DOTs to reconcile HPMS and TDM VMT estimates. Each method considers revising TDM highway network coding to incorporate either HPMS identifiers or revised facility type codes. Metropolitan Planning Organizations and State DOTs, regardless of the method selected, should carry forward the recoded highway networks through the TDM process (i.e., trip generation, distribution, mode choice, assignment) in order to report base and future forecasted VMT. Either method will allow the user to match VMT generated from the TDM process to the estimates contained in the HPMS dataset.

### METHODS

In most metropolitan areas, travel demand modelers have developed conversion factors in order to match TDM estimates of VMT with HPMS. The development of these factors vary by metropolitan area depending on the facility types coded within the TDM highway network, the level of inconsistency between TDM facility types and HPMS functional classes, the geographic scope of the modeling area, and the availability and quality of observed travel data. The method recommended for VMT reconciliation with HPMS is general in scope to account for the variable travel characteristics from one metropolitan area or state to the next. However, this method provides the guidance necessary for metropolitan areas and states to reconcile these VMT differences depending on the characteristics of their TDM and HPMS systems.

**Method 1 – Code HPMS Identifier in TDM Highway Network**

Roadways within TDM highway networks are represented by a series of link attributes typically consisting of anode and bnode, distance, speed, capacity, and facility type codes. In most TDM software, such as EMME/2, MICROTRIPS, MINUTP, TMODEL2, and TRANPLAN, additional link attribute fields are provided to incorporate user-specified attributes such as number of lanes, planning areas (i.e., neighborhoods, towns/cities), area types (i.e., rural, suburban, urban, CBD), and traffic screenline locations.

This method involves incorporating HPMS identifier codes as an attribute for each link within the TDM highway network to improve the development of TDM to HPMS conversion factors. The following application steps are required to implement this method:

- **Step 1 – Develop HPMS Identifier Coding Scheme.** The user should initially develop the HPMS identifier coding scheme in order to provide a cross-reference with specific TDM highway network links and HPMS functional classifications. For example, freeway links coded within the TDM highway network may not be consistent with a single functional class within the HPMS dataset. Multiple HPMS dataset functional classes such as interstates, primary arterial, or minor arterials typically make up TDM highway network freeway link designations.

- **Step 2 – Identify Highway Network Attribute Field.** The user should generate TDM highway network plots in order to graphically illustrate the roadways by their associated facility types currently modeled. The plots can help the user identify the attribute field (i.e., link group codes) within the TDM highway network that can be used to store and incorporate the HPMS identifier code developed in Step 1. Link group designations within most TDM software can be user-specified. For example, Link Group Code 1 can be used as the HPMS identifier code within TRANPLAN software.

- **Step 3 – Enter HPMS Identifier Code into Highway Network.** The user should generate an ASCII (i.e., text file) representation of the highway network link file using procedures within the TDM software. At this point, the user should input the highway network ASCII file into user-specified text editing software such as Brief in order to enter the HPMS identifier codes into the appropriate link attribute fields. Alternatively, the TDM graphics editor can be used to enter the HPMS identifier codes directly into the appropriate attribute fields for each link.

- **Step 4 – Build Highway Network.** The user should enter the revised ASCII highway network file within the applicable TDM software in order to build the revised highway network that includes the HPMS identifier codes.

- **Step 5 – Travel Demand Modeling and Forecasting.** The user should use the revised highway networks as part of the regional or statewide modeling process. The HPMS identifier codes can be used to match VMT generated for the base and future forecasts contained in applicable HPMS datasets.

This coding scheme provides the user with a mechanism to automate the conversion of TDM highway network VMT by coded facility types to match HPMS VMT. However, because TDM highway networks typically do not contain local roadway facility types, the unique conversion factors for local roadways developed locally by MPOs and State DOTs should be maintained.

#### ADVANTAGES

- Applicable at the state and metropolitan area levels.

- Coding scheme is straightforward.

- Can interface with several TDM packages including EMME/2, MICROTRIPS, MINUTP, TMODEL2, and TRANPLAN.

#### DISADVANTAGES

- System coding requirements are high.

- Development of conversion factors for local roadways is still required.

### Method 2 – Match Highway Network Facility Types with HPMS Functional Classifications

This method is very similar to Method 1 with the exception that the facility types coded within the TDM highway network link attribute file will be consistent with the functional classifications coded within HPMS. Therefore, the development of conversion factors will not be required because of this direct cross referencing system. The Ada Planning Association (APA) in Boise, Idaho recently used this coding approach during their regional travel model update project. Table 3-1 shows the APA coding scheme. The following steps are required to implement this method:

## TABLE 3-1

## EXAMPLE OF CONSISTENT HPMS DATASET AND TDM HIGHWAY NETWORK CODING

| Area Types | Interstate | HOV | Principal Arterial One-Way With Parking | Principal Arterial Other | Minor Arterial One-Way With Parking | Minor Arterial Other | Collector One-Way With Parking | Collector Other | Local One-Way With Parking | Local Other | Interstate Ramps | Centroid Connector |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. CBD/ Residential | N/A | N/A | 25 | 30 | 20 | 25 | 15 | 20 | 15 | 15 | 15 | 15 |
| 2. Fringe/ Residential | N/A | N/A | 25 | 30 | 20 | 25 | 20 | 20 | 15 | 15 | 25 | 15 |
| 3. Urban[1] | 55 | 55 | 30 | 30 | 25 | 25 | 20 | 20 | 15 | 15 | 25 | 15 |
| 4. Suburban | 55 | 55 | 35 | 35 | 30 | 30 | 25 | 25 | 20 | 20 | 25 | 15 |
| 5. Rural[1] | 60 | 60 | N/A | 40 | N/A | 35 | N/A | 30 | N/A | 35 | 25 | 15 |
| 6. Rural[2] | 65 | 65 | N/A | 45 | N/A | 45 | N/A | 40 | N/A | 40 | 25 | 15 |
| 7. Urban[2] | 45 | 55 | 40 | N/A | N/A | N/A | 30 | 20 | N/A | N/A | 20 | 15 |
| 8. Special Constrained | 50 | N/A | N/A | N/A | N/A | N/A | N/A | 35 | N/A | N/A | 30 | 25 |

Note: Interstate Ramps (Facility Type 19) ON RAMPS are coded with Area Types 1-5; EXIT RAMPS use Area Types 6-7.
Speeds are in miles per hour (MPH).
Cells contain representative TDM Travel Speeds.

Source: Ada Planning Association and Cambridge Systematics, Inc.

- **Step 1 – Recode TDM Highway Network Facility Types.** The user should recode TDM highway network facility type codes to be consistent with the applicable HPMS functional classifications by area type (rural, suburban, urban, CBD) and roadway type (interstate, primary arterial, minor arterial, collector, and local). This step is used to match the TDM Highway Network facility types with those contained in the HPMS dataset. The user begins this recoding process by creating TDM highway network plots in order to identify the roadways and their associated facility types currently modeled. These plots in conjunction with HPMS functional classification maps can then be used in order to cross reference the old with the new facility types contained within the TDM highway network.

- **Step 2 – Revise Speed-Capacity Lookup Table.** The user should develop the applicable speed and capacity assumptions for the area and facility types coded in Step 1. This process should be consistent with the HPMS functional classifications, transportation engineering state-of-the-practice, and local travel characteristics of the specific MPO and State DOT modeling area. A meeting comprised of local and regional transportation planners, engineers, and modelers is highly recommended at the start of this process in order to more accurately define speeds and capacities for the region.

- **Step 3 – Enter New Codes into TDM Highway Network.** Using the TDM software, the user should generate an ASCII (i.e., text file) representation of the highway network link file. The user, in conjunction with the TDM highway network plots generated in earlier steps, should then enter (i.e., recode) the link attributes within the TDM highway network to reflect the revised facility types, speeds, and capacities. It is recommended that the user enter the TDM highway network ASCII file into database software (i.e., Dbase, Foxpro) for use in generating and entering the new speeds and capacities into the link attribute fields for each link corresponding to the appropriate facility type codes. Alternatively, the TDM graphics editor can be used to enter the new codes directly into the appropriate attribute fields for each link.

- **Step 4 – Build Highway Network.** The user should enter the revised ASCII highway network file within the applicable TDM software in order to build the revised highway network that includes the revised codes.

## TABLE 3-1

## EXAMPLE OF CONSISTENT HPMS DATASET AND TDM HIGHWAY NETWORK CODING

| Area Types | Interstate | HOV | Principal Arterial One-Way With Parking | Principal Arterial Other | Minor Arterial One-Way With Parking | Minor Arterial Other | Collector One-Way With Parking | Collector Other | Local One-Way With Parking | Local Other | Interstate Ramps | Centroid Connector |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. CBD/ Residential | N/A | N/A | 25 | 30 | 20 | 25 | 15 | 20 | 15 | 15 | 15 | 15 |
| 2. Fringe/ Residential | N/A | N/A | 25 | 30 | 20 | 25 | 20 | 20 | 15 | 15 | 25 | 15 |
| 3. Urban[1] | 55 | 55 | 30 | 30 | 25 | 25 | 20 | 20 | 15 | 15 | 25 | 15 |
| 4. Suburban | 55 | 55 | 35 | 35 | 30 | 30 | 25 | 25 | 20 | 20 | 25 | 15 |
| 5. Rural[1] | 60 | 60 | N/A | 40 | N/A | 35 | N/A | 30 | N/A | 35 | 25 | 15 |
| 6. Rural[2] | 65 | 65 | N/A | 45 | N/A | 45 | N/A | 40 | N/A | 40 | 25 | 15 |
| 7. Urban[2] | 45 | 55 | 40 | N/A | N/A | N/A | 30 | 20 | N/A | N/A | 20 | 15 |
| 8. Special Constrained | 50 | N/A | N/A | N/A | N/A | N/A | N/A | 35 | N/A | N/A | 30 | 25 |

Note: Interstate Ramps (Facility Type 19) ON RAMPS are coded with Area Types 1-5; EXIT RAMPS use Area Types 6-7.
Speeds are in miles per hour (MPH).
Cells contain representative TDM Travel Speeds.

Source: Ada Planning Association and Cambridge Systematics, Inc.

- **Step 1 – Recode TDM Highway Network Facility Types.** The user should recode TDM highway network facility type codes to be consistent with the applicable HPMS functional classifications by area type (rural, suburban, urban, CBD) and roadway type (interstate, primary arterial, minor arterial, collector, and local). This step is used to match the TDM Highway Network facility types with those contained in the HPMS dataset. The user begins this recoding process by creating TDM highway network plots in order to identify the roadways and their associated facility types currently modeled. These plots in conjunction with HPMS functional classification maps can then be used in order to cross reference the old with the new facility types contained within the TDM highway network.

- **Step 2 – Revise Speed-Capacity Lookup Table.** The user should develop the applicable speed and capacity assumptions for the area and facility types coded in Step 1. This process should be consistent with the HPMS functional classifications, transportation engineering state-of-the-practice, and local travel characteristics of the specific MPO and State DOT modeling area. A meeting comprised of local and regional transportation planners, engineers, and modelers is highly recommended at the start of this process in order to more accurately define speeds and capacities for the region.

- **Step 3 – Enter New Codes into TDM Highway Network.** Using the TDM software, the user should generate an ASCII (i.e., text file) representation of the highway network link file. The user, in conjunction with the TDM highway network plots generated in earlier steps, should then enter (i.e., recode) the link attributes within the TDM highway network to reflect the revised facility types, speeds, and capacities. It is recommended that the user enter the TDM highway network ASCII file into database software (i.e., Dbase, Foxpro) for use in generating and entering the new speeds and capacities into the link attribute fields for each link corresponding to the appropriate facility type codes. Alternatively, the TDM graphics editor can be used to enter the new codes directly into the appropriate attribute fields for each link.

- **Step 4 – Build Highway Network.** The user should enter the revised ASCII highway network file within the applicable TDM software in order to build the revised highway network that includes the revised codes.

- **Step 5 – Travel Demand Modeling and Forecasting.** The user should use the revised highway networks as part of the regional or statewide modeling process. The revised network coding scheme can be used to match VMT generated for the base and future forecasts contained in applicable HPMS datasets.

As with the previous method, this coding scheme provides the user with a mechanism to automate the conversion of TDM highway network VMT to match HPMS VMT. In cases where local roadways are not coded in the TDM highway network, the unique conversion factors for local roadways developed locally by MPOs and State DOTs should be maintained.

### ADVANTAGES

- Applicable at the state and metropolitan area levels.
- Can interface with several TDM packages including EMME/2, MICROTRIPS, MINUTP, TMODEL2, and TRANPLAN.

### DISADVANTAGES

- System coding requirements are high.
- Coding scheme is not straightforward.
- Applicable in smaller metropolitan areas.

### RECOMMENDATIONS

The methods described above require the design and implementation of new highway network coding schemes within user-specified TDM software. The level of effort required for highway network coding for Method 2 compared to Method 1 is considerably more extensive because it requires the design of unique speed/capacity tables to be integrated with an established facility type coding scheme. In addition, Method 2 is more suitable for smaller metropolitan areas with a limited number of freeway facility types and less potential for coding scheme complications. Method 1 can be implemented quite easily for both large and small metropolitan areas. In either case, MPOs and State DOTs should incorporate the applicable VMT reconciliation method during the model development or model update process.

## 3.2 VEHICLE MILES OF TRAVEL AND TRIP DISTRIBUTION

Travel demand model outputs can be used to help provide both spatial and temporal allocation of vehicle activity and emissions results. Separate methods are available for spatial distribution of running emissions versus trip start and end emissions. The current state-of-the-practice for the spatial allocation of running emissions is briefly summarized in this section. This method is satisfactory for purposes of developing modeling inventories. Alternative methods for the spatial allocation of trip start and end emissions are also presented in this section.

### CURRENT PRACTICE FOR THE SPATIAL DISTRIBUTION OF RUNNING EMISSIONS

Travel demand model outputs are the preferred source of information to use in spatially allocating running emissions for modeling inventories. The current practice involves distributing the activity evenly along each link within the TDM highway network and then allocating the activity to grid cells. This allocation is typically developed using the percentage of the number of links contained within a given cell. This method also requires that the spatial coordinates of each link (i.e., anodes and bnodes) are known and are easily accessible. (In most TDM software packages, xy coordinates for each node are contained within the node dataset of the TDM highway network. The user can easily generate ASCII (i.e., text) file representations of the node data for analysis purposes. It should be noted that specific procedures for creating ASCII text files of the node coordinate information vary by TDM software package.)

Using this method, the VMT for each link can be allocated to the appropriate grid cell. If VMT is not available in this format, but is available on a regional basis by roadway functional class and area type, then the TDM highway network link coordinates can be used to spatially allocate the VMT. In this case, VMT is allocated to grid cells based on the ratio of VMT in the grid cell to the total regional VMT for each functional class and area type.

This process can be accomplished using geographical information system (GIS) software to spatially relate the TDM highway network with the modeling grid structure. Non-GIS packages exist to perform this function as well, including the GRIDEM module in the Emissions Preprocessor System.

### METHODS

Alternative state-of-the-practice methods for the spatial allocation of trip start and end emissions are presented below. The methods described below are intended to provide MPO and State DOT modelers with general instructions for application.

**Method 1 – Spatial Distribution of Trip Start and End Emissions**

When trip start and end emissions (cold start, hot start, hot soak, diurnal, and resting evaporative emissions) are estimated separately from running emissions, a number of optional procedures can be applied to spatially distribute emissions. These stationary emissions are calculated for activity within the TDM highway network at the Traffic Analysis Zone (TAZ) level. Each TAZ has a zonal connector that attaches it to the TDM highway network and serves as the origin or destination of trip activity. Traffic analysis zones typically represent some logical geography within the TDM highway network and should be consistent with census tract (and in some cases, census block) boundaries. Traffic analysis zones may also include portions of one or more grid cells. Brief descriptions of the optional methods for determining the spatial allocation of these stationary emissions at the TAZ level include:

- **Optional Method 1.1** – Allocate the stationary emissions to the grid cell containing the TAZ connector. This method considers the level of trip activity and emissions on the TAZ connector and does not allocate emissions on the links contained within the TDM highway network. Of the optional methods, this is the simplest to implement and apply.

- **Optional Method 1.2** – Distribute the activity evenly to the grid cells contained within the geographic boundary of the TAZ. The user should base this allocation on the ratio of the volume (i.e., trip activity) of the grid cell area within the TAZ to the total TAZ area. This method requires additional TDM and database processing in order to identify the applicable TAZ allocation ratios for distributing emissions.

- **Optional Method 1.3** – Distribute the activity to grid cells within the TAZ based on a spatial surrogate such as land use, housing, population, or employment. In other words, the user should develop emission distribution ratios based on the given characteristics of a TAZ. The development of these ratios is dependent on the demographic or socioeconomic data used to drive the TDM trip generation process. For example, the user could develop ratios based on population and employment data if the given TDM process is socioeconomic based.

The level of data and effort required to implement each of these optional methods varies considerably. Of these options, the data required and the level of processing effort are lowest for Option 1.1 and highest for Option 1.3. When selecting one of the above options, the metropolitan area or state should consider the phenomena that as population and employment density increase, the size of TDM highway network TAZs tends to decrease. In urban areas where there are higher emissions, the size of the

TAZ is often approximately equal to or less than the size of the grid cells. Larger TAZs that span multiple grid cells are associated with suburban and rural regions where the activity level is lower. In areas where the size of the TAZ is comparable to the grid cells, the difference in these three allocation options is insignificant.

Given this inverse relationship between activity and the size of TAZs, the choice of the spatial allocation method depends upon the characteristics of the metropolitan area or state being modeled, the purpose of the inventory, and the availability of appropriate data and resources. For most metropolitan areas, the use of Option 1.1 should be acceptable. However, Options 1.2 and 1.3 provide improved accuracy. For most MPOs and State DOTs, the choice of optional method may depend on the balance between the need for improved accuracy versus the increased level of effort required.

**Method 2 – Use of TDM Data to Develop Temporal Distributions**

Emission inventories that are being used in photochemical models may require hourly temporal distributions of emissions. Existing guidance recommends using observed traffic counts to develop temporal distributions of activity. TDM outputs can serve as quality assurance tools to compare temporal distributions, but few TDMs are configured to provide hourly traffic flow results. Many MPOs divide TDM generated daily trip tables into peak and off-peak periods such as morning and afternoon peak periods, and midday and evening (or combined midday and evening) off-peak periods. If the given TDM is configured in this manner, TDM generated traffic flows by facility type and time period could be used to compare profiles with observed traffic counts. However, except in a few cases, temporal VMT profiles generated from the TDM trip assignment are not recommended substitutes for profiles developed from observed traffic counts.

If no suitable observed traffic counts are available, then profiles developed from TDMs could be used to compare with available default VMT profiles. These default profiles are available from packages such as the Emission Preprocessor System. The use of these default profiles is not preferred since they are not based on local data sources.

## RECOMMENDATIONS

The recommended method for implementation will vary depending on the specific MPO and/or State DOT inventory purpose and availability of resources and data. Travel demand model outputs can also provide useful information for quality assurance of temporal profiles. However, in cases where observed travel data (i.e., traffic counts) are unavailable, then TDM outputs should not be considered as the primary source of temporal information.

## 3.3 Speed Estimation Methods

A variety of methods designed to improve travel speed outputs generated from TDMs and to validate travel speed inputs used in TDMs have been developed by several MPOs and State DOTs throughout the country. These methods are well documented and typically consider the implementation of enhancement modules written within specific TDM software and/or modeling systems, and the development of post-TDM processors. The methods identified herein are not intended to be inclusive of all existing techniques but are intended to provide a representative cross-section of the potential techniques available to improve the accuracy of or to validate travel speeds generated through the TDM process.

The intent of the methods identified in this section is not to provide step-by-step procedures required for implementation but rather to provide guidance for the selection of the appropriate speed estimation method that may be applicable to a given metropolitan area or state. The method selected for a given MPO and State DOT must be specified by the user and is dependent on the availability of the budgetary and staff resources committed to obtaining observed locality-specific data, purchasing post-TDM processor programs, and enhancing TDM capabilities.

### Methods

Traditionally, techniques to estimate vehicle speeds for mobile source emission inventories have included using MOBILE Model default values, observed travel speed surveys, HPMS outputs, TDM trip assignment step outputs, and volume-to-capacity ratios. These techniques have been incorporated into several methods associated with the TDM process to generate more accurate travel speeds for use in emissions modeling. These have included:

- An existing method within HPMS to generate aggregate-level travel speed estimates for various roadway functional classifications.

- Post-TDM processing methods that are applied after the TDM trip assignment to incorporate more accurate travel speeds into the TDM process. In some post-processors, adjusted travel speeds are fed back (i.e., known as feedback loops) into the TDM modeling process (typically at the trip distribution step) in order to refine travel speed outputs while other post-processors adjust travel speeds without TDM feedback.

- TDM system and simulation modules that are applied as part of the TDM process. Typically, these systems are developed as separate modules of the

TDM system that feed into highway network, trip generation, trip distribution, and trip assignment modeling steps.

Brief descriptions of the identified methods and the advantages and disadvantages of each are presented in the following sections.

**Method 1 – HPMS-AP Technique**

The Highway Performance Monitoring System Analytic Process (HPMS-AP) estimates link speeds as a function of several roadway (link) attributes including pavement condition, curves and gradients, speed change cycles and their minimum speeds, signal stop cycles, acceleration and deceleration rates, and the fraction of time spent idling. This technique generates travel speeds within the HPMS dataset and has been typically used by State DOTs without statewide TDM capabilities.

**ADVANTAGES**

- Applicable at the state-level if TDMs are not available.
- Limited resources (costs and time) are required to obtain and run the system.
- Applicable to all HPMS datasets.

**DISADVANTAGES**

- Not applicable within the TDM process.

**Method 2 – Dowling/Skabardonis Post-Processor**

The Dowling and Skabardonis post-processor combines speed changes based on congested locations with delays based on queuing in order to provide refined link travel times and average speeds within a given TDM system. This post-processor is applied after the trip assignment step of the TDM process. Once the post-processor is applied and run, its output travel speeds are recoded into the TDM highway network and incorporated back into the TDM process at the trip distribution step in a feedback loop. It takes traffic congestion and delay into account by modifying the volume to speed function (i.e., the Bureau of Public Roads or BPR formula that expresses the relationship of volume, capacity, and travel time in the TDM trip assignment) specified in the TDM trip assignment. It predicts queuing delays for all links on which volume exceeds capacity. This post-processor has recently been refined as part of the California State Department of Transportation (Caltrans) project to update the Direct Travel

Impact Model (DTIM). (DTIM, developed by the California Air Resources Board (ARB) and Caltrans, is used to generate grid and link specific emission estimates from TDM outputs for use in air quality modeling in California.)

### ADVANTAGES

- Applicable at the state and metropolitan area levels.
- Limited resources (costs) are required to obtain the system.
- Can interface with several TDM packages including EMME/2, MICROTRIPS, MINUTP, TMODEL2, and TRANPLAN.

### DISADVANTAGES

- System setup requirements may be high.
- System outputs are generated for the California-based DTIM.

**Method 3 – Boston Central Artery/Tunnel Speed Post-Processor**

The Boston Central Artery/Tunnel speed post-processor uses volume and travel speed outputs generated from the trip assignment of the TDM process in conjunction with revised capacities to estimate adjusted travel speeds. In some cases, observed volumes (if available) are also used in this process as a supplement to adjust specific highway network link travel speeds. Each facility type coded within the TDM highway network has a unique speed estimation relationship based on travel times constrained by signalization and geometrics; freeways and ramps with low and high volume-to-capacity ratios; unconstrained (free flow) travel speeds; and queues at congested locations. Highway Capacity Manual (HCM) relationships related to signalized intersections, link segments and modifications of the TDM's BPR function are used in this system. The post-processor combines the links into facilities composed of roadway sections and analyzes the facilities as a unit to determine queues by section and hour, queue lengths, delays, and travel speeds.

### ADVANTAGES

- Applicable at the state and metropolitan area levels.
- Limited resources (costs) are required to obtain the system.

- Can be refined to interface with several TDM packages including EMME/2, MICROTRIPS, MINUTP, TMODEL2, and TRANPLAN.

**DISADVANTAGES**

- System setup requirements may be high

**Method 4 – California Air Resources Board (CARB) Vehicle Speed Post-Processor**

For the CARB, Deakin Harvey Skabardonis (DHS) developed the CARB vehicle speed post-processor that combines revised volume to speed functions, queuing analysis techniques, and vehicle activity data by link type into the highway network code to provide more detailed travel speed inputs to emissions modeling components. Another component of this post-processor includes data obtained from traffic simulation models (such as INTRAS and TRAF-NETSIM) to generate travel speed and acceleration/ deceleration information by functional class.

**ADVANTAGES**

- Applicable at the state and metropolitan area levels.
- Limited resources (costs) are required to obtain the system.
- Can be refined to interface with several TDM packages including EMME/2, MICROTRIPS, MINUTP, TMODEL2, and TRANPLAN.

**DISADVANTAGES**

- Requires the development of, and outputs from, traffic simulation models.
- System setup requirements are high.

**Method 5 – Post Processor for Air Quality System**

The Post Processor for Air Quality (PPAQ) was developed by Garmen Associates to format and adjust TDM output variables for use as inputs for MOBILE5A. PPAQ reads in associated TDM outputs and performs the following functions:

- Determines peaking patterns of daily assignments;
- Adjusts peak hour volumes to account for peak spreading and congestion;

- Disaggregates TDM generated trips to match the vehicle types required for MOBILE5A;
- Traces hot/cold start vehicles to calculate percentages required for MOBILE5A;
- Adjusts TDM VMT estimates to account for seasonality;
- Calculates link and intersection approach capacities and delays;
- Calculates mid-block link travel speeds and aggregate link speeds;
- Accumulates VMT, VHT, and average speeds by various geographic representations; and
- Prepares VMT inputs for the MOBILE model.

PPAQ computes adjusted mid-block link travel speeds and aggregate link speeds by time of day and functional class based on outputs calculated in earlier PPAQ procedural steps and outputs generated from the TDM process. TDM outputs include capacities, observed speeds, free-flow coded speeds, volumes, intersection delays, and adjusted delay equations (BPR formulas).

#### ADVANTAGES

- Applicable at the state and metropolitan area levels.
- Limited resources (costs) are required to obtain the system.
- Can interface with several TDM packages including EMME/2, MICROTRIPS, MINUTP, TMODEL2, and TRANPLAN.
- Calculates and adjusts several TDM outputs for MOBILE.

#### DISADVANTAGES

- System setup requirements may be high.

### Method 6 – Basic Speed Estimation Method

Cambridge Systematics developed a post-processor for the U.S. EPA to estimate travel

speeds from the TDM trip assignment step using vehicle-to-capacity ratios. The system is very flexible and can be applied to TDMs using readily available spreadsheet and database software packages. The basic procedural steps include:
Determine the Highway Capacity Manual (HCM) chapters required to derive the appropriate speed-volume relationships for rural, suburban, and urban TDM highway network links.

- Determine the additional roadway characteristics for all links not generated by the TDM trip assignment outputs (speeds and volumes) and the TDM highway network codes related to roadway geometrics, signal coordination, and percent heavy vehicles.

- Define the general speed to volume relationships for each TDM highway network link using the information collected above including capacities, distances, free-flow speeds, number of lanes, and TDM trip assignment volumes.

- Apply these general speed to volume relationships to adjust the travel speeds generated in the TDM trip assignment process to all facilities in each link category.

This method provides a technique to estimate improved link-specific vehicle travel speeds for all facilities and link categories identified in the TDM highway network. The step-by-step procedures required to implement this method are presented later in this section.

### ADVANTAGES

- Applicable at the state and metropolitan area levels.

- Limited resources (costs) are required to implement the system.

- Can interface with several TDM packages including EMME/2, MICROTRIPS, MINUTP, TMODEL2, and TRANPLAN.

### DISADVANTAGES

- System setup requirements may be high.

### Method 7 – Volpe Simulation Process

As part of the "IVHS Benefits Assessment Model Framework", the Volpe Center and

U.S. DOT developed a system linking regional TDMs with arterial (TRANSYT-7F) and freeway (FREQ) simulation models to accurately predict traffic volumes, speeds, delay and queuing, and vehicle modal activity such as acceleration, cruise speed, and deceleration. An analytical process was developed incorporating these various models and tools to improve the sensitivity of currently available TDM software to assess the impacts and potential benefits of ITS (Intelligent Transportation Systems).

#### ADVANTAGES

- Applicable at the state and metropolitan area levels.
- Can be refined to interface with several TDM packages including EMME/2, MICROTRIPS, MINUTP, TMODEL2, and TRANPLAN.
- System is readily accessible from the Volpe Center.

#### DISADVANTAGES

- System setup requirements are high.
- Requires the development of and outputs from traffic simulation models.

### Method 8 – DVRPC Simulation Process

The Delaware Valley Regional Planning Commission (DVRPC) has implemented an iterative process within its TDM system designed to adjust and validate TDM generated travel speeds. This simulation process involves adjusting free-flow travel speeds initially coded into the TDM highway network using congested, observed travel speeds collected in the field and feedback iterations into the trip distribution, mode choice, and trip assignment steps of the TDM process.

#### ADVANTAGES

- Applicable at the state and metropolitan area levels.

#### DISADVANTAGES

- System setup requirements may be high.
- System is not readily accessible from the DVRPC.

- Requires the development of and outputs from traffic simulation models.
- Can interface with only one TDM package; TRANPLAN.

## RECOMMENDATIONS

The post-TDM processor and simulation methods described above require the development of additional enhancement modules and systems within user-specific TDM software or off-TDM spreadsheet/database software packages. In general, the budgetary resources required to obtain these methods are not costly since the majority of the methods are contained within the public domain. However, the resource requirements for setting up each method may be high relative to agency resources (i.e., staff time and commitment).

## EXAMPLE CALCULATIONS

Provided in this section is an example calculation of Method 6: Basic Speed Estimation. This method is designed to estimate travel speeds from the TDM trip assignment step using vehicle-to-capacity ratios. The system is very flexible and can be applied to TDMs of any type (EMME/2, MINUTP, et al) using readily available spreadsheet and database software packages. It also provides a technique to estimate improved link-specific vehicle travel speeds for all facilities and link categories identified in the TDM highway network. The implementation procedures are presented below.

The basic vehicle speed estimation procedure can be implemented in the form of a specially-coded computer program, a spreadsheet, or a database management system in which the link-specific traffic assignment vehicle speeds are post-processed to refine their accuracy.

### Inputs

Although local areas have significant degrees of latitude in how they specify existing and future TDM highway networks for use in travel forecasting, most areas using UTPS or equivalent microcomputer-based systems (EMME/2, MINUTP, et al) have the following information available for each highway link in each network for which TDM trip assignments have been performed:

- **Area Type**: typically CBD, CBD fringe, urban, suburban, rural.
- **Facility Type**: typically freeway, expressway, major arterial, intermediate arterial, minor arterial or collector, ramp.

- **Link Group**: typically a further breakdown of facility types by speed limit or parking availability, for example.
- **Number of Lanes.**
- **Distance** (miles).
- **Capacity** at a specified level of service (vehicles per lane per hour).
- **Free-Flow Speed** (miles per hour).
- **Free-Flow Time** (minutes).
- **Predicted Volume**: based either on an hourly traffic assignment process, or on hourly factors applied to the results of a daily traffic assignment (vehicles per hour).

Note that link speeds, as predicted by the TDM highway assignment process, are also available but will be revised by the speed estimation method described in this section. To avoid confusion, these speeds are not included in the list provided above.

In addition to link-specific data provided as part of a highway network, the major input to the basic speed estimation method is the 1994 Highway Capacity Manual (HCM), which provides detailed methods for estimating capacities and speeds for specific highway facilities. For the purposes of the basic method, capacity estimation is not important because the TDM highway network provides capacity values for each link. The speed estimation methods in the HCM, however, are very important.

**General Speed-Volume Relationships**

The first step in the basic speed estimation method involves defining general speed-volume relationships for each link category used in the TDM highway network. As used here, a link category is the group of all links having a unique combination of area type, facility type, and link group codes. Since the HCM includes speed estimation procedures requiring more link information than that provided by TDM highway networks, these procedures must be "averaged" over all facilities in a link category.

The highway characteristics which must be either averaged or assigned as representative of the typical facility within a given link category vary by link type. For freeways and expressways without traffic signals, discussed in Chapter 3 of the HCM, these characteristics consist of:

- Lane width and lateral clearance;
- Design speed;
- Heavy vehicles: trucks, buses and recreational vehicles as percentages of total flow;
- Type of terrain;
- Peak hour factor: the ratio of average 15-minute flow in the peak hour to the maximum flow per 15-minute period; and
- The driver population: weekday commuters and regular users versus weekend or occasional drivers.

For ramps providing access and egress from freeways and expressways (HCM Chapter 5), the following characteristics, not readily available in TDM highway network and TDM trip assignment output data, affect operating speeds:

- The total volume and heavy vehicle volume in the freeway or expressway lane adjacent to the ramp;
- The distance to, and volumes on, adjacent upstream and downstream ramps; and
- The type of ramp: on- or off-ramp, number of lanes at the junction, etc.

For rural and suburban multi-lane major arterials (HCM Chapter 7) without significant intersection delays, the same factors listed above for freeways and expressways may affect speeds, but are not available in network or assignment data. Additional factors for these types of facilities are:

- Type of multilane highway: divided or undivided, frequency of unsignalized inter-sections and driveways, and severity of left turning conflicts; and
- Vertical grades.

For rural two-lane arterials (HCM Chapter 8), all of the freeway and multilane facility factors, with the exception of driver population, can affect vehicle speeds. Additional factors to be considered are the percentage of segment length with no-passing zones, and the split of traffic between the two directions of travel on the facility.

Urban and suburban streets and highways (HCM Chapter 11) are signalized facilities that both serve through traffic and provide access to abutting properties. These facilities range from major arterials to collector streets and downtown streets. The speeds on these facilities at particular levels of traffic volumes are affected somewhat by their typical free-flow speed, but often largely by intersection delays. Many of the factors affecting speeds and delays on these facilities that are not typically available in network and assignment data are related to the major intersections included in an arterial segment. These factors include the following:

- Cycle length;
- Green ratio for arterial traffic;
- Progression factor;
- Conflicting pedestrian flow rates;
- Heavy vehicles as a percentage of total volume;
- Peak hour factor;
- Vertical grade;
- Number of buses;
- Number of parking maneuvers;
- Lane widths;
- Existence of exclusive left- and right-turn lanes;
- Signal type: actuated or pretimed; and
- Pedestrian signalization characteristics.

### ANALYSIS STEPS

The following steps are required to develop general speed-volume relationships for each link category:

**Step 1: Determine Applicable HCM Chapter.** Based on the area type, facility type, link group, range of capacity levels, and range of free-flow speeds, select the appropriate chapter in the HCM from which to obtain information on the speed-volume relationship. The above discussion of additional factors by facility type can be used to begin this selection process based only on area type and facility type. The additional link characteristics listed above may be necessary to determine, for example, whether a particular link category should be treated as a rural or suburban multilane highway using HCM Chapter 7, or an urban or suburban street using HCM Chapter 11.

**Step 2: Determine Average or Typical Values for All Link Characteristics not Provided by Assignment Outputs.** By drawing upon all available sources of data on street and highway facilities and vehicular travel patterns, average or typical values of the characteristics of existing and proposed future streets and highways can be selected. These sources are likely to include the following:

- Transportation agencies for previous highway facility inventories which are likely to include many of the needed characteristics;
- Public works or equivalent departments at the city, county and state levels for roadway design information such as lane and shoulder widths, design speeds, ramp configurations, no-passing zone locations, distances between intersections, curb cuts, vertical grades, and turning lane designs.
- Traffic and parking departments for traffic signal characteristics, parking availability and usage, heavy vehicle percentages, peak hour factors, and pedestrian volumes.

It should be emphasized that the focus of the data collection required in this step is on average or typical conditions for all facilities in a particular link category. In the basic method, link-specific collection of detailed characteristics is not necessarily required.

**Step 3: Define General Speed-Volume Relationship.** This step involves a conversion of the appropriate detailed speed estimation method in the HCM into a relationship which can be applied to each link in a particular link category. Each relationship can include the following link-specific variables, all of which are available as outputs of the highway network development or traffic assignment processes:

- Capacity;
- Distance;
- Free-flow speed or time;
- Number of lanes; and
- Predicted volume level.

By providing two examples of these relationships, the procedures required for all link categories and for ranges of detailed link characteristics can be clarified.

**Example 1: Urban Freeways**

A particular link category defined in the metropolitan area being considered includes all links with an area type of urban, freeway facility type, and a link group code which signifies a design speed of 50 miles per hour. A review of available data sources indicates that the average or typical facility in this link category has the following detailed characteristics:

- 6 lanes, three per direction;
- 11-foot lane widths;
- Obstructions on one side of the roadway within 4 feet of the traveled pavement;
- Peak hour factor equal to 0.87;
- Average free-flow speed equal to 45 mph;
- Average speed at LOS E equal to 25 mph;
- 8 percent heavy vehicles; and
- Driver population: predominantly regular weekday commuters.

Using Chapter 3 of the HCM, these characteristics imply a service flow rate (SF) for Level of Service (LOS) E of 1,462 passenger cars per hour per lane. This value may not correspond to the capacity coded for some or all of the links in the link category due to differences in LOS standards or due to link-to-link variations, but it represents a reference point against which the coded capacity values can be compared. The other reference point required is the coded capacity of the average or typical 50-mph urban freeway: this value, corresponding to LOS C in this case, is found to be 1,150. Thus, the first equation of the generalized speed-volume relationship is one which converts coded capacity ($C_C$) in passenger cars per hour per lane into LOS E capacity ($C_E$) in the same units:

(3-1)

$$C_E = \frac{1462}{1150} \times C_C = 1.27 \times C_C$$

The second equation required is one which uses the peak hour factor (PHF) to convert the volume level and the number of lanes (NL) predicted in the assignment process ($V_A$) into the hourly flow rate during the peak 15 minutes per lane ($V_P$):

$$V_P = \frac{V_P}{NL \times PHF} = \frac{1.15 \times V_A}{NL} \tag{3-2}$$

As an alternative approach, average hourly volumes can be used rather than peak 15-minute flow rates. In this case, Equation 3-2 would be used with PHF equal to 1.0. Equations 3-1 and 3-2 can be combined to provide a means of computing the volume-capacity ratio (V/C) required to estimate speeds:

$$V/C = \frac{V_P}{C_E} = \frac{0.906 \times V_A}{NL \times C_C} \tag{3-3}$$

Next, the volume-capacity ratio, V/C, can be used to estimate speed reduction factors (SRF) for each link by interpolating the values provided in the following table, derived from Figure 3-4 in the HCM:

| V/C | SRF |
|---|---|
| 0 | 0.000 |
| 0.1 | 0.028 |
| 0.2 | 0.040 |
| 0.3 | 0.068 |
| 0.4 | 0.119 |
| 0.5 | 0.169 |

| V/C | SRF |
|---|---|
| 0.6 | 0.243 |
| 0.7 | 0.350 |
| 0.8 | 0.492 |
| 0.9 | 0.650 |
| 1.0 | 1.000 |

Source: Highway Capacity Manual.

Finally, the predicted speed ($S_P$) on each link can be estimated using SRF, the average speed at LOS E (25 mph), and the link's free-flow speed ($S_{FF}$):

$$S_P = S_{FF} - SRF \times (S_{FF} - 25) \tag{3-4}$$

Equations 3-3 and 3-4 and the V/C-SRF table provided above represent the entire generalized relationship required for the 50-mph urban freeway link category as it is constituted for the metropolitan area being considered. The relationship makes as much use as possible of the available link-specific data and of the relationships provided in the HCM. These sources are supplemented as necessary with detailed information representing the average or typical facilities included in the link category.

**Example 2: Major CBD Arterials**

Another link category defined in the metropolitan area being considered consists of all links with an area type of CBD, major arterial facility type, and a link group code which signifies one-way facilities with no parking. Secondary data sources have been used to determine that the average or typical facility in this link category has the following detailed characteristics:

- 3 lanes;
- 12-foot lane widths;

- No significant grades;
- 5 percent heavy vehicles;
- Peak hour factor equal to 0.95;
- Average segment length equal to 0.25 miles;
- Average number of intersections per segment equal to 1;
- Average free-flow speed equal to 30 mph;
- Driver population: predominantly regular weekday commuters;
- Pre-timed signals without pedestrian push-buttons;
- 60-second cycle length;
- Green ratio equal to 0.55;
- No signal progression;
- Moderate conflicting pedestrian flows;
- 20 buses per hour;
- No right turn on red;
- Proportion of vehicles turning equal to 0.20;
- No separate turning lanes; and
- Parallel pedestrian flows permitted for the entire time of the green phase.

Following a procedure which parallels that in Example 1, but using Chapters 9 and 11 of the HCM, the following relationships can be determined:

- Capacity flow level = 889 vehicles per lane.
- Average coded capacity = 1,000 vehicles per lane.
- Link-specific capacity flow level:

$$C_L = \frac{89}{1000} \times C_C = 0.889 \times C_C$$

(3-5)

- Volume per peak 15 minutes per lane:

$$V_P = \frac{1.05 \times V_A}{NL}$$

(3-6)

- Volume/capacity ratio:

$$V/C = \frac{1.181 \times V_A}{NL \times C_C}$$

(3-7)

- Average stopped delay in seconds per vehicle per intersection (based on HCM Equations 9-18 and 11-2):

$$D_S = \frac{6.0}{1 - 0.55 \times V/C} + 225 \times V/C^2 \times \left[(V/C - 1) + \sqrt{(V/C - 1)^2 + 16.89 \times V/C/C_C}\right]$$

(3-8)

- Running time in seconds per mile:

$$RT = 3960 / S_{FF}$$

(3-9)

- Predicted speed in miles per hour (L = link length in miles):

$$S_P = \frac{L}{1.1 \times L / S_{FF} + D_S / 3600}$$

(3-10)

Equations 3-7, 3-8, and 3-10 represent the entire generalized relationship required for the major CBD arterial link category for the metropolitan area being considered.

### EXTENDING THE HCM RELATIONSHIPS

It is important to note that the speed-volume relationships derived from the HCM are limited in the range of volumes for which they are applicable. HCM's speed versus volume curves for non-intersection related facilities are undefined for volume/capacity ratios greater than 1.0, and its intersection delay equation can only be used for ratios less than 1.2. Since traffic assignment outputs can exceed these limits, some procedure must be devised to extend the generalized relationships to provide speed values for higher values of the volume/capacity ratio. In the basic method, the recommended approach is to extend the HCM-based relationships such as those derived in Examples 1 and 2 as has been done in the Phoenix metropolitan area to extend the functions used in their peak hour traffic assignment model. The resulting general relationships for volume/capacity ratios above the limits noted above are the following:

- For freeways and expressways:

$$S_P = S_{P1} \times (0.555 + 0.444 \times V/C^{-3}) \tag{3-11}$$

where $S_{P1}$ is the speed predicted for V/C=1 using a general relationship based on HCM data, as in Example 1.

- For arterials and collectors:

$$S_P = S_{P1.2} (0.663 + 0.583 \times V/C^{-3}) \tag{3-12}$$

where $S_{P1.2}$ is the speed predicted for V/C=1.2 using a general relationship based on HCM data, as in Example 2.

Since volume/capacity ratios greater than the limits discussed above are generally

Cambridge Systematics, Inc., Analysis of Temporal Demand Shifts to Improve Highway Speed Modeling, prepared for the Arizona Department of Transportation, April 1988.

impossible to achieve "in the field", observed data cannot be used to develop functions such as those presented above. However, since the basic speed estimation method calls for the use of volumes predicted in the traffic assignment process without adjustments to reflect rerouting, peak spreading, demand level reduction or other ways in which travelers respond to excessive delays, reasonable functions such as those provided above represent the best means of dealing with unadjusted assignment results.

The functions can be interpreted as approximate representations of the delays due to queuing and extended periods of stop-and-go traffic when volumes exceed capacities.

**Step 4: Apply General Speed-Volume Relationship to all Facilities in the Link Category.** In this step, TDM link-specific assignment outputs are used as inputs to the general relationships developed in Step 3. The results are estimated speeds for each link within the link category. These speeds are then available for use in calculating vehicle-hours of travel on the link and in estimating emissions rates using MOBILE5A.

### EXTENSIONS OF THE BASIC METHOD

The basic speed estimation method presented above provides a means of obtaining improved link-specific predictions of vehicle speeds on all facilities represented in a TDM highway network, but still requires a number of simplifying assumptions. This section describes a range of approaches which can be used to relax these assumptions and thus obtain even more accurate speed estimates. Of course, each extension requires additional analysis time and effort; a trade-off is required to select the appropriate levels of accuracy, analysis time, and analysis effort for a particular urban area.

The following extensions of the basic speed estimation method are described:

- Field collection of average link characteristics;
- Use of expanded link-specific information;
- Use of local capacity and speed data; and
- Special studies of critical links.

### FIELD COLLECTION OF AVERAGE LINK CHARACTERISTICS

The link data required to use the HCM speed-volume relationships that are not available from a MPO's or state DOT's TDM process will, for the most part, be available from secondary sources. Some data items, however, must either be estimated

based on professional experience or assumed to be equal to standard default values provided in the HCM. When particular data items are found to have a significant effect on predicted speeds, consideration should be given to conducting special-purpose field data collection to obtain more accurate average link characteristics. Examples of such variables are the following:

- Lane widths;
- Heavy vehicle percentages;
- Volumes in freeway and expressway lanes next to ramps;
- Unsignalized intersections and driveways per mile on rural and suburban major arterials;
- Severity of left-turning conflicts;
- Directional traffic splits;
- Cycle lengths and green ratios at intersections with vehicle-actuated signals; and
- Numbers of parking maneuvers.

In each case, characteristics such as these can be readily observed in the field. Obtaining accurate averages will require defining representative sample locations to be observed and then deploying field crews to these locations. The resulting observations can then be averaged for the appropriate link categories to provide more accurate information for use in Step 2 of the basic method discussed above.

### USE OF EXPANDED LINK-SPECIFIC INFORMATION

Some urban areas have developed highway facility inventory data files which include not only the variables required for TDM network development and trip assignment, but also many of the additional link characteristics required to use the basic method. Other areas may choose to develop such files for use in air quality planning as well as other local transportation applications. Wherever these inventory files exist or are developed, they should be used, along with the volume predictions available from TDM trip assignment outputs, as the basis for improved speed estimation procedures. In these improved procedures, all available link-specific inventory data should be used, along with supplemental information on average or typical characteristics not provided in the inventory data set, to develop link-specific speed-volume relationships in a revised

Step 3 of the method discussed above. These link-specific relationships can then be used with volumes predicted in TDM trip assignments in Step 4 to provide more accurate estimates of link speeds.

### USE OF LOCAL SPEED AND CAPACITY DATA

Throughout the HCM, its authors state that the speed and capacity relationships presented are typical conditions in the United States, but that these relationships should be replaced with local data whenever such data exists. This advice is particularly important in air quality planning, due to the strong linkages between capacities and speeds, and between speeds and emissions. Whenever local data on the variations of speeds and capacities for different operating conditions are available, they should be incorporated into the general relationships developed in Step 3. Furthermore, whenever significant variations from the HCM relationships are suspected, local planners should consider the desirability of collecting additional field data, developing local revisions of the HCM relationships, and using these to estimate link speeds more accurately.

### SPECIAL STUDIES OF CRITICAL LINKS

The basic speed estimation method is predicated upon the ability to characterize all facilities in a particular link category by a single average or typical link. Because each link category is usually specific to a particular area type, facility type, and link group, this ability usually exists for most link categories. Some link categories, however, and some unique links in otherwise ordinary categories, do not lend themselves to being analyzed using generalized procedures. Freeway and expressway ramps are perhaps the primary examples of hard-to-generalize link categories. Similarly, freeway facilities with weaving areas or those in the vicinity of other complex interchange elements frequently have speed and capacity characteristics which are quite different from other freeway links. Another example would be intersections which are frequently over-saturated causing multi-cycle queues which back up to congest adjacent intersections. In many cases such as these, accurate estimates of both existing and future speeds can only be obtained by carrying out facility-specific studies using a combination of HCM and locally observed data. Such studies will frequently require the isolation of a number of highway network links for analysis as a unit for example, a number of freeway links upstream of a bottleneck caused by a lane drop and for a detailed traffic engineering analysis of how the unit can be expected to operate under existing and future conditions. The results of these link-specific studies can then be combined with the results of more generalized approaches for non-critical links to provide the full set of travel speeds required for emissions inventories.

## 3.4 Percent Non-FTP Driving

The Federal Test Procedure (FTP) is a standardized procedure developed by the EPA to measure emissions rates from motor vehicles. The FTP is a chassis dynamometer test conducted using a standardized driving cycle under standardized conditions. The FTP includes a specific driving cycle (i.e., speed-versus-time profile), temperature, vehicle load, and starting conditions. Developed in Los Angeles over 20 years ago, the driving cycle used in the FTP (referred to as LA4) was intended to represent typical vehicle operations in urban areas. Although the FTP was developed from data intended to represent average urban driving conditions, recent research has shown that it does not match vehicle conditions in today's operating environment.

Based on data collected during the past several years for various research projects, it is now apparent that the driving cycles upon which the FTP is based do not accurately reflect the types of vehicle operation that occur under typical driving conditions. The FTP has a maximum speed of 57 mph and a maximum acceleration rate of 3.3 mph per second. Research sponsored by both the EPA and the California Air Research Board (CARB) has demonstrated that the LA4 driving cycle does not represent the full range of speed and acceleration rates occurring on urban freeways.

### Methods

Emissions modeling considers the following analytical steps and procedures. Base emission rates are developed for the vehicle fleet (by vehicle class, model year, technology category, age, and mechanical condition). These rates are based upon emission measurements from a single representative driving profile (i.e., the FTP). A series of correction factors are developed and used to adjust these rates to account for differences between the test conditions identified by the FTP measurements and those conditions encountered in the design day conditions encountered at the local level (e.g., speed, temperature, hot/cold start fractions, etc.).

Since passage of 1990 Clean Air Act Amendments (CAAA) and the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), the accuracy of emissions models has come under increasing scrutiny since these regulatory requirements allow little margin for error. Particular attention is being given to developing an improved understanding of the affects of vehicle speed and acceleration, on emissions.

Several research efforts currently are underway that have the objective of developing a fundamentally new approach to estimating vehicle emissions. These new analytical methods are explicitly being designed to determine the impacts of non-FTP driving, but are not expected to be practically available for another seven to ten years, and possibly

longer. Most are still at the stage of collecting extensive new emissions data and developing prototypical computer models. Still, these research efforts can be used as the basis for developing incremental improvements to current emissions modeling techniques.

These analytical methods are being designed and applied to identify probable vehicular enrichment events on freeway on-ramps, grades, terrain, freeway weaving and merging areas, toll-booths, construction areas, air conditioning usage, and other high engine load situations. Many of these methods are related to the efforts described above to develop new models. Commonly referred to as modal emissions models, a major objective of these models is to overcome the simplistic assumptions currently used to identify the relationship between average speed and emissions.

In modal emissions models, analysis is performed to identify the modes of vehicle operation that show significant differences in emission performance (acceleration, deceleration, idle, cruise). Tests are then performed to measure emissions of modes of operation for a sample of vehicles that represent the entire vehicle fleet. The next step considers several viewpoints about which modes of operation best characterize the range of in-use emissions performance. These include:

- **Multiple Cycle Models.** Observed in-use driving data are collected and analyzed to develop multiple driving cycles in order to characterize vehicle operation by facility type and level of congestion. Emissions measurements are then taken for a representative sample of vehicles tested on alternative cycles (e.g., containing multiple operating modes such as acceleration and deceleration, and combinations of transportation characteristics such as different congestion levels and facility types within a given cycle). Travel activity is segregated by facility type and congestion level, and combined with the appropriate emission factors to quantify emission inventory estimates. (Both the CARB and U.S. EPA have performed exploratory analysis and emission measurements to support the development of this approach.)

- **Empirical Models.** Emission measurements are taken for each mode of speed and acceleration for a representative sample of vehicles. This approach is based on measurements of emissions at fixed speed and acceleration points (i.e., the transitional impacts of acceleration or deceleration, which can be considerable, are ignored.) However, this model does not have to be based solely on fixed speed points. To prepare emission inventory estimates, travel activity for the entire vehicle fleet are supplied in units of time at the selected modes of speed and acceleration.

- **Engine Map Models.** Emission measurements are collected for a representative set of engine speed and load points (commonly referred to as engine maps of emissions) to characterize the range of engine operation and related emissions performance for a sample of vehicles. Traffic simulation models (such as the VEHSIM model) are then used to translate second-by-second driving activity into engine power demands. The power demand statistics are then matched with related emissions estimates (in most cases these estimates must be interpolated since test measurements are limited) to generate estimates of in-use emissions.

Hybrid models consisting of empirical and predictive modeling components are also currently under development. At present, four separate modal emission models are under development. While each method summarized below is currently under development and, therefore, unavailable for incorporation into emissions inventory compilation, these methods none the less can be used to establish short-term methods of estimating non-FTP emissions.

**Method 1 – Georgia Institute of Technology**

With support from EPA's Office of Research and Development, the Federal Highway Administration (FHWA), and the Georgia Research Partnership, Georgia Tech has undertaken a long-term research program to develop a modal motor vehicle emissions model integrated with a Geographic Information System (GIS) that takes into account emissions as a function of vehicle operating profiles. This model will be capable of distinguishing emissions from a wide variety of vehicle operating modes, including cruise, acceleration, deceleration, idle, and other power demand conditions that lead to enriched vehicle operating conditions. The goals of the overall research program include:

- Development of emissions relationships that improve inventory modeling procedures including explicit effects of vehicle fleet characteristics, vehicle operating conditions, and driver behavior;

- Incorporation of traffic flow parameters in the vehicle activity estimation process;

- Development of emission factors appropriate to each modal emission-producing activity (with specified uncertainty);

- Explicit incorporation of the effects of various policy initiatives and programs on fleet emission;

- Validation of emission estimates from new emission inventory models; and

- Publication of a model development handbook for Metropolitan Planning Organizations (MPOs) that would develop such a model for their own region.

**Method 2 – University of California at Riverside**

The College of Engineering - Center for Environmental Research and Technology (CE-CERT) at the University of California, Riverside is conducting NCHRP Project 25-11 - "Development of a Modal Emissions Model". The researchers have defined a new approach to modal emissions modeling based on a review of the emissions modeling literature. The new approach considers a physical, power demand modal modeling approach which is based on a parametric analytical representation of emissions production. In such a model, the entire emissions process is broken down into different components that correspond to physical phenomena associated with vehicle operation and emission production. Each component is modeled as an analytical representation consisting of various parameters that are characteristic of the emissions production process. These parameters vary according to the vehicle type, engine, and emission technology.

The authors indicate that an analysis of emissions measurement will be performed in the context of physical laws (e.g., energy loss, chemical equilibrium, etc.). Using an approach similar to earlier efforts, CE-CERT believes that it will be possible to characterize variations in fuel use and emissions with a few critical parameters (i.e., facility types, vehicle mix, roadway grade). According to CE-CERT researchers, the degree of analysis employed will be sufficient to meet accuracy requirements "interpreted in absolute terms on the basis of regulatory needs".

The planned modeling method will contain the following primary components:

- **A Tractive Power Demand Function** – Instantaneous power demand requirements placed on a vehicle at the wheels will depend on three types of parameters including environmental factors (e.g., mass density of air, road grade, etc.), static vehicle parameters (e.g., vehicle mass, rolling resistance, etc.), and dynamic vehicle parameters (e.g., commanded acceleration, velocity, etc.).

- **Engine Power Demand** - A function will be developed to translate tractive power and accessory (e.g., power steering, air conditioning, etc.) loads into demanded engine power requirements.

- **Gear Selection** – Since engine speed plays a role in fuel use and resulting emissions, a gear selection strategy or shift schedule will be needed to quantify the effect of power demand on engine speed. However, the authors do not plan to track engine speed on a second-by-second basis because they believe that regulatory accuracy targets can be satisfied with longer time intervals.

- **Emission Control Strategy** – CE-CERT plans to model the equivalence ratio, which is defined as the air/fuel ratio at stoichiometry divided by the commanded air/fuel ratio. This will be modeled in terms of driving characteristics (e.g., engine power demand, engine warm-up history, etc.) and parameters which describe the vehicle's command enrichment strategies.

- **Emission Functions** – The final component of the physical model will be a set of analytical functions designed to describe the emissions rates of the vehicle, such as engine power demand, engine speed, equivalence ratio, and temperature. CE-CERT believes that additional parameters may be required to improve the accuracy of these rates and are investigating second-by-second emissions data from EPA for a method to characterize engine-out and catalyst-out emissions.

CE-CERT indicates that once this method is developed, additional work will be required to characterize the mix of engine and emission control technologies that make up the vehicle fleet. They also acknowledge that the model focuses only on the performance of spark ignition engines equipped with closed-loop emission control systems. In other words, additional effort will be required to characterize the performance of other vehicle/technology combinations (i.e., diesel engine and gasoline engines not equipped with closed-loop controls).

In conclusion, the CE-CERT effort is a three-year project which has just recently begun. It is an extremely ambitious effort with goals to develop a modal emissions model that meets regulatory accuracy requirements, and that can be integrated with both microscale (e.g., intersection, freeway link, etc.) and macroscale (e.g., MINUTP, UTPS, etc.) travel demand models.

**Method 3 – TRANSIMS - Los Alamos National Laboratory**

The Los Alamos National Laboratory is developing a Transportation Analysis and Simulation System (TRANSIMS) designed to simulate individual vehicle behavior in a transportation system. This is a long-term model development effort intended to produce a new generation of travel demand forecasting, microsimulation, emissions, and

air quality models. Both passenger and freight travel are being considered. TRANSIMS consists of the following elements:

- Synthetic population;
- Activity demand and travel behavior;
- Intermodal route planner;
- Travel microsimulation; and
- Environmental modules.

The environmental module --that is of interest to this analysis-- uses individual vehicle speed and acceleration to compute wheel power demand. A vehicle simulation is then used to determine the state of the engine (e.g., engine rotational speed and torque). The emissions depend on the state of the engine. At present, the VEHSIME model (note that this model is different than the VEHSIM model described in the Method 1 discussion) which uses steady-state emission maps is being used. Los Alamos plans to replace the emission engine map approach with an alternative model being developed by the University of Michigan. It is believed that this model may be similar in structure to the one described above for the CE-CERT effort. The emissions results will be used as inputs to various air quality models (local and regional scales, with and without chemistry) to determine the impact on ambient air quality.

**Method 4 – Oak Ridge National Laboratory**

Under contract to the Federal Highway Administration, the Oak Ridge National Laboratory is developing a matrix of emission estimates for specific travel speed and acceleration values. This information will be used to update the emission estimates contained within TRAF-NETSIM. A test program is underway to collect data on engine operating parameters associated with specific speed/acceleration values. Vehicles are placed on dynamometers to collect data on emissions measurements under the same conditions. A method has been developed to translate these estimates into average gram per second emission rates.

**Method 5 – Lake Michigan Air Directors Consortium (LADCO)**

Heavy accelerations can substantially increase emissions. Such events may be more pronounced in major urban areas where stop-and-go driving conditions are common, especially during the early morning (i.e., peak commute) emissions period. Measurements by General Motors indicate that such "enrichment events" can increase

Volatile Organic Compounds (VOC) emissions by a factor of 40, and Carbon Monoxide (CO) emissions by a factor of 2000, while Nitrogen Oxides (NOx) emissions are not affected.

A program to calculate enrichment event emissions for ramps, toll booths, and cruise conditions was developed by LADCO. This program was included in GEMAP, a computer-based emissions simulation model developed for the San Joaquin County, California and Lake Michigan Ozone Studies to assist in air quality/photochemical modeling. The emission calculation is based on multiplying the number of emissions seconds times an emissions factor (expressed in terms of g/sec). The number of enrichment seconds were derived from surveys collected in the field on occurrence rates for ramps, toll booths, and cruise conditions, which were determined as follows:

- **Ramps.** Calculated as a function of the number of seconds on a ramp and assumed that 20 percent of the vehicles enrich where the:
  - Number of enrichment seconds = 0.2 * seconds on ramp; and
  - Seconds on ramp = {[VMT on link]/length of link]} * {speed/3.3}.
- **Toll Booths.** Calculated as a function of the volume on the link, travel speed, and assumed that 20 percent of the vehicles enrich where the:
  - Number of enrichment seconds = 0.2 * seconds on links * 2; and
  - Seconds on links = {[VMT on link]/length of link]} * {speed/3.3}.
- **Cruise Conditions.** Calculated as 0 percent below speeds of 20 mph, 2 percent above speeds of 30 mph, and varies linearly between 0 percent and 2 percent for speeds of 20 to 30 mph.

This approach was applied by LADCO to the Chicago metropolitan area using the coded TDM highway network and TDM system developed by the Chicago Area Transportation Study (CATS). Using capabilities of existing standard transportation planning computer packages, a code was defined as part of the set of network attributes to indicate those conditions (e.g. ramps, toll booths) where conditions of fuel enrichment was likely to occur.

## RECOMMENDATIONS

The current generation of travel demand models do not provide the detailed second-by-second vehicle operating data required to characterize modal emissions operations. Until these capabilities exist, a practical network-based approach to account for

non-FTP driving is to use the LADCO approach, Method 5 described above. Looking towards methodologies that could be developed in the near-term future, different concepts have emerged:

1. Develop profiles of emissions behavior into common blocks of performance (e.g., profiles of time spent at idling, accelerating, and decelerating for typical vehicular movements by facility type) so that less detailed vehicle operating information is required (may include gathering second-by-second data to provide modal emission rates); and

2. Develop profiles of vehicle operating behavior by level of service (LOS) and facility type, and linking those profiles with TDM outputs (may include gathering new dynameter data on representative cycles).

Of the two concepts outlined above, it is recommended that Concept 2 be used as part of their near-term travel demand and emissions modeling processes because:

- In the near-term, it could be integrated directly into current TDM procedures, and

- It will produce the necessary outputs required for inputs into the emissions modeling process.

The collection of new second-by-second emissions data, however, still will be required to implement Concept 2. Such an approach currently is being developed by Sierra Research, Inc., in work being sponsored by FHWA, EPA, and the National Cooperative Highway Research Program. Facility-specific speed correction factors are being developed for incorporation in EPA's MOBILE5A and CARB's existing EMFAC7F emissions factors models.

Presented below are a set of recommended analytical steps to identify and account for the likely enrichment events within the framework of the TDM highway network. It should be noted that Concept 2 is identified as Step 1 in this process.

- **Step 1 – Identify Criteria for Non-FTP Highway Network Coding Scheme.** Highway network components that are typically causing high engine load situations should be identified. These components may include freeway on-ramps, grade sections, uneven terrain sections, freeway weaving and merging areas, toll-booths, construction areas, areas with high air conditioning usage, and other fuel enrichment situations. Subsequently, these network components should be based on simple parameters such as facility type, number of lanes, traffic control characteristics, type of section

(merging, weaving, etc.), and volume-to-capacity ratio.

- **Step 2 – Identify Non-FTP Vehicle Activity Percentage and Emissions Rates for Each Fuel Enrichment Network Link.** Using research findings from modal emissions projects outlined above, identify percentages or percent ranges of vehicles whose performance is outside the FTP profile for each highway network link with likely high engine load situations. Then identify the emission rates for non-FTP vehicles by vehicle type (passenger car, light duty truck, heavy duty truck, etc.).

- **Step 3 – Code Scheme into the Highway Network.** Each of the highway network components with high engine loads can then be assigned specific codes. This may include re-classifying current ramp coding schemes. These codes can be later used to identify and summarize travel performance measures for each non-FTP network link output from the trip assignment step of the modeling process.

- **Step 4 – Run Trip Assignment to Identify Inputs for MOBILE Runs.** The travel demand model trip assignment step can be run to identify travel outputs (speeds and VMT distributions) that are required as inputs for the MOBILE model. Recent observed data can be used to validate TDM output travel speeds by facility type.

- **Step 5 – Run Modified MOBILE Model and Estimate Emissions.** Once the above procedures have been developed, run the MOBILE model using the outputs generated from Step 4 to estimate mobile emissions.

The analytical method outlined above is a cost-effective and reasonable method for near-term development and use by MPOs and State DOTs to identify probable vehicular enrichment events and estimate their impact on emissions and air quality.

## 3.5 Cold Start/Hot Start/Hot Stabilized Weighting Factors

This section presents methods for using TDM outputs in conjunction with locally collected travel data to identify cold, hot, and hot stabilized weighting factors for developing emission inventory inputs. Traditionally, TDMs have not been the basis for estimating these weighting factors. Rather, travel surveys and other data have been used to estimate default factors for input into emission inventories. Too often, these default factors have been based on national data and do not reflect the different travel characteristics associated from region to region. However, recent improvements in

TDM software have provided MPO and State DOT analysts with enhanced modules that can be used to trace and estimate cold start fractions.

## METHODS

Travel demand models can be used to estimate start fractions and to develop weighting parameters using the following methods:

- Use the distribution of origin to destination trip travel times to estimate percentage of operation in start mode;
- Use the trip tracing option available in some TDM software packages (i.e., MINUTP) to track percentage of starts on highway network links; and
- Estimate trip start emissions explicitly as instantaneous emissions occurring at the beginning of trips.

Other methods that can be implemented in metropolitan areas or states without TDMs or without using TDM outputs include:

- Analyze locally collected travel survey data to determine trip length and weighting parameters; and
- Conduct field studies to examine engine temperatures.

One limitation common to the three TDM methods described above is in determining cold versus hot starts. Travel demand models do not now provide this type of information. (Efforts, however, are now underway to incorporate the chaining of individual trips into TDM systems. The availability of this trip chaining information would permit the differentiation between cold and hot starts.) Therefore, this information must come from other sources such as the analysis of travel survey data. The methods described below are intended for application instruction.

### Method 1 – Distribution of Travel Time/Travel Distance to Estimate Start and Stabilized Operation

This method uses summary tables of travel times or travel distance distributions that can be produced from the TDM process. The user should compute the total percentage of travel time or travel distance of the identified trips exceeding established cut points for start operation. All travel less than this cut point is assumed to be operating in the start mode. All travel greater than this cut point is assumed to be operating in the stabilized

mode. The use of the start mode specifications from the Federal Test Procedures (FTP) are recommended to establish the cut points. These are travel times less than or equal to 505 seconds or trip distances less than or equal to 3.59 miles. Other cut points could be used if sufficient data can be provided to determine the time to catalyst light-off temperature.

### ADVANTAGES

- Output can be disaggregated by trip purpose, time of day, and vehicle class.
- Resources required are minimal compared to other methods.

### DISADVANTAGES

- TDMs can only estimate start versus stabilized emissions, i.e. additional data are needed to separate cold start from hot start.
- Usefulness of results may be limited by TDM capabilities to predict time of day or vehicle class variations.
- Results applicable on a regional scale; not as detailed as other methods.

### Method 2 – Use of TDM Trip Tracing Module to Track Percent of Starts on Links

Some TDM software packages have the capability to track travel in the start mode on individual links by trip purpose. In this method, the software prorates the vehicle packet on the link according to the distance traveled from the origin, a threshold distance, and the length of the link. The user specifies a threshold distance or travel time for the start period. During the trip allocation step, all travel up to the threshold time or distance is assumed to be start mode operation. The threshold distance is a user-specified option. In the absence of other data, a distance for the start mode of 505 seconds or a distance of 3.59 miles should be used (corresponding to the FTP start mode specifications).

### ADVANTAGES

- Possibility exists to develop start fractions on a link-by-link level which provides improved spatial allocation of emissions.
- Results can be aggregated to provide more regional estimates of weighting

fractions.

**DISADVANTAGES**

- Resource requirements are software-specific.
- Does not provide a distribution between hot and cold starts and other data sources are required to estimate this distribution.
- Limited capability to handle time of day variations due to TDM configuration.
- Requires more computations to implement link-level start distributions relative to Method 3, i.e. potentially, a separate series of emission factor model runs are needed for each unique set of start and stabilized distributions.

**Method 3 – Treat Start Emissions Explicitly as Instantaneous Emissions Occurring at Trip Start**

In this method, all vehicle travel on TDM highway network links are assumed to be operating in the hot stabilized mode. The incremental increase in emissions due to vehicle starts are estimated separately and are spatially allocated at the beginning of trips in TDMs. This method takes advantage of TDM capabilities to estimate the number of trip starts at their beginning location rather than allocating start emissions as part of travel on the links. This method requires separate estimates of start emission factors from stabilized emission factors. This capability to estimate 100 percent start emissions is available in the California ARB EMFAC model. Guidance for the configuration of the MOBILE model runs to derive 100 percent start emissions is provided in *Procedures for the Emission Inventory Preparation, Volume IV: Mobile Sources*, Section 3.3.5.3.

**ADVANTAGES**

- Estimates start emissions directly from TDM outputs (it does not apply regional start distributions to local trip generation at the traffic analysis zone (TAZ) where trips begin and end in TDMs).
- Provides improved spatial allocation over Method 1.
- Accuracy of spatial allocation is similar to Method 2.

- Computational requirements are lower than Method 2.
- Application is not software specific.

**DISADVANTAGES**

- Computational requirements are higher than Method 1.
- Does not provide a distribution between hot and cold starts and other data sources are required to estimate this distribution.
- Limited capability to handle time of day variations due to TDM configuration.

**RECOMMENDATIONS**

Each of the methods presented above can be implemented by MPOs and State DOTs in order to identify cold, hot, and hot stabilized weighting factors. The implementation of a given method will be dependent on the availability of TDMs, travel survey data, and applicable TDM software (i.e., EMME/2, MINUPT, et al). For example, Method 1 can be implemented by most state and local agencies using currently available TDM systems and default parameters specified in the Federal Test Procedures. The implementation of Method 2 is dependent on the TDM software currently used by an MPO or State DOT. At this point in time, MINUTP is the only TDM software package that has developed specific modules designed to trace cold start trips within the TDM trip assignment. Therefore, for those MPOs and State DOTs using other TDM software such as EMME/2 and TRANPLAN, this method cannot be immediately applied. Method 3 can be implemented more cost effectively than the previous method and provides more robust results compared to the previous two methods.

## 3.6 TRIP DURATION

This section presents an outline for using travel survey data to estimate trip duration associated with trip chaining behavior for air quality analysis. This analysis will use similar techniques described for Method 1: Distribution of Travel Time/Travel Distance to Estimate Start and Stabilized Operation to estimate factors for splitting TDM generated vehicle trip tables into "hot start" and "cold start" tables. These split factor tables will be used to estimate the proportion of vehicle operating modes associated within the individual household trip chains. These proportions can be used to identify refined trip duration profiles for use in MOBILE to improve running loss estimates. Development of the proposed method will be based on household travel survey data, which are commonly collected in many metropolitan areas and states for

use in developing TDMs.
Metropolitan Planning Organizations and State DOTs have typically conducted household travel surveys to provide information for estimating TDMs. Nearly all major metropolitan areas throughout the country have conducted at least one such survey in the past decade. In these surveys, activity or travel diary information is collected, which provides details on all trips made by household members over a recent period, usually for a specified travel day (covering 24-hours). Many household travel surveys are conducted to gather information on specific vehicle usage, as well as person travel. In others, information on vehicle use can be implied, at least for the purpose of estimating the proportion of trips made within a short period of time following a previous trip.

## METHOD

The method described in this section can be implemented using household travel survey data. Additional testing and analysis of this method should consider a variety of other survey types. For example, the travel characteristics of metropolitan areas differ considerably depending on the availability and use of transit, transportation system configuration, and land use/socioeconomic patterns. In addition, household travel surveys can be collected using different approaches including trip versus activity-based and telephone interview versus mail-out/mail-back.

For use within the method described below, the household travel survey dataset should contain the following information:

- Trip diary data collected from all licensed drivers within a surveyed household over at least a 24-hour period;
- Departure and arrival times for all trips made by household members; and
- Trip purposes for at least home based work, home based non-work, and non-home based (definitions may vary among survey types).

Once the survey dataset meets the criteria described above, the following procedures should be used to implement the proposed method:

- **Step 1 – Build and Process Household Survey Datasets.** The user should identify the statistical software package, such as SPSS or SAS, that will be used to create the base datasets containing the household travel survey information to be analyzed. The statistical software selected for preparing, processing, and analyzing the travel survey datasets will be dependent on the needs and knowledge of the user. Each of the subsequent steps

outlined in this method consider the use of statistical software to perform the analytical steps.

- **Step 2 – Categorize Survey Trips.** The user should categorize all of the vehicle (i.e., driver) trips contained in the dataset for each trip purpose using the following criteria:

  - **Category 1.** Trips starting within the "hot start period" following another trip made with the same vehicle;

  - **Category 2.** Trips not starting within the "hot start period" following another trip made with the same vehicle; and

  - **Category 3.** First trip of the day using the vehicle.

- **Step 3 – Develop Survey Proportions by Area and Household Types.** The user should examine the survey dataset to determine how the proportion of trips falling into each category varies by area (CBD, rural) and household characteristics (auto ownership) specified for the metropolitan area.

- **Step 4 – Refine Trips by Category.** For the first household trip of the day (Category 3), the user should determine whether this trips could possibly fall into Category 1. For example, most trips are typically made within the "hot start period" since the start of the travel day. In addition, Category 1 trips are typically made since the last trip at the end of the previous travel day. Since previous trip making information is not typically available, the end of the actual travel day could be used as a proxy. For survey datasets without vehicle usage data, the user should examine the feasibility of estimating or inferring these variables. Many trips will clearly be categorized outside of Category 2, even without specific vehicle usage information. This will include trips not beginning within the "hot start period." In addition, many other trips will be easily categorized, including trips by single car households, most non-home based trips, and trips made when all other vehicles are clearly not available. Since these account for the vast majority of trips, it may be reasonable to place the few remaining trips into Category 2.

- **Step 5 – Create Trip Factors in the Dataset.** Within the survey sample, the user should create the factors used to split TDM generated vehicle trip tables by trip purpose into the three categories. These split factor tables can be used to estimate the proportion of vehicle operating modes associated within the individual household members trip chain.

- **Step 6 – Apply Factors in the TDM.** The user should apply the factors created for the sample dataset across the vehicle trip tables by trip purpose within the TDM in order to determine the impacts of trip duration and operating mode associated with typical trip chaining behavior. The factors would be applied to the trip tables by trip purpose generated through the TDM process.

The TDM outputs (trip tables) generated using this method will identify the impacts of trip chaining and vehicle operating modes on the duration of trips. Traditionally, TDM vehicle trip tables are segmented by trip purpose. For example, trip segments from home to work or home to shop that are represented in the TDM do not take into account trip chaining behavior associated with each trip. Linking these trip segments together using household travel survey data will provide better estimates of trip length distributions and duration. These resulting trip tables can be run with the trip assignment step of the TDM process to identify potential impacts and to compare results with previous trip tables related to VMT, VHT, and VHD.

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# 4

# USE OF LOCAL DATA FOR VMT PROJECTIONS

This section presents guidance for gathering and using local data to develop forecasts of vehicle miles of travel (VMT) for use in emissions modeling. Various methods have been traditionally used by MPOs and State DOTs to estimate future VMT forecasts including the following analytical tools:

- Socioeconomic Forecasts and Economic Growth Factors;
- Traffic Growth Trends; and
- Travel Demand Models (TDMs).

The sections below present summaries of the current practice in forecasting VMT and outlines of applicable methods and procedures for developing VMT forecasts using socioeconomic and economic growth factors, traffic trends, TDMs, HPMS data, and combinations of these analytical tools. Recommended methods are also presented for those MPOs and State DOTs with and without TDMs.

## 4.1 CURRENT VMT FORECASTING PRACTICE

Socioeconomic forecasts of population, employment, income, and other variables are used by many State DOTs to project VMT on federal and state designated roadways. These forecasts of socioeconomic activity are typically used with observed baseline traffic count data (i.e., traffic data collected at permanent count locations) to generate future estimates of VMT. Traditionally, socioeconomic forecasts have been generated in-house by many State DOTs. In some cases, statewide socioeconomic forecasts also can be obtained for a nominal fee from private firms such as the National Planning Association Data Services, Inc. (NPA). The NPA develops socioeconomic forecasts of employment, population, income, and other variables for 50 states at the statewide and countywide levels.

State DOTs and MPOs without TDMs have also used the Economic Growth Analysis System (E-GAS) to develop VMT forecasts for emissions inventories. The primary purpose of E-GAS is to provide emissions growth factors for non-attainment areas. Detailed descriptions of the E-GAS model is presented in Section 4.2.

Travel demand models use either land use or socioeconomic data as the initial input in the traditional four-step modeling process of trip generation, trip distribution, mode choice, and trip assignment. For future year analyses, forecasts of land use or socioeconomic forecasts are used to generate the travel demand expected in the future. In many cases, socioeconomic forecasts may be derived through a process of inter-jurisdictional negotiation and sometimes represents an over estimation of potential future growth in a given metropolitan area or state.

Travel demand models are typically used to generate systemwide future VMT estimates based on the roadways that represent the region's highway network. These TDM highway networks, however, do not typically consider all roadways. For example, many urban local, collector, and minor arterial roadways are not represented in an urban TDM highway network. Highway Performance Monitoring System (HPMS) outputs on the other hand report VMT for many of the rural and urban roadways (i.e., local roadways) not reported in TDMs. Because of these inconsistencies in reporting, MPOs traditionally have developed factors to match TDM future forecasted VMT output with HPMS future VMT output. State DOTs face similar reporting inconsistencies with TDM and HPMS VMT outputs. For example, State DOTs code less detail into their statewide TDM highway networks than is contained in a MPO urban-area network because of the inter-state (versus inter-regional emphasis of MPO TDMs) nature of statewide TDMs.

Most TDMs developed by MPOs also consider only passenger travel. Therefore, developing forecasts of passenger vehicle VMT is relatively straight forward. On the other hand, a small number of MPOs have developed truck or commercial vehicle models based on observed data (i.e., commercial fleet travel surveys). Several other MPOs have developed truck or commercial vehicle models based on commercial vehicle factors obtained from other areas or collected locally. These truck factors have been used to adjust TDM passenger vehicle outputs to generate truck or commercial vehicle VMT. For example, in 1992, the Maricopa Association of Governments (MAG) developed a regional truck model using current truck travel survey data and traditional four-step travel modeling procedures (e.g., trip generation, trip distribution, and trip assignment). The truck demand relationships developed in Phoenix in 1992 were used and formatted for the TDM update project for the Pima Association of Governments (PAG) in 1993/1994.

Several State DOTs currently are developing new freight and passenger TDMs. In some cases, such as in Oregon, the emphasis will be on freight demand modeling versus passenger demand modeling. Unfortunately, only a handful of states have fully implemented statewide freight models. Currently, MPO and State DOT TDMs generate fairly accurate forecasts of future VMT for passenger vehicles whereas most of these agencies do not forecast the same level of accuracy for truck or commercial activity.

HPMS datasets contain current and future forecast (e.g., 20 year horizon) estimates of Average Annual Daily Traffic (AADT). Individual State DOTs are responsible for developing the future forecasts of AADT for each sample segment contained in this dataset. FHWA may also evaluate the forecasts developed by State DOTs using simple reasonableness checks and suggest revisions to the forecasts.

The methods used to develop forecasts contained in the HPMS datasets consider projections of past traffic trends observed on the roadway functional class system maintained and operated by the state. This method tends to over estimate future estimates of VMT because of the inherent bias of trendline data. For example, future estimates will likely be dependent on variables that have not (and will not) affect past trends of VMT such as socioeconomic growth, increased interstate through travel (e.g., vehicles with origins and destinations outside of the particular geographic area of study), and future roadway congestion. In addition, HPMS VMT estimates for a congested urban region are expected to be much higher than similar estimates for a rural region with limited traffic congestion. State DOTs have used a general method to adjust for this bias by developing regional factors to dampen potentially high forecasts of future VMT.

## METHODS

The purpose of this section is to provide local agencies with guidance in using available analytical methods to more accurately forecast future VMT. The following methods consider applying several analytical models, datasets, and procedures in order to generate locality-specific future VMT forecasts for metropolitan areas and states with and without TDMs. Typically, those areas without TDMs should rely upon socioeconomic and traffic trend growth factors while areas with TDMs should focus on using TDMs. Metropolitan Planning Organizations and State DOTs should also consider consistency issues related to TDM and HPMS dataset outputs when developing future VMT forecasts.

In many cases, combinations of socioeconomic, traffic trends, TDMs, and HPMS datasets can be effectively used by MPOs and State DOTs to predict future VMT. These analytical tools are sometimes used in combination in order to identify urban and rural activity within a given metropolitan area. For example, HPMS datasets contain future forecasts of VMT for lower-level (e.g., local roadways) and rural area roadways while TDMs are used to forecast VMT for urban area and higher-level roadway functional classes such as freeways, highways, and arterials. These tools in combination can be used by MPOs or State DOTs to predict future VMT for all roadway functional classes.

State-of-the-practice methods are presented in the following subsections for MPOs and State DOTs with and without TDMs.

## 4.2 VMT FORECASTING FOR AREAS WITHOUT TRAVEL DEMAND MODELS

Several non-TDM analytical procedures are available for MPOs and State DOTs to develop base year and future forecasts of VMT. These techniques tend to focus on developing VMT forecasts by using socioeconomic growth factors, traffic trends, and economic trends. In some cases, using combinations of these techniques can be used to generate VMT forecasts. The methods presented below can be used by MPOs and State DOTs to project VMT without the use of TDMs AND ALSO can be used to validate or check VMT forecasts generated by TDMs.

### METHOD 1. SOCIOECONOMIC FORECASTS WITH OBSERVED BASE YEAR TRAFFIC DATA

Base year and future year forecasts of socioeconomic activity are generated by the majority of MPOs and State agencies (in some cases DOTs). These forecasts are generated to predict a number of variables from travel demand to population and employment activity at the statewide and regional levels. At the statewide level, these forecasts tend to contain statewide and regional (by county) estimates of population growth, employment growth by various sector (i.e., retail, construction, farming), and income growth. If unavailable, statewide socioeconomic forecasts can also be obtained from private vendors.

Metropolitan Planning Organizations tend to develop future forecasts of socioeconomic activity for the same reasons specified above for State DOTs. Historically, these data are generated for smaller geographic units than the statewide forecasts in order to perform more disaggregate and detailed urban transportation and air quality planning. For example, socioeconomic forecasts developed at the MPO level tend to be disaggregated by Census Tract and Block.

Socioeconomic forecasts can be used in conjunction with observed base year average annual daily traffic (AADT) estimates to generate future estimates of VMT by roadway functional class. The general steps required to implement this method include:

- **Step 1. Identify Base Year AADT.** The user should identify the base year AADT to be used in order to generate future VMT. This AADT should be disaggregated by roadway functional class (i.e., interstate, principal arterial) and area type (i.e., urban, suburban, rural). Depending on the State DOT, the user may be able to draw upon several in-house datasets to identify estimates of base year traffic activity. The HPMS dataset should be the first choice of the user in identifying base year VMT

because it contains estimates of traffic data by functional classification for the entire statewide roadway system. Historically, State DOTs collect traffic count data at selected roadway locations throughout the state in order to represent daily traffic conditions on a variety of roadway functional classes. These data are typically built directly into HPMS datasets. The user could also use data obtained directly from the automated permanent traffic count location datasets. These data are collected in order to monitor traffic congestion and traffic activity at bridge, tunnel, county and state line areas. Permanent traffic count locations tend to be collected and monitored on a daily basis. Depending on the State DOT, traffic count data are also collected at key locations every two or three years and may also be collected for specific corridor, regional, and subarea transportation planning studies.

- **Step 2. Identify Base Year Socioeconomic Estimates.** The user should identify the appropriate analysis year for the base line socioeconomic estimates. Base year estimates should be based on observed data such as the 1990 Census. This will ensure that baseline socioeconomic estimates are grounded with observed socioeconomic characteristics and do not represent a short-term forecast. For example, a given MPO or State DOT could forecast socioeconomic activity for five year increments over a twenty year period from 1990 to 2015. In this case, the base year socioeconomic estimate for 1990 is based on the latest Census data. Therefore, for subsequent analysis in 1995, the agency should either maintain 1990 as its base year estimate of socioeconomic activity or estimate new base year activity based on primary survey data collected to represent 1995 socioeconomic conditions. It should not use the 1995 incremental forecast to represent base year conditions.

- **Step 3. Identify Future Year Socioeconomic Forecasts.** The user should obtain future year socioeconomic forecasts from the appropriate agency or private vendor. These forecasts must be accepted by local agencies and jurisdictions. Most MPOs develop locally supported socioeconomic forecasts that consider the approval of local jurisdictions. For example, local jurisdictions (i.e., cities, towns, and counties) that make up a particular MPO geographic area help the MPO identify locality-specific base and future year employment and population estimates. This typically involves a formal process in which socioeconomic estimates are approved and finalized with local and regional input. If socioeconomic forecasts are obtained (i.e., purchased) from a vendor, then the particular agency should develop a mechanism designed to review, update, and finalize the forecasts prior to use.

- **Step 4. Develop Socioeconomic Growth Factors.** The user should develop socioeconomic growth factors based on the estimates obtained for the base and future years in Steps 2 and 3. The growth factors should be developed at the disaggregate level to represent the geographic units of interest. For example, growth rates could be developed by individual county if the scale of analysis is statewide or by State DOT District designations. Growth rates could be developed at the Census Tract or Census Block level to represent a metropolitan area. Optimally, growth factors should be annualized and developed for five year increments in order to identify short, medium, and long term socioeconomic activity.

- **Step 5. Develop Future VMT Forecasts.** The user should apply the disaggregate socioeconomic growth factors developed in Step 4 with the base year AADT to forecast future VMT. Growth factors should be applied to predict VMT by roadway functional class and area type by each of the 5-year increments specified by the analyst.

- **Step 6.** Verify and Adjust Future VMT Forecasts. The user should verify the future VMT forecasts developed in Step 5 in order to confirm the reasonableness of the results. Several sources of information can be used to perform this task including:

  - The monthly "Traffic Volume Trends" prepared by U.S. DOT and FHWA. This publication compares VMT growth trends from year-to-year for various locations throughout the United States. The user can use previous monthly publications of this document in order to identify VMT growth trends reported for their given area and to identify reasonableness checks for future VMT estimates.

  - The recent report titled "Commuting in America II" prepared by Alan Pisarski of the ENO Transportation Foundation, Inc. This article represents the second national report on commuting patterns and trends in the U.S. It identifies the past trends of, and in some cases, identifies the future forecasts of various population, employment, and travel statistics at the national, state, and metropolitan area levels. The user can use the statistics contained in this report to help verify future VMT forecasts. Examples of information provided in this publication include travel and economic variables that have contributed to recent increases (i.e., "booms") of worker, private vehicle, suburban commuting, and emerging trends.

- In work performed by the U.S. Department of Transportation's Volpe National Transportation Systems Center in support of the "Car Talk" analysis of greenhouse gases, Schimek and Pickrell examined factors contributing to VMT growth between 1950 and 1990, and how they changed over this four decade period. These factors included consideration of the population 16 years and older, the percent of licensed drivers, labor force participation, demographics, suburbanization, vehicle ownership per licensed driver, annual VMT per vehicle, fuel price, and fuel economy. Estimates of future year VMT growth, extending to the year 2030, were based on projected changes in these underlying factors. These factors of future VMT growth are generally lower than the historical rate of VMT growth because many of the individual factors that have contributed to this historical growth are projected to slow during coming decades.

- The relationship of density-VMT also can be explored as a means to check the reasonableness of VMT forecasts generated by alternative forecasting methods (refer to Section 4.4).

The user can also compare newly generated VMT with previous VMT forecasts. This procedure provides the user with another, locally based, validation check. Based on the validation results, the user should adjust the initial VMT forecasts with one or more of the sources mentioned above.

### ADVANTAGES

- Applicable at the state and metropolitan area levels.
- Does not require a TDM.

### DISADVANTAGES

- May not provide the same level of accuracy as TDM generated VMT forecasts.
- May underestimate future VMT.

## METHOD 2. SOCIOECONOMIC FORECASTS COMBINED WITH TRAFFIC TRENDS

This method is very similar to Method 2 described in the previous section. While

Method 2 uses socioeconomic forecasts with base year traffic data to generate future VMT forecasts, this method uses traffic trend data along with socioeconomic forecasts to generate future forecasts of VMT. The application of traffic trends in conjunction with socioeconomic forecasts provides the user with more reliable estimates of future VMT than otherwise generated through the use of only socioeconomic growth factors. The general steps required to implement this method are provided below.

- **Step 1 – Identify Base Year AADT.** The user should identify the base year AADT to be used in order to generate future VMT. The user should follow the same procedures outlined in Step 1 for Method 2.

- **Step 2 – Develop Traffic Trend Profiles.** The user should develop profiles of traffic trend data that may be maintained and made available by state and local agencies. If available, the user should identify traffic counts for selected roadway functional class locations and for selected past years throughout the metropolitan area or state. For example, State DOTs tend to collect traffic count data at permanent roadway locations throughout the statewide highway system. These count locations typically remain the same from year-to-year in order to provide states with consistent traffic count data for use in evaluating traffic congestion and other related transportation issues. If possible, it is recommended that the user develop past traffic trend profiles for samples of roadway functional classes (i.e., interstates, principal arterials, minor arterials) by five year increments going back at least twenty years using available traffic data. If this level of traffic data is not available, it is recommended that the user develop traffic trend profiles using as many consistent data points (past years) as possible.

- **Step 3. Analyze Traffic Trend Profiles.** The user should analyze the traffic trends developed in Step 2 to identify past trends by roadway functional class for short, medium, and long term periods. This Step should be performed in order to evaluate and identify the fluctuations of traffic trends for various time periods that can be attributed to past economic and socioeconomic phenomena such as the energy crisis of the early and late 1970's and the changing work force mix over the past twenty years. Once evaluated, the user will have a better understanding of the socioeconomic and economic characteristics that impact overall VMT.

- **Step 4. Identify Base Year Socioeconomic Estimates.** The user should identify the appropriate analysis year for the base line socioeconomic estimates. The user should follow the same procedures outlined in Step 2 for Method 2.

- **Step 5. Identify Future Year Socioeconomic Forecasts.** The user should obtain future year socioeconomic forecasts from the appropriate agency or private vendor. The user should follow the same procedures outlined in Step 3 for Method 2.

- **Step 6. Develop Socioeconomic Growth Factors.** The user should develop socioeconomic growth factors based on the traffic trends developed and analyzed in Steps 2 and 3 and the base and future socioeconomic analysis years established in Steps 4 and 5. As part of this Step, the user should also evaluate the socioeconomic variables that closely reflect or represent past traffic trends. For example, employment growth, rather than population growth or a combination of population and employment growth, may be used as the basis for developing growth factors. In this case, employment growth may display a stronger historical relationship to traffic growth for a given area than other socioeconomic indicators. In specific situations, population, employment and population, or other socioeconomic variable (auto ownership, income level) growth may reflect the appropriate relationship with past traffic trends. As with Method 2, the growth factors should be developed at the disaggregate level to represent the geographic units of interest. Optimally, growth factors should be annualized and developed for five year increments in order to identify potential short, medium, and long term growth.

- **Step 7. Develop Future VMT Forecasts.** The user should apply the socioeconomic growth factors developed in Step 6 with the base year AADT identified in Step 1 to forecast future VMT. Growth factors should be applied to predict VMT by roadway functional class and area type for short (5-year), medium (10-year), and long (20-year) term increments.

- **Step 8. Verify and Adjust Future VMT Forecasts.** The user should verify the future VMT forecasts developed in Step 7 in order to confirm the reasonableness of the results. The user should follow the same procedures outlined in Step 6 for Method 2.

## ADVANTAGES

- Applicable at the state and metropolitan area levels.

- Does not require a TDM.

### DISADVANTAGES

- May not provide the same level of accuracy as TDM generated VMT forecasts.

### METHOD 3: ECONOMIC GROWTH ANALYSIS SYSTEM (E-GAS)

The Economic Growth Analysis System (E-GAS) has been used to develop VMT forecasts for emissions inventories in urban areas without TDMs. The primary purpose of E-GAS is to provide emissions growth factors for non-attainment areas. The E-GAS model and software was developed by the TRC Environmental Corporation for the EPA.

Several options for projecting highway mobile source activity were considered for E-GAS. These include relatively simple trend-based approaches as well as more sophisticated models comprised of detailed national level projections based on econometric methods. The method used in E-GAS to develop VMT growth factors considers the following two phases:

- Phase 1. In the first phase, linear regression of HPMS VMT data from 1985 through 1990 is used to project VMT for each year through 1996. This analysis was based on the "Historical Area-Wide VMT Method" in EPA's guidance which calls for an ordinary least squares linear regression extrapolation of the area's 1985-1990 HPMS reports for Federal Aid Urbanized Areas (FAUA). Since this method relies on a fairly limited historical data set, the EPA guidance restricts its usage to short-term projections. Thus, a second phase of E-GAS VMT growth factors was developed for beyond 1996.

- Phase 2. The second phase is based on overall national VMT growth as projected by the EPA MOBILE Highway Fuel Consumption Model. This national growth estimate is allocated to individual E-GAS geographic areas using the relative population growth predicted by that particular urban area's Regional Economic Model Incorporated (REMI) generated population projection. The national EPA VMT projections are based on longer-term VMT trends and thus are not affected by short-term fluctuations in VMT. Since this trend is essentially linear, only the overall growth rate to 2015 is used in E-GAS.

For many urban areas, the forecasts from the first and second E-GAS projection phases are reasonably consistent. Inconsistent forecasts are generally due to the influences of short-term economic fluctuations affecting the underlying HPMS data used to construct

the Phase 1 growth factors. However, the authors of the E-GAS Manual emphasize that the user should consider using more reliable and accurate HPMS or locality-specific datasets rather than the E-GAS approach. Furthermore, EPA suggests the use of TDMs when available in urban areas, as cited in EPA's *Section 187 Forecasting and Tracking Guidance*, as the preferable approach to predicting truck and passenger vehicle VMT.

#### ADVANTAGES

- Applicable at the state and metropolitan area levels.
- Does not require a TDM.

#### DISADVANTAGES

- May not provide the same level of accuracy as TDM generated VMT forecasts.
- Relies exclusively on EPA's national forecast of VMT growth.
- May underestimate future VMT.

## 4.3 VMT FORECASTING FOR AREAS WITH TRAVEL DEMAND MODELS

Various TDM analytical procedures are available for MPOs and State DOTs to develop base year and future forecasts of VMT. The majority of these techniques focus on predicting future forecasts of passenger or automobile VMT. Historically, MPOs and State DOTs have forecasted future commercial or truck VMT using commercial vehicle factors that are generated from observed vehicle classification data and applied to TDM generated outputs for passenger vehicles. The methods presented in this section consider techniques to disaggregate total estimated VMT by passenger and commercial vehicles. The methods also consider techniques to reconcile the potential differences between TDM and HPMS dataset generated VMT outputs.

### METHOD 4. DEVELOP TDM-GENERATED PASSENGER VEHICLE VMT FORECASTS

This method uses the TDM process as the basis to generate future forecasts of passenger vehicle VMT. This process is straight forward for MPOs and State DOTs with current TDM systems. Users should consider using the appropriate method shown in the previous cases of MPOs and State DOTs with TDMs currently under

development or planned for development in the short term.

Transportation modelers at MPO and State DOT agencies should conduct the following TDM evaluation analysis in order to ensure that future VMT forecasts generated from the TDM process are as representative of future conditions as possible and that local jurisdictions fully understand and accept the agencies modeling practice.

- **Document TDM Development.** Fully document TDM data, assumptions, models, calibration, and validation procedures used to estimate base year models. Documentation plans have been traditionally developed at the MPO and State DOT levels in order to provide local jurisdictions and TDM users with an understanding of the underlying data and assumptions used to develop the base year models. This step should be expanded to include short courses sponsored by MPOs and State DOTs about the TDM development and application process to area agencies that must use and rely on TDM outputs for local transportation planning efforts.

- **Local Review of Socioeconomic/Land Use Forecasts.** Metropolitan Planning Organizations and State DOTs typically develop the socioeconomic or land use forecasts used in the TDM process to generate future forecasts of travel. In some cases, the agencies responsible for modeling in a given metropolitan area or state develop a first draft of socioeconomic/land use forecasts for local jurisdictions to review, comment, and revise as necessary. This review process should be associated with the development of regional and state TDM systems in order to obtain local acceptance and approval of the data used to drive the future travel forecasts. It is recommended that standing technical advisory committees be formed to conduct this review process in order to develop locally accepted socioeconomic forecasts.

Metropolitan Planning Organizations and State DOTs, upon local jurisdiction approval of the TDM process and socioeconomic or land use forecasts, will increase the level of local understanding and acceptance of the TDM outputs generated for their particular region. It is recommended that MPOs and State DOTs cross-reference the non-TDM methods for use in checking or confirming the reliability of the TDM-based forecast. The direct result of these processes will be increased accuracy of base and future forecasts of VMT and other regional travel characteristics.

As discussed in Section 3.1 of this report, optional procedures were presented in order to generate consistent passenger vehicle future VMT from TDMs and HPMS datasets. This reconciliation of TDM and HPMS dataset future forecasts of VMT should also be implemented as part of this method. These procedures are required to generate

consistent VMT estimates from TDMs for roadway functional classes within HPMS for use in developing regional emissions inventories. Typical inconsistencies of VMT estimates include:

- Facility types coded within TDM highway networks that do not directly match the functional class system within HPMS; and

- In most metropolitan areas, travel demand modelers have developed conversion factors in order to match TDM estimates of VMT with HPMS. The development of these factors varies by metropolitan area depending on the facility types coded within the TDM highway network and the level of inconsistency between TDM facility types and HPMS functional classes.

The optional methods presented briefly below are described in detail in Section 3.1.

- **Option #1. Code HPMS Identifier in TDM Highway Network.** Roadways within TDM highway networks are represented by a series of link attributes typically consisting of anode and bnode designations, distances, speeds, capacities, and facility types. In most TDM software, additional fields are provided to incorporate user-specified attributes such as number of lanes, planning areas (i.e., neighborhoods, towns/cities), area types (i.e., rural, suburban, urban, CBD), and traffic screenline locations. This method involves incorporating HPMS identifier codes as an attribute for each link within the TDM highway network to improve the development of TDM to HPMS conversion factors. This coding scheme will provide the user with a mechanism to automate the conversion of TDM highway network VMT by coded facility types to match HPMS VMT. However, because TDM highway networks typically do not contain local roadway facility types, the unique conversion factors for local roadways (developed by the MPO) should be maintained.

- **Option #2: Match Highway Network Facility Types with HPMS Functional Classifications.** This method is very similar to the above method with the exception that the facility types coded within the TDM highway network link attribute file will be consistent with the functional classifications coded within HPMS. Therefore, the development of conversion factors will not be required because of this direct cross referencing system.

- **Option #3: Post Processor for Air Quality (PPAQ).** This optional method for VMT reconciliation is not presented in Section 3.1. This system automates the application of HPMS to TDM conversion factors

that have historically been developed by MPOs and State DOTs. The Post Processor for Air Quality (PPAQ) software (developed by Garmen Associates) contains a module that applies VMT adjustment factors to the hourly link volumes generated by TDMs. These adjustment factors are based on the link records contained in the HPMS dataset. The TDM output volumes are adjusted to account for a variety of factors including daily/seasonal variations, TDM and HPMS VMT reconciliation, and impacts of congestion mitigation strategies. VMT adjustment factors are computed outside of PPAQ and input into the system using a series of adjustment files. The adjustment factors can be expressed as arithmetic functions (addition or subtraction, multiplication) that can be applied to the transportation network roadway coding scheme. Coding schemes can be developed using a combination of variables including area type, facility type, or time of day VMT outputs. The factors are typically applied either before speed calculations, so that they will affect the speed estimate, or afterward, so that speeds are unaffected.

The advantages and disadvantages of Method 4 are presented below.

**ADVANTAGES**

- Applicable at the state and metropolitan area levels.
- Provides consistency between HPMS and TDM VMT outputs.
- VMT forecasts based on accepted and approved TDM processes.

**DISADVANTAGES**

- Approval process requires extensive agency time and resources.

The following methods present options to generate truck or commercial vehicle future VMT using passenger vehicle-based TDMs and commercial vehicle factors. Historically, passenger and commercial VMT has grown at different rates. In order to identify this difference, it is recommended that different procedures be used to forecast VMT for passenger and commercial vehicles. Historically, MPOs and State DOTs have focused on developing TDMs that consider average weekday passenger travel conditions. Typically, truck or commercial models are estimated as a separate submodel of the overall urban area TDM system. The level of truck model sophistication tends to vary by urban area. For example, a small number of larger MPOs have developed a series of robust and unique truck trip generation, trip distribution, and trip assignment models based on observed local commercial vehicle travel data collected through the implementation of user travel surveys.

Some MPOs have developed truck or commercial vehicle models based on commercial vehicle factors obtained from other areas or have developed factors from observed traffic count data (e.g., truck-to- total traffic count factors). These truck factors are typically used to adjust TDM passenger vehicle outputs to generate truck or commercial vehicle VMT. The methods presented below consider using urban truck demand models, and in the case of urban areas without truck models, alternatives to traditional truck factoring routines, in order to generate future truck VMT.

### METHOD 5: DEVELOP TRUCK DEMAND MODELS

Generating future truck VMT is straight forward for those MPOs and State DOTs which have developed regional truck or freight travel demand models. These modeling systems typically contain elements of the traditional four-step modeling process including trip generation, trip distribution, and trip assignment that represent relevant local area truck or commercial vehicle activity. Many larger MPOs have developed truck models including the Maricopa Association of Governments (MAG), the Denver Regional Council of Governments (DRCOG), the Chicago Area Transportation Study (CATS), and the Houston-Galveston Area Council (HGAC). Several State DOTs are in the process of developing statewide travel modeling systems that include truck or freight travel demand models. These states include Michigan, Oregon, and Maine.

Vehicle miles of travel and other travel statistics are output from the TDM process during the trip assignment step. These statistics can be generated per the specifications of the modeler/analyst to meet the transportation and air quality planning needs of the urban area or state. For example, future truck VMT can be output by vehicle class which typically represent different trip purposes within the truck travel modeling system. Heavy, medium, and light duty trucks could represent trip purposes 1, 2, and 3 respectively within the modeling system. Truck VMT activity can also be reported at the roadway functional class level to identify freeway, principal arterial, minor arterial, and collector roadway truck VMT.

### ADVANTAGES

- Applicable at the state and metropolitan area levels.
- Can be developed as part of several TDM packages including EMME/2, MICROTRIPS, MINUTP, TMODEL2, and TRANPLAN.
- This method is based on observed data collected through the implementation of user travel surveys.

### DISADVANTAGES

- Time and budgetary resources required to develop truck models can be significant.
- Not currently available for the majority of urban areas and states.
- May not be necessary for many urban areas.

### METHOD 6: USE QUICK RESPONSE FREIGHT MANUAL

Chapter 7 of the *Quick Response Freight Manual* prepared for the Federal Highway Administration by Cambridge Systematics in September 1996 presents various procedures for adjusting passenger vehicle travel demand model outputs to conform to external estimates of regional truck VMT, including HPMS estimates of VMT. The recommended procedure for calibrating/replicating observed truck VMT estimates considers comparing estimated truck model VMT generated from the trip assignment step to an external VMT control total.

Tables 4-1 through 4-4 show the proportions of truck VMT to total VMT by functional and vehicle class for five Metropolitan Statistical Areas (MSAs) throughout the United States. This information is contained in the *Quick Response Freight Manual.* These tables are based on HPMS data and reported truck VMT as a percentage of total VMT. Metropolitan Planning Organizations and State DOTs typically prepare estimates of total VMT for both current and future years. These agencies also calculate VMT control totals by functional and vehicle class by multiplying the total area VMT by the appropriate percentage reported in these tables.

The *Quick Response Freight Manual* recommends the following optional procedures for MPOs and State DOTs to calibrate current and generate future truck VMT:

- **Trip Generation Option.** Adjust the passenger vehicle TDM trip generation rates to represent truck trip activity. These adjustments should be applied to represent the difference between observed locality-specific control truck VMT and estimated truck VMT (i.e., divide the control VMT by the estimated VMT and multiply the ratio to the trip generation rates). The resulting truck trip generation should then be run through trip distribution and assigned to the highway network. Estimated VMT will be output from the trip assignment step. The analyst should then compare this estimated VMT to the control VMT total. If the closing criterion is met, no additional iterations in the trip generation step would be

necessary. However, if the closing criterion is not satisfied, this process would be repeated until convergence is achieved.

- **Trip Distribution Option.** The potential coarse definition of the traffic analysis zones (TDM network representation of geographic areas) coded within the transportation network may prove to be a greater source of error in the interzonal distance matrix generated in the trip distribution modeling step than in the trip generation rate definition modeling step . If this is the case, the ratio of control truck VMT over the estimated truck VMT would be used to adjust the origin-to-destination distance matrix in the trip distribution modeling step. Once completed, the adjusted distance matrix would be multiplied to the trip table to produce total VMT. Under this option only one iteration would be necessary to implement since the adjustments will result in complete convergence of the estimated VMT to the control VMT.

## TABLE 4-1

## 4 TIRE COMMERCIAL VEHICLE VMT AS A PERCENTAGE OF TOTAL VMT

| | Highway Functional Class | | | | | |
|---|---|---|---|---|---|---|
| MSA Population | Interstate | Other Freeway | Other Principal Arterial | Minor Arterial | Collector | Total |
| 0 - 100,000 | 4.8 | 5.4 | 6.4 | 6.1 | 6.7 | 6.0 |
| 100,000 - 250,000 | 4.8 | 4.5 | 5.3 | 5.3 | 5.1 | 5.1 |
| 250,000 - 500,000 | 4.6 | 4.4 | 5.3 | 5.3 | 4.8 | 5.0 |
| 500,000 - 1,000,000 | 4.6 | 4.3 | 5.2 | 5.3 | 4.8 | 4.9 |
| over 1,000,000 | 4.3 | 4.4 | 5.3 | 4.9 | 5.3 | 4.8 |
| Total | 4.4 | 4.4 | 5.3 | 5.1 | 5.1 | 4.9 |

Source: Quick Response Freight Manual.

## TABLE 4-2

## 6 TIRE, SINGLE UNIT COMMERCIAL VEHICLE VMT AS A PERCENTAGE OF TOTAL VMT

| | Highway Functional Class | | | | | |
|---|---|---|---|---|---|---|
| MSA Population | Interstate | Other Freeway | Other Principal Arterial | Minor Arterial | Collector | Total |
| 0 - 100,000 | 1.9 | 1.7 | 1.7 | 1.5 | 1.7 | 1.7 |
| 100,000 - 250,000 | 1.8 | 1.7 | 1.8 | 1.8 | 1.9 | 1.8 |
| 250,000 - 500,000 | 1.9 | 1.7 | 1.7 | 1.7 | 1.6 | 1.7 |
| 500,000 - 1,000,000 | 2.0 | 1.6 | 1.8 | 1.7 | 1.8 | 1.8 |
| over 1,000,000 | 1.8 | 1.7 | 1.7 | 1.7 | 1.9 | 1.7 |
| Total | 1.8 | 1.7 | 1.7 | 1.7 | 1.8 | 1.7 |

Source: Quick Response Freight Manual.

## TABLE 4-3

## 6 TIRE COMBINATION COMMERCIAL VEHICLE VMT AS A PERCENTAGE OF TOTAL VMT

| | Highway Functional Class | | | | | |
|---|---|---|---|---|---|---|
| MSA Population Class | Interstate | Other Freeway | Other Principal Arterial | Minor Arterial | Collector | Total |
| 0 - 100,000 | 7.6 | 2.5 | 2.3 | 1.5 | 1.5 | 2.8 |
| 100,000 - 250,000 | 5.7 | 2.7 | 3.1 | 2.1 | 2.0 | 3.1 |
| 250,000 - 500,000 | 7.2 | 2.8 | 2.8 | 1.9 | 1.6 | 3.3 |
| 500,000 - 1,000,000 | 6.5 | 3.0 | 2.8 | 2.0 | 1.7 | 3.4 |
| over 1,000,000 | 5.3 | 3.0 | 2.8 | 1.8 | 2.0 | 3.3 |
| Total | 5.7 | 2.9 | 2.8 | 1.9 | 1.9 | 3.3 |

Source: Quick Response Freight Manual.

## TABLE 4-4

## PASSENGER VEHICLE VMT AS A PERCENTAGE OF TOTAL VMT

| | Highway Functional Class | | | | | |
|---|---|---|---|---|---|---|
| MSA Population Class | Interstate | Other Freeway | Other Principal Arterial | Minor Arterial | Collector | Total |
| 0 - 100,000 | 85.7 | 90.4 | 89.6 | 90.8 | 90.1 | 89.5 |
| 100,000 - 250,000 | 87.6 | 91.1 | 89.8 | 90.8 | 91.0 | 90.0 |
| 250,000 - 500,000 | 86.2 | 91.2 | 90.3 | 91.1 | 92.0 | 90.0 |
| 500,000 - 1,000,000 | 86.9 | 91.0 | 90.2 | 91.0 | 91.7 | 89.8 |
| over 1,000,000 | 88.6 | 90.9 | 90.2 | 91.6 | 90.8 | 90.2 |
| Total | 88.1 | 91.0 | 90.1 | 91.4 | 91.1 | 90.1 |

Source: Quick Response Freight Manual.

### ADVANTAGES

- Applicable at the state and metropolitan area levels.
- Can be used with several TDM packages including EMME/2, MICROTRIPS, MINUTP, TMODEL2, and TRANPLAN.
- Does not require a truck TDM.
- Does not require a passenger vehicle TDM.

### DISADVANTAGES

- Not as accurate as truck TDM generated VMT forecasts.

### METHOD 7: DEVELOP TRUCK TDM FACTORS

Metropolitan Planning Organizations and State DOTs without full truck demand models have developed models based on truck factors. These factors are typically based on observed traffic count data collected locally or by transferring truck model to passenger model relationships from similar urban areas.

Data-based factors consider truck to total vehicle ratios collected locally by selected roadway functional class and by relevant truck vehicle types. Once developed, these ratios are applied to the MPO's passenger vehicle VMT outputs generated through the trip assignment step of the TDM process. This process generates truck VMT outputs by functional class and vehicle type. This approach is attractive to MPOs because the VMT outputs consider the travel demand relationships (i.e., trip generation, trip distribution, and trip assignment) produced by the local TDM modeling process.

Truck demand model-transfer based factors are developed by MPOs to consider truck demand model relationships generated in similar urban areas. For example, the Tucson, Arizona metropolitan area transferred the truck demand relationships estimated for the Phoenix, Arizona metropolitan area. The Maricopa Association of Governments (MAG) developed a full truck demand model for the Phoenix metropolitan area. The Pima Association of Governments (PAG) used the demand relationships estimated for Phoenix in conjunction with local truck count data to develop to generate locality-specific truck demand models. This approach is attractive to MPOs because the VMT outputs are TDM driven and also consider local data.

Optional truck TDM factor development procedures are presented below:

- **Data-Based Option.** Historically, this procedure has been used by MPOs to develop future truck VMT estimates if full truck demand models are not available. It is very similar to the procedures shown for Method 6: Quick Response Freight Manual in that factors are used to adjust passenger vehicle TDM outputs. Method 6 considers adjusting the trip generation or trip distribution steps of the TDM process while this procedure considers adjusting the trip assignment step to generate estimates of future VMT by functional class and vehicle type based on observed local data. The steps required to implement this procedure include:

  - Use the TDM process to generate passenger vehicle VMT estimates for the entire modeling area (i.e., systemwide).

  - Use the TDM highway network to disaggregate the systemwide VMT generated above by functional class. Reporting VMT estimates by functional class is straight forward and will vary by the transportation modeling software (i.e., MINUTP, TRANPLAN, EMME/2) used.

  - Develop cross reference tables consisting of observed count volumes by truck vehicle type and total vehicle volumes by roadway functional class. Roadway functional classes should be consistent with those coded into the TDM highway network.

  - Develop truck volume by vehicle class to total vehicle ratios for each of the functional classes reported in the TDM highway network.

  - Apply the ratios to the passenger vehicle VMT generated by the TDM process for the system and each of the roadway functional classes identified above.

The resulting estimates will represent systemwide and functional class truck VMT for a particular urban area.

- **Truck TDM Transfer-Based Option.** Smaller, and even some larger MPOs, have historically transferred modeling components from other urban areas in order to improve their TDM process. Mode choice models tend to be transferred more often than other modeling components. This

is the case because of the budgetary and data collection resources typically required to estimate locality-specific mode choice models. Other modeling components have also been transferred including auto ownership, trip distribution, and truck demand models. In all cases, the modeling components transferred from another urban area are adjusted to reflect local conditions:

- By incorporating locally collected travel data including transit on-board and traffic count data; and

- By adjusting locality-specific modeling components including the estimated mode choice model coefficients and trip distribution travel time distributions and friction factors.

Transferring truck demand models from urban areas with similar commercial vehicle travel characteristics is a viable option to generating future truck VMT without a full truck demand model. The general procedures to be followed include:

- Conduct a literature search to identify the urban area and MPO TDM system that contain similar commercial vehicle characteristics and activity. Emphasis should be placed on identifying vehicle activity pertaining to inter- and intra-regional truck movements, public and private truck fleets based in the region, typical vehicle classes modeled, and truck demand model components developed.
- Contact the MPO representative of the urban area selected to discuss the protocol for obtaining the truck demand modeling system components, documentation, and programs. This may require purchasing components of the modeling system.

- Once the modeling system has been obtained, design a modeling plan to incorporate the new truck demand modeling components into the local urban area TDM system. This design plan will require developing truck demand modeling adjustment features to include locality-specific observed truck data and locality-specific trip generation, trip distribution, and trip assignment TDM features. For example, local truck data could be used to adjust truck trip generation rates used in the initial urban area. These rates will reflect the truck generation characteristics of the local urban area.

- Implement the truck model design plan and incorporate the truck demand modeling components into the urban area TDM system.

The resulting VMT estimates will represent local characteristics of truck demand and activity for a particular urban area. The end result will be a truck demand model that will be fully incorporated with the local TDM system.

### ADVANTAGES

- Applicable at the state and metropolitan area levels.
- Can be developed as part of several TDM packages including EMME/2, MICROTRIPS, MINUTP, TMODEL2, and TRANPLAN.
- These methods are based on local observed truck data.

### DISADVANTAGES

- Time and budgetary resources required to develop truck model components can be large.
- May not be necessary for many urban areas.
- Not as sophisticated as full truck travel demand models.

## 4.4 OVERVIEW OF DENSITY - VMT RELATIONSHIPS

Considerable recent attention has been devoted to the relationship between VMT and the population density of an urban area. Since the density of an urban area is likely to change as that area increases in population, this relationship should be taken into consideration when developing future year VMT projections.

**Theory.** The negative relationship between population density and VMT is logical for two reasons. First, at lower densities, origins and destinations are more geographically dispersed, requiring people to travel a longer distance to reach a given activity. (All else equal, average trip length should be inversely proportional to the square root of population density, i.e., a doubling in density of population and activities would be expected to decrease the average trip length by a factor of 1.4.) Second, at higher densities the viability of transit and non-motorized transport increases, while at the same time automobile travel becomes less attractive due to congestion. Increasing density, therefore, would be expected to decrease both the length and frequency of automobile trips.

**Empirical Evidence of Density-VMT Relationships.** Studies relating VMT to population density generally show some sort of inverse relationship. Newman and Kenworthy, in a

well-known international comparison of cities, show a strong inverse relationship between urban density and gasoline use per capita, even after adjusting for income, vehicle efficiency, and gasoline prices. Holtzclaw compares neighborhoods in the San Francisco Bay Area and finds that a doubling in population density produces an approximately 25 to 30 percent reduction in VMT. Dunphy and Fisher compare daily VMT per capita (based on self-reported data from the 1990 National Personal Transportation Survey) with density at the zip code level. They find that VMT declines from just over 20 miles per day at low densities to around 15 miles per day at roughly 10,000 persons per square mile (ppsm), then drops off steadily to roughly 2.5 miles per day at 60,000 ppsm. (Note that an exponential curve fits these data fairly well, implying that the elasticity of VMT with respect to density increases as density increases.) These studies and others have also looked at the relationship between density and mode choice. Here there is considerable evidence of a "threshold" range of densities on the order of 7,500 to 15,000 ppsm, below which the automobile is dominant, and above which congestion effects become substantial and transit service becomes competitive. Newman and Kenworthy note that metropolitan areas with densities less than 20-40 persons per hectare (roughly 5,000 to 10,000 ppsm) are primarily automobile-oriented; above this range, auto ownership drops substantially and transit usage increases. Dunphy and Fisher, in their analysis of NPTS data, note that automobile trip generation rates remain relatively constant below 5,000 ppsm and decline thereafter; transit and non-motorized trips per capita begin to increase above 5,000 ppsm and exceed auto trips per capita at 30,000 ppsm. Colman confirms this result, also using NPTS data, observing that vehicle trip-rates show little decrease below 9,000 ppsm and do not decrease significantly until at least 15,000 ppsm. This holds true even when controlling for household size and income levels. Levinson and Kumar cite a density range of 7,500 to 10,000 ppsm above which transit usage becomes substantial and a relatively attractive alternative to driving.

**Confounding Factors.** Studies which relate travel variables only to density, however, have received criticism for ignoring other factors--often correlated with density--which affect VMT and mode choice. Some of these factors include:

- **Income, household size, and other socioeconomic characteristics.** Dunphy and Fisher note that there are significant differences in personal and household characteristics which are related to density levels; lower income households, for example, tend to live in inner-city neighborhoods with higher population densities. Colman (1996) notes that accounting for income differences somewhat reduces, but does not eliminate, the relationship between density and trip generation. However, Holtzclaw (1990) and Kockelman (1995), both analyzing San Francisco Bay Area data, argue that the effect of density on VMT or mode choice considerably outweighs the effect of income.

- **Transit service quality.** Transit service levels are strongly associated with population density, and the relative effects of each on VMT are not completely separable. Holtzclaw finds that transit accessibility is an important variable in addition to density in describing automobile use. Nevertheless, there is general agreement that increasing transit service has relatively little effect over a range of low population densities.

- **The scale at which density is measured.** Measuring density at the metropolitan area level may obscure the effect of smaller-scale urban form variables on trip-making and VMT. Dunphy and Fisher conclude that metropolitan residential density explains only 15 percent of the variation in per capita VMT for metropolitan areas with populations greater than one million. New York and Los Angeles, for example, have similar urbanized area densities but New York has higher transit use and lower VMT per capita, due to concentration of much of its population at transit-friendly densities in New York City. Using small-scale measures such as census tracts or zip codes is not a perfect solution, however, as they do not fully describe regional transit and automobile accessibility. High-density development around transit stations, for example, has been shown to capture a significant number of transit trips (Cervero); a similar development without transit accessibility would be expected to generate proportionally more automobile trips.

- **The effects of relative accessibility on VMT.** Levinson and Kumar note that local density acts as a proxy for distance from the center of the metropolitan region. To the extent that these variables are correlated, the effects of local residential density on VMT may be overstated. On the other hand, the greater variety of opportunities in a large metropolitan area may cause more VMT independent of other factors. To the extent that metropolitan area densities are correlated with total population, this effect may cause analysis at the metropolitan-area level to understate the effect of density on VMT. The relative contribution of this factor, however, has not been thoroughly investigated.

- **The effects of other urban form variables.** Land use mix and urban design factors have also been suggested to cause variations in vehicle-travel; specifically, mixed-use pedestrian-friendly areas may require shorter and fewer automobile trips than developments of similar density where uses are separated. Kockelman incorporates measures of local land-use mixing and balance and finds a negative relationship to both VMT and automobile mode choice. Frank, in an analysis of data from the Seattle metropolitan area, finds that density and mix are both related to mode

choice, and that urban form at both trip ends is important. Recent interest in "neo-traditional" neighborhood design has also led to investigation of the effects of the road network design on VMT; Kulash finds that a grid network substantially reduces VMT within a community compared to a standard hierarchical suburban street network.

- **Conclusions.** Overall, evidence of a general relationship between density and VMT is strong. The specific nature of the relationship is less clear, but it appears that transit use becomes substantial and VMT drops significantly at densities above 7,500 to 15,000 persons per square mile. The debate over the relative roles of density and other urban form and transportation service factors for which density may proxy, however, has not been fully resolved. It is recommended that density be used to check the reasonableness of VMT forecasts that have developed by some other means including the socioeconomic/traffic trend and TDM-based methods presented in Section 4.3.

## 4.5 RECOMMENDATIONS

The methods described in this section consider several options to forecast future year VMT for passenger vehicles and trucks. These methods consider the availability and use of socioeconomic and economic forecasts, traffic trends, TDMs, HPMS datasets, and other techniques. The requirements necessary to apply and implement the techniques presented vary greatly in terms of time and budgetary resource requirements, local applicability, and availability of passenger vehicle TDMs.

For those metropolitan areas and states without TDMs, using a combination of socioeconomic forecasts with traffic trends is recommended for implementation. Method 2 provides the user with a mechanism to dampen socioeconomic growth estimates with applicable traffic trends. This method generates VMT forecasts that can be verified using available sources of information.

The following procedures are recommended for generating future year VMT estimates for MPOs with available passenger vehicle TDMs:

- **Passenger Vehicle VMT.** Passenger vehicle VMT forecasts should be developed using TDM systems. The user should also reconcile VMT outputs generated from the TDM process with VMT estimates contained in the HPMS dataset.

- **Truck VMT.** Metropolitan Planning Organizations should use Method 5:

Develop Truck Demand Models if available to generate truck VMT estimates. This procedure will ensure highway network consistency with the passenger vehicle VMT forecasts. If full truck demand models are not available, Method 7: Develop Truck TDM Factors is recommended for implementation. The development of either option (i.e., Data-Based or Truck TDM Transfer-Based Options) presented under Method 7 could be used equally to generate truck VMT estimates and will ensure consistency with the passenger vehicle VMT outputs generated by the local TDM.

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# 5

# REFERENCES


Bachman, W., Sarasua, W. and Guensler, R. *A GIS Framework for Mobile Source Emissions Modeling.* Georgia Institute of Technology. Atlanta, Georgia.

Cambridge Systematics, Inc., COMSIS Corporation, and University of Wisconsin-Milwaukee. 1996. *Quick Response Freight Manual.* Federal Highway Administration, Office of Planning and Environment Technical Support Services For Planning Research.

Cervero, Robert. *Ridership Impacts of Transit-Focused Development in California.* National Transit Access Center, University of California at Berkeley, 1993. Colman, Steve (1996). *Does Residential Density Reduce Trip Generation?* In WesternITE (Institute of Transportation Engineers -- District 6 Newsletter), March-April 1996.

DeCorla-Souza, P., Everett, J. and Gardner, B. July 1994. *A Simplified and Rational Approach to Address New Modeling Requirements for Air Quality Analysis.* Preliminary Draft. Federal Highway Administration.

Dunphy, Robert T. and Kimberly Fisher (1994). *Transportation, Congestion, and Density: New Insights.* Presented at Transportation Research Board Conference, Jan. 1994.

Environ Corporation and Sonoma Technology, Inc., 1996. *Methodology for Gathering Locality-Specific Emission Inventory Data.* EPA, Office of Mobile Sources.

EPA. 1991. *User's Guide to MOBILE4.1 (Mobile Source Emission Factor Model).* U.S. Environmental Protection Agency, Office of Air and Radiation, Office of Mobile Sources, Emission Control Technology Division, Test and Evaluation Branch, EPA-AA-TEB-91-01. Ann Arbor, Michigan.

EPA. 1992. *Procedures for Emission Inventory Preparation. Volume IV: Mobile Sources.* U.S. Environmental Protection Agency, Office of Air and Radiation, Office of Mobile Sources and Office of Air Quality Planning and Standards, Emission Planning and Strategies Division and Technical Support Division, EPA-450/4-81-026d (Revised). Ann Arbor, Michigan and Research Triangle Park, North Carolina.

EPA. 1992. *Section 187 VMT Forecasting and Tracking Guidance.* United States Environmental Protection Agency.

FHWA. 1994. *Workshop on Transportation Air Quality Analysis. Participant's Notebook.* U.S. Department of Transportation, Federal Highway Administration, National Highway Institute, FHWA-HI-94-011. NHI Course No. 15265. Washington D.C.

FHWA. 1995. *Estimating the Impacts of Urban Transportation Alternatives. Participant's Notebook.* U.S. Department of Transportation, Federal Highway Administration, National Highway Institute, FHWA-HI-94-053. NHI Course No. 15257. Washington D.C.

Frank, Lawrence D. *The Impacts of Mixed Use and Density on the Utilization of Three Modes of Travel: The Single Occupant Vehicle, Transit, and Walking.* Presented at Transportation Research Board Conference, Jan. 1994.
Garmen Associates. 1994. *PPAQ Post-Processor for Air Quality Analysis. Program Documentation, Version 3.1.* Montville, New Jersey.

Garmen Associates. 1994. *The PPAQ System. Post-Processor for Air Quality Analysis. Getting Started, Version 3.1.* Montville, New Jersey.

Garmen Associates. April 21, 1995. *Application of PPAQ to Calculating Congestion Management System Performance Measures.*

Garmen Associates. April 21, 1995. *Specification for Incident Calculations in the PPAQ1 Program.*

Garmen Associates. April 21, 1995. *Specification for Person-Travel Calculations in the PPAQ1 Program.*

Guensler, R., Washington, S. and Sperling, D. 1993. *A Weighted Disaggregate Approach to Modeling Speed Correction Factors.* Institute of Transportation Studies. Davis, California.

Holtzclaw, John (1990). *Explaining Urban Density and Transit Impacts on Auto Use.* Natural Resources Defense Council and Sierra Club.

Holtzclaw, John (1994). *Using Residential Patterns and Transit to Decrease Auto Dependence and Costs.* Natural Resources Defense Council.

JHK and Associates and COMSIS Corporation. 1994. *IVHS Benefits Assessment Model Framework. Course Manual* U.S. Department of Transportation, Research and Special Programs, John A Volpe National Transportation Systems Center.

Kishan, S., DeFries, T.H. and Weyn, C.G. 1993. *A Study of Light-Duty Vehicle Driving Behavior: Application to Real-World Emission Inventories.* Radian Corporation. Submitted to Society of Automotive Engineers for presentation at International Fuels and Lubricants Meeting and Exposition. Philadelphia, Pennsylvania.

Kockelman, Kara M. (1995). *Which Matters More in Mode Choice: Density or Income?* Unpublished Manuscript.

Kockelman, Kara M. (1996). *Travel Behavior as a Function of Accessibility, Land Use Mixing, and Land Use Balance: Evidence from the San Francisco Bay Area.* Master's Thesis, Department of City and Regional Planning, University of California - Berkeley.

Kulash, Walter. *Traditional Neighborhood Development: Will the Traffic Work?* Real Estate Research Corporation, 1990.

Levinson, David M., and Ajay Kumar (1995). *City Size, Residential Density, and the Journey to Work.* Unpublished Manuscript.

Miller, T., Chatterjee, A., Everett, J., and McIlvaine, C. *Estimation of Travel Related Inputs to Air Quality Models.* University of Tennessee. Knoxville, Tennessee.

Newman, P.W.G. and J.R. Kenworthy (1989). *Cities and Automobile Dependence: An International Sourcebook.*

Ruiter, Earl. 1991. *Highway Vehicle Speed Estimation Procedures for Use in Emission Inventories.* Work Assignment No. 7. Cambridge Systematics, Inc. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards.

Science Applications International Corporation and Cambridge Systematics Incorporated. 1994. *Roadway Usage Patterns: Urban Case Studies.* Final Report. Volpe National Transportation Systems Center and Federal Highway Administration.

Science Applications International Corporation, Cambridge Systematics, Inc., Nichols Consulting Engineers, Chtd., and University of Tennessee. 1993. *Speed Determination Models for the Highway Performance Monitoring System.* Final Report. Federal Highway Administration.

Skarpness, B.O. and Heidtman, K. 1996. *Improved Vehicle Occupancy Data Collection Procedures.* Battelle. Presented to Federal Highway Administration, Offices of Highway Information Management, and Environment Planning.

University of Tennessee, Vanasse Hangen Brustlin, Inc., Science Applications International Corporation, Louisiana State University, and University of North Carolina at Charlotte. 1995. *NCHRP 25-7. Improving Transportation Data for Mobile Source Emission Estimates.* National Cooperative Highway Research Program.

Walker, W.T. and Peng, H. 1994. *Alternate Methods to Iterate a Regional Travel Simulation Model: Computational Practicality and Accuracy.* Delaware Valley Regional Planning Commission. Philadelphia, Pennsylvania.



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**15. SUPPLEMENTARY NOTES**

**16. ABSTRACT**

The Emission Inventory Improvement Program (EIIP) was established in 1993 to promote the development and use of standard procedures for collecting, calculating, storing, reporting, and sharing air emissions data. The EIIP is designed to promote the development of emission inventories that have targeted quality objectives, are cost-effective, and contain reliable and accessible data for end users. To this end, the EIIP is developing inventory guidance and materials which will be available to states and local agencies, the regulated community, the public and the EPA.

Volume IV presents preferred and alternative methods for estimating emissions from mobile sources.

**17. KEY WORDS AND DOCUMENT ANALYSIS**

| a. DESCRIPTORS | b. IDENTIFIERS/OPEN ENDED TERMS | c. COSATI FIELD/GROUP |
|---|---|---|
| Air Emisisons<br>Air Pollution<br>Emission Inventory<br>Inventory Guidance | Air Pollution Control<br>Emission Inventory<br>Guidance | |
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