VOLUME IV: CHAPTER 2

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

September, 1996

Final Report

Prepared by:

Cambridge Systematics, Inc.
Eastern Research Group
Radian Corporation

Prepared for:

Mobile Sources Committee
Emission Inventory Improvement Program

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

September, 1996

Final Report

Prepared by:

Stephen Decker
John Suhrbier
Krista Rhoades
Herb Weinblat

Cambridge Systematics, Inc.
1300 Clay Street, Suite 1010
Oakland, CA 94612

Garry Brooks

Eastern Research Group
1600 Perimeter Park Drive
Morrisville, NC 27560

Edmund Dickson

Radian Corporation
10389 Old Placerville Rd.
Sacramento, CA 95827

Prepared for:

Greg Janssen
U.S. Environmental Protection Agency
Office of Mobile Sources
2565 Plymouth Road
Ann Arbor, MI 48105

This page is intentionally left blank.

CONTENTS

Section **Page**

LIST OF TABLES

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.

This page is intentionally left blank.

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 1.36% LDDV
Other 2-Axle, 4-Tire Vehicles	65.71% LDGT1 33.47% LDGT2 0.82% LDDT
Buses	10.28% HDGV 89.72% HDDV
Single Unit Trucks (1)	
2-Axle, 6-Tire	87.90% HDGV 12.10% HDDV
3-Axle	50.00% HDGV 50.00% HDDV

TABLE 2-1
(CONTINUED)

HPMS Category	MOBILE5A Category
4 or More Axle	50.00% HDGV 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.

Diesel Percentage= (2-1)

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

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

(2-2)

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

(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.

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

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

- **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.

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

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

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

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

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.

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

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

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

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

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

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

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

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

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	Pass-enger Cars	Mot-orcy-cles	Per-sonal Pas-sen-ger Vehi-cles	Buses	All Pas-sen-ger Vehi-cles	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 Mot-or Vehi-cles	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	Pass-enger Cars	Mot-orcy-cles	Per-sonal Pas-sen-ger Vehi-cles	Buses	All Pas-sen-ger Vehi-cles	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 Mot-or Vehi-cles	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)

State	Passenger Vehicles					Single-Unit Trucks					Single-Trailer Combination			Multi-Trailer			All Trucks	All Motor Vehicles	AVMT
	Pass-enger Cars	Mot-orcy-cles	Per-sonal Pas-sen-ger Vehi-cles	Buses	All Pas-sen-ger Vehi-cles	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			
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.

This page is intentionally left blank.

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.

- **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:

$$C_E = \frac{1462}{1150} \times C_C = 1.27 \times C_C \tag{3-1}$$

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):

$$V_P = \frac{V_P}{NL \times PHF} = \frac{1.15 \times V_A}{NL}$$

(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:

$$V/C = \frac{V_P}{C_E} = \frac{0.906 \times V_A}{NL \times C_C}$$

(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
0.6	0.243

V/C	SRF
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}):

$$S_P = S_{FF} - SRF \times (S_{FF} - 25) \qquad (3\text{-}4)$$

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:

(3-5)

- Volume per peak 15 minutes per lane:

$$C_L = \frac{89}{1000} \text{ x } C_C = 0.889 \text{ x } C_C$$

$$V_P = \frac{1.05 \text{ x } V_A}{NL}$$

(3-6)

- Volume/capacity ratio:

$$V/C = \frac{1.181 \text{ x } V_A}{NL \text{ x } C_C}$$

(3-7)

- Average stopped delay in seconds per vehicle per intersection (based on HCM Equations 9-18 and 11-2):

$$D_S = \frac{6.0}{1 - 0.55 \text{ x } V/C} + 225 \text{ x } V/C^2 \text{ x} \left[(V/C - 1) + \sqrt{(V/C - 1)^2 + 16.89 \text{ x } V/C/C_C} \right]$$

(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):

$$S_P = \frac{L}{1.1 \text{ x } L / S_{FF} + D_S / 3600}$$

(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:

$$S_P = S_{P1} \times (0.555 + 0.444 \times V/C^{-3})$$

(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:

$$S_P = S_{P1.2} (0.663 + 0.583 \times V/C^{-3})$$

(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.

Cambridge Systematics, Inc., Analysis of Temporal Demand Shifts to Improve Highway Speed Modeling, prepared for the Arizona Department of Transportation, April 1988.

Since volume/capacity ratios greater than the limits discussed above are generally 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.

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 <u>future VMT output</u>. 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 selfreported 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.

This page is intentionally left blank.

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.