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Input Guidelines for Motor Vehicle Emissions Simulator Model, Volume 1: Practitioners' Handbook: Regional Level Inputs

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AUTHORS

Porter, Christopher; Kall, David; Beagan, Daniel; Margiotta, Richard; Koupal, John; Fincher, Scott; and Alan Stanard

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1.0 Introduction

MOVES, the Motor Vehicle Emissions Simulator Model, is the United States Environmental Protection Agency's (EPA) state-of-the-art tool for estimating emissions from highway vehicles. This handbook is a resource for MOVES users who wish to develop their own local input data for State Implementation Plan (SIP) development, regional conformity analysis, project-level analysis, or any other purpose. The handbook provides information on alternative sources of local input data and the advantages and disadvantages of each. The handbook also provides sample datasets that users may use as a template for developing their own local data, or in some cases to represent local conditions if local data are not available. Finally, the handbook describes tools available to assist MOVES users in processing data to prepare MOVES inputs. The handbook was written for MOVES 2010b but remains applicable to MOVES2014.

This handbook supplements other MOVES documentation, guidance, and tools provided by EPA, including:

- The MOVES user guide;[1]

- Guidance for use of the MOVES model in regional SIP and conformity analysis[2] greenhouse gas (GHG) analysis;[3] and particulate matter (PM) 2.5 and carbon monoxide (CO) hotspot analysis; and

- Data processing tools, such as MOBILE6 to MOVES data converters, already developed by EPA. These are available on EPA's web site.[4]

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[1] The most recent version at the time of preparation of this report was: U.S. Environmental Protection Agency (2012). *Motor Vehicle Emission Simulator (MOVES) User Guide for MOVES2010b*. EPA-420-B-12-001b. This document is referred to as "MOVES2010b User Guide" throughout this report. The User Guide for MOVES2014 was released in July 2014.

[2] The most recent version at the time of preparation of this report was: U.S. Environmental Protection Agency (2012). *Using MOVES to Prepare Emission Inventories in State Implementation Plans and Transportation Conformity: Technical Guidance for MOVES2010, 2010a and 2010b*. EPA-420-B-12-028. This document is referred to as "MOVES SIP and Conformity Guidance" throughout this report.

[3] The most recent version at the time of preparation of this report was: U.S. Environmental Protection Agency (2012). *Using MOVES for Estimating State and Local Inventories of On-Road Greenhouse Gas Emissions and Energy Consumption*. EPA-420-B-12-068. This document is referred to as "MOVES GHG Guidance" throughout this report.

[4] http://www.epa.gov/otaq/models/moves/.

The handbook does not supersede EPA guidance, and inclusion of a particular data source or method in this document does not imply EPA's endorsement. EPA, through the Metropolitan Planning Organization (MPO) or statewide interagency process, will need to approve any data or methods when MOVES is used for regulatory purposes, and MOVES practitioners should ensure they follow standard requirements for consulting with EPA and other agencies in such situations.

The handbook is presented in two volumes, addressing the use of MOVES at different domains/scales:

- **Volume 1** provides resource material on developing inputs for a "regional" (county, multicounty, or state) level of application, using the **County Domain/Scale** of MOVES. This is the scale that must be used when doing State Implementation Plan or regional conformity analysis. The model replaces national "default" allocations for each input with user-supplied data for each county and year to be analyzed.

- **Volume 2** provides resource material on developing inputs for a project level of analysis, using the **Project Domain/Scale** of MOVES. This scale allows the user to model the emission effects from a group of specific roadway links and/or a single off-network location.

The resource material is relevant to the use of MOVES for both inventory and emission rate development (calculation types). In a few cases, the choice of calculation type affects the input requirements. Differences in input requirements for inventory and emission rate calculations are noted.

The remaining sections of this volume of the handbook include:

- **Section 2.0 – Overview of MOVES Inputs.**

- **Section 3.0 – Sensitivity of Model Outputs to Inputs.** This section provides information on the relative impact of different inputs on outputs (emissions inventories or rates), to help the user in determining where to focus resources on developing and refining inputs.

- **Section 4.0 – Options for Developing Local Input Data.** This section provides detailed information in each MOVES input required for county/regional scale analysis, including alternative data sources, data processing methods, tools, and examples.

- **Section 5.0 – Examples.** This section provides examples illustrating the development of a complete set of MOVES inputs for regional-level application. Two examples are provided, one for an area with limited data availability, and one for an area for more extensive data availability.

- **Section 6.0** – References.

- **Section 7.0** – List of Acronyms.

2.0   Overview of MOVES Inputs

The MOVES inputs that may be provided for regional-level analysis are shown in Table 2.1.   Table 2.1 also summarizes EPA guidance on the use of local data versus "default" or embedded data in the model.

The MOVES user has two options for entering local data (User's Guide, p. 42):

- Entering and editing data directly via the **County Data Manager**; or

- Selecting **Manage Input Data Sets** to specify specialized user-supplied data to be read by the model during execution.

MOVES inputs in this handbook are grouped into three categories: 1) fleet inputs (characteristics of the vehicle fleet); 2) activity inputs (characteristics of vehicle activity); and 3) "other" inputs including meteorology, fuels, and emissions control programs.

Table 2.1 MOVES Regional-Level Inputs

Category	No.	MOVES Input	MOVES Input Name	Description	EPA Guidance
Fleet	1.	Age distribution by vehicle class	sourceTypeAgeDistribution	Fraction of vehicle population by age (years) for 13 source types	Recommends local (state) vehicle registration data as the primary source
	2.	Source (vehicle) type population	sourceTypeYear	Fraction of vehicle population by 13 source types	Recommends local (state) vehicle registration data and/or locally provided VMT data with national VMT:population ratios
Activity	3.	VMT by vehicle class	HPMSVTypeYear	Fraction of total VMT for 6 vehicle types	Local VMT estimates required for SIPs and regional conformity, based on travel demand model, HPMS, and/or other sources
	4.	Temporal adjustments	monthVMTFraction dayVMTFraction hourVMTFraction	Fraction of VMT occurring by month of year or 13 source types; by hour of day and weekday versus weekend for 5 road types and 13 source types	Recommends local data if available, but does not recommend a specific source
	5.	Road type distribution	roadTypeDistribution	Fraction of VMT occurring by 5 road types, for 13 source types	Requires local data for SIP/conformity analysis, based on travel demand model, HPMS, and/or other sources
	6.	Ramp fraction	roadType	Fraction of vehicle-hours of travel occurring on freeway ramps (restricted access roads)	Recommends local data if available
	7.	Average speed distribution	avgSpeedDistribution	Fraction of VMT by 16 speed bins, for 13 source types, 4 road types, 24 hours of day, and weekday versus weekend	Local data are expected for SIP and conformity analysis, preferably from postprocessing of travel demand model output
Other	8.	Weather – meteorology data	zoneMonthHour	Ambient temperature and relative humidity for each hour in the modeling scenario	For SIP and conformity analysis, recommends use of local data
	9.	Fuel formulation and supply	FuelFormulation FuelSupply	Various data describing local fuel supply	Recommends review of default data, and substitution of local data if more accurate or recent data are available
	10.	Inspection and maintenance programs	IMCoverage	Various data describing local I/M program characteristics	Begin with embedded data and revise as needed

3.0 Sensitivity of Model Outputs to Inputs

The sensitivity of MOVES outputs to inputs can be characterized as the percent change in a pollutant output corresponding to a change in the input value across a range of conditions representative of the real world. This section provides a summary of sensitivity analyses conducted on the various MOVES inputs. The findings are based on research performed by the Volpe National Transportation Systems Center and Federal Highway Administration (FHWA),[5] EPA staff,[6] and the Coordinating Research Council (CRC),[7] as well as additional sensitivity analysis performed for this study as described in the NCHRP Project 25-38 Final Report. In addition to overall sensitivity for each input parameter, in some cases, sensitivity was examined for providing different data for different source types (e.g., different speed distributions for trucks versus cars).

Table 3.1 provides a summary of MOVES inputs by sensitivity level. It takes the worst-case result for each MOVES input observed in the various studies and assigns it to one of four sensitivity ranges. This is done separately for volatile organic compounds (VOC), oxides of nitrogen (NO_x), and PM. In general temperature, vehicle-miles of travel (VMT), speed, age, and population have either substantial or very substantial sensitivity for all three pollutants. The data sources that are critical for these inputs include registration data for age and population inputs; classified traffic counts and travel demand models for VMT; and real-world and/or modeled speed data. Month and hour VMT fraction inputs (based on seasonal and hourly traffic data) have modest sensitivity for all pollutants. Ramp fraction, source type detail for road type distributions, and speeds have different sensitivity depending on the pollutant of concern.

Table 3.2 lists the various MOVES inputs along with a summary of the range (variation) in expected outputs under a typical range of input conditions tested in the various studies. Effects on five key pollutants, including VOC, CO, NO_x, PM, and carbon dioxide (CO_2), are presented.

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[5] Noel, G., and R. Wayson (2012). "MOVES2010a Regional Level Sensitivity Analysis." Volpe National Transportation Systems Center, prepared for Federal Highway Administration, DOT-VNTSC-FHWA-12-05.

[6] Choi, D., et al (undated). "MOVES Sensitivity Analysis: The Impacts of Temperature and Humidity on Emissions." U.S. Environmental Protection Agency.

[7] Eastern Research Group (2014). "Study of MOVES Inputs for the National Emissions Inventory." Prepared for Coordinating Research Council Project A-84.

All of these sensitivity analyses were conducted using some version of MOVES2010. There may be minor differences in some impacts if the same analyses were conducted using MOVES2014, due to differences in embedded data in MOVES2014. The overall conclusions about the sensitivity of the model to each input, however, should not change significantly.

Table 3.1   Summary of MOVES Inputs Falling in Different Sensitivity Ranges

Sensitivity Range	VOC	NOₓ	PM
Very Substantial (>50%)	Temperature, Speed, Age	Temperature, VMT, Speed	Temperature, VMT, Speed
Substantial (15-50%)	Population, VMT	Population, Age, Humidity	Population, Age, Ramp Fraction
Moderate (5-15%)	None	None	Source type detail for road type distance and speed
Modest (<5%)	Source type detail for road type distance and speed, Month VMT Fraction, Hour VMT Fraction, Ramp Fraction	Source type detail for road type distance and speed, Month VMT Fraction, Hour VMT Fraction, Ramp Fraction	Month VMT Fraction, Hour VMT Fraction, Humidity

Note: The worst-case sensitivity results are used for assigning inputs to the ranges in this table.

Table 3.2   Combined Sensitivity Analysis Results

MOVES Input	Source[a]	Base Case	Comparison Made	VOC	NO$_x$	PM
Fleet Inputs						
Age Distribution by Vehicle Class	Volpe/FHWA	2010 National Default Age Distribution	Move 10% of vehicles to Group 1 (0-10 years); Move 10% of vehicles to Group 2 (11-20 years); Move 5% of vehicles to Group 3 (21-30 years); completed for several vehicle types	PC: Substantial (-29% to +24%) CT: Moderate (-5% to +6%)	PC: Substantial (-20% to +16%) CT: Moderate (-9% to +9%)	PC: Substantial (-19% to +21%) CT: Moderate (-7% to +7%)
Age Distribution by Vehicle Class	ERG/CRC	Submittals for 2011 NEI	Increase average age from 10th to 90th percentile	Very Substantial (+55% HC)	Substantial (+40%)	Substantial (+45%)
Source (Vehicle) Type Population:						
Light versus Heavy-Duty Vehicles	CS/ERG	2010 National Default Source Type Distribution	Double HD vehicles and reduce LD vehicles correspondingly	Moderate (+7%)	Substantial (+36%)	Very substantial (+66%)
Passenger Cars versus Trucks			Shift 20% of passenger vehicles from cars (21) to trucks (31)	Modest (+2%)	Modest (+1%)	Modest (+1%)
Single-Unit versus Combination Trucks			Shift 25% of trucks from single unit to combination	Modest (+2%)	Moderate (+14%)	Substantial (+23%)
Short-Haul versus Long-Haul Trucks			Shift 25% of trucks from short-haul to long-haul	Modest (+2%)	Moderate (+8%)	Moderate (+10%)
Source (Vehicle) Type Population:	ERG/CRC	Submittals for 2011 NEI	Increase source type fraction of total population from 10th to 90th percentile	Substantial (+45% HC)	Moderate (+14%)	Moderate (+14%)
Regional Activity Inputs						
Regional VMT by vehicle class	ERG/CRC	Submittals for 2011 NEI	Increase HPMS type fraction of total VMT from 10th to 90th percentile	Substantial (+40% HC)	Very Substantial (+110%)	Very Substantial (+150%)
Temporal Adjustments:						
Month VMT Fractions	CS/ERG	Default Month Distribution	Change Month VMT Fractions to make summer (Jun-Aug) or winter (Dec-Feb) account for 5% more than MOVES defaults (27.4%). Decrease equal amount from all other months	Modest (<1%)	Modest (<1%)	Modest (<2%)
Hour VMT Fractions	CS/ERG	Default Hour Distribution	Change Hour VMT Fractions to show more overnight traffic (8 p.m.-7 a.m., 11% more on weekdays, 9% more on weekends)	Modest (<1%)	Modest (<1%)	Modest (<1%)

Table 3.2   Combined Sensitivity Analysis Results (continued)

MOVES Input	Source[a]	Base Case	Comparison Made	VOC	NOx	PM
Regional Activity Inputs (continued)						
Road Type Distribution	CS/ERG	MOVES National Embedded Distributions	Make the road type distribution the same for all source types	Modest (+2%)	Modest (+4%)	Moderate (+10%)
Ramp Fraction	Volpe/ FHWA	National Default (0.08)	0, 0.02, 0.04, 0.06, 0.10, 0.12 0.16, 0.20	Modest (-3% to +4%)	Modest (-2% to +3%)	PC: Substantial (-15% to +22%) CT: Modest (-3% to +5%)
Average Speed Distribution	Volpe/ FHWA	National Default Speed Distribution for Urban Interstate	LOS B, C, D, E, F	PC: Substantial (-14% to +33%) CT: Substantial (-29% to +49%)	PC: Moderate (-1% to +6%) CT: Substantial (-6% to +21%)	PC: Substantial (-6% to -16%) CT: Substantial (-20% to +53%)
Average Speed Distribution	CS/ERG		Reduce HD vehicle speed by 5 mph	Modest (+1%)	Modest (+2%)	Moderate (+6%)
Average Speed Distribution	ERG/CRC	Submittals for 2011 NEI	Decrease average speed from 90th to 10th percentile	Moderate (+8% HC)	Moderate (+10%)	Substantial (+16%)
Other Inputs						
Weather – Meteorology Data	Volpe/ FHWA	60º F	-40º, -20º, 0º, 20º, 40º, 60º, 80º, 100º, 120º F	Running: PC: Substantial above 60º F (up to 17%); no impact below. CT: No impact Starts: Substantial below 80º F; no impact above	Running: Substantial between 40 and 100º F (-20% to +32%); no impact outside that range Starts: Very Substantial at all temps below 80º F (>100%)	PC: Very substantial below 60º F (>100%); no impact above 80º F CT: Modest (<0.1%)
	Volpe/ FHWA	50% Relative Humidity	0%, 20%, 40%, 50%, 60%, 80%, 100% (Nox at 60º F and 80º F, all others at 80º F)	PC: Modest (-1% to +2%) CT: Modest (<1%)	Moderate (-12% to +15%)	Modest (<1%)

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Table 3.2   Combined Sensitivity Analysis Results (continued)

MOVES Input	Source	Base Case	Comparison Made	VOC	NOx	PM
Other Inputs (continued)						
	EPA	75º F	-40º F to 120º F in 10º increments; Calendar years 2005, 2015, and 2025	Very substantial or gasoline (~+50-70%), Substantial for diesel (~+10-30%) at 20º F	Moderate for gasoline (~+5-8%, Substantial for diesel (~+15-18%) at 20º F	Very substantial (~+400-600% at 20º F) for gasoline Modest (<1%) for diesel
	EPA	0% Relative Humidity	0-100% relative humidity in 10% increments for 6-12 different temperatures	Modest (up to ~+5%)	Substantial (up to ~-25%)	Modest (<1%)
Inspection/Maintenance (I/M) Programs	N/A					
Fuel Formulation and Supply	N/A					

ᵃ EPA Choi (undated); ERG/CRC = ERG (2014); Volpe/FHWA = Noel & Wayson (2012); CS/ERG = NCHRP Project 25-38 Final Report (2014)

Note 1:   Modest = <5%; Moderate = 5-15%; Substantial = 15-50%; Very Substantial = >50%.

Note 2:   Unless noted, Volpe/FHWA results are for running emissions for passenger cars (PC) and combination trucks (CT). CS/ERG results are for combined vehicle fleet and all processes. EPA results are for gasoline versus diesel for all source types.

4.0 Local Input Data

This section provides detailed information and examples of how local data can be developed for each MOVES input for regional-level analysis. The inputs and their respective section numbers are shown below:

1.   Age distribution by vehicle class;

2.   Source (vehicle) type population;

3.   VMT by vehicle class;

4.   Temporal adjustments;

5.   Road type distribution;

6.   Ramp fraction;

7.   Average speed distribution;

8.   Meteorology;

9.   Fuel formulation and supply; and

10. Inspection and maintenance programs.

For each input, the following information is provided:

- Description and format;

- EPA guidance and source of data embedded in MOVES;

- Overview of data source options;

- Data sources, procedures, and methods;

- Sample data and tools;

- Examples; and

- References.

Overview of Regional Scale Inputs

Table 4.0.1 contains a list of data tables populated through the County Data Manager (CDM) for county (regional) scale analysis. The inputs listed above are populated through a subset of these tables; the corresponding input section number is noted in Table 4.0.1 with the number in the fifth column. The MOVES CDM is an "importer" interface which provides templates for users to construct a county database for regional analysis via Microsoft Excel tables. The CDM allows the user to import one or more data tables to each of the tabs in the graphical user interface (GUI). For some of the tabs (as noted in the

fourth column of the table), the CDM provides the option of exporting embedded data for review and possible modification and then importing. These templates can therefore provide users with a starting point for entering local data.

EPA guidance provides different guidelines with respect to the use of local versus embedded data for each input. This handbook summarizes EPA guidance for each input, but is not a substitute for the actual guidance. EPA guidance should be consulted for more detailed information on the use of local versus embedded data.

Table 4.0.1   Regional Scale Analysis (County Data Manager) Inputs

Tab	Table Name	Table Content	Option to Export Embedded?	Sec. #
Fueltype and Technologies	avft	Diesel sales fractions	No	9
Average Speed Distribution	avgspeeddistribution	Average speed distributions	Yes	7
Vehicle Type VMT	dayvmtfraction	VMT distribution across the type of day	Yes	4
Fuel	fuelformulation	Fuel properties	Yes	9
Fuel	fuelsupply	Fuel market shares	Yes	9
Fuel	fuelsupplyyear	Same as year	Yes	9
Vehicle Type VMT	hourvmtfraction	VMT distribution by hour of the day	Yes	4
Vehicle Type VMT	hpmsvtypeyear	Total annual VMT by HPMS vehicle type	Yes	3
I/M Programs	imcoverage	I/M program parameters	Only w/ I/M Program	10
Vehicle Type VMT	monthvmtfraction	VMT distribution by month of the year	Yes	4
Road Type Distribution	roadtype	Description of the road types, ramp fraction	Yes	5, 6
Road Type Distribution	roadtypedistribution	VMT distribution across the road types	Yes	5
Age Distribution	sourcetypeagedistribution	Age distribution	Yes	1
Source Type Population	sourcetypeyear	Vehicle populations	Yes	2
Zone[a]	zone	Allocations of starts, extended idle and vehicle hours parked to the county	Yes	n/a
Meteorology Data	zonemonthhour	Meteorology input	Yes	8
Zone[a]	zoneroadtype	Allocation of road types to the county	Yes	N/A

[a] Custom Domain only.

■ 4.1 Age Distribution

4.1.1 Description and Format

4.1.1.1 Overview

Age distribution is characterized in MOVES as the fraction of total vehicle population with age = x, where x spans from 0 to 30 years old, and the sum of age distribution being one. Age distributions can be provided for each of the 13 source types. Age distribution is important because newer vehicles tend to have lower emissions than older vehicles, both because standards have become more stringent over time, and because of deterioration of older vehicles.

In MOVES, age distributions are stored within the database table sourceTypeAgeDistribution. The field ageFraction contains the age fraction data, keyed off sourceTypeID, aged and yearID, as shown in Table 4.1.1. Users can provide local data for the calendar year being modeled (yearID); if no data are provided, MOVES embedded data are used.

Table 4.1.1   Example of SourceTypeAgeDistribution Input

sourceTypeID	yearID	ageID	ageFraction
10	1999	0	0.112
10	1999	1	0.099
10	1999	2	0.095
10	1999	3	0.083
10	1999	4	0.063
10	1999	5	0.072
…	…	…	…

Age distributions can have a substantial impact on emissions. For example, Volpe/ FHWA (2012) tested sensitivity to moving 10 percent of vehicles among age groups (0-10 years, 11-20 years) and 5 percent into the oldest age group (21-30 years). Emissions varied by up to 30 percent from the base case for passenger cars, and up to 9 percent for combination trucks. Sensitivity tests conducted by local agencies also have found variations on the order of 10 percent or more from using local age distributions from different counties or years.

Age distributions can vary both across regions and at a subregional level depending upon economic and demographic factors (e.g., wealthier areas tend to have younger fleets). Age distributions also can change over time in response to economic cycles; people purchase more new vehicles in strong economic times and hang on to used vehicles longer when the economy is weak. In 2013, the average age of cars and light trucks reached an all-time high of 11.4 years, both due to the economic downturn that started in 2008, and increas-

ingly reliable vehicles which may be contributing to a long-term trend towards older vehicles (the average age has increased steadily over the past decade). Finally, age distributions can vary by region of the country due to local climate – in particular, south and west coast areas tend to have a higher number of older vehicles because they are not subject to the ravages of winter weather and road salt.

4.1.1.2 *Age Distribution versus Travel Fraction*

Age distribution is processed differently within MOVES depending on scale. At the national and county scales, age distribution is used to calculate travel fraction, which takes into account the mileage accrual rates for newer vehicles versus older vehicles. This is needed to properly apportion total activity in a region according to vehicle age, accounting for the fact that older vehicles travel less. Travel fraction for a specific age is calculated internally by MOVES based on both the fraction of the fleet and the mileage accumulation rate (MAR) for age = x. Because newer vehicles travel a higher share of overall VMT, the distribution of travel fraction tends to be younger than the age distribution. This is illustrated in Figure 4.1.1, based on default MOVES data for passenger cars. MOVES does not provide an option for user-input MAR because it is difficult to obtain reliable local data on MAR by source type. However, it is important to understand that the county-scale age distribution input represents the fraction of *vehicle population* by age – not the fraction of *vehicle travel* by age.

Figure 4.1.1 Cumulative MOVES Age Distribution and Travel Fraction
Passenger Cars
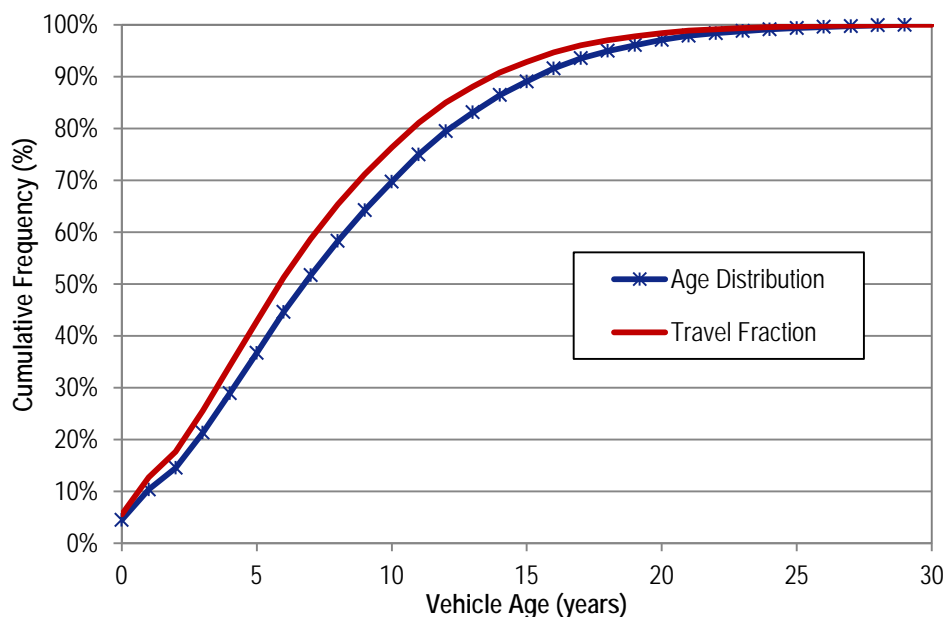
4.1.2 Source of Embedded Data and EPA Guidance

The relevant sections of the MOVES user guide, guidance documents, and data tables are:

- MOVES2010b User Guide: Section 2.3.3.4.3, Age Distribution Importer (p. 69);

- MOVES SIP and Conformity Guidance: Section 4.4, Age Distribution (p. 34);

- MOVES GHG Guidance: Section 4.5, Age Distribution (p. 48); and

- Data tables: sourceTypeAgeDistribution.

Embedded data in MOVES represent national average age distributions, and are compiled from several sources of national data based on source type. Embedded data in the MOVES database are populated for a single yearID. For national scale analysis, yearID serves as a "base" year, from which age distribution is grown dynamically year-to-year based on sales and scrappage inputs when output is requested for calendar years after the base year. The base year in MOVES2010 is 1999 but it is being updated to 2011 for MOVES2014. County and project-scale runs require the sourceTypeAgeDistribution table to be populated with the yearID equal to the year being modeled; EPA therefore provides embedded data for all years from 1999 through 2050, calculated by MOVES using the same dynamic registration methodology performed "on-the-fly" for national scale runs (see Sec. 4.1.4).

For MOVES2010, EPA generated base year age distributions by source type from multiple data sources, updating the data for MOVES2014. Sources of data used in MOVES2010 and MOVES2014 are shown in Table 4.1.2, with a description of each data source below:

- **Polk registration** databases, for light-duty vehicles and for heaver trucks are compiled annually from individual state registration records, providing the vehicle and model year populations necessary to create national age distributions inputs for MOVES. The dataset is generally considered the most comprehensive of its kind; a primary drawback is the high cost of obtaining the data.

- **The Vehicle Inventory and Use Survey (VIUS)** (formerly the Truck Inventory and Use Survey or TIUS) was a survey conducted by U.S. Department of Transportation (DOT) of several hundred thousand truck owners every five years. It represented a sample of the vehicle fleet rather than a comprehensive inventory such as registration data, but provided information not available in registration databases such as distance driven, trip purposes, etc. VIUS was discontinued after 2002, the latest year for which survey data are available.

- **The National Transit Database** (NTD) contains information on transit buses collected by the Federal Transit Administration (FTA) from public transit agencies. It includes the number of vehicles in each transit operator's fleet (by vehicle type) in five-year age groupings.

- **The School Bus Fleet Fact Book** is published by a school bus industry trade group to provide school bus fleet information by state and school district. The database is available online at SchoolBusFleet.com.

Table 4.1.2   Sources of Embedded Data

SourceType	MOVES2010 (1999 Base Year)	MOVES2014 (2011 Base Year)
Motorcycle	Polk 2008 registration database (normalized)	Unchanged
Passenger Car	Polk 1999 registration database	Polk 2011 registration database
Passenger Truck	VIUS 2002	Polk 2011/VIUS2002
Light Commercial Truck	VIUS 2002	Polk 2011/VIUS2002
Intercity Bus	VIUS 2002 Short-Haul Trucks	Unchanged
Transit Bus	National Transit Database	Sales data/National Transit Database
School Bus	Polk TIP database	School Bus Fleet Fact Book
Refuse Truck	VIUS 2002	Polk 2011/VIUS2002
Single Unit Short Haul	VIUS 2002	Polk 2011/VIUS2002
Single Unit Long Haul	VIUS 2002	Polk 2011/VIUS2002
Motorhome	Polk TIP database	Unchanged
Combination Short Haul	VIUS 2002	Polk 2011/VIUS2002
Combination Long Haul	VIUS 2002	Polk 2011/VIUS2002

EPA guidance for SIP and conformity modeling suggests local (state) vehicle registration data as the primary source of local data for age distribution input. EPA recommends taking a snapshot of registration data as of July 1st of the year it is being prepared. The EPA guidance recognizes that it is unlikely users will have local data for all 13 MOVES sources types, and suggests MOVES default (embedded) data as a fallback for those source types lacking local data, particularly for combination heavy-duty trucks.

Forecast year data. EPA guidance suggests using the same age distribution when modeling a base and future year. This means that economic conditions reflected in the base year will be reflected in the future year as well, even though future conditions may change. However, the guidance is intended to factor out projected changes in age distribution from estimating emission changes over time; specifically, the guidance states that age distributions for future years may not have a younger average age than the most recent year of actual data. This is meant to prevent future emission estimates from including reductions due to projected shifts to a younger age distribution.[8]

4.1.3   Data Sources, Procedures and Methods

Although local registration data are the recommended state-of-practice for age distribution data, as discussed in Section 4.1.3.1 they have some limitations upon which the alternative or supplemental sources of data can improve. Identifying a broader pool of data to better characterize the age distribution of vehicles operating in a particular modeling

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[8] Guidance on forecast year age distributions may change upon the release of MOVES2014; users should refer to the most recent EPA guidance documents.

domain will be important as the use of MOVES evolves past the initial stage. Local data source options are summarized in Table 4.1.3, including current state-of-the-practice, alternatives, and supplemental sources.

Table 4.1.3 Overview of Data Sources for Age Distribution

Data Source or Procedure	Current Use	Uses and Advantages	Limitations
MOVES embedded data (Table 4.1.2)	Common	Distributions are calculated for later years based on recent historical sales data and AEO projected sales estimates for all other years.	Latest data year may not be recent. National data do not take into account variations in age distributions by county due to local economic and demographic factors.
State vehicle registration data	Common	Ubiquitous and current, but availability and format can vary.	May not differentiate use type; does not include out-of-area or unregistered vehicles.
Inspection and Maintenance program records	Limited	Vehicle classes may be mapped more directly to model classes.	May not include HDVs. Does not include out-of-area or unregistered vehicles.
Fleet Databases (e.g., National Transit Database)	Limited	High-quality data specific to source types for which registration data may be sparse.	Limited to covered fleets only.
License plate information plus registration database	Experimental	For project scale, better representation of vehicles at a specific location. Captures out-of-area and unregistered vehicles.	Geographic coverage of monitoring system; requires adjustment for travel fraction to be used for county-scale.
Electronic Vehicle Registration	Experimental	For project scale, better representation of vehicles at a specific location. Captures out-of-area vehicles.	Geographic coverage of monitoring system; requires adjustment for travel fraction to be used for county scale.

The age distribution input is meant to characterize the fleet active within the modeling domain over the time period being modeled, not necessarily the fleet registered within the domain. The entire active fleet is difficult to characterize for areas with significant pass-through or commuter traffic, however, and unregistered vehicles are difficult to track. Commonly used data sources, vehicle registration data being the most prevalent, do not account for the population of vehicles from outside the modeling domain, or for unregistered vehicles. Emerging data sources such as automatic license plate detection and electronic vehicle registration provide new approaches to improve accounting for these vehicles. The various data sources are discussed below.

4.1.3.1 State Vehicle Registration Data

Based on results from the MOVES user survey conducted for this research, and confirmed by a review of data submitted by states for the 2011 National Emissions Inventory (NEI) (Eastern Research Group, 2013), state vehicle registration databases are by far the most common data source for age distribution. To varying degrees, all states maintain a database of vehicles registered in the state, at the county level. Registration data are a historical source dating back to the MOBILE series of models, and are considered best practice in EPA's technical guidance on MOVES.

While many states work directly with the databases compiled by the state department of motor vehicles, another source for these data are companies that compile and process the data nationwide. R.L. Polk (now part of IHS Automotive) is one commercial source; the company maintains and regularly updates vehicle registration databases, which are available by purchase at the level of detail desired by the user. The cost of such a data purchase depends on the scope and level of aggregation needed by the user.

Issues Mapping to MOVES Source Types

A primary issue with registration data is that each state has unique vehicle classification systems, which in general do not correspond directly with all MOVES source types. This requires a preprocessing step to map vehicles between registration categories and source types. This is not an issue new to MOVES; the same was true of MOBILE6, and many states are still relying on their mappings from state registration databases to MOBILE6 vehicle categories, and EPA-supplied tools to convert MOBILE6 to MOVES. Other states have developed mappings directly from state registration data to MOVES source types, or the aggregated Highway Performance Monitoring System (HPMS) vehicle types (see Section 4.3). Vehicle Identification Number (VIN) decoding software also can be used in conjunction with the registration database to derive vehicle type and model year (other information also can be determined from the VIN such as engine size and emission certification level, but these are not relevant to the age distribution input).

State registration data are typically broken out for motorcycles and passenger cars, allowing a direct mapping to these MOVES source use types; in some cases passenger cars are subdivided by body style (e.g., two-door, four-door), but can be mapped to the MOVES passenger car source type with simple aggregation. Crossover vehicles and trucks can pose more of a challenge, for a variety of reasons. State registration categories may be outdated, making it difficult to tell if the vehicle is really a car or truck by MOVES definition; for example, one state has a classification of "station wagon" but nothing for sport utility or crossover vehicles. Nonpassenger trucks may be classified by body style, truck purpose, or gross vehicle weight, and each has the potential for miscategorization in mapping to MOVES sources types. An example of this is the definition of passenger trucks (source type 31); in MOVES, this classification is defined by end use. Based on the VIUS survey and data on the emergence of light heavy-duty trucks for passenger use (large SUVs and pickups), "passenger truck" is assumed to contain a share of trucks above the threshold of light-duty (8,500 pounds gross vehicle weight). However, in mapping registration data to MOVES source types, this distinction may be lost.

In general, there is no set rule on how to map registration data to MOVES source types; judgment is required on the part of each state, according to knowledge of how its registration categories are defined. In some cases, direct mapping is simply not possible, resulting in miscategorization, or use of national defaults for certain source types. An illustrative example from an analysis of Texas registration data vehicle used to produce age distributions by MOVES source type for Texas' submission to the 2011 NEI (TCEQ, 2012) is shown in Table 4.1.4. As shown, passenger and light commercial trucks are mapped to all trucks below 8,500 pounds gross vehicle weight rating (GVWR), so passenger trucks by MOVES' definition above 8,500 pounds are excluded in this mapping. Single unit and combination trucks also are mapped based on weight. No mapping is

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provided for refuse trucks, buses, or motorhomes, requiring the application of national default age distributions for these.

Table 4.1.4   Example of Registration Data Mapping

MOVES Source Use Type	Texas Registration Category
Motorcycle (11)	Motorcycle
Passenger Car (21)	Passenger Vehicle
Passenger Truck, Light Commercial Truck (31,32)	Total Trucks <=8500 pounds GVWR
Single-unit Truck (52,53)	Diesel > 8500, Diesel > 10000, Diesel > 14000, Diesel > 16000
Combination Truck (61,62)	Diesel > 19500, Diesel > 26000, Diesel > 33000, Diesel > 60000

Overall, the mismatch between registration categories and MOVES source types in many states means the mapping will not capture all vehicles in the source type categories. However, although the overlap between a particular registration category and source type may not be perfect, the intersection is sufficiently large to make this approach the best proxy on which to base the source type age distributions. If states are able to add MOVES source type definitions to their registration databases it could eliminate the need for mapping in the future.

Issues Characterizing Vehicles on the Road

Another limitation of registration data is that they are only a proxy for the fleet within a modeling domain at any particular time. In areas with significant pass-through traffic due to goods movement, commuter traffic, or out-of-town visitors, local registration data may not capture the actual on-road fleet well. As discussed in Section 4.1.5, a study conducted by the University of California at Riverside (Boriboonsomsin et al, 2011) found that in Las Vegas, only about one-half of the vehicles were registered in the area. Of the remaining vehicles, about one-half were from California; an analysis of the age distribution of the California-registered fleet found different characteristics (generally newer) than the Nevada-registered fleet.

Of the MOVES source types, long-haul trucks are by definition the most likely to be registered outside of a particular modeling domain. Many areas therefore use the national average embedded MOVES age distributions for these source types, rather than local registration data. This is a fallback approach, however, as the actual distribution of long-haul trucks in a particular area may vary from the national average depending on the nature of commercial activity occurring in the modeling area.

The population of unregistered vehicles within a modeling region also can be significant; one study in Arizona found that in Maricopa County (Phoenix area), approximately 4 percent of vehicles (population of 200,000) were not registered (Eberline, 2008). From an emissions perspective this is consequential because owners may not register in part to avoid having to comply with local emission inspection and maintenance programs, in which case

these vehicles would disproportionately contribute to overall emissions. To address this, license plate readings could be used to supplement state registration data, if vehicle model year data can be estimated on the unregistered population. Studies of unregistered vehicles have been able to cross reference plate data to older registration and/or Inspection and Maintenance program databases, to determine the model year (California Air Resources Board, 2002). While comprehensive license plate detection is not practical, supplemental information for an area could be developed through targeted sampling.

Limitations of registration data are exacerbated for project-level analysis, where the actual fleet in the modeling domain will be influenced by local commercial activity and demographics that may not be well represented by countywide registration data.

4.1.3.2 Inspection and Maintenance Programs

States conducting inspection and maintenance (I/M) programs maintain a detailed data-base of vehicles in the program, which provides an alternate source for age distribution data. For the 2011 NEI, some states relied on these data to characterize age distribution instead of state registration databases. I/M program databases will overlap with state registration databases to a significant degree; successful participation in an I/M program is usually a prerequisite for obtaining vehicle registration. However, I/M databases may be easier to obtain for a state air agency, and/or may have vehicle categorization or information that is more adaptable to the MOVES framework. Limitations of I/M data are that the programs generally do not apply to heavy-duty vehicles, and do not include out-of-area or unregistered vehicles.

4.1.3.3 Fleet Databases

Data compiled for vehicle fleets are an alternative to registration data for some source types. This would apply mainly to public fleets, such as refuse trucks, transit buses, and school buses, where state registration data are often lacking. Local transit agencies or school districts may be a direct source of fleet data within a specific area. Fleet data also are compiled into national databases for some source types. For school buses, detailed sales numbers by state or school district can be purchased through commercial vendors. For transit buses, the FTA maintains the National Transit Database, which includes the number of vehicles in each transit operator's fleet (by vehicle type) in five-year age groupings. For commercial trucks, R.L. Polk compiles TIPNet, a national database of commercial vehicles that provides truck fleet information for specific areas. As with reg-istration data, these sources would not characterize out-of-area vehicles; however, for sources types such as transit buses, school buses and refuse trucks, the prevalence of out-of-area vehicles (and unregistered vehicles) is likely small.

4.1.3.4 License Plate Recognition

An emerging method to gather on-road fleet data directly is automatic license plate recorder (ALPR) systems. These systems record license plate numbers and match them with regis-tration databases from corresponding states to determine vehicle classifications and model years, which can translate to MOVES inputs for vehicle population mix and age distribu-tion. As with any use of the registration database, VIN decoding software also can be used

in conjunction with ALPR systems to help derive vehicle type and model year. This process is shown in the diagram in Figure 4.1.2. The primary advantage of this approach is that it characterizes the fleet actually on the road in an area, which is what MOVES vehicle population is meant to represent. This is the most direct method to quantify the prevalence of out-of-area and unregistered vehicles. A limitation of the approach is coverage, which depends on the extent to which the technology is implemented.

Figure 4.1.2   ALPR Process from Observation to MOVES Age Distribution
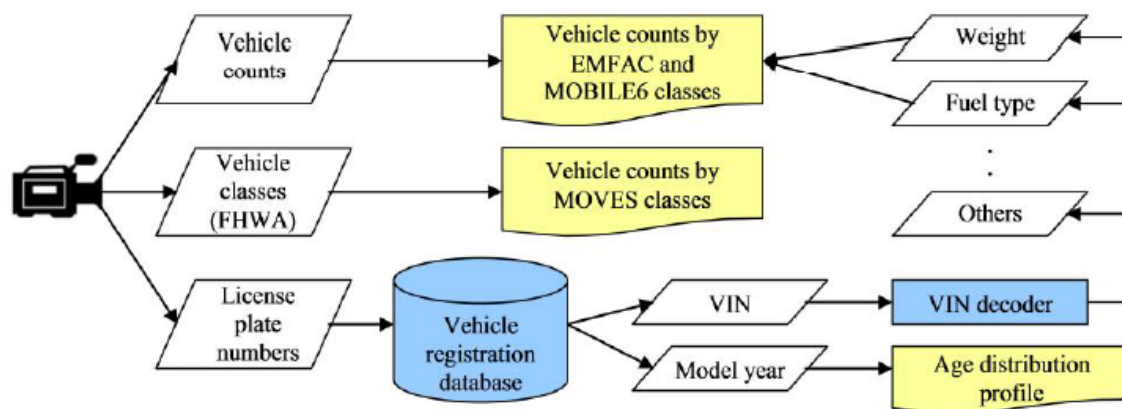
Source: Boriboonsomsin et al, 2011.

Two general approaches can be taken to implement this technology: targeted studies, such as the above-mentioned study by UC Riverside in Los Angeles and Las Vegas; and network-wide systems. Targeted studies can implement a small number of portable devices at several sites around a city, and in different cities. This approach is more cost-effective than systemwide implementation and can produce a one-time estimate of on-road fleet mix and age distribution, including out-of-area traffic. Short of quantifying the age distribution of the out-of-area fleet (which would require plate matching to registration data from other states), an intermediate approach is to use plate recognition data to quantify the percentage of vehicles from outside the area, and use regional or national age distributions to represent this segment. This is especially practical for long-haul trucks, where local registration data are usually not a good representation of the long-haul fleet traveling in the modeling domain. For long-haul trucks, a regional or national age distribution may be more accurate than local registration data.

Since ALPR data represent travel fractions by age, not population fractions, for county-scale analysis ALPR data would need to be adjusted so that they represent population fractions to account for travel fraction calculations within MOVES. Since travel fractions are calculated by multiplying the population fractions by mileage accumulation rate and then renormalizing, population fractions would be "reverse-engineered" by *dividing the travel fraction by the MAR for each year* and then renormalizing. Section 4.1.5 shows an example of how this would be done.

Systemwide implementation is an emerging option for broader goals of vehicle registration, tolling, and law enforcement systems. Input for emissions models alone would not

justify the cost of large-scale implementation, but could be a by-product. These systems are gaining a foothold outside of the U.S.; for example, London has several hundred ALPRs citywide to monitor and assess congestion charges. Within the U.S., ALPR is growing in use as a law enforcement tool, but has yet to be implemented on a large scale to assist with vehicle registration or congestion tracking. As such, systemwide ALPR is not a short-term option to provide data for inputs to MOVES.

4.1.3.5 *Electronic Vehicle Registration*

Several areas in the U.S. now use electronic vehicle registration (EVR) systems, which employ radio frequency identification (RFID) recognition technology, to automatically assess tolls. The most prevalent of these is E-Zpass, which is used in several states in the Northeast and Midwest. Other implementations of this technology include high-occupancy vehicle/toll (HOT) lanes in Southern California, and express toll routes in Ontario, Canada. For commercial trucks, similar technology is used for weigh-in-motion (WIM) systems to assess compliance with loading requirements. These data can provide a large pool of data on the vehicle fleet in a specific area, including out-of-area traffic, with a focus on long-haul trucks. A limitation is that, unlike ALPR systems, the database is restricted only to vehicles participating in the programs. For passenger vehicles in particular, this may lead to biases towards newer vehicles as well as vehicles registered locally.

4.1.4   Sample Data and Tools

EPA provides embedded age distribution data for all years from 1999 through 2050, calculated by MOVES using the same dynamic registration methodology discussed in Section 4.1.2. These data can be found via the "Tools" page on the MOVES web site (http://www.epa.gov/otaq/models/moves/tools.htm).

Available tools for age distribution focus on converting MOBILE6.2 input data to MOVES format. MOVES categorizes the vehicle fleet into different vehicle classes and more model years than MOBILE6.2. To simplify the transition from MOBILE6.2 to MOVES, EPA has created data converters that take registration distribution input files created for MOBILE6.2 or the National Mobile Inventory Model (NMIM) and convert them to the appropriate age distribution input tables for MOVES. These converters are available at www.epa.gov/otaq/models/moves/tools.htm.

An example of age distribution data developed for MOVES is shown in Figure 4.1.3 for Harris County, Texas for Passenger Cars (Source Type 21). These data were developed for the Texas Commission on Air Quality by the Texas Transportation Institute (TTI) for use in developing the 2011 statewide emissions inventory (TCEQ, 2012). These data were developed by TTI using vehicle registration data obtained from TxDOT. Figure 4.1.3 also shows a comparison of age distribution, expressed as cumulative distribution, against the MOVES embedded data for passenger cars. These data show that the Harris County age distribution is generally younger than MOVES assumes for the national average.

Figure 4.1.3   Sample Data for Age Distribution
Passenger Cars
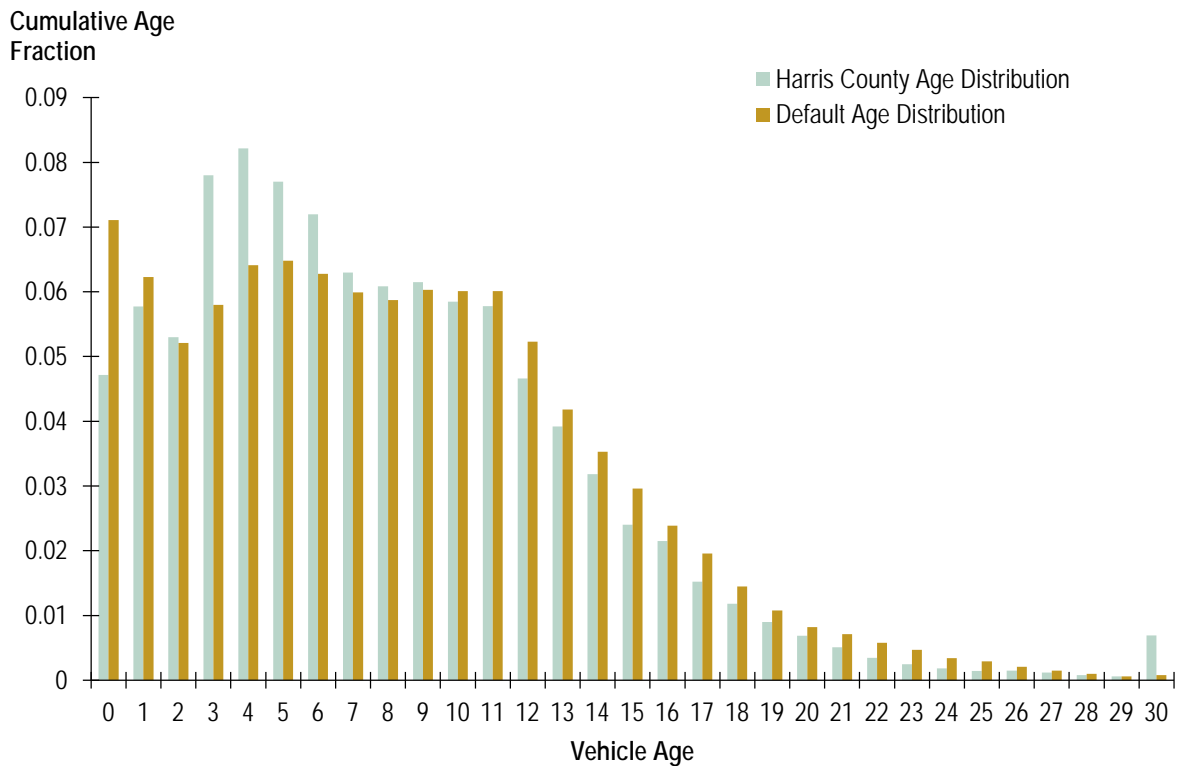
4.1.5   Example Using Supplemental Data

Use of state registration data is considered state-of-practice and is the norm among MOVES users, while the alternative and supplemental data sources discussed in Section 4.1.4 are not normally used in practice. This example is provided to demonstrate how state registration data can be supplemented with ALPR to take into account out-of-area traffic, and the impact it has on overall age distribution. Applications of ALPR for project-level and county-level analyses are demonstrated.

The ALPR data are taken from the UC Riverside study previously referenced (Boriboonsomsin et al, 2011). Researchers conducted the ALPR study to determine the make-up of vehicles entering the Los Angeles and Las Vegas metropolitan areas. Video equipment was positioned on selected overpasses looking down on three Interstate highways in each city in July 2010. The videos were examined to determine license plate state and numbers and MOVES vehicle classes. Figures 4.1.5 and 4.1.5 show the distributions of data acquired on weekdays for the count of license plates from California, Nevada, and other states (primarily Utah and Arizona) for those images where the plate's state could be determined (about 89 percent of the Los Angeles data and about 85 percent of the Las Vegas data). The figures are for all MOVES vehicle classes combined.

Figure 4.1.4 shows that about 92 percent of the vehicles entering Los Angeles were registered in California with only about 3 percent registered in Nevada. In contrast, Figure 4.1.5 shows that 68 percent of vehicles entering Las Vegas were registered in Nevada with 23 percent registered in California. Overall, only about 8 percent of vehicles observed near Los Angeles were registered out-of-state, but 32 percent of vehicles observed near Las Vegas were registered out-of-state. Based on these results, use of state registration data would be expected to better reflect the approximate age distribution of on-road fleets in Los Angeles than in Las Vegas.

Figure 4.1.4   Distribution of States Observed on Los Angeles Interstate Highways
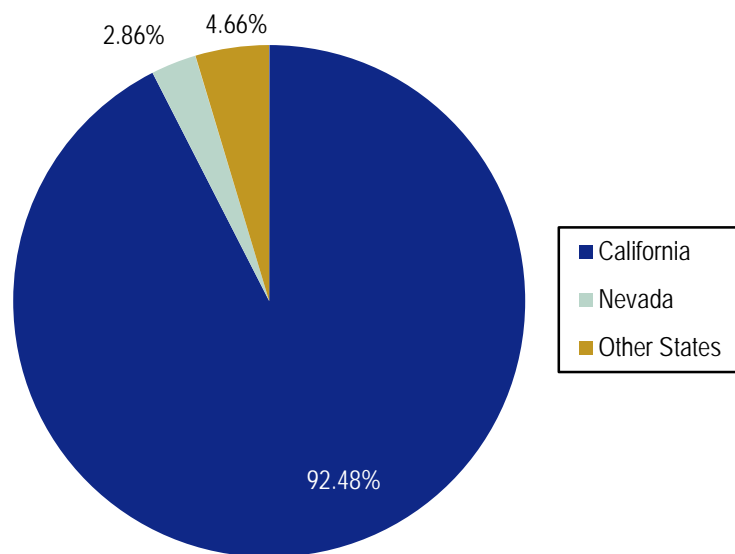
Figure 4.1.5   Distribution of States Observed on Las Vegas Interstate Highways
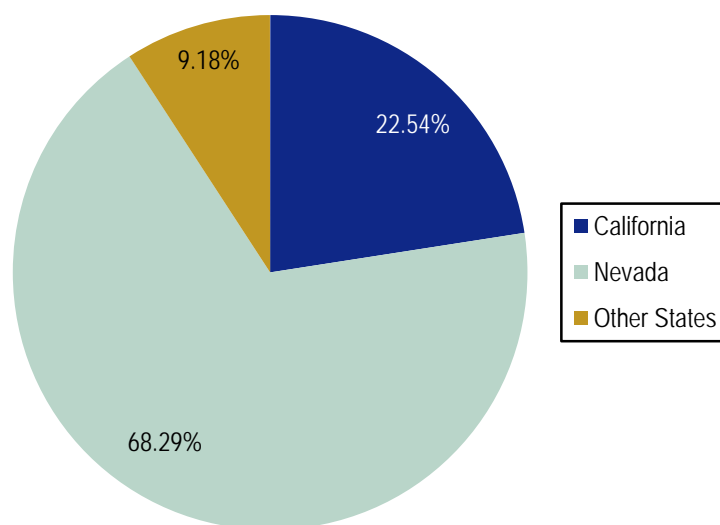
The plate numbers of California and Nevada license plates were submitted to their respective states to provide model years and other information on the individual vehicles that were videoed. Based on that information, the age distributions of the different MOVES vehicle classes were obtained for the California and Nevada vehicles in the Los Angeles and Las Vegas datasets. Figure 4.1.6 shows the cumulative age distributions of the 3,787 Nevada passenger cars and of the 1,827 California passenger cars observed in the study on weekdays near Las Vegas. The median age of the Nevada cars is about six years, and the median of the California cars is about three years. The composite age fractions for each age can be calculated as follows:

$$Age\ Fraction_{age\ x} = (NV\ Vehicles_{age\ x} + CA\ Vehicles_{age\ x})/(Total\ NV+CA\ Vehicles)$$

Figure 4.1.6   Age Distributions of Passenger Cars Observed on Las Vegas Interstate Highways on Weekdays
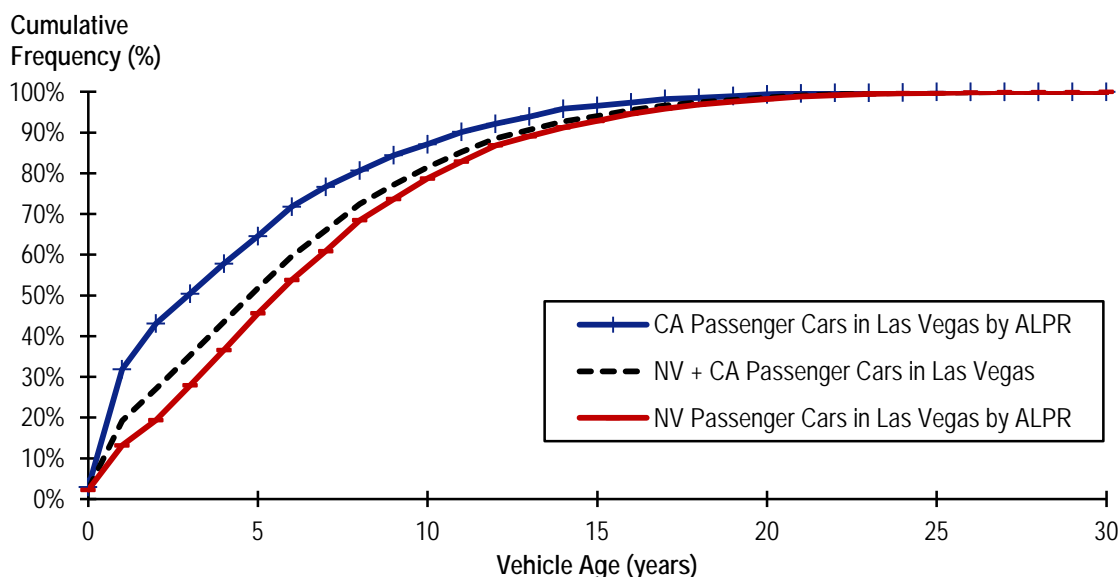
For county-level analysis, ALPR data may need to undergo conversion from travel fraction to age distribution. Figure 4.1.7 shows a comparison of Clark County, Nevada registration data for passenger cars, with an adjustment for travel fraction. Also overlaid on the chart is the Nevada ALPR data and weighted Nevada + California ALPR data from Figure 4.1.6. This comparison shows that the Nevada ALPR data and estimated travel fraction are very close, confirming in this case that observed data are more akin to travel fraction than age distribution.

Figure 4.1.7   Age Distributions and Travel Fractions of Clark County-Registered and ALPR-Observed Passenger Cars
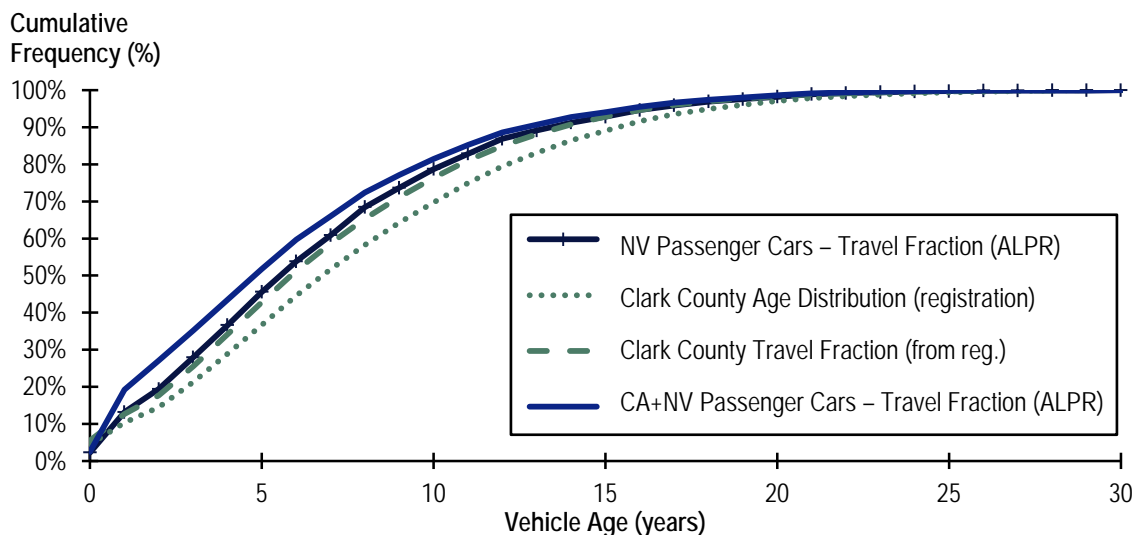
For county-level analysis, the composite age distribution is the combination of Clark County registration data and California ALPR data converted to age distribution. California ALPR data cannot be used directly because MOVES' calculation of travel fraction would lead to double counting the travel fraction effect. ALPR-observed fractions can be "converted" to age distributions using relative mileage accumulation rates (MAR) contained in the MOVES2010 database. The equation for this is as follows:

Age Fraction $_{age\ x}$ =

(ALPR Age Fraction $_{age\ x}$/Relative MAR $_{age\ x}$)/Σ (ALPR Age Fraction $_{age\ 1\text{-}30}$ * Relative MAR $_{age\ 1\text{-}30}$)

Relative MAR is used in MOVES to account for varying mileage accrual rates by age, mostly reflecting that older vehicles are driven fewer miles per year. The function of relative MAR in MOVES is for calculation of travel fraction, which allocates VMT within an HPMS class to source type and age. (The allocation across HPMS classes means that relative MAR is sometimes relative to mileage accrual of a particular age for another source type within the HPMS class). In MOBILE6 MAR was a direct user input, but for MOVES it is not presented as a user input. Embedded values are contained in the "sourceTypeYear" table, and EPA does not provide guidance on updating them.

The resulting adjusted age distribution is compared to the original ALPR data in Figure 4.1.8. The adjusted California age distribution is then weighted with the Clark County registration data to generate a composite age distribution for use in county-scale analysis. For this example, a weighting of 23/77 California ALPR/Clark County data was used, assuming the same fraction of California vehicles from ALPR shown in Figure 4.1.5, and the remainder attributed to the Clark County registrations. As shown, the weighted composite age distribution, when California ALPR is included, is younger than Clark County by itself. The average age of the weighted age distribution is 5.6 years, versus 7.6 years for the Clark County age distribution by itself. Accounting for California vehicles

on the road in Las Vegas would result in lower emissions than if only the Clark County registration data were used.

Figure 4.1.8   Adjusted CA ALPR Age Distribution and Weighted Age Distribution

Cumulative
Frequency (%)
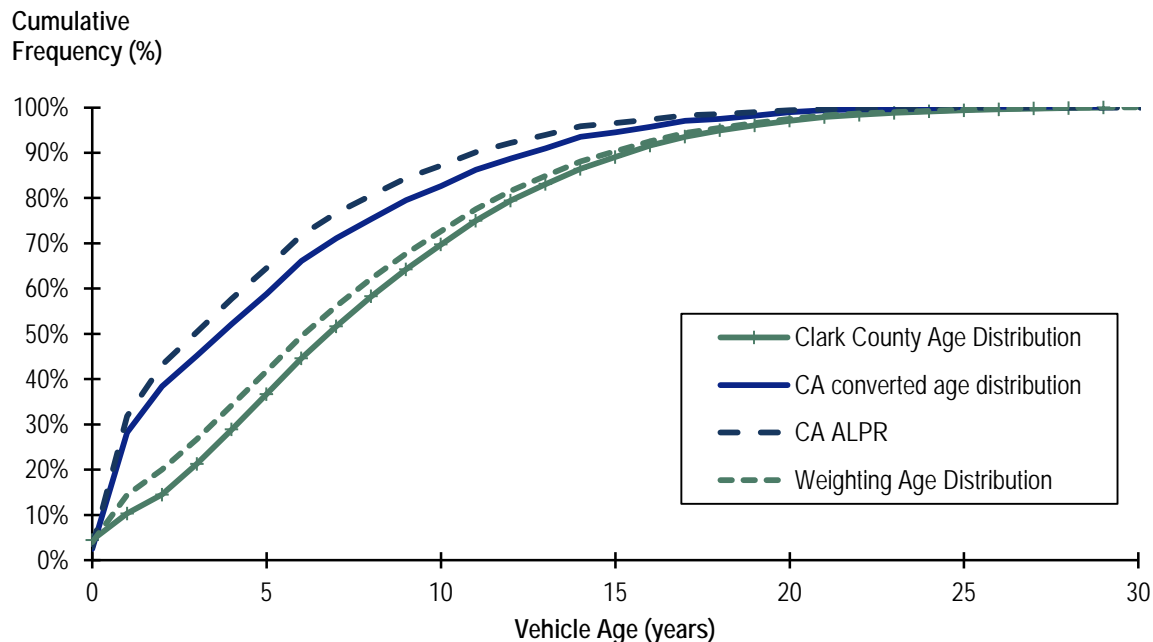
This example makes a major assumption by using the percentage of California cars observed on Interstate highways as a surrogate for the entire region. In practice, using ALPR data to improve countywide age distribution will require strategic choice of sites to acquire the video footage. It is possible that the age distributions of vehicles driving on Interstates versus non-Interstates or in one part of the city versus another part will differ. A variety of representative video acquisition sites should be chosen. Registration data are not subject to this type or error.

■ 4.2 Source (Vehicle) Type Population

4.2.1 Description and Format

Source type (vehicle) population is the total number of vehicles for each of the 13 MOVES source types. It is a new input for MOVES that was not required for MOBILE6, and is used to calculate the off-network emission processes of start exhaust and parking-related evaporative emissions. It is therefore not related to, or affected by, VMT estimates in the model. For national and county-scale applications, it is meant to represent the population of vehicles within the modeling domain for the time period being modeled, which can vary from the number of vehicles registered in the domain due to commuter traffic, pass-through traffic, and unregistered vehicles.[9] However, because of the challenge in quantifying actual population, it is often estimated using the same vehicle registration data that are used for age distributions, as recommended by EPA technical guidance. For project-level application, the term population in this context defines the number of vehicles in a specific location within the project domain.

In MOVES, source type population used for national and county scales runs are stored within the database table sourceTypeYear. The field sourceTypePopulation contains the population data, keyed off sourceTypeID and yearID, as shown in the example in Table 4.2.1.

Table 4.2.1 Example of SourceTypePopulation Input

yearID	sourceTypeID	sourceTypePopulation
2002	11	1,622
2002	21	39,398
2002	31	21,126
2002	32	7,058
2002	41	29
2002	42	18
2002	43	201
2002	51	27
2002	52	1,413
2002	53	113
2002	54	300
2002	61	354
2002	62	316

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[9] "Commuter" traffic may be considered as having one end of the trip inside the modeling domain and one end outside. "Pass-through" traffic includes trips that both start and end outside the modeling domain. Commuter and pass-through traffic is also known as "vehicle migration."

Users performing a county-scale run must provide data for the calendar year being modeled (yearID); these data can be derived from local sources, or developed external to MOVES based on VMT and MOVES embedded data as described below.

4.2.2   Source of Embedded Data and EPA Guidance

The relevant sections of the MOVES user guide, guidance documents, and data tables are:

- MOVES2010b User Guide: Section 2.3.3.4.2, Source Type Population Importer (p. 68);

- MOVES SIP and Conformity Guidance: Section 4.3, Source Type Population (p. 34);

- MOVES GHG Guidance: Section 4.4, Source Type Population (p. 48); and

- Data tables: sourceTypeYear.

Embedded data in MOVES represent different meanings for national versus county-scale runs. Unlike age distribution, for which the same input can apply regardless of scale, population is specific to the scale and domain being modeled. The MOVES database only includes embedded data directly for the entire U.S., for a single base year. The sources of these data for MOVES2010 and proposed for the next update of MOVES are shown in Table 4.2.2. For the national scale, yearID serves as a "base" year, from which population is grown dynamically year-to-year based on sales and scrappage inputs when output is requested for calendar years after the base year. In MOVES2010 the base year is 1999; the base year is updated to 2011 for MOVES20214 (U.S. EPA, 2013).

Table 4.2.2   Sources of Embedded Data

SourceType	MOVES2010 (1999 Base Year)	Proposed MOVES2014 (2011 Base Year)
Motorcycle	FHWA/Motorcycle Industry Council	Unchanged
Passenger Car	FHWA/Polk	Polk 2011 registration database
Passenger Truck	FHWA/Polk/VIUS 2002	Polk 2011/VIUS2002
Light Commercial Truck	FHWA/Polk/VIUS 2002	Polk 2011/VIUS2002
Intercity Bus	FHWA/Motorcoach Census	Unchanged
Transit Bus	FHWA/FTA database	Sales data/National Transit Database
School Bus	FHWA/Polk TIP/School Bus Fleet Fact Book	School Bus Fleet Fact Book
Refuse Truck	FHWA/Polk/VIUS 2002	Polk 2011/VIUS2002
Single Unit Short Haul	FHWA/Polk/VIUS 2002	Polk 2011/VIUS2002
Single Unit Long Haul	FHWA/Polk/VIUS 2002	Polk 2011/VIUS2002
Motorhome	Polk TIP/NHTS	Unchanged
Combination Short Haul	FHWA/Polk/VIUS 2002	Polk 2011/VIUS2002
Combination Long Haul	FHWA/Polk/VIUS 2002	Polk 2011/VIUS2002

As detailed in Section 4.3 of the MOVES User Guide, county-scale runs require the sourceTypeYear table to be populated with the yearID equal to the year being modeled. Embedded county-level populations can be output by MOVES when doing national-scale runs, calculated from embedded national values and county-level allocations. However, embedded populations should not be used for county-scale analysis, especially when the model is used for regulatory purposes. Embedded county populations in MOVES2010 are based on a national growth rate from the base year 1999. The farther out from the base data year, the greater the likely divergence between the default and actual county vehicle populations. The MOVES SIP and Conformity Guidance states that, "Because vehicle population directly determines start, extended idle, and evaporative emissions, users must develop local data for this input."

EPA guidance suggests an approach for developing county-level source type population estimates when local population data (such as from a registration database) are not directly available. Because users are required to input county-level VMT data (see Section 4.3) the MOVES SIP and Conformity Guidance suggests that for areas lacking requisite population data, estimates can be based on locally provided VMT data and VMT:population ratios (i.e., miles per vehicle) calculated from the national level embedded data. This approach is meant to make the population in a particular county consistent with updated VMT provided by the user.

Forecast year data. EPA guidance does not specifically address the development of forecast year source type populations. If VMT-based methods are used (i.e., estimating population based on VMT and miles per vehicle by source type), VMT forecasts can be applied using the same method to obtain future year source type population estimates. If a direct observation of source type population is made (e.g., from registration data), future year vehicle population can be estimated using a logical growth factor such as a projection of local VMT or human population growth.

4.2.3   Data Sources, Procedures and Methods

Local data source options are summarized in Table 4.2.3. Because there are several sources that serve different purposes, these data sources are categorized according to: a) direct estimates of population; b) VMT-based estimates of population; or c) supplemental data sources to improve characterization of commuter and pass-through traffic or unregistered vehicles.

Table 4.2.3   Overview of Data Sources for Source Type Population

Data Source or Procedure	Current Use	Uses and Advantages	Limitations
Direct Estimates			
MOVES embedded data	Common	MOVES will output county-level population, derived from embedded national values and county allocations; can be produced with a simple MOVES run.	Embedded populations extrapolated from base year and may not reflect actual local growth rates. Not acceptable for regulatory purposes, discouraged for other uses.
State vehicle registration data	Common	Provides count of vehicles registered in area. Ubiquitous and current, but availability, vehicle types and format can vary.	Requires mapping to MOVES source types; does not include out-of-area or unregistered vehicles.
Inspection/Maintenance program data	Limited	Vehicle classes may be mapped more directly to MOVES classes.	May not include HDVs. Does not include out-of-area or unregistered vehicles.
Fleet Databases (e.g., National Transit Database, School Bus Fleet Survey)	Limited	High-quality data specific to source types for which registration data may be sparse.	Specific source types only.
VMT-Based Estimates			
Highway Performance Monitoring System	Common	EPA's suggested fallback if local data are not available. Guidance provides approach to estimate population from local VMT data and embedded VMT:population ratios. Local data on VMT:population ratios may be used if available.	Assumes parking and start activity by source type are proportional to VMT by source type (and that same population:VMT ratios hold locally when using embedded data).
State-operated automatic vehicle classification sensors	Limited	Provides direct observation of vehicles on roadways; may be used to supplement HPMS estimates for substate areas if sufficient counting stations are available.	Limited to specific sampling locations. Weighted by amount of use; must be adjusted by VMT/vehicle to estimate populations.
Supplemental Sources			
Travel models	Limited	Supplemental – to account for commuting flow (see example).	Requires registration data to make adjustment for vehicles from outside the domain.
Commercial vehicle registration databases	Experimental	Supplemental – to account for commercial vehicle (truck) activity.	May not differentiate short-haul from long-haul; self-reported VMT.
Commercial vehicle surveys	Experimental	Supplemental – to account for commercial vehicle (truck) activity.	Only available for a few areas.
Freight Analysis Framework	Experimental	Supplemental – to improve estimates of short- versus long-haul truck population.	Limited to major roadways, so only applicable to long-haul trucks; based on AADT; limited years.
Supplemental Sources (continued)			
License plate information plus vehicle identification number (VIN) decoders and registration database	Experimental	Supplemental – captures out-of-area and unregistered vehicles.	Coverage; on-network focus.
Electronic Vehicle Registration	Experimental	Supplemental – Captures out-of-area vehicles.	Coverage; on-network focus.
Weigh-in-Motion	Experimental	Supplemental – Captures out-of-area vehicles (heavy trucks).	Coverage; on-network focus.
National Household Travel Survey	Experimental	Supplemental – proportion of light-duty automobiles versus light trucks.	Limited sample size, no heavy vehicles.

Source type population is meant to characterize the fleet starting and parking within the modeling domain over the time period being modeled, not necessarily the fleet registered within the domain. This is difficult to accomplish for areas with significant vehicle migration due to commuting, commercial activity, tourism, and/or pass-through traffic, however. In addition, unregistered vehicles are difficult to track, and may not be trivial in number. An additional challenge is that population is assumed constant in MOVES – it does not allow for ebb and flow in population throughout a day that occurs due to commuting and other interarea travel, unless a day is broken up into multiple runs with varying populations. Ideally, population would account for all vehicles starting and parking in the domain, including unregistered and migrating vehicles. While no single source of data provides this information, supplemental data sources can help improve the accounting.

4.2.3.1 Direct Population/Count Estimates

State Vehicle Registration Data

Based on results from the MOVES user survey conducted as part of this research, vehicle registration databases are by far the most common data source for population. Registration data is considered best practice in EPA's technical guidance on MOVES. Challenges in working with registration data are discussed in the age distribution section: namely, there may not be complete coverage of all MOVES source types, and vehicle groupings in-state registration databases require mapping to MOVES source types, the details of which will vary state-to-state. Beyond this, the primary limitation of registration data is that they do not account for unregistered or migrating vehicles, and thus are only a proxy for the fleet within a modeling domain at any particular time. In addition, commercial vehicles often register in states outside of their principal state of operation. However, because population is used only to quantify off-network emissions (starts and parking-related evaporative emissions processes), registration data may be a better proxy for actual population than for age distribution.

Inspection/Maintenance Data

States conducting inspection and maintenance programs maintain a detailed database of vehicles in the program, which provides an alternate source for population data. I/M program databases will overlap with state registration databases to a significant degree; successful participation in an I/M program is usually a prerequisite for obtaining vehicle registration. However, I/M databases may be easier to obtain for a state air agency, and/or may have vehicle categorization or information that is more adaptable to the MOVES framework. Limitations of I/M data are that the programs often do not apply to heavy-duty vehicles, often exempt newer (and more populous) model years, and do not include unregistered/migrating vehicles.

Fleet Databases

Data compiled for vehicle fleets are an alternative to registration data for some source types. This would apply mainly to public fleets, such as refuse trucks, transit buses, and school buses. For population, these vehicles are more likely to remain in their "home" area, and out-of-area vehicles are less likely to enter the modeling domain – so fleet populations can be a good source of data for certain source types.

Local transit agencies or school districts may be a direct source of fleet data within a specific area. Fleet data also are compiled into national databases for some source types. For school buses, detailed sales numbers by state or school district can be purchased through commercial vendors. For transit buses, the FTA maintains the National Transit Database. For commercial trucks, R.L. Polk compiles TIPNet, a national database of commercial vehicles that provides truck fleet information for specific areas. The cost of these data will depend on the scope and level of detail needed by the user. These databases can serve as supplemental sources for bus or truck source types, particularly where state registration data are lacking.

4.2.3.2 VMT-Based Approach

Highway Performance Monitoring System

An indirect method to estimate local population is to multiply state- or county-level VMT data from the HPMS by VMT:population ratios, which can be derived from numerous sources. As discussed in more detail in Section 4.3 on VMT inputs, traffic count data (including some vehicle classification data) are collected by states from sample sections, expanded to represent all VMT in the state, and reported to FHWA as part of the HPMS. State DOTs typically provide county-level data on their web sites or they may be obtained from the HPMS coordinator. However, the number of classification stations is typically not large enough to provide reliable estimates of vehicle type populations at the county level, so county-level total VMT must typically be combined with state-level proportions of VMT by vehicle type.

EPA's technical guidance suggests the use of HPMS as a fallback option where registration data are not available, by adjusting VMT by vehicle type by VMT:population ratios derived from the national totals embedded in MOVES. Local or regional data on VMT:population can be an improvement over the national embedded data. Sources for these ratios may include:

- FHWA Highway Statistics, which publishes state-level vehicle population and mileage estimates in the Highway Statistics series for six HPMS vehicle classes;

- The National Household Travel Survey (for light-duty vehicles only), which includes information on daily travel as well as vehicle ownership from a nationwide sample of households;

- Regional household travel surveys (again for light-duty vehicles only), which may include information on vehicle ownership as well as daily travel;

- Inspection and Maintenance program data, from which annual mileage driven can be determined from odometer readings from consecutive inspections of the same vehicles;

- State or national commercial vehicle registration databases, such as the Motor Carrier Management Information System (MCMIS) maintained by the Federal Motor Carrier Safety Administration (FMCSA), which provide number of vehicles by owner along

with user-reported estimates of miles driven for each fleet (see "sample data and tools"); and

- Commercial vehicle surveys, which may be used to identify fractions of travel by type of heavy-duty vehicle and also may be one of the only ways to estimate the proportion of trucks used for short-haul versus long-haul purposes.

A concern with VMT-based methods is that they assume that off-network (parking and start) activity in the modeling domain is proportional to VMT in the domain. Parking and start to VMT ratios may vary locally depending upon local travel characteristics such as average trip lengths. Furthermore, this approach may underestimate off-network activity for local areas that have major off-network facilities (such as intermodal terminals), and conversely may over-estimate such activity for areas with a lot of pass-through traffic (such as a rural county traversed by an Interstate highway). An advantage of the approach, however, is that by scaling population to VMT, it will account for migrating or unregistered vehicles.

State Vehicle Classification Counts

Vehicle classification count data are generally available from state DOTs, who use automatic classification counters to tally the number of vehicles on specific roadways for use in developing VMT estimates. These classifications are typically made according to HPMS-defined vehicle classes. While MOVES source types were developed to be a subset of the six primary HPMS vehicle types (also used in MOVES for VMT), vehicle count data that are collected in the expanded set of 13 FHWA classifications requires mapping to MOVES source types. Classification counts are used in developing the HPMS VMT estimates described above, but also may be obtained and analyzed directly. If sufficient numbers of observations are available (which is not usually the case), classification counter data could be used to develop estimates of vehicles by vehicle type specific to substate areas. They also may indicate variation by months, days, and hour if detailed population specific to individual time periods is needed.

While classification counts may appear to be a direct observation of the number of vehicles, vehicles that drive more miles will be over-counted, and therefore the count data need to be adjusted by VMT per vehicle in the same way as described for the VMT data from the HPMS. They also, like the HPMS data, do not capture off-network vehicle operation.

4.2.3.3 Supplemental Data Sources

The following data sources are not sufficient to quantify population entirely for a region, but can be used to supplement registration, fleet, or VMT-based estimates to better account for migrating and/or unregistered vehicles, or to provide local estimates of miles per vehicle for making adjustments to VMT-based estimates.

Travel Models

Origin/destination output from travel models provides a basis for estimating the number of trips entering and leaving the modeling area. In one example, an analysis for the New Jersey DOT developed "migration factors" for each county based on travel model origins

and destinations. These migration factors were developed by county and time of day, and varied from roughly 0.6 (i.e., 40 percent drop in vehicle population due to outgoing commutes) to 1.4 (40 percent increase due to incoming commutes). These are more extreme because they reflect specific time periods, and would be lower over an entire day. However, they demonstrate the large impact accounting for commuting could have on population estimates.

Commercial Vehicle Registration Data

The Motor Carrier Management Information System contains information related to the safety fitness of commercial motor carriers. The FMCSA can provide summary data tabulations to the public for a small fee. The MCMIS database can be used to characterize average annual VMT by truck by state of primary registration. The database includes the number of tractors and single-unit trucks registered to each carrier, and the annual miles driven (self-reported) by that carrier's vehicles.

The database also identifies trucks registered for intrastate use only, versus for interstate use. Using intrastate as a proxy for short-haul, it could therefore serve as a rough source for developing estimates of annual VMT per vehicle for the MOVES categories of single-unit versus combination truck and short-haul versus long-haul. However, these will not be precise estimates for a number of reasons. For example, VMT for some fleets includes both single-unit and tractor trucks; some trucks may be registered for interstate use but primarily used for local travel; some states are large enough that intrastate trips could be considered long-haul; and self-reported VMT is notoriously unreliable. An example of the use of the MCMIS data is provided in "sample data and tools."

States also may keep databases of registered motor carriers operating in the state separate from the state's vehicle registration database. For example, the Texas Motor Carrier Database includes information collected directly from all registered motor carriers in the state. Its collection is independent of the state's vehicle registration database and it is updated monthly. The database contains the VINs for all commercial vehicles. From this source, data on the size and characteristics of engines, as well as make and model, can be decoded. It is available through a web interface[10] and on CD from the Texas Department of Motor Vehicles.

Commercial Vehicle Survey Data

Commercial vehicle surveys have been conducted in a handful of cities across the U.S., generally with the intent to improve tracking and modeling of truck activity within the modeling domain. While using travel models to estimate migration factors would focus on passenger travel, commercial vehicle surveys could be used to fill out migration patterns for larger trucks. This can be useful for determining the share of trucks that are local versus long-haul. Cambridge Systematics (2003) provides a description of commercial studies that had been conducted in Atlanta, Denver, Detroit, and the Triad region of North

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[10] Texas Motor Carrier Registration Database, Available at: http://apps.txdmv.gov/apps/mccs/ truckstop/.

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Carolina. While providing valuable data, such surveys are not often done due to cost and logistical challenges.

Freight Analysis Framework

The Freight Analysis Framework (FAF) is produced by FHWA (FHWA, 2013) to provide detailed data and analysis on freight movement in the U.S. The FAF integrates information from a number of transportation and commodity flow data sources to allow a more detailed assessment of travel and population related to goods movement in each region of the U.S. The FAF only includes loaded traffic. It is built on bills of lading and typically does not include sources of truck traffic such as deliveries of construction material from a mine to a job site or deliveries from a retail warehouse to a retail store. It also does not include unloaded deadheading trips. The FAF can be used to model average annual daily traffic (AADT) for long-haul trucks reported for specific segments of highways by commodity. The activity estimates are derived in large part from the 2008 HPMS.

The FAF provides data on long-haul and local truck activity through FAF and NONFAF estimates. NONFAF is derived by taking total truck traffic and subtracting out the traffic that can be accounted for by FAF tonnage estimates. A FAF trip table can be used to measure truck production/attraction. The tool also provides estimates of FAF and NONFAF activity which are rough proxies for long-haul and short-haul truck movements. In most cases, NONFAF should be regarded as a subset of local traffic as there are some local deliveries that will be accounted for by FAF. Breaking down combination truck populations into short- and long-haul is a significant challenge for MOVES users which the FAF may help address. Furthermore, the upcoming version of FAF (FAF4), expected to be released in the fall of 2015, is expected to have improved functionality for describing county to county movements.

License Plate Recognition

Automatic license plate recognition systems discussed under age distribution also can be a supplemental source of data for characterizing population. The primary advantage of this approach is that it characterizes the fleet actually on the road in an area and therefore includes out-of-area and unregistered vehicles. A limitation of the approach is that it may be expensive to deploy systems and analyze data on enough roads to obtain a representative sample for the entire modeling domain at a county or multicounty level.

Targeted studies can implement a small number of portable devices at several sites around a city, and in different cities. Vehicles identified through ALPR can be compared with vehicles in the state's registration database to quantify the percentage of vehicles from outside the area, and the percentage unregistered. These data can then be used to develop adjustments to registration data to improve actual population estimates. For major tourist destinations, the population of vehicles in the area may be much larger than the number of vehicle registered; as noted in Section 4.1.5, a study in Las Vegas found that one-half of the vehicles were registered out of the area. Unregistered vehicle populations can be significant as well, with one study estimating 200,000 unregistered vehicles in Maricopa County, AZ.

Electronic Vehicle Registration and Weigh-in-Motion

Electronic vehicle registration and weigh-in-motion systems could potentially provide another data source for quantifying the amount of commuting or pass-through traffic, with the WIM focusing on long-haul trucks. A limitation is that, unlike ALPR systems, the databases are restricted only to vehicles participating in the programs. However, these data could be used to deduce the rate of vehicles entering an area registered in other locations without resorting to an ALPR program.

National Household Travel Survey

The National Household Travel Survey (NHTS) is conducted by the U.S. DOT every six to eight years and provides information on trip, vehicle, and household characteristics for a sample of travelers nationwide. The information collected in the survey includes type of vehicle and model year. Analysis of survey data can be conducted at the state level and for the 50 largest metropolitan areas, using an online query tool or by obtaining the data from U.S. DOT.[11] In some states with larger sample sizes, the raw survey data may permit analysis at a more detailed geographic level, if it can be obtained from the state NHTS coordinator.

NHTS may be useful as a supplemental source in identifying source type populations, and specifically for identifying the proportion of light-duty vehicles that are automobiles (type 21) versus light trucks (type 31). This may be a supplemental source if problems are encountered obtaining or analyzing registration data. The proportion of source type 21 and 31 can be used to break out total VMT for these categories if classification counts do not appear reliable (Section 4.3).

As with registration data, NHTS data will not include out-of-area vehicles. Because the sample size is relatively small, this source is regarded as inferior to registration and probably I/M program data, and should only be used if other data sources are not available.

4.2.4 Sample Data and Tools

As source type population is a new input into MOVES, tools have not been developed specifically for producing population data. Since population was not required for MOBILE6, there is no need for conversion of data from MOBILE6 inputs.

Sample data are provided below from analysis of various supplemental data sources, including the NHTS for light-duty vehicles, and the MCMIS data and a California study for heavy-duty vehicles.

National Household Travel Survey

The project team analyzed data from the 2009 NHTS to determine its utility for assisting in developing source type populations and age distributions. Table 4.2.4 shows sample data

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[11] http://nhts.ornl.gov/.

shows the fraction of household vehicles in the survey that are in each of these classes. While it is preferable to use county-level fractions from registration data, if registration data are not available the NHTS data could be applied to total light-duty VMT as an improvement over the auto/light truck splits estimated from traffic counters. These fractions also could be applied to total vehicle population counts, if breakdowns between car and truck are not available at the state/county level.

Table 4.2.4   Light-Duty Vehicle Proportions from 2009 NHTS

State	Automobile	Light Truck
AK	36.70%	63.30%
AL	49.39%	50.61%
AR	35.30%	64.70%
AZ	43.00%	57.00%
CA	55.39%	44.61%
CO	48.19%	51.81%
CT	59.12%	40.88%
DC	61.21%	38.79%
DE	53.48%	46.52%
FL	52.88%	47.12%
GA	48.25%	51.75%
HI	51.23%	48.77%
IA	48.63%	51.37%
ID	44.32%	55.68%
IL	57.39%	42.61%
IN	49.03%	50.97%
KS	45.65%	54.35%
KY	42.96%	57.04%
LA	43.77%	56.23%
MA	57.17%	42.83%
MD	52.58%	47.42%
ME	52.84%	47.16%
MI	43.58%	56.42%
MN	52.62%	47.38%

Table 4.2.4   Light-Duty Vehicle Proportions from 2009 NHTS (continued)

State	Automobile	Light Truck
MO	53.86%	46.14%
MS	38.11%	61.89%
MT	40.13%	59.87%
NC	49.19%	50.81%
ND	41.36%	58.64%
NE	44.59%	55.41%
NH	55.67%	44.33%
NJ	50.20%	49.80%
NM	46.11%	53.89%
NV	45.95%	54.05%
NY	56.58%	43.42%
OH	50.71%	49.29%
OK	48.32%	51.68%
OR	49.25%	50.75%
PA	51.94%	48.06%
RI	59.09%	40.91%
SC	49.56%	50.44%
SD	39.19%	60.81%
TN	47.93%	52.07%
TX	44.80%	55.20%
UT	51.31%	48.69%
VA	50.76%	49.24%
VT	48.49%	51.51%
WA	46.22%	53.78%
WI	48.34%	51.66%
WV	49.98%	50.02%
WY	35.47%	64.53%
United States	49.93%	50.07%

Source: Analysis of 2009 NHTS data by Cambridge Systematics, Inc.

Motor Carrier Management and Information System

As part of this research, the research team acquired data from MCMIS for the year 2012 that reported the activity of over one million firms operating in the U.S. Key data elements used in the analysis include the number of total power units (number of trucks and tractors) and the reported firm VMT. These two data elements were used to develop average VMT per truck. Table 4.2.5 shows the number of registered trucks by registration type and the average miles per year per truck. Miles per truck also is shown for single-unit versus tractors, and for trucks registered only for intrastate use versus interstate use. All of the statistics in Table 4.2.5 are based on fleets that contained only one truck type and

therefore are likely biased towards smaller fleets. The number of vehicles shown in this table is much smaller than the total truck population and should not be used as such.

Table 4.2.5   Truck Data from MCMIS

State	Vehicles in Fleets of One Type		Miles/Truck/Year – All Trucks	Miles/Truck/Year – Intrastate Registrations		Miles/Truck/Year – Interstate Registrations	
	Single-Unit	Tractors		Single-Unit	Tractors	Single-Unit	Tractors
AK	5,406	1,069	18,239	15,297	25,680	21,049	41,596
AL	31,807	10,387	23,237	11,260	46,675	22,659	51,718
AR	4,722	8,894	40,787	31,974	46,625	22,610	50,074
AZ	13,205	6,850	40,056	28,822	58,298	23,572	66,664
CA	17,533	50,349	50,767	24,826	51,464	23,929	60,579
CO	31,193	8,952	21,817	14,736	27,782	16,487	54,085
CT	16,841	2,028	22,650	17,303	35,710	20,116	54,507
DE	4,244	916	26,221	14,105	30,655	19,159	60,882
FL	58,023	31,108	35,851	40,747	54,313	9,671	58,262
GA	42,981	20,733	34,579	24,958	53,364	25,448	54,314
HI	522	249	21,972	13,046	53,798	14,974	35,417
IA	11,821	16,483	37,582	20,676	35,629	18,003	53,977
ID	4,946	6,829	32,243	19,123	23,456	17,716	44,487
IL	33,010	26,376	29,051	3,395	43,567	20,201	49,813
IN	22,705	11,036	25,279	14,083	20,744	16,879	47,755
KS	16,765	7,212	27,784	20,021	34,096	16,962	52,314
KY	21,175	7,945	28,374	21,423	34,131	20,926	51,436
LA	7,324	7,274	35,475	31,226	52,316	24,079	45,353
MA	22,553	4,587	24,892	19,988	71,632	21,706	40,410
MD	44,226	4,332	21,451	10,654	60,765	23,917	56,725
ME	10,759	2,944	23,807	13,835	35,838	20,082	63,985
MI	61,295	15,226	23,241	16,583	32,507	21,856	51,207
MN	47,077	15,518	26,648	19,055	37,819	18,553	54,177
MO	21,361	11,356	31,916	24,565	40,293	18,551	56,423
MS	3,976	8,942	45,287	37,476	49,236	26,642	53,381
MT	4,186	4,440	31,205	16,343	35,140	18,061	45,728
NC	16,945	17,429	38,828	26,224	48,079	22,556	54,493
ND	3,323	5,437	33,050	17,988	36,014	18,231	42,892
NE	12,057	9,825	31,016	16,158	31,433	16,323	51,934
NH	8,649	1,394	23,112	26,534	78,303	17,593	52,131
NJ	26,584	12,047	29,880	22,472	43,883	22,839	45,627
NM	5,185	6,472	25,719	13,469	18,015	20,873	38,171
NV	5,286	2,451	26,729	21,543	53,754	10,959	59,104

Table 4.2.5 Truck Data from MCMIS (continued)

| State | Vehicles in Fleets of One Type | | Miles/Truck/Year – All Trucks | Miles/Truck/Year – Intrastate Registrations | | Miles/Truck/Year – Interstate Registrations | |
	Single-Unit	Tractors		Single-Unit	Tractors	Single-Unit	Tractors
NY	141,462	21,481	13,608	9,421	9,966	20,369	53,168
OH	22,686	14,630	32,628	26,987	45,489	20,517	50,009
OK	11,046	11,018	33,037	24,262	37,171	23,604	43,732
OR	13,677	8,223	35,369	25,028	43,335	19,299	62,103
PA	54,837	13,905	27,406	17,235	47,712	20,392	61,459
RI	5,423	739	25,865	20,842	18,062	22,414	52,647
SC	9,201	7,060	38,284	26,572	57,292	23,796	55,843
SD	3,531	5,490	33,609	18,097	25,696	15,973	46,273
TN	15,543	10,930	33,247	24,054	35,027	19,867	52,277
TX	31,982	88,269	31,709	40,071	18,075	24,671	51,237
UT	9,079	5,676	36,455	29,345	53,778	19,084	58,607
VA	14,175	7,707	34,897	23,466	49,790	21,913	59,080
VT	3,469	831	23,150	14,125	40,054	15,896	55,176
WA	20,826	12,839	37,494	28,568	50,104	21,543	58,201
WI	37,285	11,160	28,678	20,493	34,731	19,442	64,561
WV	13,203	1,873	18,736	16,844	38,206	13,258	51,563
WY	3,660	2,931	25,645	13,414	32,897	16,488	39,248
All States	**1,048,770**	**571,852**	**29,296**	**18,110**	**30,211**	**20,063**	**53,600**

Source: Federal Motor Carrier Safety Administration, Motor Carrier Management Information System, 2012. Note that the data exclude fleets with multiple truck types.

California Truck Inventory and Impact Study

The California Hybrid, Efficient, and Advanced Truck Research Center (CalHEAT) undertook the **California Truck Inventory and Impact Study** to better understand the various types of trucks used in California, their relative populations, and how they are used. As part of the study, the population of 1.5 million trucks and buses registered in California was characterized based on Polk registration data. A custom classification system was developed that used the model of the truck to sort the vehicles into six different use categories. These categories distinguish short-haul and long-haul uses as well as single-unit and combination trucks, and therefore provide a sample source of data roughly corresponding to MOVES source types. The study also produced data on VMT, fuel type, fuel use, age distribution, and CO_2 emissions by truck category. The methodology could potentially be applied to truck registration data from other states.

An example of the data resulting from the CalHEAT study is shown in Table 4.2.6. A reclassification of these data to correspond with MOVES source type categories is shown in Table 4.2.7. Class 3 – 8 Work – Urban and Work Site trucks are assumed to be short-haul single-unit trucks, while Class 3 – 8 Work – Rural/Intercity are assumed to be long-

haul single-unit trucks (although many of these may actually be short-haul). Class 2B/3 vans/pickups are excluded as these are assumed to be part of MOVES source type 32 (Light Commercial Truck). For single unit (work) trucks, CalHEAT appears to show a much more balanced split between short-haul and long-haul than MOVES, where short-haul dominates. The combination truck categories (tractors) are closer, especially in terms of population, but CalHEAT shows a higher VMT per vehicle for long-haul trucks than MOVES (85,000 versus 60,000 miles per year). Differences could be due to at least three factors – vehicle definitions and classification methods (especially the assumption that all rural/intercity work trucks are long-haul); use conditions in California versus the U.S. (note the higher-than-average VMT per vehicle in California from the MCMIS data); and changes over time between development of the MOVES and CalHEAT data.

Table 4.2.6   Truck Population by Category in California
2010

Vehicle Category	Truck Population	% Population	Average VMT
Tractors – Over-the-Road	175,000	12%	85,000
Tractors – Short Haul/Regional	111,000	8%	55,000
Class 3 – 8 Work – Urban	253,000	17%	25,000
Class 3 – 8 Work – Rural/Intracity	295,000	20%	35,000
Class 3 – 8 Work – Work Site	77,000	5%	13,000
Class 2B/3 vans/pickups	531,000	36%	21,000
Unknown	15,000	1%	8,192
Total	**1,457,000**	**100%**	**34,255**

Source: CalHEAT, 2013.

Table 4.2.7   Comparison of CalHEAT and MOVES Truck Populations and VMT

MOVES Source Type	CalHEAT Categories	CalHEAT California Data (2010)					MOVES Embedded Data		
		Truck Population	Avg. VMT/Truck	Total VMT (Millions)	Percent Pop. (M/H Trucks)	Percent of Total VMT	Mi/Year/ Truck	Percent of Truck Pop	Percent of Truck VMT
52 – Single Unit Short-Haul Truck	Class 3 – 8 Work – Urban Class 3 – 8 Work – Work Site	330,000	22,200	7,326	36%	19%	14,464	62%	32%
53 – Single Unit Long-Haul Truck	Class 3 – 8 Work – Rural/ Intracity	295,000	35,000	10,325	32%	27%	15,262	8%	5%
61 – Combination Short-Haul Truck	Tractors – Short Haul/ Regional	111,000	55,000	6,105	12%	16%	50,215	14%	24%
62 – Combination Long-Haul Truck	Tractors – Over-the-Road	175,000	85,000	14,875	19%	39%	59,233	17%	39%
Total		911,000		38,631	100%	100%		100%	100%

Sources: CalHEAT (2013) and MOVES2010a embedded data.

4.2.5 Examples

4.2.5.1 Freight Analysis Framework Data

This example shows how Freight Analysis Framework data can be used to develop population estimates for long-haul trucks at the county level. The FAF Origin-Destination (O/D) database from 2007 provides AADT for long-haul trucks for Interstates and state highways at the road segment level;[12] the 2011 FAF is in the process of being prepared. Some truck traffic is not captured by FAF and is designated NONFAF. For this example, data were queried for Lake County, Indiana, just outside of Chicago. This county contains the confluence of Interstates 80, 90, and 65 and would be expected to have a particularly high share of long-haul trucks in the total vehicle population.

The FAF data for Lake County include Interstate highways, other freeways, state highways, and principal arterials. Because only major roads are included, FAF is best for quantifying long-haul trucks, which can be assumed to travel primarily on this subset of roads. For Lake County, the 2007 FAF O/D dataset has 190 entries, covering multiple segments on 19 roadways. An example of these FAF O/D database entries is shown in Table 4.2.8.

Table 4.2.8　FAF Origin-Destination Data Example

ID _Link ID_	SIGN1 _Posted Sign_	STATE	CTFIPS _County FIPS_	BEG_MP _Beginning Mileage_	END_MP _Ending Mileage_	AADT07 _Total AADT 2007_	AADTT07 _Truck AADT 2007_	FAF07 _LH Truck AADT 2007_	NONFAF07 _Local Truck AADT 2007_
122500	S55	IN	89	100.530	104.251	19614	1569	15	1554
122501	U231	IN	89	292.881	295.616	11197	945	0	945
122502	U41	IN	89	257.337	258.325	16429	1971	435	1536
124453	I65	IN	89	246.852	249.599	40869	11622	11321	301
124455	U231	IN	89	298.573	305.204	13488	1079	0	1079
125024	I65	IN	89	233.820	239.004	32901	11335	11335	0
125025	S2	IN	89	15.165	19.100	7001	630	0	630
122528	S2	IN	89	7.076	10.143	10126	1012	0	1012
122558	U41	IN	89	241.120	249.383	9689	1550	435	1115
125028	I65	IN	89	239.004	239.298	32901	11335	11335	0
122526	U41	IN	89	249.383	254.122	16429	1971	435	1536
122527	S2	IN	89	6.090	7.076	10126	1012	0	1012
122512	U41	IN	89	254.122	257.337	16429	1971	435	1536
124454	U231	IN	89	295.616	298.219	13495	1079	15	1064
124456	I65	IN	89	239.551	246.480	40240	12232	11336	896

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[12] http://www.ops.fhwa.dot.gov/freight/freight_analysis/faf/.

Total AADT matches that from the HPMS universal dataset. AADTT07 is the subset for truck traffic, encompassing the single unit and combination trucks. FAF07 and NONFAF07 further subdivides this into long-haul trucks and local trucks, respectively. Though not included in Table 4.2.8, the O/D database also contains fields for AADT projected in 2040, and volume, capacity and speed estimates by link for both years. While this example is focused on long-haul population only, these fields could be useful for a number of MOVES inputs related to VMT and speed on Interstates, freeways and principal arterials, particularly for long-haul trucks.

Table 4.2.9 shows the VMT calculated from this method for long-haul trucks and compares it with MOVES embedded data. Source types 53 (single-unit) and 62 (combination) are used for long-haul in the MOVES embedded data. As shown, the FAF estimates that long-haul VMT is more than twice that in the MOVES embedded data.

Table 4.2.9   Long-Haul VMT Estimates for Lake County, Indiana

Data Source	Long-Haul Truck VMT
MOVES Embedded (2007)	128 million
FAF (2007)	298 million

The FAF should be used with caution and only if better data are not available. The FAF estimates are not measured, but rather are derived using HPMS data and commodity flow estimates from the Economic Census. The estimates are not updated annually (2007 is the most recent year with direct estimates). While FAF can add value to long-haul truck VMT, the data are not meant to provide accurate link-level estimates. The FAF is therefore better used for broader regional areas, and on a relative rather than absolute basis.

■ 4.3 Regional VMT by Vehicle Class

4.3.1 Description and Format

This input represents annual vehicle-miles of travel in the modeling region for each of six vehicle types in MOVES2010. MOVES2014 consolidates vehicle types 20 and 30 so that only five vehicle types are included; these vehicle types are hard to distinguish with most traffic monitoring systems.[13] The vehicle types are consistent with those used in the Highway Performance Monitoring System. Table 4.3.1 shows an example of the format for this input. Each analysis year should have total VMT for each of the five or six vehicle types. The option to model off-network VMT is disabled in MOVES2010 versions; users should enter zeros in the baseYearOffNetVMT column.

Table 4.3.1   Example of Regional VMT Input

HPMSVtypeID	yearID	HPMSBaseYearVMT	baseYearOffNetVMT
10	2002	165,354	0
20	2002	35,332,808	0
30	2002	20,086,413	0
40	2002	383,910	0
50	2002	1,934,527	0
60	2002	4,240,177	0

The MOVES source types are subsets of the HPMS vehicle types. Table 4.3.2 shows how the two categories map to each other. VMT is input by HPMS vehicle type because it is easier to obtain VMT data at this level than for 13 source types. VMT is a required input in emission rate mode as well as inventory mode; it is used in emission rate mode to develop an estimate of VMT per vehicle population, which affects evaporative emissions.

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[13] This change was identified too late in the report development process to update all of the tables and examples in this document.

Table 4.3.2   Mapping of Six HPMS Vehicle Types to 13 MOVES Source Types

HPMS Vehicle Type	HPMSVtypeID	MOVES Source Type	Source Type ID
Motorcycle	10	Motorcycle	11
Passenger Car	20	Passenger Car	21
Other Four-Tire, Two-Axle	30	Passenger Truck	31
		Light Commercial Truck	32
Buses	40	Intercity Bus	41
		Transit Bus	42
		School Bus	43
Single Unit Trucks	50	Refuse Truck	51
		Single Unit Short-Haul Truck	52
		Single Unit Long-Haul Truck	53
		Motor Home	54
Combination Trucks	60	Combination Short-Haul Truck	61
		Combination Long-Haul Truck	62

4.3.2   Source of Embedded Data and EPA Guidance

The relevant sections of the MOVES user guide, guidance documents, and data tables are:

- MOVES2010b User Guide: Section 2.3.3.4.4, Vehicle Type VMT and VMT Fractions (p. 69);

- MOVES SIP and Conformity Guidance: Section 4.5, Vehicle Type Vehicle Miles Traveled (p. 35);

- MOVES GHG Guidance: Section 4.6, Vehicle Type VMT (p. 49); and

- Data tables: HPMSVTypeYear.

The VMT data contained in MOVES are county-level data intended for national-scale runs. Base year data in MOVES2010 are taken from the 1990 and 1999 FHWA Highway Statistics (based on HPMS). For years 2000 to 2050, growth rates are derived using data from a number of sources and applied to the 1999 base year VMT. Data sources include FHWA Highway Statistics and the Transportation Energy Data Book for years through 2008. Projections for all later years are taken from various editions of the Annual Energy Outlook (AEO) published by the U.S. Department of Energy (DOE), Energy Information Administration and from EPA assumptions for some of the years closest to 2050. For MOVES2014, the base year VMT estimates are updated to 2011 using Highway Statistics, and projected using a method similar to MOVES2010 but with updated AEO data.

EPA expects users to develop local VMT estimates for SIPs and regional conformity analyses. Local VMT estimates also should be used for GHG and energy analysis. EPA notes that travel demand forecasting models and/or HPMS are often used, but does not require the use of these sources.

Forecast year data. EPA guidance does not specifically address the development of future year VMT inputs. If a travel demand forecasting model is used, the model will typically produce future year VMT estimates along with base year estimates. (If output for the required year is not available, output from other years may be interpolated.) If HPMS or other count-based data are used, a method to inflate base year to future year volumes (such as growth factors or trend extrapolation) is required.

4.3.3   Data Sources, Procedures, and Methods

Local data source options for this input are summarized in Table 4.3.3.

Table 4.3.3   Summary of Options for Regional VMT by Vehicle Class

Data Source or Procedure	Use	Uses and Advantages	Limitations
Monitoring – Historical Only			
Highway Performance Monitoring System – statewide submittal or sample data	Common	All states maintain HPMS count stations and prepare annual reports to FHWA. Vehicle types are consistent with those required for inputs.	Vehicle class distributions typically available only at statewide, not substate level. Equipment may have trouble distinguishing between passenger cars and light trucks.
Other local counts – automated traffic recorders or manual visual classification	Limited	May be used to supplement HPMS stations if additional local counting stations are available.	Very few sites are typically present in any given urban area.
ITS traffic monitoring data and technologies (loops, radar, video)	Experimental	May be used to supplement HPMS stations if additional local counting stations are available, for example, to provide local/regional breakdown of light versus heavy vehicles.	Usually deployed only on freeways – not representative of entire network. Limited ability to distinguish different vehicle classes consistent with HPMS types.
State vehicle registration data (registered vehicle fractions)	Limited	May provide more accurate identification of passenger car versus light truck than traffic counters.	May not accurately represent heavy-duty vehicle population or VMT. Because different vehicle types are driven different amounts, need to adjust by mileage accumulation rates to obtain VMT fractions.
Inspection/Maintenance records	Limited	May be used to identify local mileage accumulation rates to apply to registered vehicle fractions.	Only an option in areas where entire vehicle population is inspected regularly and odometer readings are recorded.
Federal Transit Administration National Transit Database	Limited	Fleet-specific source of transit bus VMT, which otherwise may not be distinguishable in traffic monitoring data.	Public fleet transit buses only.

Table 4.3.3   Summary of Options for Regional VMT by Vehicle Class (continued)

Data Source or Procedure	Use	Uses and Advantages	Limitations
Modeling – Historical and Forecast Year			
Travel demand forecasting model	Common	Provides forecast as well as base year VMT.	Only provides total VMT, unless a truck model is included. Additional factors needed to allocate to six vehicle classes.
Trend extrapolation	Common	Simple forecasting/extrapolation methods can be used to forecast VMT when a travel demand model is not available.	Generally simplistic, based only on continuation of past trends.

Three basic methods are available for developing estimates of VMT by HPMS vehicle type, as shown in Figure 4.3.1.

Figure 4.3.1   Methods to Estimate VMT by Vehicle Type
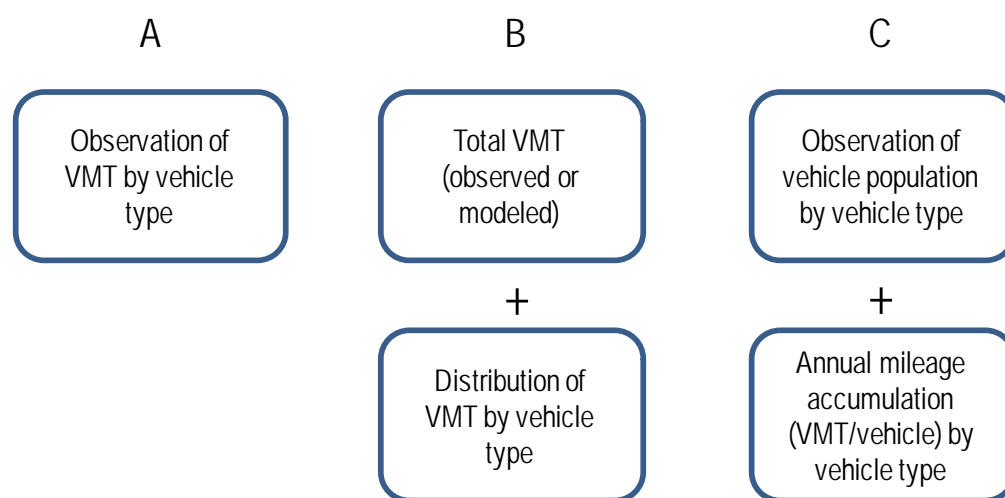
Method A – direct observation of VMT by vehicle type – can be done if a sufficiently representative sample of classified vehicle counts is available for the study area. This can be done using HPMS data or other local counts.

If sufficient classified counts are not available for the study area, **Method B** may be used, in which an estimate of total VMT (observed or modeled) is allocated among HPMS vehicle types using a distribution which is assumed to be representative of the area. Total VMT can generally be observed at a county level for historical years, or modeled for future years, but observed vehicle classifications may not be available at this level of geography and travel models typically do not contain information on vehicle type. The allocation by vehicle type may be based on a statewide average, source type population (number of vehicles registered or otherwise based in the area), or some other source. If it

is done according to source type population, adjustments should be made for differences in annual mileage accumulation by source type (see Example 4.3.1).

Method C is theoretically possible but agencies have not reported using it in practice. It combines information from a state registration database, from which the number of vehicles by type registered in a given county may be determined, with annual mileage accumulation by vehicle type. Mileage accumulation may be obtained if consecutive odometer readings are taken for registration purposes or from a local Inspection and Maintenance program, or using another source such as MOVES embedded data (which are based on national data). The primary drawback of Method C is that the registration-based source type population may not be representative of all vehicles operating in the study area, especially for heavy-duty vehicles which often cross state boundaries.

EPA's regional conformity guidance (EPA 2010) notes that travel demand forecasting models are often the source of information used to estimate VMT, often adjusted to HPMS VMT or local traffic counts.

4.3.3.1 Highway Performance Monitoring System

The Highway Performance Monitoring System can be used to obtain historical or base-year VMT by the six HPMS vehicle classes at a state level, or total VMT at a county level. The HPMS includes data on the extent, condition, performance, use, and operating characteristics of the Nation's highways, including traffic volumes by vehicle type. State DOTs annually submit data to FHWA from the network of HPMS monitors established within the state, by June 15th of each year for the previous year's data. The data are collected and submitted using a standard data format specified in FHWA's *Traffic Monitoring Guide*. Highway sections are monitored with short-term (typically 48-hour) counts conducted at least every three years. Short-term counts are adjusted to annual averages based on a smaller number of permanent count stations. Traffic volumes measured for each highway section are multiplied by section lengths to estimate vehicle-miles of travel. VMT from monitored sections are expanded to represent the universe of all road segments using expansion factors.

HPMS data are assembled at three levels: 1) Full Extent; 2) Sample Panel; and 3) Ramps. The Full Extent has a limited number of data items but for all highways in the country where HPMS data are supposed to be reported. The Sample Panel has many more data items but for a sample of highway sections.

Vehicle classification counts are only conducted on the Sample Panel. The distribution of vehicles by class is estimated from this sample. The vehicle class distributions are only reported at the state level because there are usually not enough classification stations to provide statistically valid estimates at substate levels. Even for the Sample Panel the vehicle classification data have limitations. Only three classes are reported – total traffic, single-unit trucks, and combination trucks. Furthermore, standard vehicle classification counters, which work based on axle spacing, are not very good at distinguishing passenger cars from light trucks, which both have two axles with relatively similar wheelbases. Therefore, the MOVES user may want to use a split of passenger cars versus light trucks

from a different source than the roadway-based classification counts, such as registration data or a household travel survey that includes vehicle information.

The statewide HPMS submittal to FHWA includes VMT by vehicle class and roadway functional class. Most state DOTs post reports on-line from their HPMS data with annual average daily VMT by county and roadway functional class. Figure 4.3.2 shows an example of such a report. Data not available on the state's web site may be obtained from the state HPMS coordinator. Segment counts also may be obtained that provide annual average daily traffic by segment. This information can be used along with the reported segment length to estimate VMT at a substate (e.g., county) level (see Figure 4.3.3).

Figure 4.3.2 Example of State HPMS Traffic Report by County

HPMS 2010 DVMT

Rural and Urban

Reg	Co #	County	Interstate		Freeways		Principal Arterial		Minor Arterial		Major Collector	Collector	Minor Collector	Local		County Total
			Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Rural	Urban	
1	1	ANDERSON	465,825	0	0	0	115,524	603,157	74,128	227,780	265,086	64,800	98,041	103,993	129,662	2,147,996
3	2	BEDFORD	16,785	0	0	0	196,744	230,085	176,849	64,901	113,639	33,146	102,034	101,510	69,432	1,105,125
4	3	BENTON	304,381	0	0	0	133,226	0	69,481	0	93,773	0	49,912	42,079	0	692,852
2	4	BLEDSOE	0	0	0	0	121,150	0	43,549	0	24,672	0	48,072	43,744	0	281,187
1	5	BLOUNT	0	84,808	0	27,851	308,195	901,753	97,543	447,900	42,459	343,995	110,879	186,587	453,118	3,005,088
2	6	BRADLEY	472,329	436,340	0	137,921	100,381	463,126	129,559	392,481	117,940	115,897	73,740	109,176	350,391	2,899,281
1	7	CAMPBELL	845,080	0	0	0	161,375	142,449	40,240	9,600	125,971	11,358	131,283	134,758	21,391	1,623,505
2	8	CANNON	0	0	0	0	114,877	0	81,306	0	36,341	0	50,146	40,399	0	323,069
4	9	CARROLL	23,443	0	0	0	214,953	53,878	186,155	17,216	108,451	6,877	63,000	62,950	15,550	752,473
1	10	CARTER	0	55,091	0	0	62,829	342,837	107,579	232,838	61,079	72,861	28,573	43,372	93,269	1,100,328
3	11	CHEATHAM	550,705	0	0	0	0	0	317,931	0	171,571	0	100,959	114,888	0	1,256,054
4	12	CHESTER	0	0	0	0	50,436	74,387	79,406	16,608	37,706	41,067	36,184	33,323	33,137	402,254
1	13	CLAIBORNE	0	0	0	0	412,872	0	151,209	0	36,861	0	107,538	99,721	0	808,201
2	14	CLAY	0	0	0	0	87,505	0	37,623	0	13,270	0	20,183	26,327	0	184,908
1	15	COCKE	465,036	55,209	0	0	0	157,091	258,604	20,179	58,835	8,883	82,213	108,674	19,078	1,233,802
2	16	COFFEE	937,963	106,124	0	0	99,592	303,681	51,829	219,158	155,811	54,107	141,102	126,328	104,126	2,299,821
4	17	CROCKETT	0	0	0	0	243,985	0	46,357	0	113,021	0	49,531	37,597	0	490,491
2	18	CUMBERLAND	997,914	74,061	0	0	140,592	151,929	101,892	117,292	305,631	32,634	88,057	157,574	84,087	2,251,663
3	19	DAVIDSON	739,873	8,264,213	0	1,389,591	138,545	3,235,029	399,600	2,958,789	60,884	878,985	103,500	119,077	3,097,520	21,385,606
4	20	DECATUR	201,788	0	0	0	188,427	0	21,046	0	41,038	0	36,082	34,978	0	523,359
2	21	DE KALB	0	0	0	0	0	0	294,157	0	61,793	0	44,467	69,797	0	470,214
3	22	DICKSON	540,889	25,882	0	0	10,605	250,798	415,650	53,714	118,109	42,785	86,779	104,336	61,373	1,710,920
4	23	DYER	114,817	40,929	0	25,563	306,866	124,884	47,512	93,066	149,911	43,209	94,627	76,602	73,060	1,191,046
4	24	FAYETTE	447,594	0	0	0	411,688	0	280,495	0	181,377	0	86,532	86,719	0	1,494,405
2	25	FENTRESS	0	0	0	0	160,779	0	101,466	0	43,725	0	82,626	123,386	0	511,982
2	26	FRANKLIN	0	0	0	0	257,987	103,115	95,310	63,343	161,138	21,540	77,601	106,710	34,206	920,950
4	27	GIBSON	0	0	0	0	267,629	198,222	168,526	48,622	189,163	13,927	114,314	96,947	28,439	1,125,789
3	28	GILES	408,564	0	0	0	133,595	37,431	195,431	63,353	95,834	7,898	100,654	89,766	18,133	1,150,659
1	29	GRAINGER	0	0	0	0	251,819	0	173,386	0	75,376	0	59,403	62,940	0	622,924
1	30	GREENE	737,426	0	0	0	264,856	333,982	230,295	73,521	157,234	48,772	216,568	216,935	84,431	2,364,020
2	31	GRUNDY	233,836	0	0	0	312	0	133,577	0	75,800	0	13,521	34,907	0	491,953
1	32	HAMBLEN	348,337	19,353	0	0	0	690,475	42,176	193,024	59,909	139,864	61,634	62,585	168,910	1,786,267
2	33	HAMILTON	94,271	2,528,579	0	1,195,769	202,963	1,763,175	64,380	2,217,240	48,468	394,249	66,040	92,056	1,097,883	9,765,073
1	34	HANCOCK	0	0	0	0	0	0	59,241	0	16,633	0	13,145	13,648	0	102,667
4	35	HARDEMAN	0	0	0	0	90,489	86,503	285,881	14,378	32,547	6,944	92,506	64,641	10,949	684,838

Source: Tennessee Department of Transportation, http://www.tdot.state.tn.us/hpms/.

FHWA's annual Highway Statistics publication contains tables (VM-2, Functional System Travel: Annual Vehicle-Miles, and VM-4, Distribution of Annual Vehicle Distance Traveled) that may be used to estimate the fraction of statewide VMT by HPMS vehicle class. An Excel tool combining these two tables to provide a pivot table of VMT by state, based on 2010 data, is provided in conjunction with this report ("MOVES Highway Statistics Tool"). Sample data from this tool are provided in Section 4.3.4.

FHWA's Vehicle Travel Information System (VTRIS) is a related data source that contains traffic data from permanent traffic count stations as well as truck weigh stations (as collected by states and reported to FHWA). The VTRIS data can be used to obtain temporal distributions of VMT by vehicle and roadway class and is discussed further in Section 4.4, Temporal Adjustments.

4.3.3.2 Other Local Counts and ITS Data

Other local counting equipment, including automated traffic recorders or intelligent transportation systems (ITS) equipment such as loop detectors, radar, or video, may be used to supplement HPMS stations if available. However, ATR sites not part of the HPMS are rarely present in sufficient numbers to provide an areawide VMT estimate.

A variety of ITS technologies are used, including in-pavement loops as well as nonintrusive devices installed on the roadside (radar and video image processing are the two most common). ITS equipment is usually deployed primarily on freeways and therefore only provides coverage for the urban restricted road type. Some technologies, including radar and video, are capable of length-based vehicle classification. This information can be used to develop rough estimates of the percentage of light-duty (type 10, 20, and 30), single-unit heavy-duty (type 40 and 50), and combination heavy-duty (type 60) vehicles.

ITS detectors are usually spaced at approximately one-half-mile intervals. Data are archived at various levels from 20 seconds to 15 minutes; 5 minutes is most common. Another limitation of ITS data is that field equipment is often not maintained or calibrated due to cost. (There can be thousands of detectors in major urban areas.) Users interested in these data sources should work with local transportation officials to determine whether available sources are suitable for areawide VMT estimation.

4.3.3.3 State Vehicle Registration Data

State vehicle registration databases can provide information on the types of vehicles registered within the state, with geographic information on place of registration (e.g., county). Vehicle registration data are discussed in more detail under fleet inputs. Registration data may be used to supplement other data in developing VMT distributions. In particular, for MOVES2010 users, registration data may provide a more accurate estimate of the breakdown of light-duty vehicles into passenger cars (20) and light trucks (30) than are available from traffic counters.

Because they count vehicle populations rather than VMT, population fractions must be weighted by mileage accumulation rates (average annual distance driven per vehicle) to obtain VMT fractions. The distribution of registered vehicles also may not precisely correspond to the distribution of VMT within the same geographic area, especially if a lot of the traffic in the area is pass-through traffic. Finally, state registration databases may not accurately represent heavy-duty vehicle populations which are often registered out-of-state.

4.3.3.4 I/M Program Data

Some areas operate inspection and maintenance programs in which vehicles are inspected at regular intervals (usually annually or every two years) for emissions and/or safety purposes. Odometer readings from the same vehicle may be matched across consecutive inspections to obtain estimates of annual miles driven per vehicle, by vehicle type. This can serve as an alternative source of mileage accumulation rates to the embedded data in MOVES, to apply to source type population estimates to obtain distributions of VMT by vehicle type.

I/M program data are most applicable for light-duty vehicles as heavy-duty vehicles may not be covered. Also, newer model vehicles may not be covered in some areas. This could skew the estimate of mileage accumulation since older vehicles tend to be driven less.

4.3.3.5 National Transit Database

The Federal Transit Administration's National Transit Database is a repository of operational data for all Federally funded public transit systems in the U.S. Transit operators submit NTD reports annually to FTA. Among the data reported are annual vehicle-miles of travel by mode. VMT for bus modes (motor bus, MB and demand responsive, DR) can be used to estimate VMT within a region for Source Type 42, Transit Bus. However, this will not include VMT by school buses, intercity buses, or private bus operators (Source Types 41 and 43).

4.3.3.6 Travel Demand Forecasting Models

A travel demand model may be used to estimate total base and/or forecast year VMT. Most travel demand models only forecast aggregate VMT, or at best include a truck model or a factor to proportion VMT between light and heavy-duty vehicles. Therefore, further factoring is needed to allocate VMT among the six vehicle types. This is often done using base year proportions from the HPMS, although as discussed previously, HPMS has trouble distinguishing among some of these vehicle types and further adjustments may be needed.

Base year VMT forecasts from the travel demand model may differ from HPMS estimates for the same year. Both the traffic counts and the model may be subject to error. About 10 to 15 percent of travel occurs on local roads (Chatterjee and Miller, 1994), which are not well-captured by either traffic counting systems or travel models. Section 3.0 of EPA (1996) discusses how to reconcile traffic demand model results with HPMS VMT estimates.

The nonattainment region may not be the same as the modeled area, which also complicates the use of VMT from travel models. Unlike nonattainment areas, which are defined along county boundaries, travel model areas are not necessarily contiguous with county geography. If the nonattainment area is a subset of the modeled area, only the links within the nonattainment area can be selected and VMT measured on those links. If the nonattainment area extends beyond the modeled area, a separate estimate must be developed of VMT external to the model area.

4.3.3.7 Other VMT Projection Methods

In areas not covered by a travel demand model, forecast year VMT may be developed from historical HPMS VMT data using statistical methods to project growth, based on past trends. The trend analysis may be performed at different levels of data aggregation. It also may be enhanced through the consideration of other contributing factors such as forecast population, employment, and/or income growth.

A **regression analysis** using a linear, logistic, or other function can be applied to a group of recent years of HPMS VMT data to generate a VMT estimate for planning horizon year(s). Each local area must decide the appropriate number of years to include in their

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regression analysis, but in general 10 to 20 years seems to be appropriate for the longer-term forecasts often used in air quality planning. A shorter time period (10 years) may be more appropriate if it appears that structural factors are leading to a significantly different trend in the past decade compared to previous decades, and if this new trend is expected to continue in the future. The choice of time period can make a significant difference, as shown in Example 4.3.2.

A separate regression analysis can be performed at the county level for each functional roadway classification. For rural areas along Interstate highways, a large portion of the county's VMT can be made up of through traffic. For these rural areas the VMT for the Interstate facility should be forecasted separately from the VMT for the rest of the county. Linear regression can result in some VMT trends for individual functional classifications becoming negative due to historically decreasing traffic counts, or as a result of changes to urban/rural HPMS designation which shift the functional class bin in which traffic counts are reported. For situations where this occurs, VMT may be held constant at the level of the latest year for which HPMS data is collected to provide a conservative estimate of VMT.

Statistical analysis of past VMT trends can be enhanced through consideration of contributing factors to VMT growth. The various drivers of VMT (e.g., regional population, economic activity, vehicle trip rates, trip lengths, vehicle occupancy) may change over time in ways that do not reflect past trends. An improved approach that does not involve significantly more effort than a simple trend extrapolation is to forecast VMT *per capita* based on past trends, and multiply that by population projections from official sources, as shown:

$$VMT_{year} = ForecastPopulation_{year} * ProjectedVMT/Capita_{year}$$

Growth in freight truck traffic is often assumed to be consistent with economic growth (gross regional product or GRP) rather than population growth. If economic forecasts are available for the study area, truck VMT (HPMS types 50 and 60) may be forecast separately from passenger vehicle VMT, for example:

$$TruckVMT_{year} = GRP_{year} * ProjectedTruckVMT/GRP_{year}$$

An even more detailed projection could involve analysis of multiple factors such as trip rates by household income level and size, trip lengths, mode shares, vehicle occupancy, and/or economic activity. For example, per capita VMT could be modeled as a function of population, household size, and area employment, using historical data. The model would then be used to develop future per-capita VMT projections, using forecasts of these driving variables.

4.3.4   Sample Data and Tools

EPA provides a series of eight VMT converters for creating MOVES VMT and source type age distribution inputs from MOBILE6 and NMIM data formats. Four converters allow the user to enter total VMT data for each HPMS road type; the other four require the user enter the specific VMT of a vehicle type on a road type. The converters take data from 28,

16, 12, and 8 vehicle types and convert them to MOVES vehicle and source types. The converters are available here: http://www.epa.gov/otaq/models/moves/tools.htm.

Table 4.3.4 shows estimates of total VMT by state and the fraction of VMT by each HPMS vehicle type, for 2010. The underlying data are also provided in the Excel file, "MOVES Highway Statistics Tool." These estimates are developed from estimates of total VMT by road type and state combined with classified count data from states, as submitted to FHWA as part of the HPMS, and reported in Highway Statistics Series Tables VM-2 and VM-4. As discussed previously, classification counters are not viewed as a reliable way of distinguishing class 20 and class 30 vehicles. For example, at a state level, the light-duty vehicle population fractions from the 2009 National Household Travel Survey (Table 4.2.5) show an average of a 50:50 split between passenger cars and light trucks across all states, compared to the greater than 3:1 ratio of cars to trucks shown in Table 4.18., MOVES users can make adjustments to VMT data by allocating total class 20 and 30 VMT between these two classes based on MOVES county or state-level population fractions, MOVES embedded VMT fractions, or travel survey data such as the NHTS data shown in Table 4.2.5. To correctly adjust using population fractions, the population fraction should be weighted by average annual miles per vehicle for each vehicle type, as illustrated in the example in Section 4.3.5.

Table 4.3.4 Estimated VMT by Vehicle Type
by State, 2010

State	Total VMT (Millions)	10 – MC	20 – PC	30 – LT	40 – Bus	50 – SUT	60 – CT
Alabama	6,416,515	0.84%	65.65%	21.72%	0.64%	4.24%	6.92%
Alaska	479,826	0.24%	62.02%	30.47%	0.17%	5.72%	1.39%
Arizona	5,999,516	0.44%	69.83%	19.93%	0.51%	3.30%	6.00%
Arkansas	3,350,443	0.56%	56.38%	27.60%	0.61%	2.35%	12.51%
California	32,284,940	0.51%	66.94%	24.84%	0.19%	2.83%	4.69%
Colorado	4,693,993	0.85%	68.02%	25.29%	0.48%	1.91%	3.45%
Connecticut	3,129,442	0.41%	79.96%	13.70%	0.14%	2.52%	3.27%
Delaware	894,767	0.99%	72.76%	15.52%	1.35%	5.82%	3.56%
Dist. of Columbia	359,082	0.83%	79.65%	15.66%	1.11%	2.35%	0.41%
Florida	19,575,471	0.65%	72.78%	18.85%	0.53%	3.34%	3.85%
Georgia	11,172,247	0.78%	66.16%	21.20%	0.86%	5.00%	5.99%
Hawaii	999,465	0.88%	75.56%	19.85%	0.56%	2.37%	0.77%
Idaho	1,580,121	1.38%	46.13%	37.32%	0.46%	10.71%	4.00%
Illinois	10,578,785	0.71%	78.95%	10.04%	0.83%	2.86%	6.61%
Indiana	7,576,051	0.80%	63.19%	20.97%	0.79%	3.85%	10.40%
Iowa	3,138,862	0.27%	77.56%	10.81%	0.37%	2.74%	8.25%
Kansas	2,989,966	0.68%	65.79%	23.40%	0.08%	2.29%	7.77%
Kentucky	4,800,674	0.77%	69.09%	17.38%	0.79%	3.88%	8.08%
Louisiana	4,543,869	0.28%	58.43%	25.07%	0.69%	6.37%	9.16%

Table 4.3.4   Estimated VMT by Vehicle Type
By State, 2010 (continued)

State	Total VMT (Millions)	10 – MC	20 – PC	30 – LT	40 – Bus	50 – SUT	60 – CT
Maine	1,454,938	1.06%	68.82%	20.39%	0.77%	4.13%	4.83%
Maryland	5,612,552	0.30%	77.04%	15.01%	0.66%	3.58%	3.41%
Massachusetts	5,436,199	0.90%	80.83%	13.39%	0.83%	2.14%	1.91%
Michigan	9,756,736	0.81%	69.71%	21.70%	0.14%	2.09%	5.55%
Minnesota	5,638,749	0.93%	65.18%	27.27%	0.41%	2.61%	3.59%
Mississippi	3,984,103	0.35%	65.02%	23.24%	0.56%	3.80%	7.04%
Missouri	7,086,400	0.88%	60.83%	22.98%	0.43%	3.85%	11.03%
Montana	1,118,981	0.85%	50.97%	36.35%	0.81%	3.10%	7.93%
Nebraska	1,943,795	0.41%	57.29%	29.63%	0.14%	2.25%	10.27%
Nevada	2,220,142	0.27%	86.31%	5.47%	0.52%	2.37%	5.06%
New Hampshire	1,306,522	1.19%	69.88%	22.08%	0.47%	3.69%	2.68%
New Jersey	7,302,766	0.15%	72.92%	18.96%	0.23%	3.12%	4.62%
New Mexico	2,527,368	0.61%	53.63%	24.29%	1.40%	8.14%	11.93%
New York	13,125,206	0.56%	76.18%	16.40%	0.54%	2.79%	3.52%
North Carolina	10,238,497	0.57%	71.87%	17.37%	0.74%	3.81%	5.63%
North Dakota	826,226	1.91%	45.19%	31.32%	1.34%	6.98%	13.26%
Ohio	11,183,573	0.67%	73.13%	15.91%	0.00%	1.99%	8.31%
Oklahoma	4,774,592	0.36%	57.26%	27.37%	0.35%	6.02%	8.63%
Oregon	3,377,411	0.66%	54.70%	31.05%	0.72%	5.21%	7.65%
Pennsylvania	10,032,871	0.91%	67.65%	15.11%	0.50%	6.56%	9.27%
Rhode Island	828,022	0.36%	77.93%	17.37%	0.36%	1.94%	2.04%
South Carolina	4,912,434	0.55%	72.88%	15.63%	0.67%	3.83%	6.44%
South Dakota	886,598	1.84%	54.42%	28.96%	0.14%	11.92%	2.72%
Tennessee	7,043,882	1.22%	64.70%	22.75%	0.10%	2.71%	8.53%
Texas	23,401,591	0.30%	63.75%	23.68%	0.24%	4.49%	7.54%
Utah	2,658,522	0.83%	53.46%	23.50%	0.56%	10.32%	11.34%
Vermont	724,756	1.18%	68.26%	21.47%	0.85%	4.79%	3.45%
Virginia	8,217,061	0.38%	75.14%	17.59%	0.58%	1.45%	4.87%
Washington	5,719,044	0.38%	62.24%	27.38%	0.25%	5.28%	4.48%
West Virginia	1,920,303	0.78%	68.42%	20.26%	0.72%	4.09%	5.73%
Wisconsin	5,942,027	0.55%	68.20%	17.75%	0.71%	6.98%	5.81%
Wyoming	936,279	0.32%	43.17%	39.25%	0.50%	2.22%	14.54%
Total, All States	**296,702,178**	**0.62%**	**68.30%**	**20.63%**	**0.47%**	**3.73%**	**6.25%**

Source: Cambridge Systematics analysis of FHWA data from Highway Statistics 2010. See the NCHRP 25-38 Final
Report for a discussion of analysis procedures.

4.3.5   Examples

Example 4.3.1 – Developing VMT Inputs from Travel Demand Model Output

In this example, the MOVES user has obtained VMT outputs by road type from the regional travel demand model. Distributions of VMT by vehicle type and road type are obtained from statewide classification counts and used to apportion the regional VMT among HPMS vehicle classes. The sample data are from Hamilton County, the Tennessee portion of the Chattanooga, Tennessee air quality nonattainment area, for the year 2009. The example also could be applied to a group of counties with the same MOVES inputs.

Step 1:   Aggregate travel demand model VMT output (annual average daily VMT, or AADVMT) by road type. The model contains 12 road types which must be aggregated into the four MOVES road types (Table 4.3.5).

Table 4.3.5   VMT from Travel Demand Model

HPMS Code	HPMS Functional Class Description	AADVMT (Model Output)	MOVES Road Type Code	MOVES Road Type Description	AADVMT	Percent of AADVMT
1	Rural Interstate	206,773	2	Rural Restricted Access	206,773	2.17%
2	Rural Principal Arterial	238,856	3	Rural Unrestricted Access	803,077	8.43%
6	Rural Minor Arterial	250,486				
7	Rural Major Collector	198,727				
8	Rural Minor Collector	52,935				
9	Rural Local	62,072				
11	Urban Interstate	2,695,864	4	Urban Restricted Access	3,643,077	38.23%
12	Urban Freeway	947,214				
14	Urban Other Arterial	1,990,353	5	Urban Unrestricted Access	4,876,509	51.17%
16	Urban Minor Arterial	1,903,958				
17	Urban Collector	375,352				
19	Urban Local	606,846				
	Total	9,529,436			9,529,436	100.00%

Step 2: Develop statewide split of VMT by road type (four MOVES road types) and vehicle type (six HPMS types). This can be done at a substate or county level if data are available. However, in this situation vehicle classifications are only available at the state level. An example of the state-provided data is shown in Figure 4.3.3. Using motorcycles as an example, Table 4.3.6 illustrates how VMT fractions by four MOVES road types, were derived from distributions for nine HPMS types provided in the three years of state data. For MOVES road types with multiple corresponding HPMS road types, VMT fractions were weighted by the percentage of VMT on each road type, e.g.:

Urban Restricted Access = (0.42% * 11,414 + 0.26% * 2,000)/(11,414 + 2,000) = 0.39%

Figure 4.3.3   Example of Statewide Classification Count Report

```
2010 VEHICLE CLASSIFICATION SUMMARY SHEET


FUNCTIONAL SYSTEM:   RURAL PRINCIPAL ART                              02



        VEHICLE TYPE                        PERCENT OF TOTAL

CARS                                             64.83

MOTORCYCLES                                       1.35

PICKUPS,PANELS,VANS                              22.80

TOTAL PASSENGER VEHICLES                         88.98

BUSSES                                            0.05

SINGLE          DUAL REAR TIRE                    1.07
UNIT            3-AXLE                            1.72
TRUCKS          4-AXLE                            0.49

                SUBTOTAL                          3.33


TRACTOR         2S-1,3S-1,2S-2                     2.66
SEMITRAILER     3S-2,2S-3                          3.87
COMBINATIONS    3S-3,3S-4                          0.22

                SUBTOTAL                          6.75


TRACTOR         2S-1-2                            0.28
AND TWIN        2S-2-2,3S-1-2                      0.11
TRAILERS        7 AXLE                            0.55

                SUBTOTAL                          0.94

        SUBTOTAL COMBINATIONS                     7.69


TOTAL TRUCKS                                     11.02

OTHER VEHICLES                                    0.00

TOTAL VEHICLES                                  100.00
```

Source: Tennessee Department of Transportation.

Table 4.3.6   VMT Fraction by Vehicle Type: HPMS to MOVES Mapping
Example for Motorcycles

HPMS Road Type	2008	2009	2010	Avg.	2008 HPMS VMT (1,000s)	MOVES Road Type	
Rural Interstate	0.95%	1.06%	3.88%	1.96%	8,686	2 – Rural Restricted Access	1.96%
Rural Principal Arterial	2.63%	2.02%	1.35%	2.00%	5,360	3 – Rural Unrestricted Access	1.38%
Rural Minor Arterial	0.93%	1.18%	1.18%	1.10%	5,043		
Rural Major Collector	2.23%	0.44%	1.37%	1.35%	2,981		
Rural Minor Collector	1.75%	0.41%	0.40%	0.85%	2,981		
Urban Interstate	0.58%	0.23%	0.44%	0.42%	11,414	4 – Urban Restricted Access	0.39%
Urban Freeway	0.09%	0.26%	0.44%	0.26%	2,000		
Urban Principal Arterial	1.51%	0.57%	0.51%	0.86%	10,953	5 – Urban Unrestricted Access	0.91%
Urban Minor Arterial	0.88%	1.35%	0.82%	1.02%	8,170		
Urban Collector	2.03%	0.32%	0.32%	0.89%	2,967		
Total	0.86%	0.65%	1.27%	0.93%	69,661		

Step 3: For each vehicle type, weight the statewide VMT proportion across road types by the percent of travel on each road type from the regional travel model (Table 4.3.2). The result is shown in the "All" column of Table 4.3.6 (where the percentages in the column labeled 2, 3, 4, and 5 come from the right-most column of Table 4.3.7). For example, for motorcycles:

All motorcycles = 1.96% * 2.17% + 1.38% * 8.43% + 0.39% * 38.23% + 0.91% * 51.17% = 0.77%

Table 4.3.7   Statewide VMT Distribution by HPMS Vehicle Type and MOVES Road Type

		MOVES Road Type				Model Area
Code	HPMS Vehicle Type	2	3	4	5	All Road Types
10	Motorcycles	1.96%	1.38%	0.39%	0.91%	0.77%
20	Passenger Cars	52.73%	65.86%	65.04%	72.64%	68.73%
30	Other 2-axle 4-tire vehicles	18.47%	26.47%	21.06%	19.99%	20.91%
40	Buses	0.55%	0.08%	0.30%	0.11%	0.19%
50	Single-Unit Trucks	4.47%	2.46%	3.02%	1.92%	2.43%
60	Combination Trucks	22.11%	3.74%	10.19%	4.43%	6.96%
		100.00%	100.00%	100.00%	100.00%	100.00%

Step 4: Multiply the percentages shown in the "All" column by total VMT in the study region to obtain the VMT inputs for MOVES as shown in Table 4.3.8, for example:

$$\text{Motorcycle VMT} = 9{,}529{,}436 * 0.77\% = 73{,}671$$

Table 4.3.8   MOVES VMT Inputs for Example 1

HPMS Vehicle Type	HPMSVtypeID	yearID	HPMSBaseYearVMT	baseYearOffNetVMT
Motorcycle	10	2009	73,671	0
Passenger Car	20	2009	6,549,802	0
Light Truck	30	2009	1,993,001	0
Buses	40	2009	18,038	0
Single Unit Truck	50	2009	232,026	0
Combination Truck	60	2009	662,897	0

Refinement for Passenger Car/Light Truck Split

Standard vehicle classification counters, which work based on axle spacing, are relatively good at distinguishing motorcycles, passenger vehicles, buses, single-unit trucks, and combination trucks. However, they are not so good at distinguishing passenger cars from light trucks, which both have two axles with relatively similar wheelbases. Therefore, users of MOVES2010 may want to use a split of passenger cars versus light trucks from a different source than the roadway-based classification counts. MOVES2014 avoids this issue by requesting a single input for passenger car and light truck VMT.

One source is the population data embedded data in MOVES, which shows a split of 59.95 percent passenger cars and 40.05 percent light trucks in 2009 (the split varies by year). Another source would be to use state registration data to identify the percentage of vehicles registered in the county or study area that are passenger cars versus light trucks. These percentages should be weighted by the average annual mileage accumulation by vehicle type, which can be taken from MOVES embedded data unless data are available from a local source (such as a household travel survey or I/M program). A hypothetical example is shown in Table 4.3.9. Both of these methods would be preferable to the statewide classification counts, which show roughly a 3:1 split. The MOVES embedded data vary for future years reflecting projected changes in the vehicle fleet, but are not based on the current local vehicle fleet.

Table 4.3.9   Example of Passenger Vehicle VMT Weighting

Vehicle Type	Passenger Vehicles Registered	Average Annual Mileage	Fraction of Passenger Vehicle VMT
Passenger Car	57.60%	13,917	65.66%
Light Truck	42.40%	9,890	34.34%

4-50

A sample calculation for this table follows:

Passenger Car VMT % = (57.60% * 13,917)/[(57.60% * 13,917) + (42.40% * 9,890)] = 65.66%

The VMT fractions shown in this table must be reapplied to the total percent of class 20 and 30 vehicles shown in Table 4.3.5 (68.73% + 20.91% = 89.64%). So the new fraction of class 20 (passenger car) vehicles would be 89.64% * 65.66% = 58.86%, and the new fraction of class 30 (light truck) vehicles would be 89.64% * 34.34% = 30.79%.

Example 4.3.2 – VMT Trend Projections

This hypothetical example illustrates how projections of population and VMT per capita can be used to forecast future VMT, using data from Massachusetts. Historical data from 1990 through 2010 are used to project VMT through 2030. The steps are as follows, with excerpts of the data shown in Table 4.3.10:

1. Historical population estimates for 1990 through 2010 are taken from the U.S. Bureau of the Census. (Note that years between the decennial census are estimates that are not as accurate as the decennial census years).

2. Population projections for 2020 and 2030 are taken from state sources and intermediate years were obtained using linear interpolation. Population is projected to increase by 5.5 percent in 2030, compared to 2010.

3. Annual VMT for the state is obtained from FHWA's Highway Statistics, Table VM-2.

4. VMT per capita is calculated for each year between 1990 and 2010.

5. Trendlines are used to extrapolate VMT per capita (Figure 4.3.4). Two trendlines are established: using the 1990 to 2010 time period, and using only the last decade (2001 to 2010). Note that VMT per capita actually declined over the past decade compared with strong growth in the previous decade.

6. As a sensitivity analysis, three VMT projections are developed: 1) one using the higher rate of VMT growth (20-year trend); 2) using the decline observed over the past decade (10-year trend); and 3) assuming constant VMT per capita at the average level observed over the 2001 to 2010 period (Figure 4.3.5). These estimates show total VMT increasing by 2 to 15 percent over the 2008 to 2030 timeframe.

Figure 4.3.4   Historical (Estimated) and Projected VMT per Capita
Massachusetts

VMT per Capita

1990-2010 trendline
$y = 37.754x + 7693.4$

2001-2010 trendline
$y = -13.092x + 8536.4$
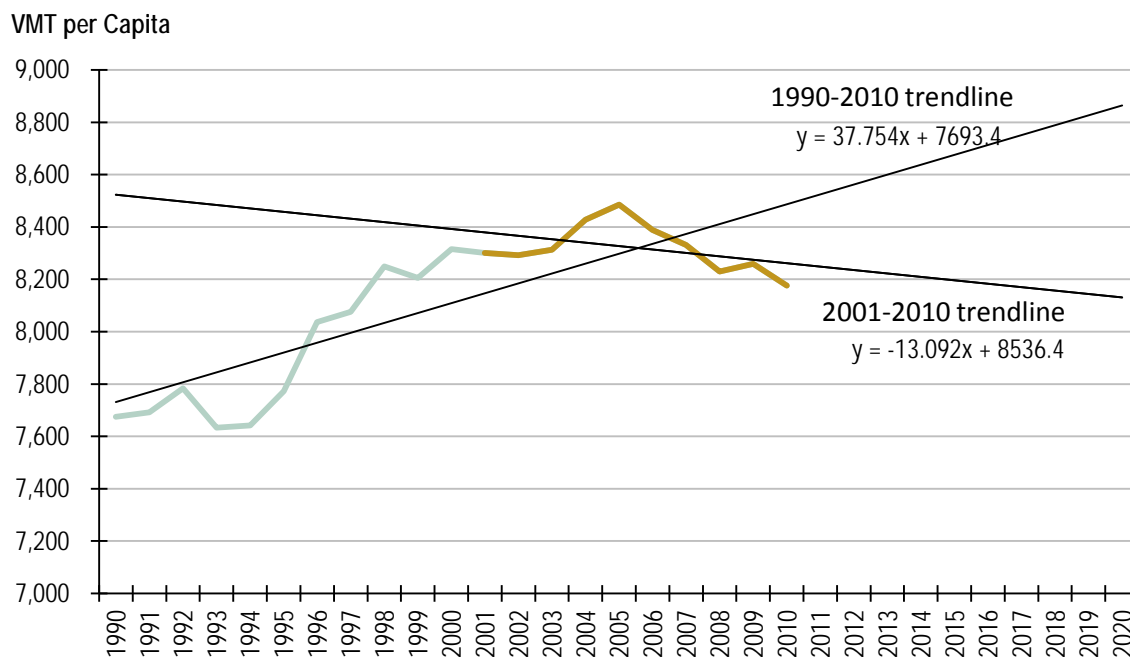
Figure 4.3.5   Historical and Projected Total VMT
Massachusetts

Total VMT (Millions)

- - - 20-year trend projection
——— Flat per capita @ 10-year avg
——— 10-year trend projection
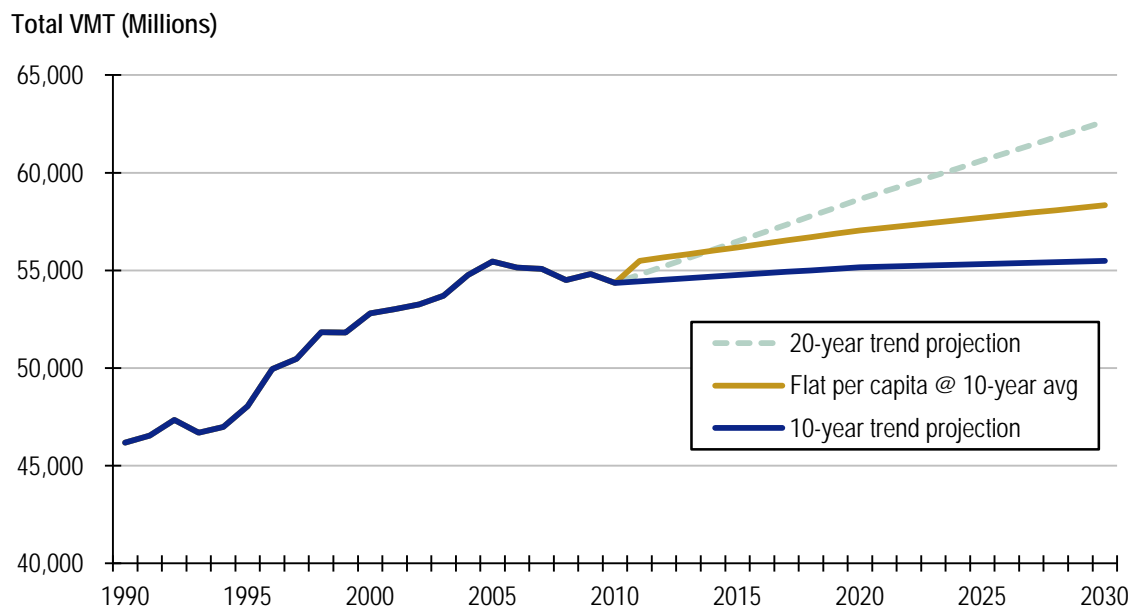
Table 4.3.10   Sample VMT and Population Data from Massachusetts

Year	Population	Annual VMT (Millions)	VMT per Capita				Projected Total VMT		
			Historical	10-Year Trend	Flat per Capita	20-Year Trend	10-Year Trend	Flat per Capita	20-Year Trend
1990	6,016,425	46,177	7,675						
…									
2000	6,349,097	52,796	8,316						
…									
2008	6,623,273	54,505	8,229						
2009	6,636,136	54,812	8,260						
2010	6,649,000	54,362	8,176	8,176	8,176	8,176	54,362	54,362	54,362
2011	6,669,700			8,163	8,320	8,214	54,444	55,494	54,783
2012	6,690,400			8,150	8,320	8,252	54,525	55,667	55,206
…									
2020	6,856,000			8,045	8,320	8,554	55,156	57,044	58,646
…									
2030	7,012,000			7,914	8,320	8,932	55,493	58,342	62,631
2030 versus 2010	5.5%			-3.2%		9.2%	2.1%	7.3%	15.2%

Example 4.3.3 – Using HPMS Segment Data to Develop County-Level VMT Estimates

In this example, the MOVES user needs to develop an estimate of total county-level VMT by road type. (The method can be used to develop a VMT estimate for any area for which the discrete highway segments can be identified, such as an urban area that does not coincide with county boundaries.) Since it is not already summarized elsewhere, the analyst obtains the HPMS segment data and develops an estimate using this data. An excerpt of the HPMS segment data is shown in Table 4.3.11, from Middlesex County, Massachusetts for 2007. Only selected fields of interest to this example are shown.

Table 4.3.11 HPMS Segment Data
Example

SECTION_ID	LENGTH	AADT	YEAR	STATE	COUNTY	FUNCLASS	AADVMT
6	0.23	3,000	2007	25	17	17	690
16	0.9	3,000	2007	25	17	17	2,700
56	1.24	7,700	2007	25	17	16	9,548
78	0.1	3,000	2007	25	17	17	300
120	0.24	13,600	2007	25	17	14	3,264
123	0.32	3,000	2007	25	17	17	960
126	0.17	3,000	2007	25	17	17	510
130	0.11	13,600	2007	25	17	14	1,496
169	0.13	3,300	2007	25	17	17	429
184	0.15	3,000	2007	25	17	17	450
194	0.09	700	2007	25	17	17	63
Etc…							

Step 1: Compute AADVMT. The last column of Table 4.3.8, AADVMT (annual average daily VMT), was not part of the HPMS file, but instead is computed by the analyst by multiplying the segment length (LENGTH) by traffic volume (AADT). For example, for Section ID 6:

$$AADVMT = 0.23 * 3000 = 690$$

Step 2: Sum AADVMT by HPMS functional class. This can be done by creating a pivot table if the calculation is performed in Microsoft Excel. The data should be filtered by year and county.

Step 3: Combine AADVMT by functional class into the four MOVES road types.

Step 4: Compute the percent of AADVMT by MOVES road type. The results of Steps 2 and 3 are shown in Table 4.3.12. The resulting VMT total and percentages by road type can be used in combination with state-level VMT distributions by vehicle type, as shown in Example 4.3.11.

Table 4.3.12   County VMT Summary

FUNCLASS	Functional Class Description	Sum of AADVMT	
6	Rural Minor Arterial	292,320	
7	Rural Major Collector	186,865	
11	Urban Interstate	24,222,041	
12	Urban Freeway	5,410,510	
14	Urban Other Arterial	14,087,197	
16	Urban Minor Arterial	8,719,096	
17	Urban Collector	4,149,957	
19	Urban Local	67,046	
	Total	**57,135,032**	
FType	**MOVES Road Type Description**	**Sum of AADVMT**	**Percent of AADVMT**
2	Rural Restricted Access	–	0.00%
3	Rural Unrestricted Access	479,185	0.84%
4	Urban Restricted Access	29,632,551	51.86%
5	Urban Unrestricted Access	27,023,296	47.30%
	Total	**57,135,032**	**100.00%**

■ 4.4 Temporal VMT Adjustments

4.4.1 Description and Format

Temporal VMT adjustments include month, day, and hour VMT fractions. These represent the fraction of total annual VMT that occurs in a given month, the fraction of total monthly VMT that occurs on weekdays (dayID = 5) versus weekends (dayID = 2), and the fraction of total daily VMT that occurs in a given hour, respectively. In all three cases, MOVES asks for these fractions for each of the 13 MOVES source types. For day and hour VMT fraction, it also asks for them by the four MOVES road types. For month VMT fraction, the user also must identify whether the analysis year is a leap year.

For the development of annual emissions inventories, the primary effect of different hourly and monthly distributions is the relationship between emissions and meteorological inputs (temperature and humidity), which vary by hour and by month. The sensitivity analysis conducted for this project found that changing hour and month distributions had modest (typically less than 1 to 2 percent) impacts on total annual emissions. However, hour fraction inputs can be more important for hotspot analysis, which focuses on peak-hour concentrations, and also to produce hourly outputs for regional ozone modeling. Analysis of hourly, daily (e.g., for comparison with a 24-hour standard), or episodic emissions estimates also will be affected by the relative amount of VMT in the month(s) being analyzed.

Tables 4.4.1, 4.4.2, and 4.4.3 show samples of the input format for these data tables. (The month and day fractions are the embedded MOVES distributions; the hour fractions are embedded MOVES distributions for urban roads on weekdays. The embedded distributions do not vary by source type.) Month VMT fraction has 156 lines of input (13 source types * 12 months); day VMT fraction has 1,560 lines of input (13 source types * 12 months * 5 road types * 2 day types); and hour VMT fraction has 3,120 lines of input (13 source types * 5 road types * 2 day types * 24 hours).

Table 4.4.1 Example of Month VMT Fraction Input

sourceTypeID	isLeapYear	monthID	monthVMTFraction[a]
11	N	1	0.0730856
11	N	2	0.0697126
11	N	3	0.0817315
11	N	4	0.0823022
11	N	5	0.0875028
11	N	6	0.0882716
11	N	7	0.0923251
11	N	8	0.0934297

Table 4.4.1   Example of Month VMT Fraction Input (continued)

sourceTypeID	isLeapYear	monthID	monthVMTFraction[a]
11	N	9	0.0846806
11	N	10	0.0865160
11	N	11	0.0802282
11	N	12	0.0802141
21	N	1	0.0730856
21	N	2	0.0697126
Etc.			

[a]MonthVMTfraction must sum to 1 for each for each source type.

Table 4.4.2   Example of Day VMT Fraction Input

sourceTypeID	monthID	roadTypeID	dayID[a]	dayVMTFraction[b]
11	1	1	2	0.237635
11	1	1	5	0.762365
11	1	2	2	0.278820
11	1	2	5	0.721180
11	1	3	2	0.278820
11	1	3	5	0.721180
11	1	4	2	0.237635
11	1	4	5	0.762365
11	1	5	2	0.237635
11	1	5	5	0.762365
11	2	1	2	0.237635
11	2	1	5	0.762365
Etc.				

[a]DayID = 2 represents weekends; dayID = 5 represents weekdays.

[b]dayVMTFraction must sum to 1 for each source type-month-road type combination.

Table 4.4.3   Example of Hour VMT Fraction Input

sourceTypeID	roadTypeID	dayID	hourID[a]	hourVMTFraction[b]
11	4	5	1	0.009862
11	4	5	2	0.006272
11	4	5	3	0.005058
11	4	5	4	0.004667
11	4	5	5	0.006995
11	4	5	6	0.018494
11	4	5	7	0.045957
11	4	5	8	0.069644
11	4	5	9	0.060828
11	4	5	10	0.050286
11	4	5	11	0.049935
11	4	5	12	0.054365
11	4	5	13	0.057646
11	4	5	14	0.058032
11	4	5	15	0.062255
11	4	5	16	0.071005
11	4	5	17	0.076973
11	4	5	18	0.077432
11	4	5	19	0.059783
11	4	5	20	0.044392
11	4	5	21	0.035446
11	4	5	22	0.031824
11	4	5	23	0.024942
11	4	5	24	0.017907
11	4	5	1	0.009862
Etc.			…	

[a] HourID = 1 represents 12:00 midnight to 1:00 a.m.; hourID = 2 represents 1:00 a.m. to 2:00 a.m.; etc.

[b] HourVMTfraction must sum to 1 for each for each source type-road type-type of day combination.

Broad temporal patterns (month, day, and hour VMT fractions for all vehicles) can be developed with relative ease from traffic monitoring stations. It is more difficult to obtain data to make temporal adjustments specific to source type, since the network of stations providing vehicle classification is small and may not be representative of the modeled area. However, temporal patterns (especially hourly) do vary by source type, most

notably for passenger vehicles versus heavy trucks. Illustrative data are provided in Section 4.4.4 to show how distributions vary by source type.

Some temporal inputs may not be important depending upon how the model is used. For example, some MOVES users run the model on a daily basis for SIP and conformity pur-poses, entering seasonally adjusted weekday VMT for the period being modeled. However, in such a situation month VMT adjustment factors may still need to be applied "off-model."

4.4.2   Source of Embedded Data and EPA Guidance

The relevant sections of the MOVES User Guide, guidance documents, and data tables are:

- MOVES2010b User Guide (2012):   Section 2.3.3.4.4, Vehicle Type VMT, and VMT Fractions (p. 69).   Note that temporal distributions are entered on the "Vehicle Type VMT" tab in the County Data Manager.

- MOVES SIP and Conformity Guidance (2012): Section 4.5, Vehicle Type Vehicle Miles Traveled (p. 35), although this document does not provide guidance specifically with respect to temporal distributions.

- MOVES GHG Guidance (2012): Section 4.6, Vehicle Type VMT (p. 49).

- Data tables: Embedded temporal distributions can be found in the EPA converter file, the "AAD VMT Calculator HPMS" (see "Sample Data and Tools").

Embedded data in MOVES2010 are based on a U.S. DOT research study (Festin, 1996) which analyzed data from a sample of 5,000 continuous traffic counters distributed through the U.S. Since the report does not provide values by vehicle or source type, the same temporal distributions are assumed for all source types. Further details on the development of the MOVES2010 embedded data are provided in EPA (2010).   For MOVES2014, updates are being made to temporal VMT allocations for motorcycles, based on Bureau of Transportation Statistics crash statistics. Temporal allocations for other source types will not be changed.

EPA does not recommend specific local data sources for temporal distribution (VMT frac-tion) inputs, but does recommend using local data if available. Sources recommended for the VehicleTypeVMT input, which also could be used for some or all of the temporal inputs, could include HPMS, local counts, and travel demand model data. As an alterna-tive, national defaults are available in MOVES for all three inputs.

For most emissions analyses for SIP or transportation conformity purposes, the use of weekday data is recommended. Weekday data should be used for any inventory that rep-resents a typical summer or winter day. Weekend day data may be used if the user needs to prepare an inventory for a multiday period that includes weekend days, and if week-end day data with different speed distributions, daily VMT fractions, and/or hourly VMT fractions are available.

Forecast year data. EPA guidance does not specifically address the development of forecast year temporal adjustments. For the most part, forecasting methods do not predict temporal VMT distributions that differ from the base year. The exception is VMT fractions by time period from a travel demand forecasting model, which may show different distributions of travel by time of day in different years. The model period distributions can be subdivided into hour distributions based on historical data as described below. Models are typically not available to forecast day and month VMT fractions, so the most recent historical VMT fractions are typically used for these parameters.

4.4.3 Data Sources, Procedures, and Methods

Local data source options for this input are summarized in Table 4.4.4.

Table 4.4.4 Summary of Options for Temporal Adjustments

Data Source or Procedure	Use	Uses and Advantages	Limitations
MOVES embedded data	Common	Temporal adjustments fairly stable over time and across geographies.	Based on FHWA research study from 1996; does not vary by vehicle type.
ATR and other local counts	Common	Local data source for hour, day, and month fractions.	Limited number of sites.
VTRIS	Limited	Data from a sampling of HPMS monitoring stations available nationwide.	Not readily available to public. Not suitable for month fractions.
Model (TDFM) VMT fractions by time of day (for HourVMTFraction)	Limited	Use for three to four time-of-day periods.	Must be disaggregated further with MOVES defaults. Not suitable for day or month fractions.
ITS data (collected via loops, radar, video)	Experimental	ITS traffic monitoring systems exist in many cities.	Typically do not distinguish vehicle types. Usually only deployed on restricted access roads.
Vehicle-based traffic monitoring methods (GPS, cell phone, Bluetooth)	Experimental	Sources primarily used for travel time/speed data may be suitable for identifying certain temporal distributions.	Typically do not distinguish vehicle types.

4.4.3.1 *Automated Traffic Recorders and Other Local Counts*

Existing local traffic monitoring systems can be used for all three types of temporal adjustments if data can be obtained from the state DOT or a local traffic authority. Short-term monitoring stations can be used to develop hour VMT fractions, but only permanent monitoring stations (of which there is a much smaller number) can be used to develop day and month fractions. Traffic monitoring systems should cover all the MOVES road types. However, only stations with classification count equipment can be used to develop VMT fractions specific to different MOVES source types. The classification counts will typically distinguish HPMS source types (see Section 4.3) and the temporal distributions for MOVES source types within each HPMS type (e.g., short- versus long-haul single unit trucks) must be assumed to be the same.

Using local data on temporal distributions may be preferable to using default data from national sources. However, the MOVES user should ensure that the stations are in locations where traffic patterns will be "typical" of regional patterns. Data from locations near major traffic generators with non-typical demand patterns (e.g., an airport, stadium, large industrial facility, or major tourist destination) may not be representative of average regional patterns. The suitability may depend upon the type of VMT fraction (hourly, day versus weekend, month).

Traffic counts are often conducted internally by transportation agency staff. However, if contracted out, costs for one-time counts can be in the range of a few hundred to a thousand dollars per site.

4.4.3.2 Vehicle Travel Information System

FHWA's Vehicle Travel Information System contains traffic data from permanent traffic count stations as well as truck weigh stations, as collected by states and reported to FHWA. The VTRIS data can be used to obtain temporal distributions of VMT by vehicle and roadway class for states that report data to FHWA. These data can be obtained by request from FHWA but are not readily available to the general public.

Lindhjem and Shepard (2007) examined data from VTRIS and FHWA's Travel Volume Trends (TVT) reports (also developed from vehicle counts and classification data) to examine temporal differences in vehicle mix, using 13 axle/unit-based vehicle type categories defined by FHWA. They found significant differences in source type by time of day, with smaller differences by day of week and no clear seasonal patterns. Vehicle mix and temporal patterns were examined by state and by road type, although some states were missing data due lack of classification count coverage. Variations by state appeared to be largely related to urban versus rural traffic, and to differences for coastal versus mid-country locations.

VTRIS data reported for 2012 were analyzed for the development of this resource document. An Excel tool providing hour and day VMT fractions by HPMS vehicle type is provided along with this document ("MOVES VTRIS Tool"), and the analysis procedures are described in the NCHRP 25-38 Final Report. Only 27 states reported data to FHWA for VTRIS in 2012, and of these states, some reported data for only a small number of stations. Therefore the reported data in some states may not be representative for all road types. Also, a full year's worth of data were only available for one state (Maine) and only for rural roads in that state, so the VTRIS data could not serve as a source of month fractions by source type. Examples are provided in Section 4.4.4.

4.4.3.3 Travel Demand Forecasting Models

Travel demand models are typically developed for up to four time periods, including a.m. peak, midday, p.m. peak, and overnight. Some models may only include two or three time periods (e.g., peak, off-peak). These models are based on various assumptions of trip characteristics by time period and calibrated against observed traffic counts, providing a distribution of VMT by the time periods. For historical year data, it may be more straightforward just to use the traffic counts to develop the hourly fractions, rather than using the

model period fractions and distributing these by hour. However, it may be preferable to use model data if consistency is desired between historical and future year period fractions.

The time period VMT distribution must be further subdivided into the 24 hours required by MOVES. This can be done by evenly distributing the VMT within a time period across the hours within that time period, but a better method is probably to use hourly distributions from another sources (MOVES embedded data, or local traffic counts) to proportion the modeled period distributions. When a model time period is based on fractional hours (e.g., 4:30 to 7:30 p.m.), the most "correct" way of assigning VMT to the MOVES hours is in proportion to the hour overlapped, but an approximation of simply shifting the peak to the nearest set of whole hours (e.g., 4:00 to 7:00 p.m.) is simpler and probably will result in a negligible difference in emissions outputs. Example 4.4.1 provides some illustrations of developing hourly adjustments using a travel demand forecasting model.

4.4.3.4 *Infrastructure-Based Intelligent Transportation Systems*

Intelligent Transportation Systems data refers here to traffic data collected by public agencies (state DOT, regional transportation system operator, or local transportation department) to support day-to-day operation of the transportation system, performance measurement, and longer-term planning. This section focuses on infrastructure-based data collection methods, including loop detectors, radar, and video cameras.

Data may be archived at intervals of five minutes or even less. Data processing is generally required to aggregate the data into the time periods required for MOVES (e.g., aggregating five-minute volumes into hourly volumes). One limitation for the development of MOVES inputs is that in most areas, ITS monitoring equipment is only deployed on limited-access highways, although in some places major arterial corridors are seeing increasing deployment. Also, information on vehicle type is typically not collected and archived. The equipment may be capable of making length-based vehicle classifications which may be associated with broad vehicle classes (e.g., light-duty car and truck, single-unit truck, combination truck) but this is usually done only for specific studies when classification information is required.

Where deployed on the regional highway system, archived ITS sources will typically provide much more comprehensive coverage than permanent count stations. However, because of the extensiveness of the network, equipment failures can be common and data quality must be carefully evaluated.

Examples of temporal distributions developed from ITS data are provided below under "Sample Tools and Data."

4.4.3.5 *Vehicle-Based Traffic Monitoring Methods*

Vehicle-based traffic monitoring methods refer to the use of global positioning systems (GPS), cell phones, Bluetooth, or other sensors located on or within vehicles. These methods are evolving rapidly. They are often collected by private companies and made available for a fee to public entities after data have been aggregated and any identifying information stripped. Fees typically range from a few thousand to a few tens of thou-

sands of dollars, depending upon the area size and level of disaggregation; and public agencies can often obtain licensing discounts if the data already are being provided for another purpose. The primary vehicle-based sources of traffic monitoring data currently include GPS navigational units, Bluetooth readers, and cell phones. These sources are discussed in more detail in Section 4.7, Speed Distributions.

The primary objective of data collection from these sources is to provide real-time information on travel speeds and times, but they also may have other uses such as examining temporal distributions in traffic. From sources with a broad vehicle population base such as GPS units and cell phones, the relative density of traffic could be used to develop hour, day, and month VMT fractions. However, this information would need to be developed from raw data by the private data aggregator. Data gathered from instrumented fleets would need to be reviewed to ensure the fleets are likely to have temporal patterns representative of non-instrumented vehicles.

All of these sources can provide broader coverage of the road network than infrastructure-based ITS monitoring sources which are primarily deployed on freeways. The data are typically provided in geographic information systems (GIS) format so that they can be associated with a road network. For MOVES purposes this allows the data to be matched with MOVES road types. However, the sources rarely contain information on the type of vehicle and therefore cannot be used to develop information by source type. One exception is the Highway Visibility System (HIVIS), a private database of telematics data collected from truck fleets, which can provide temporal information specific to combination trucks.

4.4.4 Sample Data and Tools

Spreadsheet Converters

EPA provides a series of eight spreadsheet tools that convert VMT based on MOBILE6 or NMIM vehicle types and road types (at varying levels of detail) to MOVES vehicle (source) types and road types. An additional spreadsheet, the "AAD VMT Calculator HPMS" tool, accepts input from these other spreadsheets and performs the following functions:

• Uses Annual Average Weekday Vehicles Miles Traveled (AADVMT) at the HPMS level to calculate type of day, monthly and yearly VMT in terms of HPMS and/or MOVES source types;

• Generates the HPMSVTypeYear, monthVMTFraction, and dayVMTFraction tables from AADVMT and monthly/weekend-day adjustment factors;[14] and

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[14] The monthly adjustment factors are ratios of observed monthly VMT to one-twelfth of annual VMT, i.e., if distributed evenly over 12 months. The weekend-day adjustment factors are ratios of average weekend day traffic to average weekday traffic.

- Provides the user with the default temporal allocation tables if local inputs are not known.

The converters are available under "VMT Converters" at: http://www.epa.gov/otaq/ models/moves/tools.htm.

VTRIS Tool

Produced in conjunction with this report is an Excel tool ("MOVES VTRIS Tool") for analyzing 2012 VTRIS data reported by 27 states. Pivot tables and charts are set up to allow users to extract or compare hour and day VMT fractions for available states, road types, and HPMS vehicle types. The data may not be reliable for states with a small number of classification counters. Also, month VMT fractions could not be obtained from the VTRIS data since year-round counts typically were not provided. Examples are provided below.

Hour VMT Fractions

Figures 4.4.1 and 4.4.2 show examples of hour VMT fractions by source type for urban restricted access and unrestricted access roads in Florida. The charts compare the embedded MOVES distribution (same for all source types) with source type distributions derived from VTRIS data. (Florida had one of the largest numbers of counting stations – 225 – reporting to VTRIS and so the data should be robust.) The chart for restricted access roads also shows the Jacksonville metro area hour fractions as derived from ITS monitoring data.

Figure 4.4.1   Hour Fractions, Florida, Restricted Access Urban Roads
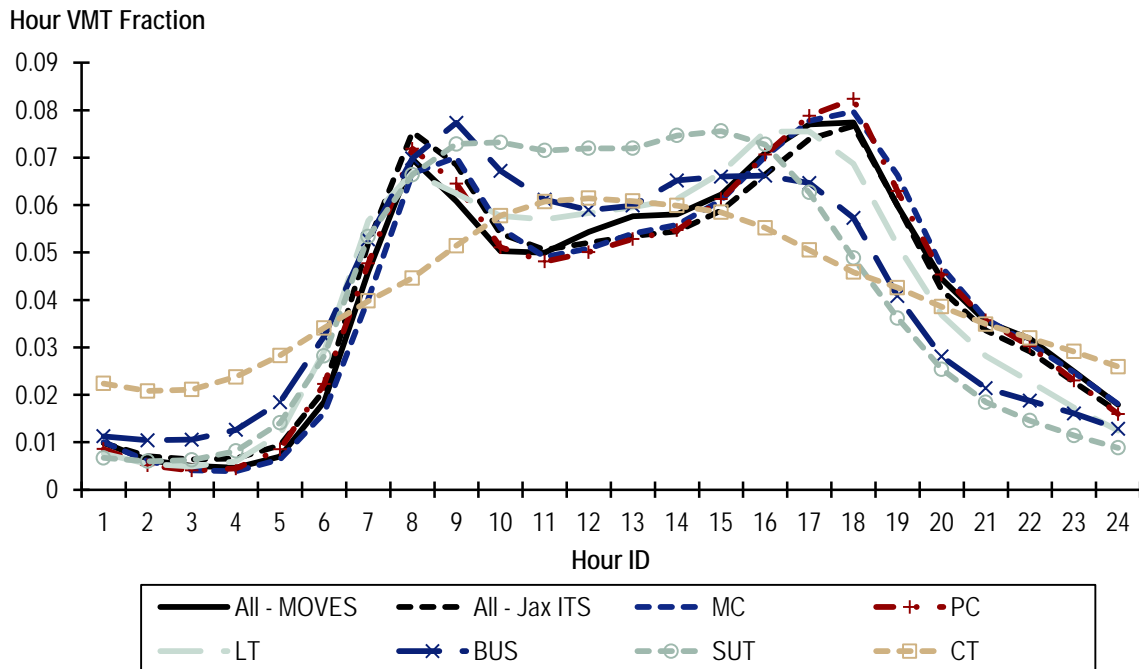
Sources: MOVES model; ITS data for Jacksonville metro area freeways for 2012 obtained from Florida DOT; FHWA VTRIS data for 2012 for State of Florida.

Figure 4.4.2   Hour Fractions, Florida, Unrestricted Access Urban Roads
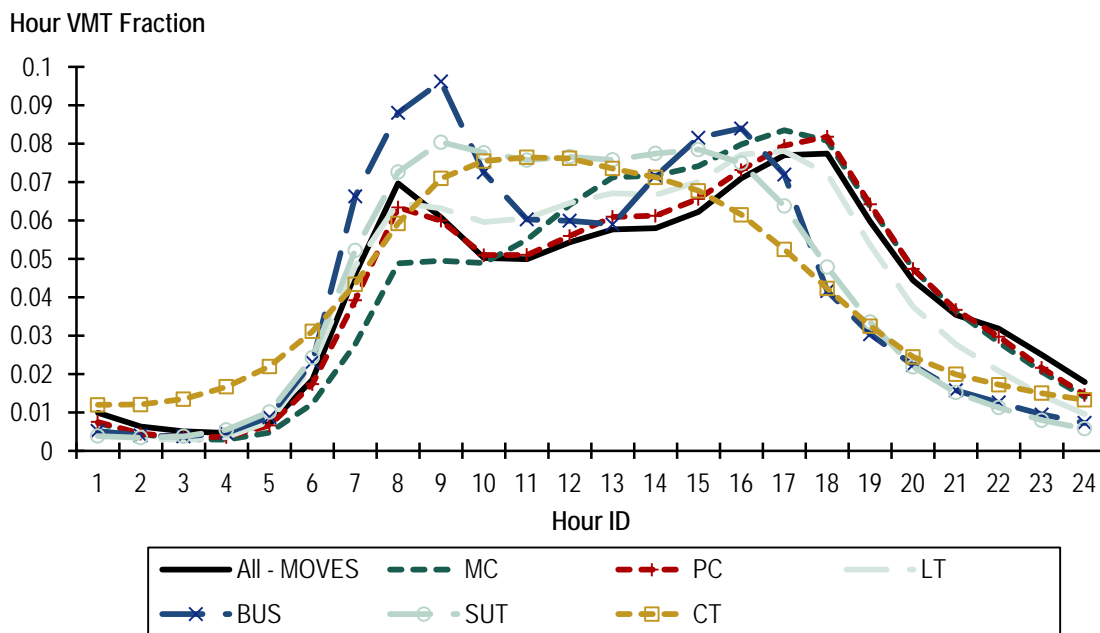
Hour VMT Fraction

Sources: MOVES model; ITS data for Jacksonville metro area freeways for 2012 obtained from Florida DOT; FHWA
          VTRIS data for 2012 for State of Florida.

Both the Jacksonville ITS data and the HPMS data for passenger cars closely mirror the embedded MOVES hour fractions. Light trucks show slightly higher midday and lower evening traffic, probably reflecting their use in part as commercial vehicles. Single-unit trucks show a relatively even distribution of usage from the morning peak to late after-noon. Combination truck usage peaks during the middle of the day but is also higher overnight than for other vehicle types.

Figure 4.4.3 compares passenger car hour fractions across states for urban restricted access roads, for states reporting to VTRIS. Figure 4.4.4 presents similar data for combination trucks. While there are some differences among states, the overall patterns are similar and most states are within plus or minus one percent of each other in a given hour. In some states, the data are taken from a very limited number of counters and therefore may not be representative of the temporal distributions for that road type. For example, the data from Maryland, New Hampshire, and West Virginia – which appear to be outliers – are based on only one to three stations in each state. Readers can explore these data further using the spreadsheet VTRIS analysis tool provided with this resource document.

Figure 4.4.3   Hour Fractions, Passenger Cars on Restricted Access Urban Roads
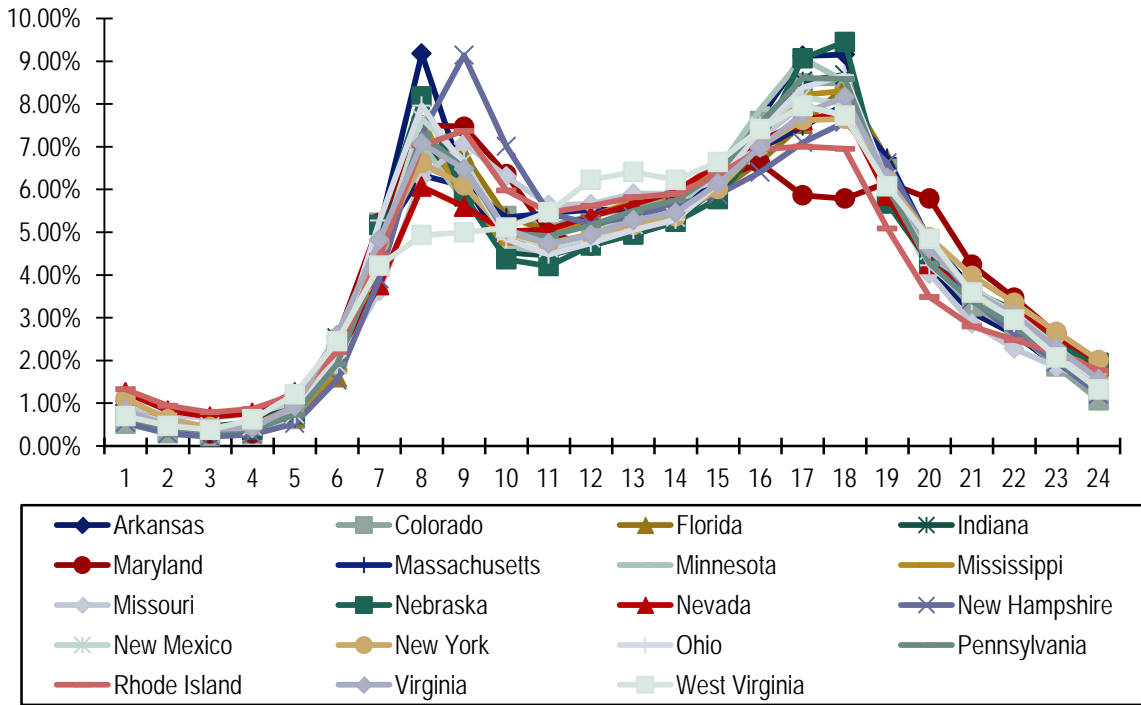
Source: FHWA VTRIS data for 2012.

Figure 4.4.4   Hour Fractions, Combination Trucks on Restricted Access Urban Roads
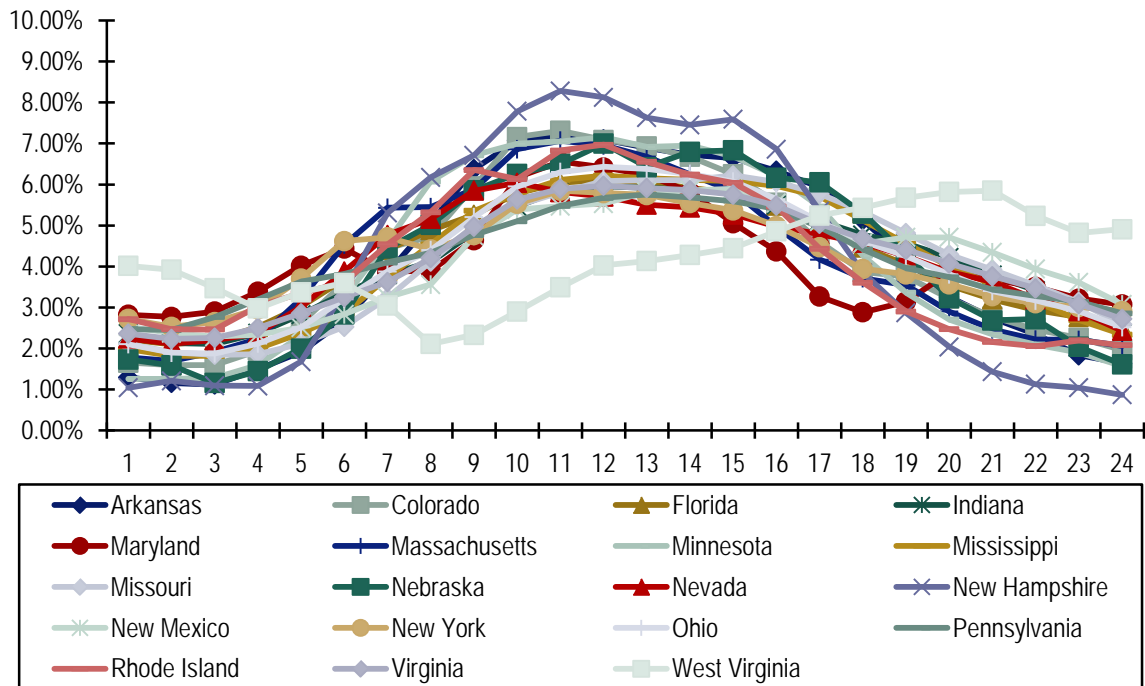
Source: FHWA VTRIS data for 2012.

Given the data limitations, MOVES users in most areas could *either* develop county-specific temporal profiles that are the same for all source types, *or* use a statewide or national temporal distribution that is different for each source type. If an accurate time-of-day profile is important (as it might be for regional air quality modeling), the second method might be preferable to the first, given that profiles vary substantially by source type but appear to show much less variation by geography. Further sensitivity testing would be required to confirm this. However, the choice of temporal distribution should have little impact on daily or annual emissions estimates as demonstrated in the sensitivity analysis (Section 3.0).

Day Fractions

Figure 4.4.5 compares day fractions for the same sources as compared above. The figure shows weekend VMT fraction (daytypeID = 2). The distribution on Jacksonville area freeways is almost identical to the MOVES embedded distribution with 23 percent of VMT occurring on weekends and 77 percent on weekdays. However, there are noticeable differences by source type. In particular, motorcycles, passenger cars, and to a lesser extent light trucks have higher-than-average VMT on weekends, whereas truck volumes are lower.

Figure 4.4.5   Weekend VMT Fractions, Florida, Urban Roads
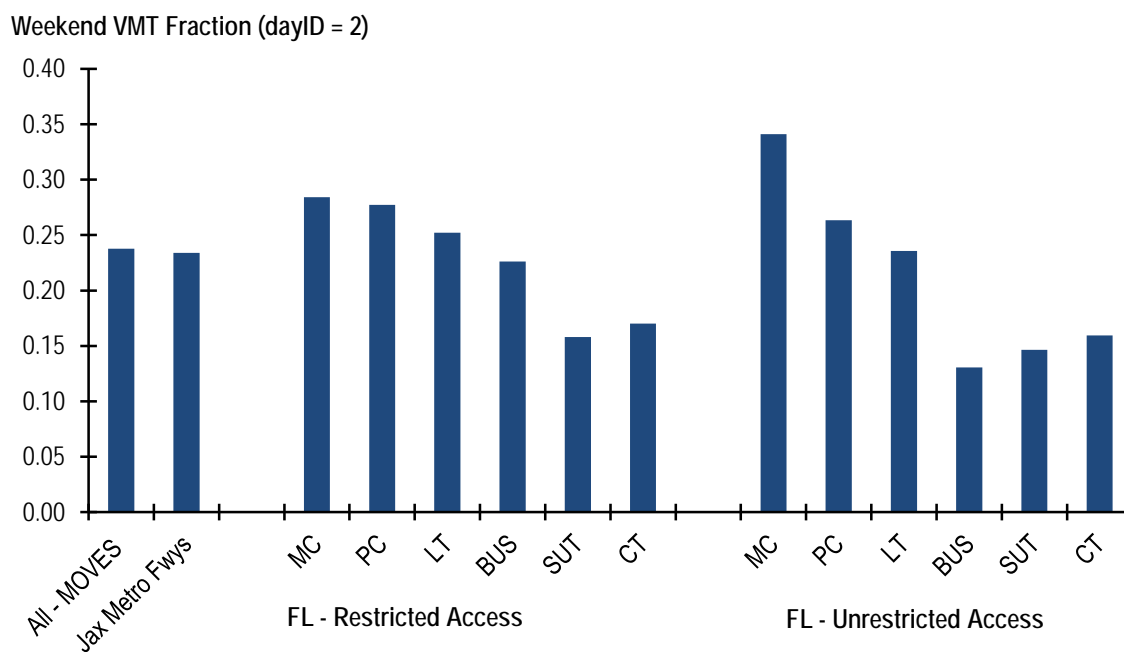
Sources: MOVES model; ITS data for Jacksonville metro area freeways for 2011 to 2012 obtained from Florida DOT; VTRIS data obtained from FHWA for 2011 for State of Florida.

Day fractions can be input separately by month. Table 4.4.5 compares day fractions for the Jacksonville metro area for January and July with the annual average. The variation is within the range of 1 percent in either direction, with July showing slightly higher weekend traffic volumes. The VTRIS data for Florida do not include an entire year of counts so this data source could not be included in the comparison.

Table 4.4.5   Day of Week Fractions by Month, Jacksonville Freeways

Day of Week	MOVES	Annual	January	July
Weekend (2)	23.8%	23.4%	22.4%	24.2%
Weekday (5)	26.2%	76.6%	77.6%	75.8%

Source: ITS data for Jacksonville metro area freeways for 2011 to 2012 obtained from Florida DOT.

Boriboonsomsin, Sheckler, and Barth (2012) compared day and hour fractions for a nationwide fleet of GPS-instrumented heavy-duty vehicles with the defaults in MOVES.[15] As shown in Table 4.4.6, they found that the VMT fraction on weekdays was about 10 per-cent higher than the MOVES default values (e.g., 0.86 versus 0.76 for urban roads in January) and the weekend VMT fraction was correspondingly lower. They hypothesized that this is because heavy trucks do not accumulate miles from social and recreational travel on weekends as passenger vehicles do. Weekday fractions were higher in urban areas. With respect to hourly fractions they found relatively higher VMT during the mid-dle of the day and overnight hours compared to MOVES defaults; the overnight fraction was higher on rural roads than urban roads. One limitation of their dataset was that it includes only 2,000 vehicles and the composition of the vehicle/fleet types in the dataset can change.

Table 4.4.6   Day of Week Distributions for Heavy-Duty Vehicles

| | Boriboonsomsin, Sheckler, and Barth (2012) | | | | MOVES2010 | |
| | January 2010 | | July 2010 | | 1995 | |
Day	Rural	Urban	Rural	Urban	Rural	Urban
Weekday	0.8207	0.8594	0.7967	0.8621	0.7212	0.7624
Weekend	0.1793	0.1406	0.2033	0.1379	0.2788	0.2376
Total	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

4.4.5   Examples

Example 4.4.1   Developing Hour VMT Fractions from Travel Demand Model Output

This example illustrates how hour VMT fractions may be developed from the output of a travel demand model. The model has four time periods: 1) a.m. peak (7:00-10:00 a.m.), 2) midday (10:00 a.m.-4:30 p.m.), 3) p.m. peak (4:30-7:30 p.m.), and 4) nighttime (7:30 p.m.-

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[15] This is the Highway Visibility System dataset, a private database containing several hundred million records of commercial vehicle activity data from the telematics-based tracking and monitoring systems in the vehicles of participating fleets. The monitored trucks were mostly based in California and the Northeast. The dataset analyzed was comprised of 90 percent combination trucks and 10 percent single-unit trucks.

7:00 a.m.). This example is taken from the First Coast MPO's model for the Jacksonville, Florida region, for 2005. The steps in this example are as follows:

1. Code network links in the model output file by MOVES road type, if not already done (see Section 4.5 for a discussion of road type mapping).

2. If VMT is not part of the model output file, calculate for each network link as:

    VMT = Vehicle count * Length of the link (in miles)

3. Sum VMT for each MOVES road type for each of the four time periods. In this example, auto and truck VMT are summed separately because the model has a separate truck model.[16] For example (see table):

    Day VMT (RT=4) = 12,509,306

    A.M. VMT (RT=4) = 2,229,154 = 15.96% of Day VMT

MOVES Road Type	Auto A.M. VMT	Auto Midday VMT	Auto P.M. VMT	Auto NT VMT	Auto Day VMT
2	285,593	587,389	431,174	485,453	1,789,610
3	818,678	1,509,393	1,191,997	1,336,520	4,856,587
4	**2,229,154**	3,726,748	3,295,679	3,257,724	**12,509,306**
5	3,672,245	6,514,581	5,418,495	5,775,527	21,380,847

4. To compute an Hour VMT Fraction not adjusted for hourly differences within the time period, allocate the fraction of VMT in the period evenly over the hours within that time period.

    Example: Hour VMT Fraction (RT=4) for hours 8, 9, and 10 = 0.1596/3 = 0.0532

5. To compute an Hour VMT Fraction adjusted for hourly differences based on MOVES defaults, allocate the period VMT fraction in proportion to the MOVES default hour fractions within each period. A similar procedure can be applied to adjust model fractions using hourly distributions as observed from traffic counters.

    Example: Adjusted Hour Fraction (Hour 8) = 0.1596 * (0.0696/0.1808) = 0.0615 (see table)

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[16] Most travel demand models do not have a separate truck forecasting model, but simply proportion VMT by auto versus truck based on traffic counts, in which case the hour fractions for a given road type will be the same for all source types.

HourID	Hour Fraction of VMT		
	MOVES	Model	Adjusted
8	0.0696	0.0532	0.0615
9	0.0608	0.0532	0.0537
10	0.0503	0.0532	0.0444
Sum – a.m. period	0.1808	0.1596	0.1596

6. Repeat this calculation for each road type and time period, and separately for auto and truck (if auto and truck VMT and provided as separate model outputs). The auto VMT fractions can be used for source types 11-32, and the truck fractions for source types 41-62 (buses and heavy trucks). (Alternatively, truck fractions could be used for source type 32 – commercial light trucks – and auto fractions for buses, assuming that temporal distributions are more similar for passenger vehicles versus goods and service vehicles. However the impact will be small.)

Figure 4.4.6 illustrates how VMT distributions can vary by road type and vehicle type. In this example using data from the Jacksonville model, truck VMT is somewhat lower in the peak periods and higher in the off-peak periods, especially midday, compared to auto VMT. Differences in period VMT fractions for urban restricted versus unrestricted roads are small, less than 1 percent in most cases.

Figure 4.4.6   VMT Fractions by Time Period, Jacksonville Model
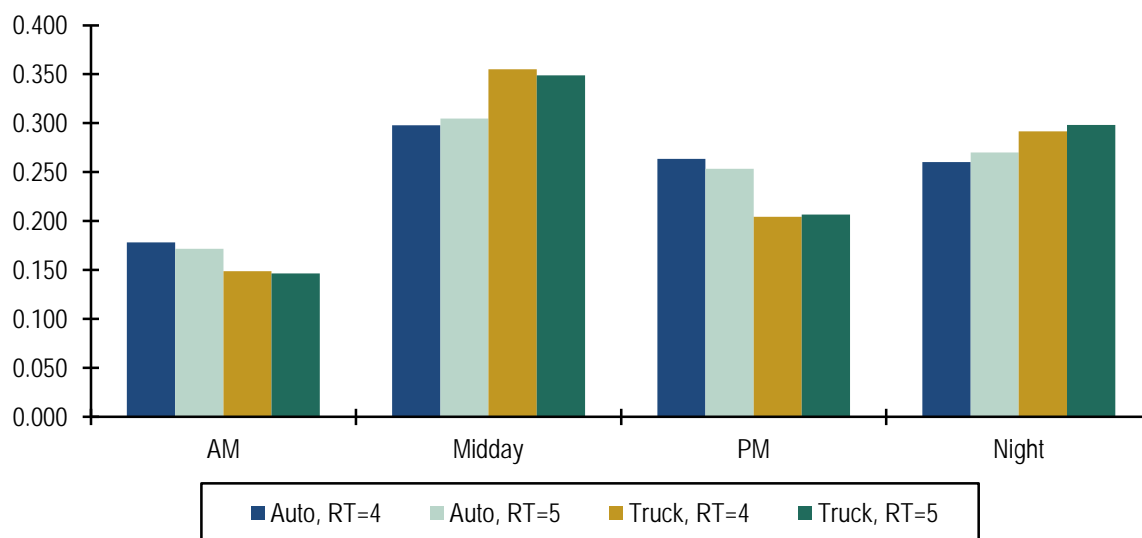
■ 4.5 Road Type Distribution

4.5.1 Description and Format

Road type distribution is a set of five fractions that sum to 1, which represents the percent of VMT on each of five road types used in MOVES. These road types are off-network, rural restricted access, rural unrestricted access, urban restricted access, and urban unrestricted access. Currently the option to model off-network VMT in MOVES is disabled. Users should enter zeros for road type 1 to avoid having MOVES discard that portion of the VMT. Table 4.5.1 shows an example of the format for this input. MOVES requests this distribution for each of the 13 source (vehicle) types.

Table 4.5.1   Example of Road Type Distribution Input

sourceTypeID	roadTypeID	roadTypeVMTFraction
11	1	0
11	2	0.166473
11	3	0.244940
11	4	0.235751
11	5	0.352836
21	1	0
21	2	0.166473
Etc.	…	…

Road type was an input in MOBILE6, but different road types were used (highway, arterial/collector, local, ramp). This information is required for emissions modeling because the traffic conditions on different types of roads affect the emission rates. For example, arterials and local roads have more stop and go conditions with more acceleration/deceleration patterns than highways.

HPMS and many travel demand models categorize road types by the FHWA functional classification system. Table 4.5.2 provides a general map between FHWA functional class and MOVES road types. It should be noted that functional class 2 "rural principal arterial – other" and 12 "urban principal arterial – other freeways and expressways" sometimes contain both restricted and unrestricted access facilities (or partially restricted access facilities). Therefore, manual coding of MOVES road type for model network links with these two functional classes may be necessary, but using the assumptions shown in Table 4.5.2 (that most functional class 2 map to MOVES road type 3, and most functional class 12 map to MOVES road type 4) is a good starting point.

Table 4.5.2   FHWA Functional Classification Mapped to MOVES Road Types

Functional Class Code	Functional Class Name	MOVES Road Type ID	MOVES Road Type
1	Rural Principal Arterial – Interstate	2	Rural Restricted Access
2	Rural Principal Arterial – Other	3	Rural Unrestricted Access
6	Rural Minor Arterial	3	Rural Unrestricted Access
7	Rural Major Collector	3	Rural Unrestricted Access
8	Rural Minor Collector	3	Rural Unrestricted Access
9	Rural Local	3	Rural Unrestricted Access
11	Urban Principal Arterial – Interstate	4	Urban Restricted Access
12	Urban Principal Arterial – Other Freeways and Expressways	4	Urban Restricted Access
14	Urban Principal Arterial – Other	5	Urban Unrestricted Access
16	Urban Minor Arterial	5	Urban Unrestricted Access
17	Urban Collector	5	Urban Unrestricted Access
19	Urban Local	5	Urban Unrestricted Access

The sensitivity analysis conducted for this project tested the impact of making the road type distribution the same for all 13 source (vehicle) types as opposed to the MOVES embedded road type distributions, which provide a different distribution for each the six HPMS vehicle types (groups of the 13 source types). This analysis found that using the same distribution for all 13 source types has only a modest impact on most pollutants (increase of less than 5 percent for VOC, CO, NO_x, and CO_2) and a moderate impact for PM_{10} (increase of approximately 10 percent). The nonattainment/maintenance status for different pollutants can be used in combination with these sensitivity analysis results to help an area decide if it is worth the extra effort to develop road type distributions for each source type.

4.5.2   Source of Embedded Data and EPA Guidance

The relevant sections of the MOVES User Guide, guidance documents, and data tables are:

- MOVES2010b User Guide: Section 2.3.3.4.6, Road Type Distribution Importer (p. 72);

- MOVES SIP and Conformity Guidance: Section 4.7, Road Type Distribution (p. 40);

- MOVES GHG Guidance: Section 4.8, Vehicle Type VMT (p. 55); and

- Data tables from MOVES default database: movesdb20120410: roadTypeDistribution.

The "roadTypeDistribution" table in the MOVES2010 default database is a national esti-mate intended for national-scale runs. This is based on 1999 FHWA Highway Statistics Table VM-1 and VM-2, which provide a different distribution by HPMS vehicle type, but not by 13 MOVES source types. For MOVES2014, VMT estimates are updated to a 2011 base year using the 2011 Highway Statistics report. The County Data Manager does not export default data for road type distribution for a county-scale run.

The national-scale road type distribution is not acceptable for use in SIP/conformity anal-ysis, and locally developed estimates must be used. Local road type distributions also should be used for GHG and energy analysis. EPA recommends using travel demand forecasting data, HPMS, or other sources for obtaining VMT by road type. EPA notes that they do not expect users to develop road type distributions for all 13 source types and that the same road type distribution can be used for all source types within the same HPMS vehicle class or even across multiple HPMS vehicle classes if more detailed information is not available. The next section provides options for preparing road type distributions with and without source type detail.

Forecast year data. EPA does not provide specific guidance on the development of fore-cast year road type VMT fractions. However, travel demand forecasting models, which are often used to develop road type fractions, may show different distributions for the forecast versus base year as travel patterns and roadway investments change. Even with-out a forecasting model, the state DOT may associate growth factors with roadway links that vary by road type (typically derived from historical trends). In the absence of such forecasting methods, current year road type distributions are typically used to represent future conditions.

4.5.3   Data Sources, Procedures, and Methods

Three basic methods are available for developing estimates of road type distribution, as shown in Figure 4.5.1.

Figure 4.5.1   Methods to Estimate Road Type Distribution
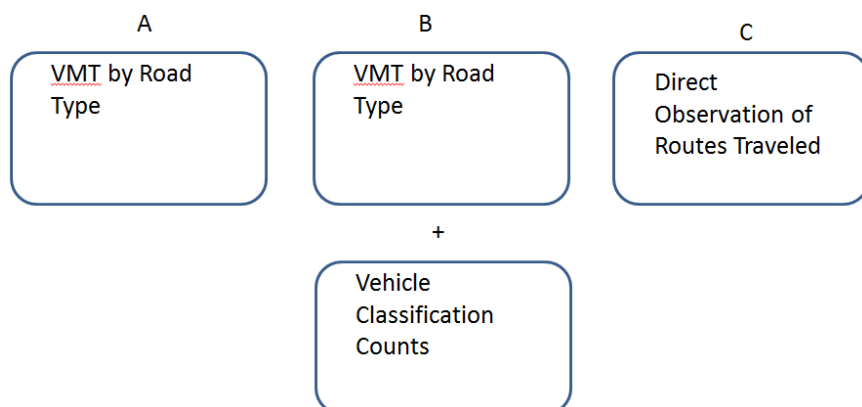
Method A is the simplest method that repeats a single road type distribution for each of the 13 MOVES source types. VMT by road type can be obtained from HPMS for historical years or from a travel demand model for historical and future years.

Method B expands upon Method A by adding vehicle classification counts to the HPMS or travel demand model VMT data. The classification counts provide a distribution of VMT by vehicle type for each road type so that different road type distributions can be developed for each of the six HPMS vehicle types. Vehicle classification counts may be obtained from the state DOT or local agencies maintaining traffic monitoring systems. Also, state-level VMT fractions by vehicle type, based on classification counts, are reported to FHWA as part of the HPMS and are published in Highway Statistics.

Method C uses instrumented vehicle information to directly produce road type distributions for certain vehicle types, assuming that enough vehicles are instrumented to provide a representative sample for that vehicle type. This method would likely have to be combined with either Method A or Method B since it would probably only produce a road type distribution for source types with a limited number of vehicles that would be easy to instrument with GPS devices, such as transit buses (source type 42), school buses (source type 43), or refuse haulers (source type 51).

Local data source options for the data elements described in the methods above are summarized in Table 4.5.3.

Table 4.5.3   Summary of Options for Road Type Distribution

Data Source or Procedure	Use	Uses and Advantages	Limitations
Highway Performance Monitoring System	Common	Typically available for every county in a state for historical years. May contain vehicle type detail for six HPMS vehicle classes at the statewide level.	Typically does not provide vehicle type detail for single counties or urban areas. Individual road types may have very limited samples at the county level.
Travel demand fore-casting model	Common	Provides road type distributions for future years.	Does not provide vehicle type detail unless there is a well calibrated truck component, which may provide up to three vehicle types.
Vehicle classification counts	Common	State DOTs often compile and process this information and could provide to MOVES users directly with short lag times. Typically based on both permanent continuous counters and temporary classification counts.	Some DOTs may only have raw classification counts and not process the information as much as Highway Statistics. Sample size is often very limited and sampled roads may not represent universe of roads of that type well.
Highway Statistics Tables VM-2 and VM-4	Limited	May serve as a national data source for vehicle classification data in 50 states if this information cannot be obtained from State DOTs. Based on both permanent continuous counters and temporary classification counts.	Some processing required to combine Tables VM-2 and VM-4. Table VM-4 has multiyear lag before it is posted online.
GPS-instrumented vehicles	Limited	Could be used to produce source type-specific distributions directly for source types with a small enough fleet to instrument a representative sample (e.g., transit buses, school buses, refuse trucks).	Would need a large fleet of instrumented vehicles to provide a representative sample. Would likely only provide road type distribution for a few source types.

The following subsections examine in more detail each of the data sources listed in Table 4.35. The example in section 4.5.5 illustrates how VMT and vehicle classification data can be combined to produce the road type distribution input table for MOVES.

4.5.3.1 Highway Performance Monitoring System

Data collected through the Highway Performance Monitoring System can be used to obtain historical or base-year VMT by road type at a county level. Most state DOTs post reports on-line from their HPMS data with annual average daily VMT by county and roadway functional class. Figure 4.5.2 shows such an example of such a report. Table 4.5.2 above can be used to aggregate the functional classes into MOVES road types. Then summaries of VMT by MOVES road type can be used to create a single road type distribution if using Method A or combined with vehicle type detail if using Method B.

Data not available on the state's web site may be obtained from the state HPMS coordinator. When the information is needed for partial county areas, such as a donut area not covered by a travel demand model, segment counts also may be obtained that provide annual average daily traffic by segment. This information can be used along with the reported segment length to estimate VMT for a customized geographic area (see Example 4.3.3 in Section 4.3, VMT by Vehicle Class).

The HPMS system may include a relatively small number of sampled road segments at the county level. The data from these sampled segments are expanded to represent the universe of all VMT. While there is not likely to be a better source of data on VMT by road type, users should recognize that the data may not be very accurate, especially at a small-scale of reporting.

4.5.3.2 Travel Demand Models

A travel demand model may be used to estimate total base- and/or forecast-year VMT by road type. Most travel demand models code network links by FHWA Functional Class, which can be mapped to MOVES road types using Table 4.35 above. Then summaries of VMT by MOVES road type can be used to create a single road type distribution if using Method A or combined with vehicle type detail if using Method B.

Base-year VMT forecasts from the travel demand model may differ from HPMS estimates for the same year. Section 3.0 of U.S. EPA (1996) discusses how to reconcile traffic demand model results with HPMS VMT estimates using HPMS adjustment factors by roadway functional class.

Some travel demand models have a truck model that breaks down VMT into two or three vehicle types. For example, in Figure 4.5.2 the second column shows that some travel models may provide VMT by light-duty vehicle, medium trucks, and heavy trucks. Other models may only include light-duty and heavy-duty vehicles (medium and heavy trucks combined). In either case these could be mapped to the six HPMS vehicle types, as shown in the figure, and combined with statewide vehicle classification counts, which contain the six HPMS vehicle types. When a travel demand model contains trucks it allows some

local vehicle classification data to be used instead of relying completely on statewide vehicle classification counts to provide information on vehicle type.

Figure 4.5.2 Vehicle Type Mapping
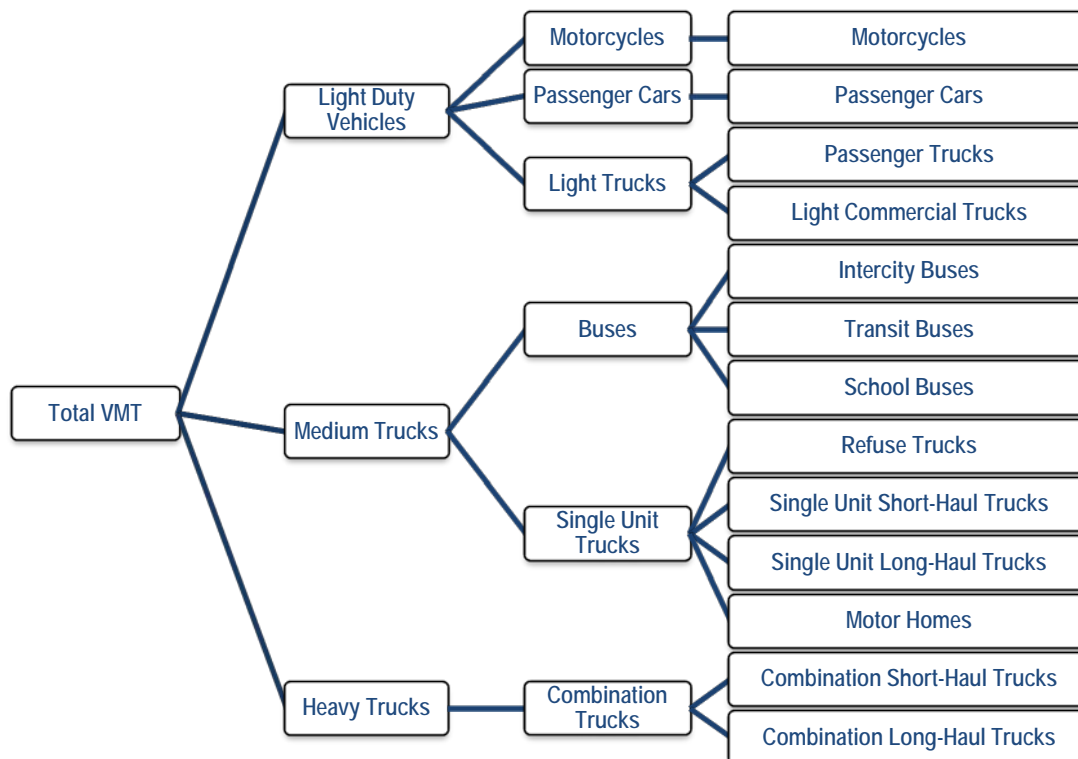
4.5.3.3 State and Local Vehicle Classification Counts

Vehicle classification counts may be obtained from the state DOT or local classification counts may be obtained from county or local governments. This information would typically have percent of traffic by vehicle type for each different roadway type. Traffic volumes may be multiplied by segment lengths to obtain VMT, or the percent of traffic on the sampled segments may be assumed to be similar to the percent of total VMT (traffic volume * segment length). Classification data are typically compiled from both permanent continuous classification counters and temporary classification counts using either pneumatic tubes or manual observation. One caveat is that the number of counting sites may be small and the sites may not be representative of all traffic on that roadway type in the state. Figure 4.5.3 is an example of a statewide classification count report for rural principal arterials. This information would be repeated for other roadway types.

4.5.3.5 Highway Statistics (Tables VM-4 and VM-2)

FHWA's Highway Statistics series include Table VM-4, which provides percent of VMT by six HPMS vehicle types for six different roadway types and all 50 states. Two of the six roadway types match up directly with MOVES road types (rural restricted access and urban restricted access), while percentages for the remaining four (rural other arterials,

rural other, urban other arterials, and urban other) must be combined with VMT information from Table VM-2 to provide the proper VMT weighted average for the remaining two MOVES road types (rural unrestricted access and urban unrestricted access). The information in Table VM-4 is based on continuous classification count stations and temporary classification counts (either from pneumatic tubes or manual observation) submitted by state DOTs to FHWA to meet HPMS requirements. FHWA processes and expands these data to provide the information in Table VM-4. One disadvantage of using Table VM-4 is that there appears to be a multiyear lag time due to the time it takes for state to submit the data to FHWA and for FHWA to process it. For example, 2010 was the most recent year for Table VM-4 as of December 2013.

A spreadsheet tool combining Tables VM-2 and VM-4 using 2010 data was developed for this project ("MOVES Highway Statistics Tool"). See Section 4.5.4, Example Data and Tools.

4.5.3.7 *Instrumented Fleets*

Vehicle fleets that are instrumented with GPS equipment could provide direct observation of routes traveled, which could be used to produce a road type distribution for a specific type of vehicle that is instrumented. This would provide a direct way to calculate a road type distribution using one data source instead of combining HPMS/travel demand model VMT with vehicle classification counts. This method is currently experimental and to the knowledge of the project team it has only been used in research papers so far. For example, Boriboonsomsin *et al* (2011) evaluated telematics-based vehicle tracking and monitoring to determine their potential for generating heavy-duty truck activity data inputs for MOVES. Telematics data were obtained from the Highway Visibility System to identify VMT fraction by road type, day, and hour, average speed distributions, and trip start locations. The dataset comes from a collective fleet of more than 2,000 Class 8 trucks traveling across the U.S. for the entire year of 2010, although it is heavily weighted to the Northeast and California.

Data from a subsample of GPS-instrumented travelers in Atlanta were analyzed for this project to develop speed distributions. The data also could be used to estimate road type fractions for light-duty vehicles.

4.5.4 Sample Data and Tools

The "MOVES Highway Statistics Tool" provided with this project provides sample road type distributions for each MOVES HPMS vehicle type for all states. This information is based on Highway Statistics Tables VM-2 and VM-4 reported for 2010. The file is set up so that users query for an individual state to show the road type distribution for each vehicle type. Users also can replace tables VM-2 and VM-4 with more recent data as they are published. An example is shown in Table 4.5.4 for the State of Connecticut.

Table 4.5.4   Sample VMT Fractions
State of Connecticut, 2010

MOVES HPMS Vehicle Type	Moves Road Type	Annual VMT (Millions)	Fraction
10 Motorcycle	2 Rural Restricted	–	–
	3 Rural Unrestricted	3,087	0.238
	4 Urban Restricted	676	0.052
	5 Urban Unrestricted	9,186	0.709
10 Motorcycle Total		**12,949**	
20 Passenger Cars	2 Rural Restricted	77,590	0.031
	3 Rural Unrestricted	225,188	0.090
	4 Urban Restricted	1,063,788	0.425
	5 Urban Unrestricted	1,135,770	0.454
20 Passenger Cars Total		**2,502,335**	
30 Light Trucks	2 Rural Restricted	14,214	0.033
	3 Rural Unrestricted	47,897	0.112
	4 Urban Restricted	164,138	0.383
	5 Urban Unrestricted	202,630	0.472
30 Light Trucks Total		**428,879**	
40 Buses	2 Rural Restricted	261	0.061
	3 Rural Unrestricted	106	0.024
	4 Urban Restricted	3,110	0.721
	5 Urban Unrestricted	838	0.194
40 Buses Total		**4,314**	
50 Single-Unit Trucks	2 Rural Restricted	3,791	0.048
	3 Rural Unrestricted	6,476	0.082
	4 Urban Restricted	40,156	0.510
	5 Urban Unrestricted	28,340	0.360
50 Single-Unit Trucks Total		**78,763**	
60 Combination Trucks	2 Rural Restricted	8,585	0.084
	3 Rural Unrestricted	2,989	0.029
	4 Urban Restricted	80,176	0.784
	5 Urban Unrestricted	10,451	0.102
60 Combination Trucks Total		**102,202**	
Grand Total		**3,129,442**	

Source   Cambridge Systematics, Inc. analysis of FHWA Highway Statistics Tables VM-2 and VM-4.

4.5.5   Examples

Example 4.5.1 – Combining VMT by Road Type with Vehicle Classification Counts (Method B)

In this example, the MOVES user has obtained VMT by road type from HPMS or the regional travel demand model. The user also has obtained vehicle classification count information that shows the percent distribution of VMT by HPMS vehicle type for FHWA roadway functional classes. The sample data are from Hamilton County, the Tennessee portion of the Chattanooga, Tennessee air quality nonattainment area, for the year 2009. The example also could be applied to a group of counties with the same MOVES inputs. The vehicle classification count percentages are from the Tennessee DOT, but the same process can be followed using vehicle classification percentages developed from other sources discussed above.

Step 1:   Aggregate VMT from the travel demand model or HPMS by road type.   The model in this example contains 12 road types which must be aggregated into the four MOVES road types (Table 4.5.5). HPMS VMT would come in the same format and would be aggregated the same way.

Table 4.5.5   VMT From Travel Demand Model

HPMS Code	HPMS Functional Class Description	AADVMT (Model Output)	MOVES Road Type Code	MOVES Road Type Description	AADVMT	Percent of AADVMT
1	Rural Interstate	206,773	2	Rural Restricted Access	206,773	2.17%
2	Rural Principal Arterial	238,856	3	Rural Unrestricted Access	803,077	8.43%
6	Rural Minor Arterial	250,486				
7	Rural Major Collector	198,727				
8	Rural Minor Collector	52,935				
9	Rural Local	62,072				
11	Urban Interstate	2,695,864	4	Urban Restricted Access	3,643,077	38.23%
12	Urban Freeway	947,214				
14	Urban Other Arterial	1,990,353	5	Urban Unrestricted Access	4,876,509	51.17%
16	Urban Minor Arterial	1,903,958				
17	Urban Collector	375,352				
19	Urban Local	606,846				
Total		9,529,436			9,529,436	100.00%

Step 2: Develop statewide split of VMT by vehicle type (six HPMS types) for each of four MOVES road types. This can be done at a substate or county level if data are available, but most states do not have an adequate sample of vehicle classification stations to do so. Table 4.38 (columns 2, 3, and 4) shows an example of the statewide distribution of VMT for Tennessee as obtained from vehicle classification data provided by the state DOT, based on 2008 to 2010 classification counts. An example of the state-provided data is shown in Figure 4.5.3. Using motorcycles as an example, Table 4.5.6 illustrates how VMT fractions by four MOVES road types were derived from distributions for nine HPMS types provided in the three years of state data. For MOVES road types with multiple corresponding HPMS road types, VMT fractions were weighted by the percentage of VMT on each road type, e.g.:

Urban Restricted Access = (0.42% * 11,414 + 0.26% * 2,000)/(11,414 + 2,000) = 0.39%

Table 4.5.6   VMT Fraction by Vehicle Type – HPMS to MOVES Mapping *Example for Motorcycles*

HPMS Road Type	2008-2010 Avg. MC Fract.	Annual Statewide 2008 HPMS VMT (Millions)	MOVES Road Type	
Rural Interstate	1.96%	8,686	2 – Rural Restricted Access	1.96%
Rural Principal Arterial	2.00%	5,360	3 – Rural Unrestricted Access	1.38%
Rural Minor Arterial	1.10%	5,043		
Rural Major Collector	1.35%	2,981		
Rural Minor Collector	0.85%	2,981		
Urban Interstate	0.42%	11,414	4 – Urban Restricted Access	0.39%
Urban Freeway	0.26%	2,000		
Urban Principal Arterial	0.86%	10,953	5 – Urban Unrestricted Access	0.91%
Urban Minor Arterial	1.02%	8,170		
Urban Collector	0.89%	2,967		
Total	**0.93%**	**69,661**		

Figure 4.5.3   Example of Statewide Vehicle Classification Count Report

2010 VEHICLE CLASSIFICATION SUMMARY SHEET

FUNCTIONAL SYSTEM: RURAL PRINCIPAL ART   02

VEHICLE TYPE		PERCENT OF TOTAL
CARS		64.83
MOTORCYCLES		1.35
PICKUPS,PANELS,VANS		22.80
TOTAL PASSENGER VEHICLES		88.98
BUSSES		0.05
SINGLE	DUAL REAR TIRE	1.07
UNIT	3-AXLE	1.72
TRUCKS	4-AXLE	0.49
	SUBTOTAL	3.33
TRACTOR	2S-1,3S-1,2S-2	2.66
SEMITRAILER	3S-2,2S-3	3.87
COMBINATIONS	3S-3,3S-4	0.22
	SUBTOTAL	6.75
TRACTOR	2S-1-2	0.28
AND TWIN	2S-2-2,3S-1-2	0.11
TRAILERS	7 AXLE	0.55
	SUBTOTAL	0.94
	SUBTOTAL COMBINATIONS	7.69
TOTAL TRUCKS		11.02
OTHER VEHICLES		0.00
TOTAL VEHICLES		100.00

Source: Tennessee Department of Transportation.

Step 3: Multiply the results of Step 2 (rows 1-6 in Table 4.5.7) by the AADVMT from the travel demand model, which was compiled in Step 1 (row 7 in Table 4.5.7). This results in VMT by HPMS vehicle type and road type (rows 9-14 in Table 4.5.7). For example, motorcycle VMT for MOVES road type 2 is found using the following equation:

$$\text{VMT (motorcycles, road type 2} = 1.96\% * 206{,}773 = 4{,}060$$

Step 4: The road type distribution for each HPMS vehicle type is then found by dividing VMT for a specific road type by VMT for all road types. The result is shown in rows 15-20 of Table 4.5.7. The example equations are:

VMT (motorcycles, all road types) = 4,060 +11,050 +14,435 +44,217 = 73,671

Road Type Distribution (motorcycles, road type 2)= 4,060/73,671 =5.51%

Table 4.5.7 Statewide VMT Distribution by HPMS Vehicle Type and MOVES Road Type

Row	HPMS Code	HPMS Vehicle Type	MOVES Road Type				All Road Types
			2	3	4	5	
Percent of Road Type VMT by Vehicle Type							
1	10	Motorcycles	1.96%	1.38%	0.39%	0.91%	
2	20	Passenger Cars	52.73%	65.86%	65.04%	72.64%	
3	30	Other 2-axle 4-tire vehicles	18.47%	26.47%	21.06%	19.99%	
4	40	Buses	0.55%	0.08%	0.30%	0.11%	
5	50	Single Unit Trucks	4.17%	2.46%	3.02%	1.92%	
6	60	Combination Trucks	22.11%	3.74%	10.19%	4.43%	
7		Total	100.00%	100.00%	100.00%	100.00%	
Total VMT by Vehicle Type and Road Type							
8		AADVMT from travel demand model	206,773	803,077	3,643,077	4,876,509	
9	10	Motorcycles	4,060	11,050	14,345	44,217	73,671
10	20	Passenger Cars	109,032	528,923	2,369,401	3,542,447	6,549,802
11	30	Other 2-axle 4-tire vehicles	38,191	212,588	767,185	975,037	1,993,001
12	40	Buses	1,144	681	11,057	5,156	18,038
13	50	Single Unit Trucks	8,622	19,786	110,010	93,608	232,026
14	60	Combination Trucks	45,724	30,048	371,080	216,045	662,897
Percent of Vehicle Type VMT by Road Type							
15	10	Motorcycles	5.51%	15.00%	19.47%	60.02%	100.00%
16	20	Passenger Cars	1.66%	8.08%	36.18%	54.08%	100.00%
17	30	Other 2-axle 4-tire vehicles	1.92%	10.67%	38.49%	48.92%	100.00%
18	40	Buses	6.34%	3.78%	61.30%	28.58%	100.00%
19	50	Single Unit Trucks	3.72%	8.53%	47.41%	40.34%	100.00%
20	60	Combination Trucks	6.90%	4.53%	55.98%	32.59%	100.00%

■ 4.6 Ramp Fraction

4.6.1 Description and Format

Ramp fraction is a county-level input in MOVES that indicates the percent of vehicle-hours traveled (VHT) that occurs on ramps for rural restricted access roadways (road type 2) and urban restricted access roadways (road type 4). This input is not available if the MOVES run excludes road types 2 and 4. Table 4.6.1 shows an example of the format for this input. In this example 2.5 percent of the VHT on rural restricted access roadways occurs on ramps, while 4.6 percent of the VHT on urban restricted access roadways occurs on ramps. The default value programmed into MOVES for ramp fractions is 8 percent for both road types. Users may be able to identify local ramp fractions from travel demand model output or other local information, such as traffic counts on ramps.

Table 4.6.1   Example of Road Type Distribution Input

roadTypeID	rampFraction
2	0.025
4	0.046

It is important to note that the ramp fraction input requests the fraction to be a percent of vehicle-**hours** traveled, and not vehicle-**miles** traveled like the road type distribution input. This is due to the fact that MOVES applies the ramp fraction in its internal calculations after VMT has been converted to VHT by using speed distributions.

Ramps were treated as a separate road type in MOBILE6, and separate emission rates were output for ramps that were typically matched to ramp VMT by speed bin. Therefore, MOVES requires less detailed data about ramps than MOBILE6 since it treats them as part of the restricted access roadway types and makes internal assumptions about how speeds on ramps relate to speeds on the mainline of highways.

The FHWA/Volpe MOVES regional sensitivity analysis examined the impact of varying ramp fraction from zero to 20 percent (using values of 0, 0.02, 0.04, 0.06, 0.10, 0.12 0.16, 0.20) compared to the base case of the 8 percent national default value. In general, it found that emission rates for running exhaust increased in a linear fashion as the ramp fraction increased, although some pollutant/vehicle combinations were basically flat. It found a modest impact (less than 5 percent difference from base case) for all pollutants (CO, NO_x, $PM_{2.5}$, and VOC) and all vehicle types, except for:

- $PM_{2.5}$ from light-duty vehicles, which was substantial (-15 to +22 percent);
- CO from light-duty vehicles, which was moderate (-8 to +12 percent);

- PM$_{2.5}$ from school buses, which was moderate (-4 to +6 percent); and

- NO$_x$ from single-unit short- and long-haul trucks, which was moderate (-4 to +6 percent).

These sensitivity results could suggest that areas in nonattainment or maintenance for PM$_{2.5}$ and CO may want to spend more effort finding local data for the ramp fraction input than would ozone nonattainment and maintenance areas.

4.6.2 Source of Embedded Data and EPA Guidance

The relevant sections of the MOVES User Guide, guidance documents, and data tables are:

- MOVES2010b User Guide: Section 2.3.3.4.7, Ramp Fraction Importer (pp. 73-74);

- MOVES SIP and Conformity Guidance: Section 4.8, Road Type Distribution (pp. 40-41);

- MOVES GHG Guidance: Section 4.9, Ramp Fraction (pp. 56-57); and

- Data tables from MOVES default database: movesdb20121030: roadtype.

The "roadtype" table in the MOVES default database includes the national default assumption of 8 percent for road types 2 and 4. This value was carried over from MOBILE6, which based the assumption on a 1997 study by the Charlotte Department of Transportation (U.S. EPA, 2001 and Charlotte DOT, 1997). This study reported values in VMT-based percentages of 19.4 percent for the central business district, 8.7 percent for commercial areas, and 2.4 percent for residential and rural areas. Therefore, the MOVES default value of 8 percent may not represent dense urban areas or rural areas very well.

EPA guidance states that use of the ramp fraction input is optional, but that users that have good local data indicating a different fraction (other than the national default 8 per-cent) should use it. Guidance is not provided on forecast year versus base year ramp fractions, but if these fractions are derived from a local travel demand forecasting model, they may differ for the forecast year.

4.6.3 Data Sources, Procedures, and Methods

Data source options for this input are summarized in Table 4.41.

Table 4.6.2   Summary of Options for Road Type Distribution

Data Source or Procedure	Use	Uses and Advantages	Limitations
MOVES embedded data	Common	Readily available and acceptable to use.	May not reflect the ramp fraction based on local data, especially in dense urban or rural areas.
Travel demand forecasting model	Common	Provides a reliable source of local data if ramps are included in the model.	Ramp counts may not be available to validate ramp volumes from the travel demand model.

The following subsections examine in more detail each of the data sources listed in Table 4.41.   The example in section 4.6.5 illustrates how to use travel demand model results to produce urban and rural ramp fractions.

4.6.3.1 MOVES Embedded Data

Using the national default ramp fraction of 8 percent is acceptable for SIP and conformity analyses as stated in EPA guidance, although use of local data is preferred if it is available. In a survey of MOVES users conducted for this project, 25 percent of the respondents reported using MOVES default ramp fractions. Some MOVES users may choose to examine local travel demand model data, but still use MOVES defaults if the result is not significantly different.

4.6.3.2 Travel Demand Models

A travel demand model may be used to estimate VHT by urban/rural ramps and urban/rural restricted access links (MOVES road type 2 and 4). Ramps are not part of the FHWA functional classification system, but most travel demand models denote ramps as a separate roadway type. Procedures to code travel demand model links by MOVES road type are discussed in the road type distribution chapter of this document.

The VHT on the ramps would be divided by the VHT on the controlled access links to produce the ramp fractions as shown in Example 4.6.1 below. Ramp validation results that use local ramp counts should be considered to ensure some level of comfort with the ramp fractions produced from the travel demand model results. Ramp fractions could be produced for base and future years or simply for a base year and applied to all future years.

4.6.4   Sample Data and Tools

There are no sample data or tools available to aid in the development of ramp fraction inputs for MOVES.

4.6.5 Examples

Example 4.6.1 – Using a Travel Demand Model to Calculate Ramp Fraction

In this example, the MOVES user has a travel demand model with VHT as a field in the table of links. If a field for VHT is not available it could be calculated for each link by dividing VMT by speed (in miles per hour).

Step 1: Aggregate VHT from the travel demand model urban/rural ramps and urban/rural restricted access roadways. Table 4.6.3 shows an example of these results from the Chattanooga travel demand model. The AB and BA designations are for separate directions when both directions are modeled on the same link; however, only the total is used to calculate the ramp fraction.

Table 4.6.3   VHT from Travel Demand Model

	Ramp Links			Restricted Access Links			
	AB	BA	Total	AB	BA	Total	Ramp Fraction
Rural Links	724	93	817	24,845	10,747	35,592	2.29%
Urban Links	2,466	481	2,948	52,905	12,633	65,538	4.50%

Step 2: Divide total VHT for rural ramps by total VHT for rural restricted access roadways to obtain the ramp fraction for road type 2. Divide total VHT for urban ramps by total VHT for urban restricted access roadways to obtain the ramp fraction for road type 4. The following calculations use the example numbers from Table 4.6.3:

Ramp Fraction for MOVES Road Type 2 = 817/35,592 = 2.29%

Ramp Fraction for MOVES Road Type 4 = 2,948/65,538 = 4.50%

■ 4.7 Average Speed Distribution

4.7.1 Description and Format

This input is a set of 16 fractions that sum to 1, which represents the distribution of vehicle-**hours** traveled among 16 speed bins, as shown in Table 4.7.1. MOVES requires this information for every combination of 13 source (vehicle) types, four road types, 24 hours of the day, and two types of days (weekdays/weekends). Therefore, it effectively asks for 2,496 distributions. Travel demand model output is a common source of these data, but other methods relating volume and capacity to speeds on roadways (such as Highway Capacity Manual formulas) may be used. For historical year data, there are also a number of emerging sources on observed travel speeds such as cell phone, GPS, and Bluetooth-based monitoring.

Table 4.7.1 Example Average Speed Distribution Input

sourcetypeID	roadtypeID	hourdayID	avgSpeedBinID	avgSpeedFraction
11	2	185	1	0.0000000
11	2	185	2	0.0000000
11	2	185	3	0.0000000
11	2	185	4	0.0000000
11	2	185	5	0.0000000
11	2	185	6	0.0000000
11	2	185	7	0.0212651
11	2	185	8	0.0027255
11	2	185	9	0.0000000
11	2	185	10	0.0000000
11	2	185	11	0.0000000
11	2	185	12	0.0000000
11	2	185	13	0.3890143
11	2	185	14	0.0590208
11	2	185	15	0.5279743
11	2	185	16	0.0000000

The average speed distribution can have a substantial effect on emissions. For example, the Volpe/FHWA sensitivity analysis (Noel and Wayson, 2012) tested speed distributions for urban Interstates corresponding to different levels of service and found a variation of up to 33 percent for passenger car VOC emissions and up to 49 percent for combination truck VOC emissions, compared to the national default speed distribution for this road type. PM emissions varied by up to 16 percent for passenger cars and 53 percent for combination trucks.

While speed distributions specific to source type are rarely used in practice due to data availability, evidence from California suggests that truck speeds on freeways can be significantly lower than average speeds for all traffic. Specifically, Boriboonsomsin, Zhu, and Barth (2011) used statistical analysis of data from multiple sources to predict heavy truck speeds as a function of general traffic speeds. Their speed distribution shows a mode (maximum frequency) for trucks of about 60 mph, versus just over 70 mph for all vehicles. Variations by source type can have a modest to moderate effect on emissions. For the California study, using the heavy-duty diesel truck-specific speed distribution rather than the overall speed distribution reduced the estimates of NO_x emissions by 4 percent and PM emissions by 26 percent, by reducing the amount of truck VMT at unrealistically high speeds with high PM emissions.[17] In contrast, a sensitivity analysis performed for this research found that reducing the average speed of trucks by 5 mph compared to the MOVES default distribution (for all road types) increased overall VOC emissions by 1.2 percent, NO_x by 2.4 percent, and PM_{10} by 5.7 percent.

If seasonality has a significant local effect on traffic patterns, MOVES users can vary speeds by running MOVES for different time periods (e.g., months) with different speed distributions. (See Section 4.7.4 for examples of seasonal variations.) MOVES allows users to provide different speed distributions for weekday versus weekend in a single MOVES run. Even accounting for seasonality effects and day of week, speeds on a given network link can vary from day to day due to nonrecurring congestion caused by incidents, weather conditions, etc. The speed estimates developed from models, as well as most observed data sources, typically reflect average speeds for a given link and time period and the range of speeds may therefore be somewhat compressed compared to reality. Continuously collected, disaggregate sources, if available, are preferable for emissions modeling as they capture the full range of speed conditions occurring throughout the year.

Speed distributions for rural and urban restricted access highways should not include speeds on highway entrance and exit ramps. MOVES automatically calculates a speed distribution for ramp activity based on the speed distribution of vehicles traveling on the highway. Even if ramps are handled separately from highways (see Section 4.6), the speed distribution entered in MOVES should be the speed distribution for the associated highways, not a ramp-specific speed distribution.

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[17] This study used EMFAC2007 emission rates; results would likely be different if MOVES emission rates were used.

4.7.2   Source of Embedded Data and EPA Guidance

The relevant sections of the MOVES User Guide, guidance documents, and data tables are:

- MOVES User Guide: 2.3.3.4.5 Average Speed Distribution Importer (p. 71);

- MOVES SIP and Conformity Guidance: Section 4.6, Average Speed Distribution (p. 36);

- MOVES GHG Guidance: Section 4.7, Average Speed Distribution (p. 51). The guidance in this document is similar to that in the SIP and Conformity Guidance; and

- Data tables from MOVES default database: movesdb20121030: avgspeeddistribution.

EPA notes that for SIP and conformity analysis, states are expected to develop and use local estimates of average speed. EPA urges users to develop the most detailed local speed information that is reasonable to obtain, but acknowledges that average speed distribution information may not be available at the level of detail that MOVES allows. For example, states can use the same average speed distribution for all source types within an HPMS vehicle class or across multiple HPMS classes.

EPA's recommended approach for estimating average speeds is to postprocess the output from a local travel demand network model. In most transportation models, speed is primarily a measure of impedance affecting traveler choice rather than a prediction of accurate vehicle link travel times, and must be adjusted to properly estimate vehicle travel speeds. The difference is essentially that travel demand models include reliability in the form of planning time within the time impedance that is considered in travel choice, while MOVES requires vehicle operating speeds, which excludes this planning time.[18] Postprocessed speeds estimated in the validation year should be compared with speeds empirically observed during the peak- and off-peak periods. This approach would provide speed distributions for VMT by road type and potentially by peak and off-peak periods, but not distributions for specific source types or by individual hour of the day.

EPA provides the following additional guidance on average speed distributions for SIP, conformity, GHG, and energy analysis:

- The use of peak and off-peak average speed distributions (as is commonly produced by travel demand models) rather than a distinct distribution for each hour of the day is acceptable. However, generating a single daily average speed distribution for a highway network with a considerable number of highly congested links is not generally recommended.

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[18] "Planning" time is also sometimes called "just-in-case" time (Texas Transportation Institute, 2006). Emissions are produced only during actual travel time. The inclusion of planning time in travel demand models is one reason why their travel speeds must be postprocessed for use in emissions models.

- Average speed distributions for local roadway activity should be included as part of a weighted distribution of average speed across all unrestricted roads.

- For rural and urban restricted access highways, users should enter the speed distribution of vehicles traveling on the highway only, not including any activity that occurs on entrance and exit ramps. MOVES automatically calculates a speed distribution for ramp activity based on the speed distribution of vehicles traveling on the highway.

- EPA provides a formula for generating a distribution if only a single average speed is available that is not identical to the average speed in any one bin.

FHWA guidance on transportation conformity (FHWA, 2006) also recommends that speeds be estimated in a separate step after traffic assignment, using refined speed-volume relationships and final assigned traffic volumes. Postprocessed speeds estimated in the validation year should be compared with speeds empirically observed during the peak- and off-peak periods. These comparisons may be made for typical facilities, for example, by facility class/area type category. Based on these comparisons, speed-volume relationships used for speed postprocessing should be adjusted to obtain reasonable agreement with observed speeds.

For MOVES2010, the average speed fractions for urban roads were derived from the default speed distributions (SVMT) in MOBILE6. Rural road speed distributions are based on "chase car" studies performed by the California Department of Transportation. The procedures for importing these data into MOVES are described in EPA (2010). Note that speed distributions by source type do not vary in the underlying data, but they do vary slightly in MOVES. This is a result of mapping speed distributions to MOVES road types, where the weightings of road type vary by source type. For MOVES2014, EPA developed updated speed distributions based on national data from in-vehicle devices, purchased from a private provider.

Forecast year data. The MOVES SIP and Conformity Guidance states that, "Average speed estimates for calendar years other than the calendar year on which the average speed estimates are based must be logically related to the current year methodology and estimates. Future average speed estimates should account for the effect of growth in overall fleet VMT on roadway congestion and average speeds." This suggests the use of a travel demand model to develop forecast year speed estimates consistent with the base year. If a travel demand model or other speed forecasting method is not available, it may be necessary to use base year speed distributions to represent forecast year distributions. This may be reasonable in rural areas or other locations where congestion is not present or is not expected to change significantly.

4.7.3   Data Sources, Procedures, and Methods

There are two basic approaches to traffic speed estimation: 1) *measurement* of current or historical year speeds; and 2) *modeling* of speeds for current or future conditions, based on observed or forecast traffic volumes and network characteristics.   There also are different methods of defining and measuring speeds, as described in the sidebar.   Local data source options for this input are summarized in Table 4.7.2.

Table 4.7.2   Summary of Options for Average Speed Distributions

Data Source or Procedure	Use	Uses and Advantages	Limitations
Monitoring – Historical Only			
MOVES embedded data	Common	Can be used in national default mode.	No defaults available for county mode required for SIP and conformity analysis.
Study-specific field surveys	Common	Field data collection of traffic speeds for a specific purpose. Methods can be customized for MOVES user needs.	May be costly to sample enough segments to develop a regional speed distribution.
Public agency ITS systems (loops, radar, video)	Limited	Makes use of public agencies' ITS traffic monitoring system data which exist in many cities.	Typically do not distinguish vehicle types. Usually only deployed on urban restricted access roads.
Vehicle-based monitoring systems (GPS, cell phone, Bluetooth)	Experimental	Potentially broad coverage providing accurate historical year speed distributions.	Typically do not distinguish vehicle types. Generally must be purchased.
Modeling – Historical and Forecast Year			
Stand-alone volume-delay functions	Common	Equations relating volume and capacity to speeds to develop distributions for roads not incorporated in TDFM.	Calculations must be performed for each road segment in study area and aggregated.
Travel demand forecasting model	Common	Provides forecasts as well as current year data; commonly available by road type and subset of time periods (e.g., peak, off-peak).	Direct model outputs may not be very accurate. Does not provide distributions by source type, weekend days, or for each hour of the day.
TDFM speed postprocessing methods	Common	Can improve speed distributions directly output by TDFMs.	Most models and postprocessing methods still have inherent limitations in predicting speeds.

Traditional methods of measuring speeds include floating car studies and instrumented vehicle methods using on-board computers and/or GPS devices. In the past two decades, infrastructure-based ITS systems using loop detectors, video, and/or radar also have provided a source of speed data, primarily on limited-access highways. Within the past five years, the range of options for speed data has expanded more rapidly with the rapid growth in use of personal communications and navigations devices (telematics) that can provide locational information.   These sources represent a good opportunity for improving information on current speed distributions, and for calibrating and/or validating speed

estimates produced by travel demand models and postprocessors. However, the utility of all these sources as direct MOVES inputs is limited because they are not a forecasting method.

Travel demand forecasting models (TDFM) are widely used for estimating vehicle speed distributions for input to emissions models, since they can produce forecast year as well as historical year speed estimates and therefore fulfill the requirement that methods for estimating forecast-year emissions be consistent with base-year estimation methods. However, they also have a number of limitations for speed estimation. Volume-delay functions and related methods are often used to postprocess travel demand forecasting model output to improve modeled speed estimates. For areas without a travel demand forecasting model, or to validate TDFM outputs, volume-delay functions may be used on a stand-alone basis to estimate both existing and future speeds based on roadway capacities and traffic volumes. Traffic microsimulation models can produce much more accurate speed estimates but are expensive to develop and generally not applied at a regional scale.

Speed Definitions and Measurement

Speed can be defined and measured in different ways. How it is defined and measured can effect estimates of emissions.

- **Average Travel Speed** is the length of a segment of road divided by the average travel time of the vehicles traversing that segment.

- **Space Mean Speed** is the average speed of all vehicles present on a given segment of road at a particular point in time. It is equal to average travel speed.

- **Time Mean Speed** is the average speed of all vehicles passing a given point over a certain period. Unless all vehicles are traveling the same speed over the road segment, it is <u>not</u> equal to space mean speed.

Different measurement methods provide different types of speed:

- Aerial photographs (where speed is calculated from the position of the same vehicle recorded in two consecutive photographs) and floating car methods measure space mean speeds.

- Loops, radar, microwave, LIDAR, and video are spot measurement techniques and therefore measure time mean speeds.

- Bluetooth devices and automatic license plate readers measure the average speed of individual vehicles over a distance. An arithmetic average of the individual speed values produces time mean speed. To obtain space mean speed, instead of averaging the vehicle's speeds, the length of the segment traversed should be divided by the average of the *travel times* of each vehicle.

Space mean speed will be lower than time mean speed if speeds for all vehicles are not equal. The greater the speed variation, the greater the difference. Space mean speed is the preferred measure because the average speed can be multiplied by the length of the facility to obtain total vehicle-hours of travel. This is also consistent with the average speed produced by travel demand models. The time mean speed is biased because it gives greater weight to faster-moving vehicles, which pass a given point more often in a given time period than slower vehicles. The difference can be as little as 1 mph on an uncongested expressway or as great as 7 to 10 mph on a signalized arterial or congested freeway (Dowling et al, 1996).

Space mean speed is the harmonic mean of the speeds of many vehicles. In addition to calculating from average segment travel times as described above, it can be calculated from a set of spot or segment speed measurements as follows:

$$s_{sms} = \frac{N}{\sum_i \frac{1}{s_i}}$$

Where:

s_{sms} = the space mean speed for the segment

s_i = the average travel speed for vehicle i

N = the number of vehicles

D = the length of the segment

Source: Dowling, et al (1996).

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4.7.3.1 Study-Specific Field Surveys

A variety of methods exist for measuring traffic speeds through field surveys conducted for a specific purpose. One of the oldest is the floating car method, in which drivers trail other cars on the road segment(s) of interest and measure point-to-point travel times. More recently, floating car surveys have been enhanced with the use of GPS equipment to record vehicle trajectories. Travel time data collection methods have evolved rapidly in recent years due to new advances in technology. Other measurement tools that can be deployed for specific studies include:

- Automated license plate readers, which match license plates between two or more points using either manual matching or image recognition technology. Average vehicle speed between the readers is calculated based on time stamps associated with the video.

- Radar, microwave, or lidar units placed at the roadside.

- Video image processing (machine vision) to measure speeds of individual vehicles from multiple frames of a single video. This technique is fairly new and more experimental.

The latter techniques are spot-measurement methods and care should be taken to calculate space mean speeds rather than time mean speeds, as described in the sidebar. In addition they may be poorly suited to measurement of speeds on signalized arterials or in other situations where there is considerable variation in vehicle speeds over space (e.g., due to queuing at intersections). They are more appropriate for freeways or arterials with long segments of unsignalized travel.

For the purposes of MOVES input development, field surveys are more likely to be used for developing project-specific average speeds than regional average speed distributions. A large number of monitoring stations, or a large set of floating car runs, is generally required to obtain regionally representative distributions for multiple time-of-day periods and roadway types. For this reason the regional MOVES user is more likely to rely on modeled speeds and/or sources of speed data that already exist, such as those described in the following sections. However, field data collection does have the advantage that it can be tailored to the needs of MOVES users. For example, any system that can detect vehicle length can be used for basic classification (e.g., heavy versus light vehicles) to develop different speed distributions for these vehicle types. Floating car studies also can distinguish vehicle types.

4.7.3.2 Public Agency Intelligent Transportation Systems

Intelligent Transportation Systems data generally refers to traffic data collected by public agencies (state DOT, regional transportation system operator, or local transportation department) to support day-to-day operation of the transportation system, performance measurement, and longer-term planning. This section focuses on infrastructure-based data collection methods deployed by public agencies. These methods, which are also described in FHWA (2013), include:

- **In-Pavement Magnetic and Inductive Loop Detectors.** These are installed in the pavement and detect the presence of a vehicle passing over them. Paired loops can be used to measure spot speeds. Methods also have been developed to measure speeds using single loops by matching "signatures" passing over sequential detectors. Loop detectors are probably the most common source of ITS traffic data.

- **Radar, Microwave, or Lidar.** An active sensor emits radio waves (radar), microwaves, or a laser beam (lidar), which reflects off of vehicles. These technologies measure spot speeds.

- **Video Cameras (Machine Vision).** Video cameras are widely used in ITS systems for the purpose of monitoring traffic conditions and speeding response to incidents. Recently, machine vision image processing techniques have been developed to estimate vehicle speeds from sequential frames of video. Video also measures spot speeds.

- **Bluetooth Readers.** Bluetooth is a nonproprietary wireless technology standard that allows electronic devices to communicate directly with one another over relatively short distances using radio frequency communication. Bluetooth signals can be detected via roadside readers at a distance of up to roughly 100 meters. Signals are matched for the same vehicle when it passes the beginning and end of a monitored segment. Recently, the proliferation of Bluetooth-enabled devices has made this a viable, and inexpensive, method for measuring travel speeds.

- **Toll Tag Readers.** Toll tag readers, also known as automatic vehicle identification (AVI) systems, detect the unique radio frequency IDs of motorists' automated toll tags (e.g., E-Zpass) at multiple locations and calculate travel times based on the arrival time at each location. They can be deployed at locations other than toll booths and provide a measurement technique functionally similar to Bluetooth readers. However, their use is limited to areas in which electronic tolling is practiced and a substantial fraction of the vehicle fleet has toll tags.

Data collected in agencies' ITS systems are typically archived at intervals of five minutes or even less. Data processing is required to aggregate the data into the time periods required for MOVES (e.g., aggregating five-minute volumes into hourly volumes). There are different ways of aggregating data which can provide different results. An example of data aggregation and a discussion of some of the issues involved is provided in Example 4.7.1.

One limitation for the development of MOVES inputs is that in most areas, ITS monitoring equipment is only deployed on limited-access highways, although in some places major arterial corridors are seeing increasing deployment. Also, information on vehicle type is typically not collected and archived. The equipment may be capable of making length-based vehicle classifications which may be associated with broad vehicle classes (e.g., light-duty car and truck, single-unit truck, combination truck) but this is usually done only for specific studies when classification information is required.

Also, because of the extensiveness of the network, equipment failures can be common and data quality must be carefully evaluated. It is important to identify and discard suspect data. However, this may introduce bias with some data collection methods; for example, loop detectors do a poor job of measuring very low speeds. A data cleaning procedure that discards low values will also bias the speed distribution upwards, omitting the most congested conditions.

4.7.3.3 *Vehicle-Based Monitoring Systems*

A growing number of primarily private sources are collecting and aggregating travel time data using vehicle-based monitoring methods, including GPS navigation units and cell phones. These methods are evolving rapidly. Their primary objective is to provide real-time information on travel speeds and times. Data are collected by private companies and made available for a fee to other public or private entities after data has been aggregated and any identifying information stripped.

As described in FHWA (2013), the primary vehicle-based sources of traffic monitoring data currently include:

- **GPS-Based "Crowdsourcing."** Drivers' vehicles or mobile devices provide information on their location, speed, and possibly additional information to a public or private entity, and that information is used to generate traffic/travel time information. Crowdsourcing data providers include INRIX, HERE (formerly known as NAVTEQ), Google, TomTom, and Waze. For example, TomTom resells aggregated travel speed data (speeds by network link) gathered from their own TomTom GPS navigational units.[19]

- **Cell Phone Signal Monitoring.** Cell phone signal monitoring provides locational data from mobile devices without the use of GPS. Location is determined based on triangulation among cell phone towers. Vehicle trajectories are associated with the nearest roadway network link using GIS methods. Private providers such as AirSage and Cellint may package and sell these data (in anonymized, aggregate format). Uses may include segment or point-to-point travel times as well as other purposes such as origin-destination mapping and time-of-day traffic. The uses of these data are evolving rapidly and accuracy for various purposes is still under investigation.

- **GPS-Based Fleet Monitoring.** The Highway Visibility System is a privately maintained data source of GPS records of a sample of commercial vehicle movements, primarily combination trucks, which is available for purchase. An example of its use is

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[19] FHWA has purchased a national sample of travel time data, for segments on the National Highway System, from NAVTEQ. These data are being used for performance monitoring and are made available to state DOTs and MPOs for this purpose. However, they are not currently licensed for uses other than performance monitoring. A nationwide data source such as this could potentially be used for the development of consistent actual speed distributions across different areas.

shown in Section 4.7.5, Sample Data and Tools. The American Transportation Research Institute also maintains a similar truck GPS dataset to which it sells access.

- **GPS Travel Surveys.** While not providing real-time data, travel speed data also may be available for a sample of personal vehicles from household travel surveys in some areas. For example, the Transportation Secure Data Center, hosted by the National Renewable Energy Laboratory, has an archive of GPS travel survey data, which currently contains surveys from Atlanta, Chicago, the Puget Sound region, southern California, and various Texas cities. These data could be used to develop temporal distributions for light-duty vehicles, although general traffic monitoring methods that include all vehicles may be preferable.

The most common use of all of these sources is to provide information on travel speeds and times. Speed data can be aggregated on an hourly basis and examined for weekends versus weekdays. All of these sources can provide broader coverage of the road network than infrastructure-based ITS monitoring sources which are primarily deployed on freeways. The data are typically provided in GIS format so that they can be associated with a road network. For MOVES purposes this allows the data to be matched with MOVES road types. However, the sources rarely contain information on the type of vehicle and therefore cannot be used to develop speed distributions by source type.

Travel speed data from private providers currently have other limitations. First, they are typically estimated and aggregated by road segment by the private provider, using proprietary methods which are not disclosed. An annual average travel speed for a given roadway segment and time period may not reflect the distribution of travel speeds that results from changing day-to-day conditions (such as nonrecurring congestion). Triangulation from cell towers requires approximations and a speed measured between two towers may cover more than one roadway segment.

The travel speeds also must be weighted by volumes to determine vehicle-hours of travel on each segment. This can be done by matching traffic volumes from the travel demand model with the reported speeds. However, travel speeds are usually reported using the traffic management center or other network that is not identical to the travel demand model network. If a correspondence file has not been created, the two networks must be conflated using GIS methods. This can be a labor-intensive process, especially if the TDFM network is a "stick" network and is not geographically accurate. Network conflation issues, using the project team's examples in Atlanta and Jacksonville, are discussed in more detail in the NCHRP 25-38 Final Report.

4.7.3.4 *Volume-Delay Functions*

Volume-delay functions (VDF) describe a relationship between the capacity and volume on a roadway segment and the travel speed on that segment. They are incorporated into travel demand models and other traffic analysis tools, but also may be used on a standalone basis to estimate link-level speeds. (When included in travel models their calibration may reflect planning time accounted for by travelers rather than actual speeds on the network.) Volume-delay functions are mathematical approximations to what is a complex phenomenon, rather than precise descriptions of physical reality. Average speeds across a

roadway segment are related to a variety of factors, including capacity at bottlenecks along that segment (such as intersections and merge points), backups from downstream bottlenecks, as well as other factors such interference from merging or exiting vehicles, design speeds, roadway grade, etc. They also fail to represent dynamic effects as queues form and dissipate over time.

The so-called Bureau of Public Roads (BPR) formula may be the most often applied speed-flow formula. The standard BPR equation is:

$$S = S_f/[1 + \alpha(V/C)^\beta]$$

Where:

S = predicted mean speed

S_f = free-flow speed (defined as 1.15 times the speed at "practical capacity")

V = volume

C = practical capacity (defined as 80 percent of capacity)

The standard BPR coefficient values for α and β are 0.15 and 4.00 respectively. Dowling *et al* (2005) reprint a table developed by FHWA showing practical capacity and free-flow speeds for a number of different facility and area type combinations. Capacity estimates can be refined based on facility-specific factors (such as lane widths and shoulder widths) using methods from the Highway Capacity Manual or other sources.

The standard BPR curve has a number of limitations in addition to the general problems noted above. For example, it is not facility-type specific. It has been found in some cases to poorly match real world conditions, especially as volume-to-capacity (v/c) ratios approach or exceed 1.0, dropping too soon before capacity is reached, and dropping too slowly above capacity (Dowling Associates et al, 1996). Enhancements noted in a 2009 Travel Model Improvement Program synthesis on speed estimation include:

- Variations of the BPR formula (i.e., modifying the alpha and beta coefficients, generally to achieve better calibration with locally measured speed data).

- Developing user specified VDFs for each facility type (e.g., freeway, expressway, arterials) and possibly area type in the network. The slope of the curve can be modified to better reflect the different speed-flow characteristics between access controlled facilities, such as freeways, and facilities with signalized controlled intersections (e.g., arterials) by varying the α and β parameters for each facility type.

- Conical functions and other alternative formulae, such as Akçelik's formula, to progressively decay speeds faster with increasing v/c ratios.

- Developing VDFs that produce different curves for v/c conditions above 1.0 and for conditions below 1.0.

- Setting minimum allowable speeds so speeds do not decay to unrealistically low values under high v/c ratios.

FHWA's Highway Economic Requirements System (HERS) model includes somewhat more sophisticated procedures for estimating link-level delays and speeds.[20] HERS includes procedures to calculate speeds that reflect delay due to incidents, other congestion, and traffic signals on freeways and signalized arterials, using parameters that include bottlenecks per mile and an incident rate factor. Procedures also are included for calculating free-flow speeds based on speed limit, grade, curvature, and pavement roughness. Capacities are calculated using procedures from the HPMS Field Manual and from the Highway Capacity Manual (HCM) 2000, with different capacities calculated for peak, counter-peak, and off-peak periods.[21] Because HERS is designed to work with daily rather than hourly volumes, the equations consider the ratio of annual average daily traffic to capacity as well as hourly peaking factors. For unsignalized two-lane roads, the delay depends only on the ratio of AADT to capacity.

The Akçelik equation (Akçelik, 1991) is a time-dependent modified form of the Davidson's function to model flows near and above capacity. The function is derived from queuing theory. A noteworthy characteristic is that travel *rate* (time/distance) increases in linear proportion to v/c at ratios over 1.0. The predicted travel speed remains close to free-flow as v/c approaches 1.0, then drops off quite steeply. Research by Dowling, Singh, and Cheng (1998) focused on refining the speed estimates of network assignment models by using the Akçelik speed-flow model. The researchers concluded that the Akçelik model produces significantly improved traffic assignment run times and provides more accurate speed estimates. The Akçelik speed-flow model is as follows (Singh, 1999):

$$t = t_0 + 0.25T \left\{ (x-1) + \sqrt{(x-1)^2 + \frac{8J_a x}{QT}} \right\}$$

Where:

t = average travel time per unit distance (hours/mile)

t_o = free-flow travel time per unit distance (hours/mile)

T = flow period, i.e., the time interval in hours, during which an average arrival (demand) flow rate, v, persists

Q = Capacity

x = the degree of saturation i.e., v/Q

J_a = the delay parameter

Representative parameters are given in Singh (1999).

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[20] The HERS model performs calculations on a sample of highway segments nationwide to estimate the economic benefits of improvements; its equations have been used to develop speed estimates for emissions modeling.

[21] HERS Technical Report (2005). Capacity is discussed in Section 4.4 and delay calculations in Section 5.4.

Node delay procedures are generally considered to be more accurate than link-based procedures, since node-based procedures take into account the demands on the conflicting approaches at an intersection (Dowling et al, 2006). The Highway Capacity Manual (TRB 2010) includes procedures to estimate capacity and delay for approaches to signalized intersections. These procedures include adjustments for a variety of factors such as lane widths, approach grade, parking, heavy vehicles, and turning movements. FHWA (Dowling Associates, 1997) and NCHRP Report 387 present procedures for implementing improved link-based speed and delay estimation procedures in travel demand models using HCM methods. These procedures use a speed-flow equation based on a modified Akçelik equation, which accounts for signal spacing and control delay.

4.7.3.5 Travel Demand Forecasting Models

Travel demand forecasting models can produce forecast year as well as historical year speed estimates and are widely used for estimating vehicle speed distributions for input to emissions models. The traffic assignment step commonly included in state-of-practice models contains algorithms relating link-level volume-to-capacity ratios to speed of travel through volume-delay functions as described above. Capacity is based on number of lanes, facility type, and sometimes other factors such as intersection density, traffic management methods, etc. Speeds are primarily used for the purposes of allocating flows on the network based on point-to-point travel times (impedances).

State-of-practice travel demand models have a number of limitations for speed estimation. First, models are not calibrated to match speeds, but rather to match traffic counts. Second, the impedances, which represent zone-to-zone travel times and costs, reflect the fact that travelers make decisions based on "planning time," which accounts for near worst-case times due to incidents, rather than actual travel times. Third, they do not provide the full range of speed distribution inputs that MOVES is capable of accepting (i.e., distinct distributions by hour of day, day of week, and source type). In addition, the quality of speed estimates can be limited. For example, speed is usually a simple function of link-level V/C ratios without explicit modeling of intersection delay or spillback from downstream bottlenecks, and the effect of nonrecurring congestion is not represented. Only two to four time periods of the day are modeled so the speed distributions may not account for short-term fluctuation in conditions.

Postprocessing techniques (see next section) can be applied to improve model speed estimates, but do not eliminate some of the more fundamental limitations. Some of the more advanced travel demand modeling platforms incorporate techniques such as intersection delay modeling and dynamic traffic assignment, which should provide improved speed estimates.

4.7.3.6 TDFM Speed Postprocessing Methods

Some TDFM users obtain speed data directly from traffic assignment estimates of congested speeds using congestion-delay curves, if the model produces reasonably accurate speed estimates. Others postprocess outputs to make modeled speeds more accurately reflect real-world conditions. For the purpose of developing MOVES inputs, postprocessing can be done at the hourly level, rather than the three or four time periods typically

used in TDFMs, so that hourly speed distributions can be created. This is done through the following steps, which are further illustrated in Example 4.7.2:

1. Allocate link-level VMT for each modeled time period by hour based on hour fractions derived from another source such as traffic counts or MOVES defaults (see Section 4.4);

2. Recompute link-level speeds for each set of hourly volumes using either the speed-volume/capacity equation from the model or a different equation; and

3. Summarize speeds (VHT-weighted) across all links in the model for each hour of the day, for each MOVES road type, to obtain speed distribution inputs.

Miller (2002) describes an example of a postprocessor developed for the Virginia DOT to estimate vehicle speeds for the purposes of conducting air quality conformity analysis using the MOBILE model. The postprocessor converts 24-hour link VMT to hourly volumes within three time periods (a.m. peak, p.m. peak, and off-peak), divides each link volume by the link's capacity, uses this ratio with a simple formula to estimate a link speed for each of three periods, and then computes VMT and VHT for each link and for each period. The postprocessor then aggregates link-specific volumes, speeds, VMT, and VHT by period and facility type. The postprocessor reports total volume, total VMT, average speed, and total VHT by facility type and within that category by time period.

Some MPOs also apply peak-spreading algorithms to allocate traffic from highly congested periods, when modeled volume exceeds capacity, to adjacent time periods. This reduces the problem of having unrealistically high v/c ratios. For example, the Metropolitan Washington Council of Governments developed an in-house postprocessor that operates as follows:[22]

1. The a.m. and p.m. peak-hour volumes (hours 8 and 18) are compared against link capacity. If volume exceeds capacity, the volume is reassigned to the preceding and subsequent hours (e.g., 7 and 9) on a 50/50 basis.

2. Volumes for other hours are compared and reallocated sequentially working backwards and forwards from each peak hour. For example, if the volume occurring in hour 7 exceeds capacity then the hour 7 volume is set to capacity and the excess volume portion is added to the volume of hour 6 volume, etc.

3. Speeds in each hour are recomputed using the new v/c ratios.

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[22] Internal memorandum from Ronald Milone & Hamid Humeida, Metropolitan Washington Council of Governments, May 30, 2012.

There are a number of issues to consider in developing a postprocessing method:

- **Choice of a Speed-Flow Relationship.** There are a number of alternative volume-delay functions and function parameters as described above. The analyst can either use equations and parameters that have been validated in the region or elsewhere, or can spend time comparing postprocessed versus observed speed distributions and picking equations and parameters that provide the best fit. Some agencies use speed-flow relationships that differ by time period. In theory the relationships should be consistent across time periods but this adjustment may be done to more closely match observed patterns which may result, for example, if travelers factor in more planning time in peak hours because of lower reliability.

- **Validation of Postprocessed Speeds.** Speed-flow relationships cannot be directly validated against observed speeds at v/c ratios greater than 1.0. Typically, other model outputs are validated. In model calibration and validation, the model is validated against observed traffic counts; if actual counts match modeled flows, the equations in the model (including speed equations) are assumed to accurately reflect the travel times expected or perceived by travelers. For the purposes of postprocessing for MOVES inputs, speed distributions can be compared against real-world speed distributions.

- **Definition of Capacity.** Capacity is generally taken as a given. However, the capacity of a road segment depends on many different parameters and may not be known with certainty. The analyst should be careful *not* to use a "composite capacity" that already has been adjusted to account for usages within time periods (e.g., a 3 hour a.m. peak "capacity" may be 60 percent of the engineering design hour capacity from 6-7 a.m., 100 percent from 7-8 a.m., and 80 percent from 8-9 a.m.). And if "capacity" is coded as vehicles per lane per hour (vphpl) instead of passenger cars per lane per hour (pcphpl), then the vphpl should already consider different truck demand within each hour.

Other general references on postprocessing techniques for air quality analysis include Chatterjee and Miller (1994) and Dowling (1997).

4.7.4 Sample Data and Tools

EPA has provided data converters that convert MOBILE6.2 speed distribution inputs to MOVES format (an additional data converter is available to convert NMIM-formatted speed distributions to MOVES format). These converters also handle the conversion of a VMT-based speed distribution to a VHT-based speed distribution.

The converters are available under "VMT Converters" at: http://www.epa.gov/otaq/models/moves/tools.htm.

4.7.4.1   Comparison of Speed Data from Multiple Sources

As part of the research project the research team obtained speed data from multiple sources for two metropolitan areas – Atlanta and Jacksonville. These sources included:

- Atlanta:
  - Travel demand model output, including unprocessed and postprocessed by the Atlanta Regional Commission (ARC);
  - ITS data from the Georgia DOT (freeways only);
  - GPS travel survey data; and
  - NAVTEQ data.

- Jacksonville:
  - Travel demand model output;
  - ITS data from the Florida DOT (freeways only); and
  - INRIX data.

The data and analysis methods are described more fully in the Final Report for NCHRP Project 25-38. Most data are from 2010 to 2012 timeframe, except for the Jacksonville model which is from 2005. It is challenging to compare speed distributions because there are numerous metrics that could be applied, and because each hour of the day has a different distribution. Simple statistics such as average speed do not capture the variation in speeds that is critically important to emissions modeling. The analysis focused on four "representative" time periods – 5-6 a.m. (overnight period), 7-8 a.m. (morning peak), 11 a.m.-12 p.m. (midday), and 5-6 p.m. (evening peak), as well as summary statistics of average speed by time period and percent of VHT less than 27.5 mph (representing congested conditions with higher emissions). Running emissions also were calculated for each distribution, based on representative emission rates by speed, to show how much difference the choice of different speed estimation methods can make on emissions.

Difficulties were encountered in using the private sources (NAVTEQ and INRIX) for the purpose of creating speed distributions. These data are associated with traffic management center networks, but must be associated with traffic volumes from the travel demand model in order to weight the speeds appropriately by volume. The TMC and travel model networks are different in both cities and could not be easily conflated, requiring significant manual coding in order to create the associations. The comparisons presented here do not include the private sources because it exceeded the available scope/budget to perform these conversions. Therefore, the comparisons also focus primarily on freeways since the public ITS monitoring systems only cover the freeway networks.

Figures 4.7.1 to 4.7.3 show speed distributions for Jacksonville freeways, from unprocessed travel demand model output, postprocessed output using the metropolitan planning organization (MPO) BPR coefficients, and observed data from the ITS system. The comparisons use the ITS data as likely to be closest to "ground truth." The unprocessed

model results show more travel at low speeds (<20 mph) than either the processed results or the ITS data. Both sets of model results also show a strong peak at 65 mph (free-flow on many road segments), whereas the ITS data show higher speeds somewhat more evenly distributed over the 60-75 mph range. The a.m. and p.m. peak-hour distributions are fairly similar in the observed ITS data, whereas the model shows higher levels of congestion in the p.m. peak compared to the a.m. peak.

Figure 4.7.1 Speed Distribution, Jacksonville Freeways, Travel Demand Model
Not Postprocessed
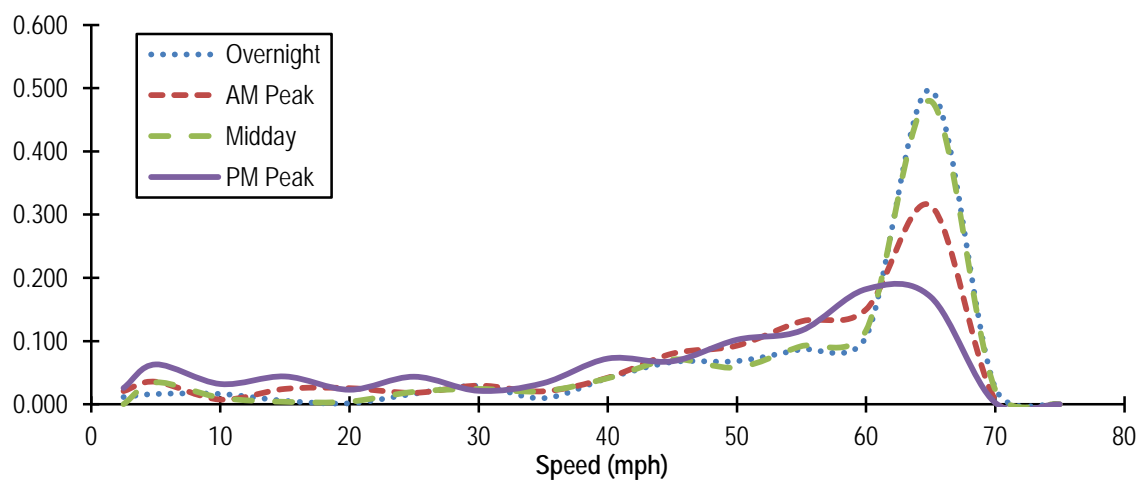
Figure 4.7.2 Speed Distribution, Jacksonville Freeways, Travel Demand Model
Postprocessed
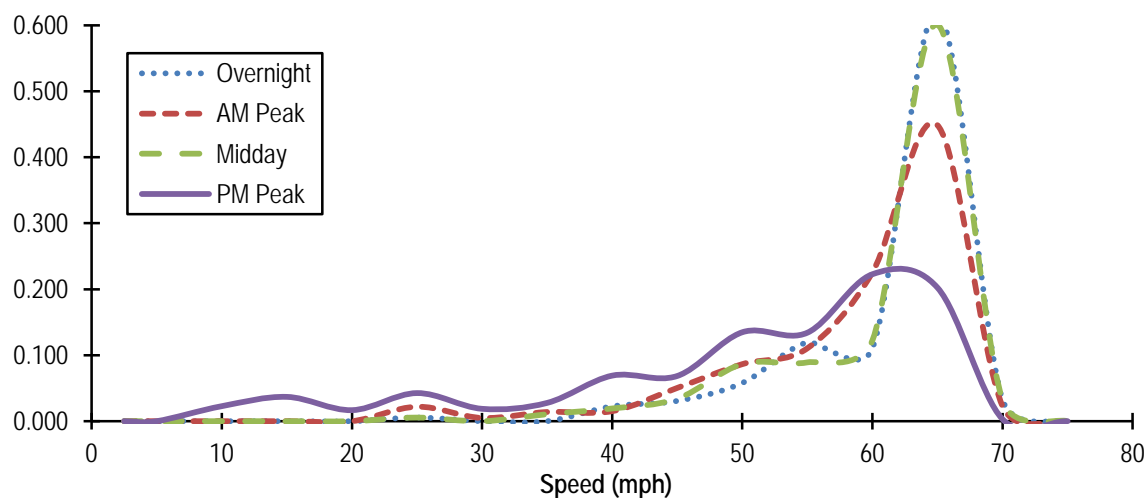
Figure 4.7.3   Speed Distribution, Jacksonville Freeways, ITS
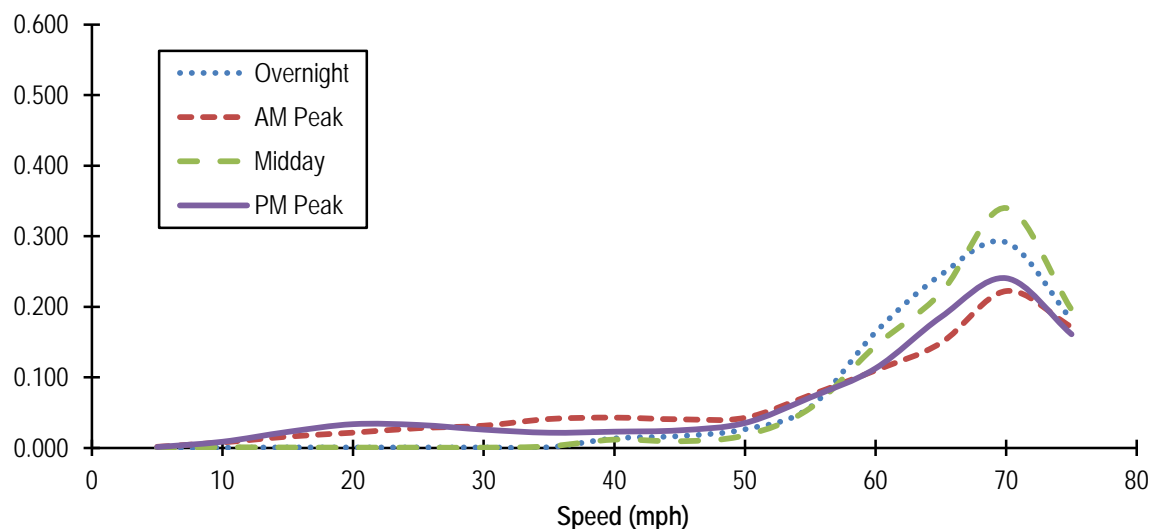
Figure 4.7.4 shows the average speed on Jacksonville freeways from the travel demand model, both unpostprocessed and postprocessed, alongside the ITS observed speeds. Figure 4.7.5 shows similar data for Atlanta, adding the speeds observed from the GPS-instrumented travel survey participants.   (The Atlanta chart shows model speeds postprocessed using two different methods, one based on local adjustment factors and one based on the BPR curve with Jacksonville coefficients.[23]) It is apparent that the average speed estimates differ substantially, by up to 20 percent or even more. In both Atlanta and Jacksonville, the model estimated speeds are considerably lower on average than the ITS speeds. Postprocessing improves this substantially in Jacksonville, but even the post-processed speeds are 5-10 percent lower than the observed ITS speeds. In Atlanta, the average speeds from the GPS travel surveys are even higher than the ITS speeds. It is not clear what aspect of the household survey sampling procedure might create such a bias. It is clear, however, that the use of model "free-flow" speeds, typically set at posted speed limits of 55 to 65 mph, underrepresent high-speed vehicle travel, as the average speeds observed in off-peak periods ranged from 64 to 67 mph.

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[23] ARC has updated its speed postprocessing procedures and the local adjustment factors used in this example are no longer used. The results are shown only to illustrate the difference that the choice of alternative postprocessing methods can make.

Figure 4.7.4   Average Speed, Jacksonville Freeways

Avg. speed, mph
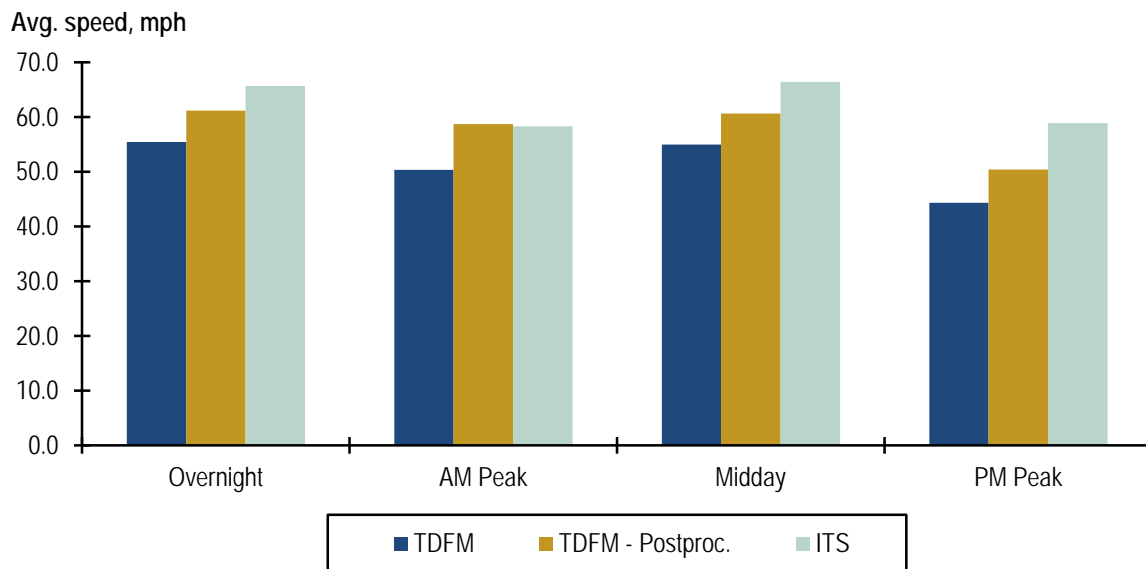
Figure 4.7.5   Average Speed, Atlanta Freeways

Avg. speed, mph
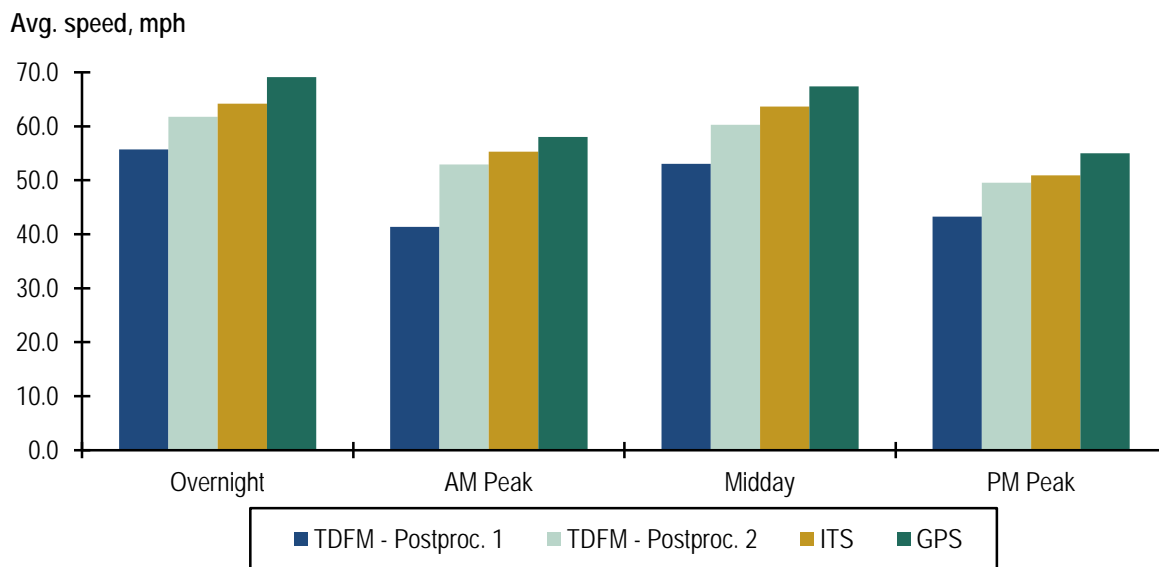
Emissions can also be compared, using representative emission factors.[24] The results, expressing emissions as a percent of emissions under the ITS speed distribution, are shown in Tables 4.7.3 and 4.7.4. For Jacksonville freeways, the unpostprocessed model emissions are significantly higher than the emissions calculated based on ITS observed speeds. The largest differences are observed for VOC (30-70 percent higher), followed by truck $PM_{2.5}$ (20-40 percent higher), CO_2e (10-30 percent higher), and NO_x (up to 20 percent higher). However, the postprocessing of Jacksonville model speeds brings the emissions estimates much closer to the estimates based on observed ITS speeds, within 5 percent in most cases.

For Atlanta freeways, use of the ITS and GPS speed distributions leads to fairly similar emissions results. The model speeds postprocessed using ARC's old procedures (no longer in use) show significantly higher emissions in peak periods, especially for VOC and truck $PM_{2.5}$, which are about 10-30 percent higher depending on the time period. Alternative postprocessing of Atlanta model speeds, using the BPR function with Jacksonville's coefficients, provides emission estimates that are much closer to the ITS and GPS-based estimates (within 3 percent in all cases).

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[24] Running emission factors by speed for Hillsborough County, Florida were used, based MOVES embedded inputs for 2006. The emission output for each speed distribution is a g/mi factor calculated as the weighted average of emission factors by speed (at the midpoint of the speed bin), weighted by VHT in each speed bin.

Table 4.7.3   Relative Emissions versus ITS Speed Distribution, VOC, and NO$_x$

Metro Area/Source	VOC				NO$_x$			
	Overnight (5:00-6:00 a.m.)	A.M. Peak (7:00-8:00 a.m.)	Midday (11:00 a.m.-12:00 p.m.)	P.M. Peak (5:00-6:00 p.m.)	Overnight (5:00-6:00 a.m.)	A.M. Peak (7:00-8:00 a.m.)	Midday (11:00 a.m.-12:00 p.m.)	P.M. Peak (5:00-6:00 p.m.)
Jacksonville								
TDFM	136%	142%	132%	173%	106%	111%	104%	120%
TDFM – Postproc.	100%	89%	101%	107%	97%	94%	96%	97%
ITS	100%	100%	100%	100%	100%	100%	100%	100%
Atlanta								
TDFM – Postproc. 1	108%	132%	112%	129%	96%	106%	97%	108%
TDFM – Postproc. 2	100%	97%	101%	97%	98%	97%	98%	97%
ITS	100%	100%	100%	100%	100%	100%	100%	100%
GPS	97%	92%	97%	87%	103%	98%	102%	96%

Table 4.7.4   Relative Emissions versus ITS Speed Distribution, CO$_2$e, and PM$_{2.5}$

Metro Area/Source	CO$_2$e				PM$_{2.5}$ (Combination Long-Haul Trucks)			
	Overnight (5:00-6:00 a.m.)	A.M. Peak (7:00-8:00 a.m.)	Midday (11:00 a.m.-12:00 p.m.)	P.M. Peak (5:00-6:00 p.m.)	Overnight (5:00-6:00 a.m.)	A.M. Peak (7:00-8:00 a.m.)	Midday (11:00 a.m.-12:00 p.m.)	P.M. Peak (5:00-6:00 p.m.)
Jacksonville								
TDFM	111%	116%	109%	128%	126%	121%	124%	140%
TDFM – Postproc.	98%	94%	98%	100%	101%	88%	103%	107%
ITS	100%	100%	100%	100%	100%	100%	100%	100%
Atlanta								
TDFM – Postproc. 1	99%	111%	100%	112%	109%	125%	114%	112%
TDFM – Postproc. 2	99%	97%	99%	97%	102%	98%	103%	97%
ITS	100%	100%	100%	100%	100%	100%	100%	100%
GPS	101%	97%	101%	95%	98%	95%	98%	92%

4.7.4.2 Seasonal Speed Variations

The ITS data sources in Atlanta and Jacksonville are continuously collected and can there-fore be used to examine seasonal variations in speeds. Figures 4.7.6 and 4.7.7 compare speed distributions on Atlanta freeways in January and July. More congestion is observed in the p.m. peak in July, and slightly more in the off-peak and overnight periods, but less in the a.m. peak. Table 4.7.5 shows the average speed and percent of VHT below 27.5 mph in both months, as well as the relative difference in emission rates (July versus January). Most values fall within a few percent, with the largest differences being 12 percent lower VOC in the July a.m. peak, and 8 percent higher truck $PM_{2.5}$ (source type 62) in the July overnight period. Note that these show speed effects only and are not adjusted for differ-ences in traffic volumes.

Figure 4.7.6   Fraction of VHT by Speed
Atlanta Freeways, January
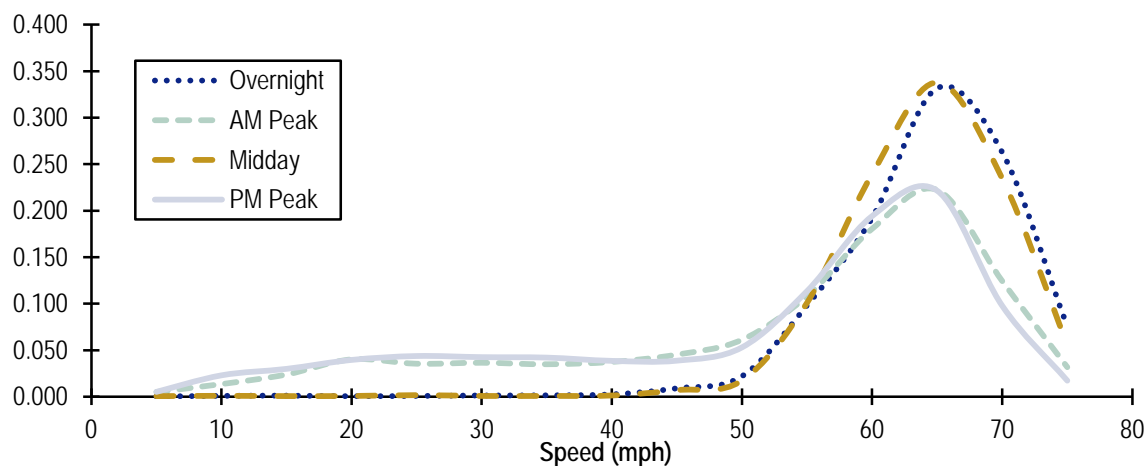
Figure 4.7.7   Fraction of VHT by Speed
Atlanta Freeways, July
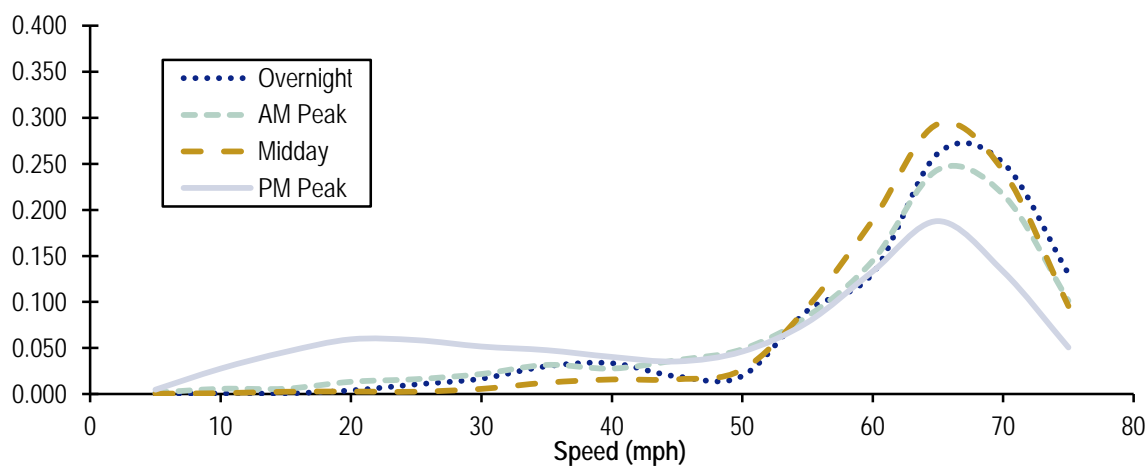
Table 4.7.5   Comparison of Speeds and Emissions
Atlanta Freeways, January, and July

	Overnight 5:00-6:00 a.m.	A.M. Peak 7:00-8:00 a.m.	Midday 11:00 a.m.-12:00 p.m.	P.M. Peak 5:00-6:00 p.m.
Avg. speed – Jan.	64.3	53.4	63.8	51.7
Avg. speed – July	62.3	59.7	63.2	50.0
%VHT < 27.5 mph – January	0%	12%	0%	14%
%VHT < 27.5 mph – July	1%	3%	1%	14%
Percent difference in emission rates, July versus January				
VOC	105%	88%	102%	106%
CO	104%	101%	103%	105%
NO_x	101%	99%	101%	103%
CO_2e	102%	96%	101%	103%
$PM_{2.5}$ (combo long-haul truck)	108%	89%	104%	107%

4.7.4.3   *Comparison of Speed Postprocessing Methods*

The research team applied a variety of volume-delay functions to calculate speed distri-butions and compared the distributions with real-world data. The initial comparison was made on Atlanta freeways, since observed speed data were available from the ITS data-base. Also, the VDFs are less data-intensive for freeways than arterials, since some of the VDFs incorporate additional parameters (such as signal spacing) which were not available to the project team. The various VDFs were applied using link capacities contained in the ARC travel demand model. Table 4.7.6 provides a summary of the VDFs compared; additional documentation is provided in the NCHRP 25-38 Final Report.

Table 4.7.6   Volume-Delay Functions Compared on Atlanta Freeways

Volume-Delay Function	Description	Key Parameters
ARC model	Empirically derived parameters used to postprocess ARC model output	
BPR default	BPR formula, default coefficients	a = 0.15, B = 4
BPR Jax	BPR formula, coefficients used by Jacksonville MPO	a = 0.45, B = 6.75
BPR MTC	BPR formula, coefficients used by Metropolitan Transportation Commission, Oakland, California[a]	a = 0.2, B = 10
CSI_JHK	BPR formula, alternative coefficients	a = 0.1225, B = 8
Akçelik Davidson	Formula as presented above, with following coefficients:	Capacity = 2200 t_0 =1/70 T = 0.333 Q = 2200 J_a = 0.1
ARC_Conical	ARC/GRTA Conical Speed Function (no published documentation)	
ITS	Observed speeds from ITS system	NA

[a] As reported in Singh (1999); may not reflect current practice.

Figures 4.7.8 to 4.7.10 compare modeled and observed speeds for representative time periods of 5-6 a.m. (overnight), 7-8 a.m., and 5-6 p.m. Table 4.7.7 shows the average speed compared to the ITS speed, percent of speed below 27.5 mph, and the root mean square error (RMSE) of the speed distribution compared to the ITS distribution.[25] In the overnight period, most of the speeds in all methods are greater than 55 mph; however, the ITS data show more speeds in the 70-75 mph range compared to the functions which are limited to a free-flow speed of 65 mph. (The free-flow speed could be increased to 70 mph and the curves would shift to the right, but would then show too little travel in the 60-65 mph range. If a free-flow speed of 60 mph is used, as is common, the curves would under predict average speeds by a greater amount.)

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[25] Calculated as the square root of the average of the squares of the difference in VHT fractions for each speed bin.

Figure 4.7.8   Speed Distributions
Atlanta Freeways, 5-6 a.m.
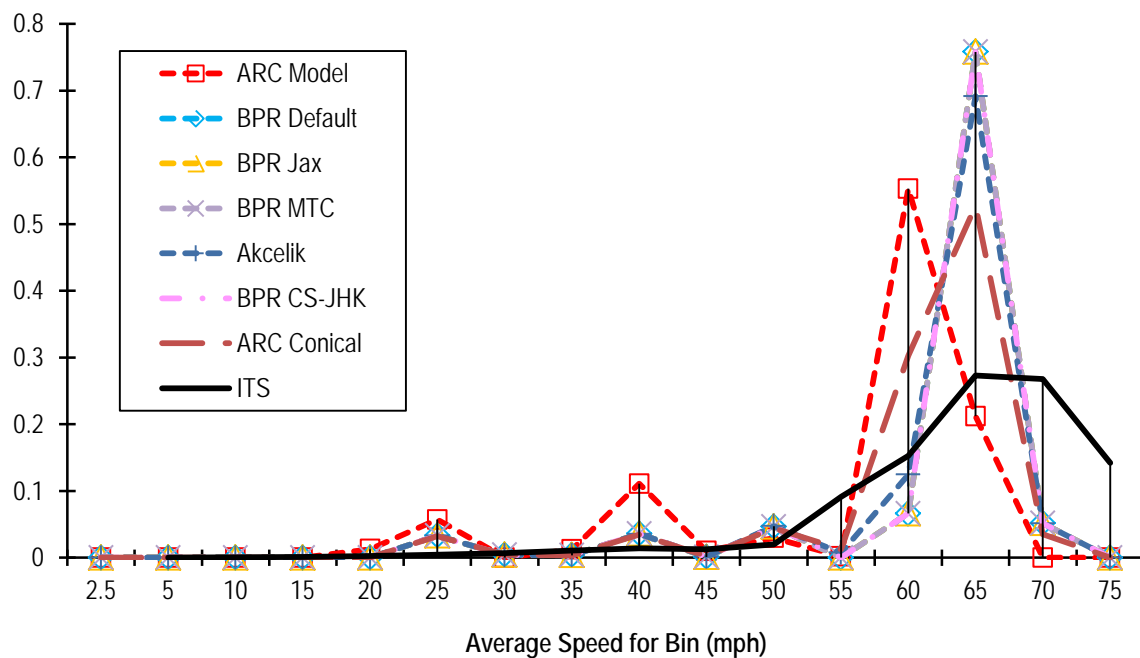
Figure 4.7.9   Speed Distributions
Atlanta Freeways, 7-8 a.m.
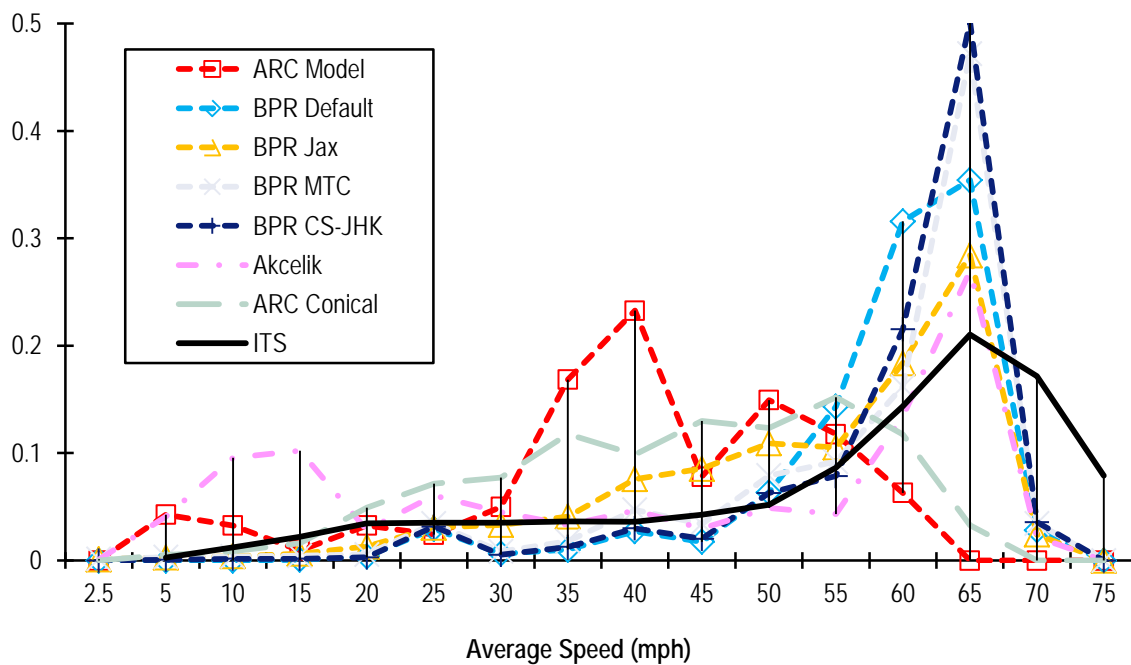
Figure 4.7.10   Speed Distributions
Atlanta Freeways, 5-6 p.m.
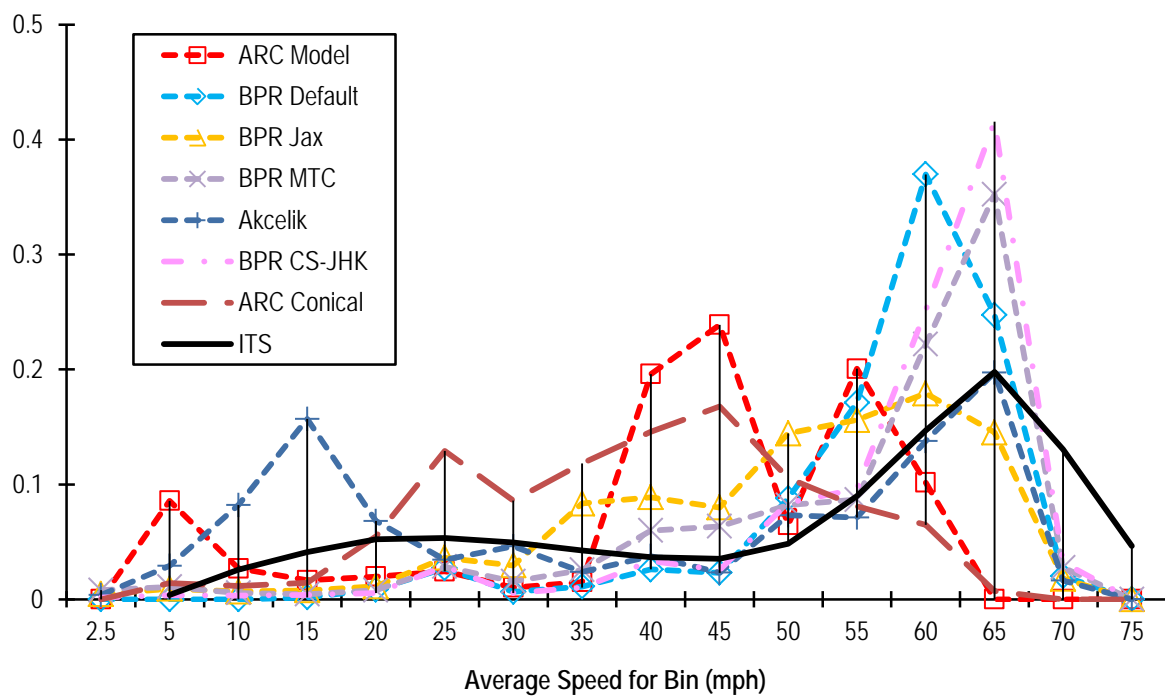
Table 4.7.7   Summary Statistics for Speed Distributions
Atlanta Freeways

Source	Overnight (5-6 a.m.)				Morning Peak (7-8 a.m.)				Evening Peak (5-6 p.m.)			
	Avg. (mph)	Avg. versus ITS	% < 27.5 mph	RMSE	Avg. (mph)	Avg. versus ITS	% < 27.5 mph	RMSE	Avg. (mph)	Avg. versus ITS	% < 27.5 mph	RMSE
ARC model	55.6	-13%	7%	0.136	39.8	-28%	14%	0.102	41.7	-18%	17%	0.100
BPR default	61.7	-4%	3%	0.146	58.2	5%	3%	0.075	57.0	12%	4%	0.074
BPR Jax	61.7	-4%	3%	0.146	52.9	-4%	6%	0.053	49.6	-3%	8%	0.053
BPR MTC	61.7	-4%	3%	0.146	57.2	3%	5%	0.080	54.7	7%	6%	0.058
CSI_JHK	61.7	-4%	3%	0.146	59.1	7%	4%	0.089	57.8	13%	5%	0.073
Akçelik Davidson	61.4	-4%	3%	0.130	42.4	-23%	33%	0.058	40.1	-21%	37%	0.048
ARC Conical	60.4	-6%	3%	0.106	43.1	-22%	15%	0.081	38.9	-24%	22%	0.085
ITS – Observed	64.2	N/A	1%	N/A	55.3	N/A	11%	N/A	50.9	N/A	18%	N/A

Examining the peak periods, the Akçelik function appears to provide the best match in the upper speed ranges, but over predicts VHT in the lowest speed ranges (<20 mph). The ARC model and conical functions also show too much speed in the mid ranges and not enough at higher speeds, in essence over predicting congestion. Most of the BPR curves, in contrast, show not enough travel in the lower speed ranges and too much in the 60-65 mph range. None of the curves provide an ideal match to the observed ITS speed distribution and the summary statistics also show variances across each statistic.

Interestingly, while the Akçelik equation is furthest from the ITS data as measured by average speed and fraction of low-speed travel, it has one of the lowest RMSE. The coefficients in the Akçelik equation can be adjusted like the BPR coefficients can, but preliminary explorations by the project team did not find a substantially better fit.

While further testing of equations on both freeway and arterial data would be beneficial, a few preliminary conclusions may be drawn:

- Postprocessing of travel demand model outputs generally is beneficial in improving the fit of modeled to observed speed distributions.

- The output of the speed equations should be compared against local data, and coefficients of the VDFs adjusted to attempt to match local conditions.

- As others have observed, the BPR equation is generally improved through the use of coefficients other than the standard values of 0.15 and 4. In this case, coefficients used in Jacksonville appeared to do a reasonable job of predicting speeds in Atlanta.

- The Akçelik formula appears to do a better job than the BPR formula at predicting the distribution of speeds at higher speed ranges. However, it can show a very high drop-off in speeds at v/c > 1.0, leading to over-prediction of congested conditions. Further evaluation of this function using alternative parameters may be warranted.

- Difficulties are observed in predicting the high end of the speed range (distribution of speeds under free-flow conditions), as well as the low end (congested conditions). If the analyst is in a situation where congestion is limited (such as a rural setting) or is not likely to change substantially in the future, use of observed rather than modeled speeds may be preferable.

- Given the serious theoretical and practical difficulties in making accurate speed predictions from a conventional travel demand model, substantial improvements in speed prediction capabilities are likely to occur only with the more widespread use of new-generation simulation models with dynamic traffic assignment.

4.7.4.5 Truck Speeds

Boriboonsomsin, Sheckler, and Barth (2012) show speed distributions from a nationwide fleet of 2,000 GPS-instrumented heavy-duty vehicles, by hour of day for urban restricted

and unrestricted roads.[26] They find that for urban restricted roads, heavy trucks spent most of their time at free-flow speeds around 60-65 mph, with a fair amount of time in the 2.5 mph speed bin, probably due to idling on roadsides or rest stops. For urban unrestricted roads, the heavy trucks spent the largest fraction of their time each hour in the 2.5 mph speed bin, probably idling at traffic lights or loading/unloading zones. The most dominant nonidle speed range is 30-40 mph, which is consistent with the typical speed limits found on that type of road. This example does not show how speeds may vary among urban areas.

As discussed above, another research project (Boriboonsomsin, Zhu, and Barth, 2011) also found significant speed differentials between heavy-duty trucks and other vehicles, at least on the Southern California freeways which were investigated. Figure 4.7.11 compares speed distributions for heavy trucks versus all vehicles, which differ by about 10 mph. This may reflect a 10 mph difference in speed limits for cars versus trucks and it is not known whether areas without a speed limit difference would see corresponding differences in speeds. The authors conclude that a separate speed distribution for heavy-duty trucks should be developed for emissions modeling, especially in areas where a differential speed limit is enforced.

Figure 4.7.11   VMT versus Speed Distribution on Southern California Freeways
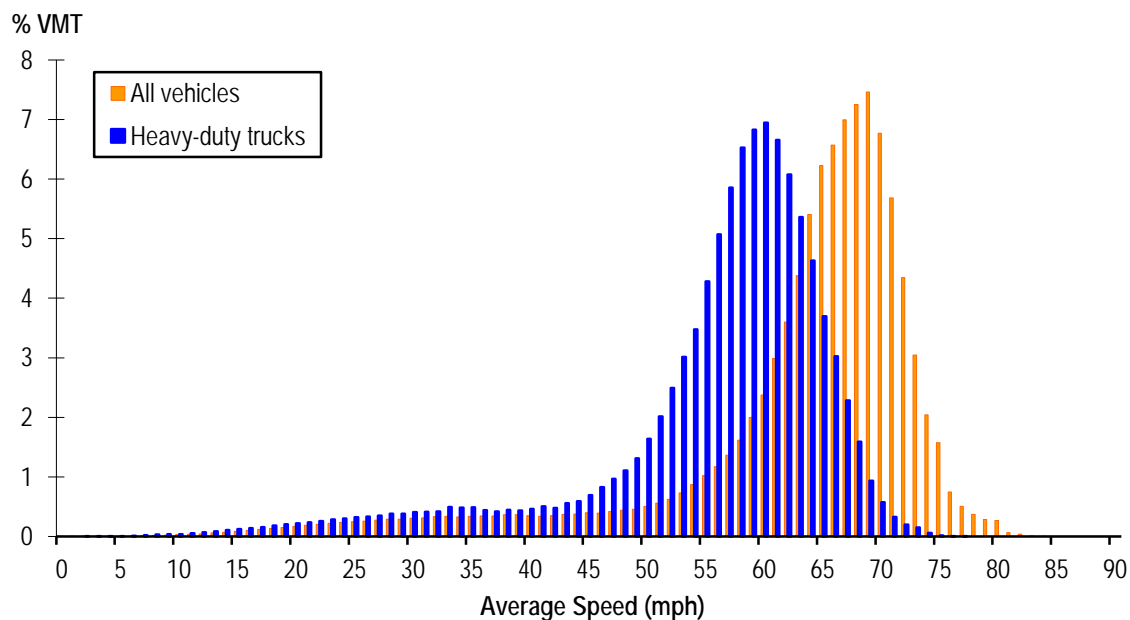
Source: Boriboonsomsin, Zhu, and Barth, 2011.

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[26] This is the Highway Visibility System dataset, a private database containing several hundred million records of commercial vehicle activity data from the telematics-based tracking and monitoring systems in the vehicles of participating fleets. The monitored trucks were mostly based in California and the Northeast. The dataset analyzed was comprised of 90 percent combination trucks and 10 percent single-unit trucks.

4.7.5   Examples

Example 4.7.1 – Aggregation of Speed Data from ITS Detectors

This example illustrates how speed data as obtained from ITS archives can be aggregated into the format required for MOVES inputs.

The Georgia Department of Transportation (GDOT) maintains an archive of traffic data collected through a network of video cameras on freeways within a seven-county portion of the Atlanta metropolitan area. Video image processing is used to derive volumes, speeds, and lane occupancies at five-minute intervals. Each detector is associated with a segment length, which is about 0.37 mile between two adjacent detectors. Data were obtained from 2010 (the ITS had a major upgrade in 2011, and the data were not complete during the upgrade period). Only weekday's data were used.

The steps for processing the five-minute lane data into speed distributions for MOVES were as follows:

1. Conduct quality control checks on the data records, following guidelines published by FHWA (2004). All the speeds less than 5 mph were reset to null since past studies suggested that data were not reliable when speed was less than 5 mph. Null values due to reset speeds, and missing data due to equipment failures, were discarded from the dataset. In the Atlanta dataset, 37 percent of time intervals have a valid VHT number. The data were evaluated to ensure there was not a bias in the missing data to a specific time period (hour of the day).

2. Aggregate speeds and traffic volumes across lanes to obtain an average speed and total volume by direction for each link. This was done by summing the individual lane traffic volumes, and averaging the speed for each lane, weighted by the volume in the lane.

3. Calculate the VHT on each link as follows: VHT = Volume * length (mi)/speed (mi/hr).

4. Assign each five-minute link directional speed to a MOVES speed bin.

5. Sum the VHT in each speed bin across all link segments and all five-minute intervals in each hour time period.

6. Divide VHT in each speed bin by total VHT for the hour time period to obtain the fraction of VHT by speed bin for the hour. Repeat for all 24 hours.

Example 4.7.2 – Postprocessing Travel Demand Forecasting Model Speeds

This example illustrates issues commonly addressed in postprocessing TDFM speeds. In particular it illustrates:

- Recomputing speeds for each hour of the day, based on VMT fractions allocated by hour; and

- Aggregating link-level speeds into average speed distributions by road type and hour as required for MOVES input.

The Jacksonville travel demand forecasting model's assignment process develops traffic flow by four time-of-day periods. The time-of-day periods are:

- A.M. period includes 8 a.m., 9 a.m., and 10 a.m.;

- Midday period includes 11 a.m. to 4 p.m.;

- P.M. period includes 5 p.m. to 7 p.m.; and

- Night period includes the rest of day.

The model assignment process develops a congested travel time and congested speed on each link for each of the four time-of-day periods. The model assumes that the speed remains constant within each of the time periods. In reality, the speed is likely to vary. In order to get a speed that varies by hour, the model data were postprocessed. The BPR volume delay function shown in equation (1) was used to calculate the hourly speed.

$$t_c = t_0 \left(1 + \alpha \left(\frac{V}{C} \right)^\beta \right) \tag{1}$$

Where:

t_c = Congested travel time

t_0 = Free-flow travel time

α, β = Constants

V = Hourly traffic flow

C = Hourly capacity

Congested travel time was calculated for each link of the network and for each hour of the day using equation (1). Free-flow travel time was calculated from free-flow speed and distance coded in the model's highway network. The model network has the values of α and β coded for each link. These values were used in the speed calculation. The highway network database has per lane per hour capacity for each link. This value was multiplied by the number of lanes to get the hourly link capacity.

The model also develops the traffic flow (vehicle volumes) for each of the four time periods. The hourly volumes were calculated from the period volumes, based on the relative distribution of VMT by hour within each time period. This distribution was based on the

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MOVES program's embedded hourly VMT distribution by road type and vehicle type. Equation (2) shows how the MOVES hour fractions (d_{hr}) were used to calculate the hourly volumes from the period volumes.[27]

$$V_{hr} = \left(\frac{d_{hr}}{\sum_t d_{hr}}\right) * V_t \tag{2}$$

Where:

V_{hr}= Hour volume

d_{hr}= Hour fraction of VMT

t = Time-of-day period (a.m., midday, p.m., or night)

V_t= Traffic volume in time-of-day period t

The average speed distribution was then calculated using the equation (3).

$$SD_{ijkl} = \left(\frac{VHT_{ijkl}}{\sum_l VHT_{ijk}}\right) \tag{3}$$

Where:

SD_{ijkl} = Average speed distribution for source type i, road type j, hour k and speed bin l

VHT_{ijkl} = Vehicle hours of travel for source type i, road type j, hour k and speed bin l

The value of VHT was calculated using equation (4).

$$VHT_{ijkl} = \left(VMT_{ijkl}\right)/Spd_l \tag{4}$$

Where:

VMT_{ijkl}= Model VMT for source type i, road type j, hour k and speed bin l.

Spd_l= Average speed for bin l

Nonfreeway ramps were excluded from the calculation of VMT_{ijkl}.

Hourly speed bins were coded in the model network database based on the hourly link congested speed calculated using equation (1). The model network database includes model VMT by vehicle type (auto and truck) and by time-of-day period (a.m., midday, p.m. and night). The auto VMT and truck VMT by time-of-day period were summarized for each combination of road type and hourly speed bin from the model network database as follows:

- A.M. VMT was used for hour IDs 8-10;

- Midday VMT was used for hours 11-16;

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[27] The same procedure could be applied to a 24-hour model (a daily model with no time periods). The calculation would be simpler, since V_{hr} would simply be equal to $d_{hr} * V_{24,}$ where V_{24} is the daily volume.

- P.M. VMT was used for hours 17-19; and

- Night VMT was used for hours 1-7 and 20-24.

The hourly VMT was calculated from the time-of-day VMT by using the equation (2). The hourly auto VMT was used for the MOVES source type categories 11 to 43 and the truck VMT was used for the source type categories 51 to 62.

Table 4.7.8 provides some sample travel demand model data. The first two columns show the start and end notes for each link. Facility type is a local classification that was recoded into MOVES road type (4 = urban restricted). A.M. VMT (auto) is the morning peak period VMT on that link. Speeds are shown before and after postprocessing, and the speed bin is the MOVES speed bin corresponding to the calculated speed. See Section 5.0, Example 2 for a more detailed example of the use of travel demand model data to develop speed distributions.

Table 4.7.8   Example of Travel Demand Model Data

A Node	B Node	Capacity	Facility Type	MOVES Road Type	A.M. VMT (Auto)	Speed (Before)	Speed Bin (Before)	Speed (After)	Speed Bin (After)
23120	23488	1132	75	4	542	14.74	4	21.41	5
23488	23911	1132	75	4	682	14.74	4	21.41	5
23638	23442	1132	71	4	340	2.41	1	4.29	2
23894	23638	1132	71	4	604	2.41	1	4.29	2
23911	23953	1132	75	4	187	14.98	4	21.65	5
23954	23894	1132	71	4	181	2.97	2	5.24	2
24024	23954	1132	71	4	125	0.88	1	1.62	1
24033	24116	1132	71	4	433	7.43	2	12.10	3
24116	24643	1132	71	4	1083	2.48	1	4.40	2
24643	24741	1132	71	4	259	2.48	1	4.40	2
24671	24221	1132	75	4	850	6.42	2	10.64	3
24741	24951	1132	71	4	388	2.48	1	4.40	2
24890	24671	1132	75	4	374	6.41	2	10.64	3

■ 4.8 Meteorology

4.8.1 Description and Format

Ambient temperature has significant effects on emissions from on-road vehicles for most pollutant processes. Likewise, relative humidity influences estimates of NO_x emissions. The MOVES model requires input of temperature and humidity data for each hour within a modeling scenario.

In most cases, users will choose to provide actual hourly meteorological data for use in their MOVES modeling. In other cases, hourly data derived from minimum and maximum diurnal temperatures for a given time period may be sufficient. The choice may depend on the purpose of the modeling being conducted (e.g., specific exceedance episode modeling versus generic modeling of average summer ozone). Sources for obtaining actual hourly meteorological data are discussed in the following sections. EPA also provides a tool for generating hourly inputs based on typical climatic profiles.

The meteorology data for MOVES is contained in the zoneMonthHour table of the MOVES database. Table 4.8.1 shows the field in this table that must be populated with data to complete a MOVES modeling:

- **MonthID** – corresponds to the numeric representation of the month;

- **ZoneID** – represents the two-digit state FIPS code and three-digit county Federal Information Processing Standards (FIPS) code followed by a zero;

- **HourID** –the numeric representation of the hour of the day: hour 1 begins at 12:00 midnight; hour 2 begins at 1:00 a.m., etc.;

- **Temperature** – average temperature (degrees Fahrenheit); and

- **RelHumidity** – relative humidity (percent).

Table 4.8.1   Example of Meteorology Import Template (zoneMonthHour)

monthID	zoneID	hourID	temperature	relHumidity
1	481410	1	40	42
1	481410	2	40	42
1	481410	3	39	44
1	481410	4	39	44
1	481410	5	38	46
1	481410	6	37	47
1	481410	7	37	48
1	481410	8	38	46

Table 4.8.1   Example of Meteorology Import Template (zoneMonthHour) (continued)

monthID	zoneID	hourID	temperature	relHumidity
1	481410	9	41	41
1	481410	10	45	37
1	481410	11	48	32
1	481410	12	51	29
1	481410	13	53	27
1	481410	14	55	25
1	481410	15	55	24
1	481410	16	55	24
1	481410	17	54	25
1	481410	18	52	28
1	481410	19	49	30
1	481410	20	47	33
1	481410	21	45	35
1	481410	22	44	37
1	481410	23	43	39
1	481410	24	42	40

4.8.2   Source of Embedded Data and EPA Guidance

The relevant sections of the MOVES User Guide, guidance documents, and data tables are:

- MOVES User Guide: Section 2.3.3.4.1, Meteorology Data Importer (p. 68);

- MOVES SIP and Conformity Guidance: Section 4.2, Meteorology (p. 31); and

- MOVES GHG Guidance: Section 4.3, Meteorology (p. 45).

- Data tables from MOVES2010b default database: movesdb20120410: zoneMonthHour.

The meteorological data contained within MOVES2010 consists of average monthly temperature and humidity data for every county in the United States, based on 30-year National Climatic Data Center (NCDC) climatic normals from 1971 to 2000. MOVES2014 defaults are updated using NCDC data from a single year (2011).

For analyses conducted for non-regulatory purposes, embedded MOVES data may be sufficient. However, EPA does not recommend using default meteorological values for SIPs or regional conformity analyses. The MOVES SIP and Conformity Guidance states that

temperature assumptions must be consistent with those used to establish the emissions budget in the SIP, as required in the transportation conformity rule.

For generic modeling of average summer or winter day ozone or CO conditions, users should input average daily temperature profiles for those months in which exceedances can occur. For emissions and air quality modeling of a specific exceedance episode, actual hourly meteorological data for the episode or a longer period may be required.

Forecast year data. EPA guidance does not address forecast year meteorological data as different than base-year data. The same data are typically used for the forecast year as for the base year.

4.8.3   Data Sources, Procedures, and Methods

The source of all meteorological data is the National Climatic Data Center. Source data can be obtained directly from the NCDC. Historical NCDC data also have been processed in various formats for use in MOVES (as embedded values) and in the National Mobile Inventory Model. A summary of the primary and secondary data sources for this input is shown in Table 4.8.2.

Table 4.8.2   Summary of Options for Meteorology Data

Data Source or Procedure	Use	Uses and Advantages	Limitations
MOVES embedded data (from National Climatic Data Center, 1971-2000)	Common	Simplest option	Historical data, prior to 2000; does not include current conditions; not recommended by EPA
			30-year averages do not represent more extreme weather conditions contributing to pollutant formation
National Climatic Data Center	Common	Comprehensive, up-to-date data from across the United States	Requires some data processing work to obtain and format hourly data
National Mobile Inventory Model	Limited	Data interpolated for every county in the U.S.; requires less data processing than NCDC	May not include most current conditions

4.8.3.1   National Climatic Data Center

The National Oceanic and Atmospheric Administration National Climatic Data Center maintains the world's largest climate data archive. The NCDC local climatological data (LCD) is collected via land-based stations, ships, buoys, weather balloons, radars, satel-lites, as well as weather and climate models.

Hourly climate data for use in MOVES can be downloaded, by specific weather station and year, from the NCDC web site at http://www.ncdc.noaa.gov/IPS/lcd/lcd.html. The process for downloading and formatting hourly climatic data for importing into MOVES using the import template is described in Example 4.8.1.

4.8.3.2 National Mobile Inventory Model

The National Mobile Inventory Model is a computer application developed by EPA to help develop estimates of current and future emission inventories for on-road motor vehicles and nonroad equipment. NMIM contains meteorological data for every county in the U.S., which is developed from NCDC data. The current version, NMIM2008, includes two types of meteorological data:

- Twenty-year (1981 to 2000) average historical temperature and relative humidity by month and hour (CountyMonthHour table); and

- Historical temperature and relative humidity by month and hour for each year from 1999 to 2008 (CountyYearMonthHour table).

The CountyMonthHour table provides data similar to the embedded data in MOVES, only based on 20 rather than 30 years of historical data. However, the CountyYearMonthHour table provides an advantage over MOVES defaults in that a particular year can be selected. It also provides an advantage over the NCDC web site in that data are provided for every county in every state (data for counties without weather stations are interpolated from nearby stations). It also requires less processing to convert it to MOVES format. The NMIM documentation and databases are available at: http://www.epa.gov/oms/nmim.htm.

EPA does not recommend using this approach to develop MOVES inputs as the data are not current. In addition, NMIM will not be supported indefinitely given EPA's transition to including nonroad emissions in MOVES.

4.8.4 Sample Data and Tools

The preferred method of providing scenario-specific, hourly data is discussed above, including the use of the template for importing hourly temperature and relative humidity data provided by the MOVES County Data Manager. The format for the template is shown in Table 4.8.1.

However, as stated in Section 4.8.1, there are instances where generic hourly temperature profiles may be utilized to run MOVES. To this end, EPA provides two meteorological data converter tools on their web site (one for MOBILE6-formatted data, and one for NMIM-formatted data) for modelers to use. The tools are available for download at www.epa.gov/otaq/models/moves/tools.htm. The tools use minimum and maximum daily temperatures to create hourly temperature data for use in MOVES by applying generic hourly climate profiles. Each of these tools contains a worksheet titled "Instructions" which should be followed to generate the generic hourly profiles for MOVES modeling.

A new tool was also developed for this project to assist MOVES users in converting NCDC data into MOVES input format. This utility program, called LCD-to-MOVES, reads the NCDC LCD ASCII data and carry out most of the steps in the previous section to convert it to MOVES temperature/relative humidity CSV input format. The tool is

provided as a stand-alone utility and is documented in the "MOVES Tool Documentation" provided with the NCHRP 25-38 project reports.

4.8.5   Examples

Example 4.8.1 – National Climatic Data Center

This section provides an example of the process for downloading and formatting hourly climatic data for importing into MOVES using the import template. The example uses data from the NCDC web site at http://www.ncdc.noaa.gov/IPS/lcd/lcd.html.

Step 1: Select the state you are interested in modeling and click [Next >].

Figure 4.8.1   State Selection Screen – NCDC Local Climatological Data Report
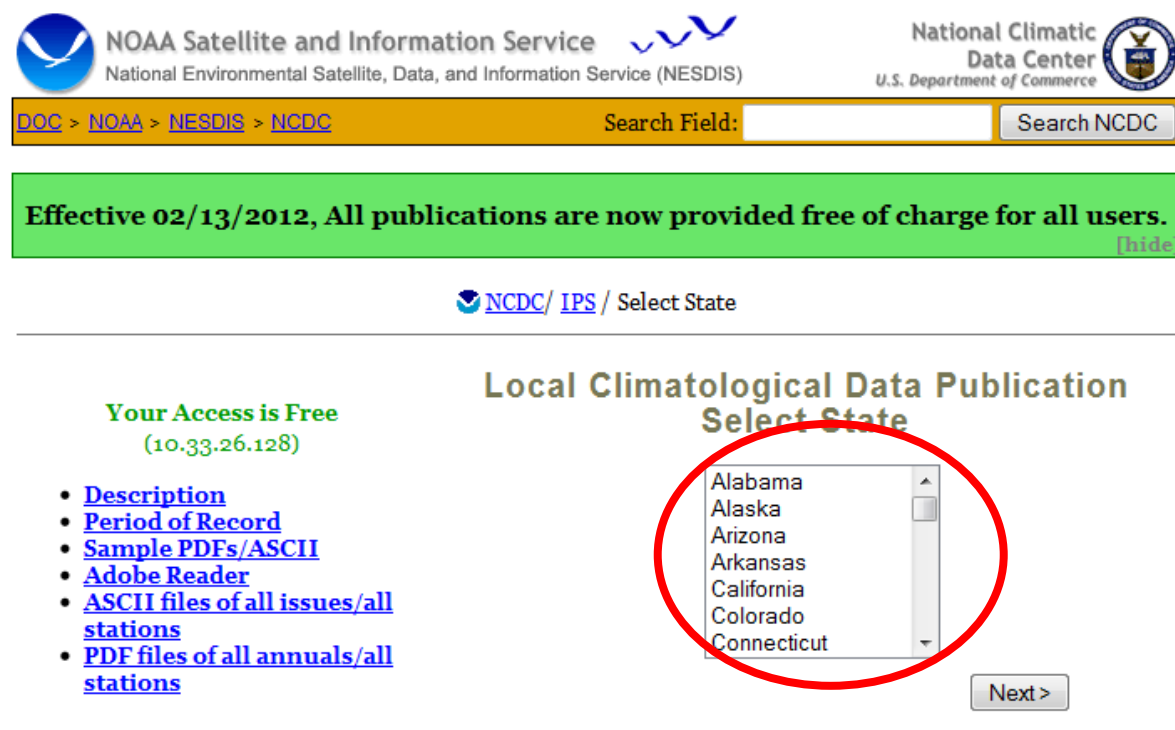
Step 2: Select the appropriate weather station and date range applicable to a modeling scenario and click ⬚Next >⬚. Pick a station representative of each county you are modeling. For most users an airport Automated Surface Observing System (ASOS) station will be the best choice. Note that users modeling multiple counties and multiple years will need to repeat this process for each county and year identified within a modeling scenario.

Figure 4.8.2   Station Selection Screen – NCDC Local Climatological Data Report

Step 3:   Select the report for the year and month of the modeling scenario and click Next >. If modeling more than one month (i.e., an annual run), repeat this process until a report for each year and month within the modeling scenario has been downloaded.

Figure 4.8.3   Year and Month Selection Screen – NCDC Local Climatological Data Report

Step 4: Hourly climate data are available in two forms for download. The PDF report presents the data in table format, as seen in Figure 4.8.4, and can usually be found on page 6 of the PDF report. An ASCII report is also available for download. The data in the ASCII report are presented in comma-delimited format, as seen in Figure 4.8.5. Click on the link to open the preferred report format. If using the ASCII data, skip ahead to Step 6.

Figure 4.8.4   Hourly Climate Data
PDF Version

SUMMARY BY HOUR

HOUR (LST)	AVERAGES										RESULTANT WIND (MPH)	
	CHILOMETER	EFF CLD AMT	DRY BULB	DEW POINT	WET BULB	RELATIVE HUMIDITY	PRESSURE (Inches, HG) STATION	SEA LEVEL	VISIBILITY (Miles)	WIND SPEED (MPH)	SPEED	DIRECTION
01			48	42	46	80	29.40	30.07	9.32	5	3	20
02			48	41	45	79	29.41	30.09	9.94	5	3	21
03			47	41	45	81	29.42	30.09	9.68	6	3	22
04			46	41	44	83	29.41	30.09	9.50	6	3	23
05			46	41	44	83	29.42	30.09	9.29	6	4	23
06			46	41	43	84	29.43	30.10	9.21	5	3	20
07			45	41	43	85	29.44	30.12	8.92	5	2	20
08			47	42	45	83	29.45	30.13	8.30	5	2	17
09			50	43	47	76	29.46	30.14	8.75	7	2	21
10			52	42	48	70	29.47	30.14	8.76	8	2	21
11			54	42	48	66	29.46	30.13	9.02	8	2	22
12			56	42	49	63	29.43	30.10	9.11	8	3	23
13			57	41	50	60	29.41	30.08	9.48	8	3	24
14			58	41	50	58	29.40	30.07	9.65	8	3	23
15			58	41	50	58	29.40	30.07	9.68	8	3	24
16			56	41	49	59	29.40	30.07	9.61	8	2	23
17			54	41	48	63	29.40	30.07	9.45	6	2	20
18			52	41	47	69	29.41	30.08	9.44	5	3	21
19			51	42	47	73	29.42	30.09	9.23	5	2	17
20			50	42	46	74	29.42	30.09	9.52	5	2	18
21			50	41	46	75	29.42	30.09	9.61	6	2	17
22			49	41	46	75	29.42	30.09	9.74	6	2	19
23			49	41	45	77	29.42	30.09	9.77	5	2	16
24			48	41	45	78	29.41	30.09	9.52	6	2	18

Figure 4.8.5   Hourly Climate Data
ASCII Version (.csv file)

```
01,,,,48,42,46,80,29.40,30.07,9.32,5,3,20
02,,,,48,41,45,79,29.41,30.09,9.94,5,3,21
03,,,,47,41,45,81,29.42,30.09,9.68,6,3,22
04,,,,46,41,44,83,29.41,30.09,9.50,6,3,23
05,,,,46,41,44,83,29.42,30.09,9.29,6,4,23
06,,,,46,41,43,84,29.43,30.10,9.21,5,3,20
07,,,,45,41,43,85,29.44,30.12,8.92,5,2,20
08,,,,47,42,45,83,29.45,30.13,8.30,5,2,17
09,,,,50,43,47,76,29.46,30.14,8.75,7,2,21
10,,,,52,42,48,70,29.47,30.14,8.76,8,2,21
11,,,,54,42,48,66,29.46,30.13,9.02,8,2,22
12,,,,56,42,49,63,29.43,30.10,9.11,8,3,23
13,,,,57,41,50,60,29.41,30.08,9.48,8,3,24
14,,,,58,41,50,58,29.40,30.07,9.65,8,3,23
15,,,,58,41,50,58,29.40,30.07,9.68,8,3,24
16,,,,56,41,49,59,29.40,30.07,9.61,8,2,23
17,,,,54,41,48,63,29.40,30.07,9.45,6,2,20
18,,,,52,41,47,69,29.41,30.08,9.44,5,3,21
19,,,,51,42,47,73,29.42,30.09,9.23,5,2,17
20,,,,50,42,46,74,29.42,30.09,9.52,5,2,18
21,,,,50,41,46,75,29.42,30.09,9.61,6,2,17
22,,,,49,41,46,75,29.42,30.09,9.74,6,2,19
23,,,,49,41,45,77,29.42,30.09,9.77,5,2,16
24,,,,48,41,45,78,29.41,30.09,9.52,6,2,18
```

Step 5: Find the "Summary By Hour" data and copy the contents to an Excel file. Format the pasted data into column format by selecting *"Text-to-Columns"* from the Excel > Data menu. Add the header row. The fields of interest for the data importer are indicated by the red arrows in Figure 4.8.6. (Temperature data is represented by the "DRY BULB" measurements.)

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Figure 4.8.6 Hourly Climate Data Required Fields for Data Importer
PDF Version

SUMMARY BY HOUR

HOUR (LST)	CEILOMETER	EFF CLD AMT	DRY BULB	DEW POINT	WET BULB	RELATIVE HUMIDITY	PRESSURE (Inches, HG) STATION	PRESSURE (Inches, HG) SEA LEVEL	VISIBILITY (Miles)	WIND SPEED (MPH)	RESULTANT WIND (MPH) SPEED	RESULTANT WIND (MPH) DIRECTION
01			58	49	53	74	29.40	30.06	9.59	6	4	16
02			57	49	53	76	29.39	30.05	9.53	5	3	17
03			56	49	52	78	29.39	30.05	9.67	5	3	17
04			56	48	52	78	29.40	30.06	9.47	5	4	16
05			55	47	51	78	29.41	30.07	9.30	5	3	16
06			55	48	51	78	29.43	30.09	9.43	5	3	16
07			58	48	53	73	29.44	30.11	9.30	7	4	14
08			60	48	54	67	29.45	30.12	9.57	8	3	15
09			63	49	55	62	29.46	30.12	9.47	8	3	14
10			65	48	56	57	29.46	30.13	9.40	9	3	16
11			67	48	57	54	29.45	30.12	9.70	9	3	15
12			69	48	58	50	29.43	30.10	9.90	9	3	17
13			70	48	58	48	29.41	30.08	9.63	9	3	20
14			71	48	58	47	29.39	30.05	9.77	9	3	15
15			71	47	58	47	29.38	30.04	9.50	9	2	18
16			71	47	58	47	29.39	30.05	9.58	9	2	18
17			70	47	58	50	29.37	30.04	9.40	9	3	16
18			68	48	57	53	29.37	30.03	9.67	7	3	14
19			65	49	57	60	29.38	30.04	9.73	5	4	14
20			63	50	56	64	29.39	30.05	9.87	4	4	15
21			62	50	55	68	29.40	30.07	9.70	5	4	15
22			61	50	55	70	29.41	30.07	9.70	5	4	15
23			60	50	54	72	29.41	30.07	9.67	5	4	16
24			59	49	54	71	29.40	30.07	9.90	6	3	15

Step 6: Add a column for Month ID to your file and populate it with the numerical representation of the month for the report. If multiple months, years, and counties are to be modeled, users may find it most straightforward to append each set of hourly data to the previous dataset, creating a single file for import into MOVES.

Step 7: Import the data using the MOVES County Data Manager.[28]

- **Step 7a** – Export the Meteorology Data Template from MOVES by selecting the Meteorology Data tab in the MOVES County Data Manager and clicking the Create Template button. Save the template as an Excel file.

- **Step 7b** – Populate the zoneMonthHour tab of the template by pasting the formatted data into it, and save the file.

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[28] Some users may instead use the MOVES Data Importer if performing a run at scales other than the county level. The interface for importing meteorological data is quite similar in either case.

- **Step 7c** – Browse to the populated template by clicking the Browse button and select the file to be imported.

- **Step 7d** – Select the zoneMonthHour worksheet from the pop-up window.

- **Step 7e** – Import the populated template by clicking the Import button. Confirmation of a successful import will appear in the Messages section of the CDM.

■ 4.9 Fuel Formulation and Supply

4.9.1 Description and Format

Decades of emissions research has shown that fuel properties have a strong influence on vehicle emissions, and that modification of fuel properties is a key strategy for reducing mobile source emissions. In particular, controls on gasoline Reid vapor pressure (RVP) and oxygenate content have been in place for years, as has sulfur control for both gasoline and diesel. Renewable fuels such as ethanol and biodiesel have continued to grow under Federal and state mandates. Regional variability in fuel properties can be significant, a function of variation in oil feedstock, distribution streams and local controls. An additional source of local variation is that national fuel standards for sulfur and renewables are focused on refinery volume averages, meaning that any given gallon of fuel will vary around the average standards. Finally, different fuel providers in any given area obtain fuel from their own fuel streams, adding to the variability in a region. Although characterizing fuel properties in a region is important, it can be very challenging to obtain complete data. EPA therefore provides detailed embedded data for fuel properties and market share by county, and allows use of this for local MOVES modeling, as discussed later in this section.

MOVES first characterizes fuel by fuel technology types (e.g., gasoline, diesel, shown in Table 4.9.1). A placeholder fuel type is included so that more fuel types can be included in future versions of MOVES. These technology types are further subdivided into fuel subtypes, shown in Table 4.9.2. Fuel subtypes account for broad differences in fuel properties that can still operate on the same technology vehicle.

Table 4.9.1   Fuel Types within MOVES

fuelTypeID	defaultFormulationID	fuelTypeDesc
1	10	Gasoline
2	20	Diesel Fuel
3	30	Compressed Natural Gas (CNG)
4	40	Liquefied Petroleum Gas (LPG)
9	90	Electricity
5	25001	Placeholder Fuel Type

Table 4.9.2   Fuel Subtypes within MOVES

fuelSubtypeID	fuelTypeID	fuelSubtypeDesc
10	1	Conventional Gasoline
11	1	Reformulated Gasoline (RFG)
12	1	Gasohol (E10)
13	1	Gasohol (E8)
14	1	Gasohol (E5)
15	1	Gasohol (E15)
20	2	Conventional Diesel Fuel
21	2	Biodiesel (BD20)
22	2	Fischer-Tropsch Diesel (FTD100)
30	3	Compressed Natural Gas (CNG)
40	4	Liquefied Petroleum Gas (LPG)
18	5	Ethanol (E20)
50	5	Ethanol
51	5	Ethanol (E85)
52	5	Ethanol (E70)
90	9	Electricity

Within fuel subtypes, detailed fuel properties are defined through the fuelFormulation table (Table 4.9.3), and the mix of fuels is defined in the fuelSupply table (Table 4.9.4). These are the tables users modify through the MOVES County Data Manager to customize local fuels. Fuel formulation defines a specific fuel within a fuel subtype based on primary properties of the fuel. The Fuel Supply table allows a user to associate a fuel formulation, using the FuelFormulationID, to specific counties (or fuel regions in MOVES2014), months, and years. The Fuel Supply table assigns a market share percentage to each fuel type, which must sum to one across all fuel formulations within a fuel type (e.g., all gasoline formulations sum to one, all diesel formulations sum to one).

Table 4.9.3   Fuel Formulation Table Data Fields

Data Field	Description
fuelFormulationID	Fuel formulation identification number. Must be greater than 100 and less than 25,000
fuel SubType	Fuel Subtype coding (see Table 4.9.4)
RVP	Reid vapor pressure in psi
sulfurLevel	Fuel sulfur level in ppm
ETOHVolume	Ethanol volume (%vol)
MTBEVolume	MTBE volume (%vol)
ETBEVolume	ETBE volume (%vol)
TAMEVolume	TAME volume (%vol)
aromaticContent	Aromatic content (%wt)
olefinContent	Olefin content (%wt)
benzeneContent	Benzene content (%wt)
e200	Lower volatility percentage (%)
e300	Upper volatility percentage (%)
VolToWtPercentOxy	Volume to weight percent oxygenate – a constant based on oxygenate type
BioDieselEsterVolume	Biodiesel ester volume (%)
Cetane Index	Not Implemented – NULL
PAHContent	Not Implemented – NULL [placeholder for future model versions]
T50	Temperature for distillation fraction – 50%
T90	Temperature for distillation fraction – 90%

Table 4.9.4   Fuel Supply Table Data Fields

Data Field	Description
CountyID[b]	State and County FIPS ID
FuelYearID	Year
MonthGroupID	Month ID
FuelFormulationID	Fuel Formulation ID from the Fuel Formulation Table
MarketShare	Market share fraction
MarketShareCV[a]	Coefficient of variation for market share for defining uncertainty in calculations

[a] This function in MOVES is currently not utilized.
[b] In MOVES2014, the fuel supply table has a column for fuelregionID rather than countyid. Using the MOVES2010b to MOVES2014 converter will automatically add the appropriate fuel region ID to the fuel supply table.

By editing the properties and market shares of fuel formulations, users can account for local fuels data and variation by seasons. These two approaches may be used independently or in conjunction with the other to make edits to fuel inputs within MOVES to accurately reflect local conditions for modeling scenarios. Fuel formulations and market shares are ever-changing and should be revisited for accurate modeling results. Users should note the fuelyearID does not necessarily correspond to a calendar year, but is a specific fuel year. The latest fuel year in MOVES2010b is 2012. Users should enter 2012 as the fuel year if editing the fuel property data, as MOVES2010b will use default fuel data if the fuelyear is 2013 or later.

4.9.2 Source of Embedded Data and EPA Guidance

The relevant sections of the MOVES User Guide, guidance documents, and data tables are:

- MOVES User Guide: Section 2.3.3.4.8, Fuel (p. 74);

- MOVES SIP and Conformity Guidance: Section 4.10, Fuel (Formulation and Supply) (p. 43);

- MOVES GHG Guidance: Section 4.11, Fuel (Formulation and Supply) (p. 59); and

- Data tables from MOVES2010b default database: fuelformulation, fuelsupply, and fuelsupplyyear.

The database supplied with MOVES contains default fuel supply and fuel formulation data for every county-year-month combination. Defaults in MOVES2010b were derived from the NMIM County Database (NCD) and the Energy Information Administration's Annual Energy Outlook. When originally populated, the NCD incorporated data from local, regional (refinery-level) and RFG fuel surveys, for years up to 2005. Using the Annual Energy Outlook, which projects annual fuel usage, values for some fuel properties were interpolated to gap-fill and create consistent trends where data were missing.[29] MOVES2010b default fuel supply data were obtained by Alliance of Automobile Manufacturers fuel surveys, RFG surveys, and state and county surveys. Because MOVES requires fuel formulation and fuel supply data for every calendar year, carryover and/or interpolation of data from other calendar years is common; users therefore should pay close attention to the embedded data used for these "intermediate" years, as these inputs are not based on data collected from those years.

The MOVES PM and CO Guidance recommend that users first review the default data available in the database for the modeled location and make changes only if more recent or more accurate fuel properties data are available. The guidance specifically draws out an exception for RVP, for which it is suggested that the user enter an RVP value that

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[29] EPA, Technical Guidance on the Use of MOVES2010 for Emission Inventory Preparation in State Implementation Plans and Transportation Conformity.

reflects the regulatory requirements and differences between ethanol- and nonethanol-blended gasoline that exist for the modeled location.

Updates to the defaults used in rule development (e.g., Renewable Fuel Standard Rule, Tier 3 Rule) and the National Emissions Inventory are available in databases posted with the rules and inventories and are embedded in the MOVES2014 database, but the MOVES model may not always be current with future updates. Users should consult any external rule and NEI fuel databases, as they will reflect EPA's most recent thinking on correct embedded fuels formulation and supply.

Forecast year data. In general the fuels data embedded in the default MOVES2010 database are now quite out of date. The embedded MOVES data for forecast years assume constant fuel properties and market shares from 2012 forward. EPA has developed updated fuels tables for MOVES as part of NEI and rule-making analyses, particularly the Tier 3 rule (http://www.epa.gov/otaq/tier3.htm), which are embedded in MOVES2014.

Significant changes are made for MOVES2014 related to fuels. These include changes to underlying fuel effects in the model, addition of E-85, default fuel formulation and fuel supply entries, and in the ability of the user to update local fuels information (U.S. EPA, 2013). Analysis of the refinery compliance data is integrated into MOVES2014 default fuel supply data. Default fuels are provided on a regional level through calendar year 2050, reflecting projected changes in fuel properties due to the Tier 3 and RFS requirements. MOVES2014 also includes a "Fuel Wizard" which will allow a user to edit fuel property data to more easily take advantage of refinery modeling data, and to more easily account for the impacts of ethanol splash blending on overall fuel properties.

Other information about fuels, including data from new RFG surveys and refinery data, can be found on EPA's web site at http://www.epa.gov/otaq/fuels/index.htm.

4.9.3 Data Sources, Procedures and Methods

Table 4.9.5 provides an overview of potential data sources for this input.

Table 4.9.5   Summary of Options for Fuels Input

Data Source or Procedure	Current Use	Uses and Advantages	Limitations
MOVES embedded data	Common	Provides framework and starting point for local areas to update information; embedded in County/Project Data Manager templates. Does reflect major Federal rules (e.g., RFG, low sulfur).	Embedded data for MOVES2010 are out of date relative to subsequent rule inventories/NEI.
Fuel surveys	Common	The most direct way to characterize properties of fuel being sold in a region.	A significant effort to design survey, collect and analyze samples, and distill into regional MOVES inputs.
Published surveys	Common	Third-party fuel surveys (e.g., by EPA, DOE, or trade groups) can provide fuel survey data directly.	Only in select areas, so may not provide needed geographic coverage. Some surveys have been discontinued.
EPA data developed for rule inventories and/or NEI	Limited	Reflects EPA's latest data and projections based on updated survey data, renewable projections, etc.	Publicly available, but requires finding and extracting MOVES databases from rule dockets and/or NEI documentation.
State tax and compliance records	Limited	Another potential source of third-party fuel surveys.	Will depend on state requirements; geographic or temporal coverage may not be sufficient.
Refinery data	Limited	Fuel property data by batch can be obtained directly from refineries supplying a given area.	Does not account for blending that occurs post refinery (aka "splash" blending). This is particularly relevant with biofuels, where splash blending is common, and can significantly affect properties of fuel at the pump.

EPA's guidance on fuels encourages users to first review the embedded data on fuel supply and fuel formulation for relevant counties, and make changes where improved data are available. Like most inputs to MOVES, some data for fuel supply and formulations may not accurately reflect local fuel usage and properties. As mentioned above, users should pay particular attention to the embedded data for "intermediate" years derived from carryover or interpolation the years where survey data was available. However, like most MOVES input data sources, any one data collection approach may provide only a piece of the required information. For example, while fuel surveys used to collect and speciate fuel samples for an area are likely to provide accurate fuel formulation information, they may not provide an accurate picture of market share required by the fuel supply table. The following suggestions for alternative fuel data sources are presented in the general hierarchy of usefulness.

4.9.3.1   *Rules and Regulations*

Rules and regulations can provide information governing fuel usage and formulations specific to a given area and/or time period. At the national level, EPA has updated the MOVES embedded data with fuel supply and formulation inputs to support the 2011 NEI and Tier 3 rule, with inputs available on EPA's web site. At the local level, local and or regional mandates may dictate the use of specific blends of ethanol in gasoline or the use of biodiesel. A good example is the Texas Low Emission Diesel (TxLED) program which

requires diesel sold in 110 central and eastern Texas counties contain less than 10 percent aromatic hydrocarbons by volume and have a cetane number of 48 or greater. A user may check with state and local government entities for rules governing fuel blends and usage, and alter MOVES inputs accordingly to reflect local conditions in a modeling scenario. EPA also has a list of "boutique" (i.e., state-specific program) fuels for SIPs available at http://www.epa.gov/otaq/fuels/boutiquefuels/boutiquelist.htm.

4.9.3.2 Fuel Surveys

As an alternative, state and local governments may choose to conduct fuel surveys that will generate area-specific, as well as seasonal, fuel information. However, the user must be aware of cautions urged by EPA in the MOVES technical guidance. According to the guidance, multiple sampled fuels should not be averaged to create one generic fuel pro-file, as market share information for a specific fuel in an area is an important consideration within MOVES. That is why MOVES allows the user to enter multiple fuel formulations for a given area-year-month and assign specific market share information to each formu-lation. Different feedstreams by refinery or fuel provider would be one way to divide fuel formulations and market shares, if resources exist to parse the surveys accordingly. EPA states that if market share information is not available, users should rely on the MOVES default values for most properties (RVP being the exception to this rule).

When selecting retail sites to be sampled, several factors must be taken into consideration, including adequate geographic representation, varied temporal times by hour of day for collection, varied data collection by season, adequate sample size, and weight by throughput, if possible. Under most circumstances, sampling every station within a geo-graphic area of interest is unreasonable. Thus, station selection should be weighted towards high-volume stations in order to best represent the fuel usage for the area. Some distinctions to consider when selecting a site for sampling include whether the pump has public access or is used for private fleet refueling only; and whether the station is a "branded flagship station" or "independent station" to help account for potential varia-tions in fuel sources. Another consideration to make is the season in which the fuel is being collected. Fuel formulations change to account for variations in climatic conditions. Fuels used during the warmer summer months do not have the same formulation requirements as fuels used in cold winter months. If funds or time are limited, it is rec-ommended to focus sampling efforts during those times in which air pollution problems most plague the area of interest (e.g., summer months for ozone nonattainment areas). Time of day of sample collection also should be noted. When conducting sampling, it is recommended that samples be taken at varying times of day, weighting towards higher usage times if necessary, to account for these variations in fuel properties as temperatures change throughout the day.

Once the sampling plan is established, fuel samples of various fuel types (e.g., gasoline versus diesel), as well as varying grades of fuel (e.g., regular, mid-grade and premium gasoline samples), are collected at the pump using DOT and International Air Transport Association (IATA)-approved clean and dry fuel sample containers and shipping cartons. Accredited labs can usually provide specific guidelines for collecting valid fuel samples which may include steps such as purging gasoline from the pump nozzle prior to

obtaining the sample and how full to fill each container. In addition, certain characteristics at the pump, as well as ambient conditions, can be recorded at the time of sample collection. These data points may include ambient observations such as temperature and/or what type of surface is at the pump (concrete versus asphalt). Once this information is collected, the fuel samples are then shipped to an accredited lab for analysis and speciation. As recommended in the Alliance of Automobile Manufacturers' Worldwide Fuel Charter, the latest methods should be used for testing fuels, unless otherwise indicated by specific method year. A table with recommended methods can be found in this report. Furthermore, a complete listing of petroleum standards and ASTM test methods can be found at http://www.astm.org/Standards/petroleum-standards.html. The Texas Commission on Environmental Quality has conducted multiple fuel sampling and analyses. A list of the test methods used in their latest study for 2011 is shown in Table 4.9.6.

Table 4.9.6   TCEQ Fuel Sampling Test Methods

Fuel Property	ASTM Test
Gasoline Fuel	
Reid Vapor Pressure (RVP)	ASTM D5191-10b
Sulfur	ASTM D2622-10
Distillation	ASTM D86-10a
Benzene	ASTM D3606-EPA Method
Total Aromatics and Olefins	ASTM D1319-10
Oxygenates	ASTM D5599-00 (2010)
Detailed Hydrocarbon Analysis	ASTM D6729-04 (2009)
Diesel Fuel	
Cetane Number	ASTM D613-10a
Calculated Cetane Index	ASTM D976-06
API Gravity	ASTM D4052 (2009)
Sulfur	ASTM D5453-09
Nitrogen	ASTM D4629-10
Aromaticity	ASTM D1319-10
Total Aromatic Content	ASTM D5186-03 (2009)
Polycyclic Aromatic Content	ASTM D5186-03 (2009)
Distillation	ASTM D86-10a
Flashpoint	ASTM D93-10a

There are a number of factors that affect the cost of a fuel survey. These include the number of samples to be taken, grades to be sampled, compositing versus not compositing of samples, second round sampling, and which tests to be performed. Costs can vary widely depends on how these factors are addressed.

4.9.3.3 Published Survey Reports

Published real-world data are available in some areas to review and improve the MOVES embedded data. For example, in areas that use reformulated gasoline, fuel property information is publicly available on EPA's web site (http://www.epa.gov/otaq/fuels/

rfgsurvey.htm). RFG surveys have hundreds of survey points for each RFG area. Other areas may use publicly available data from the U.S. Department of Energy (http://energy.gov/data/open-energy-data). The U.S. DOE consists of many offices, as well as lab and technology centers, giving them access to a wide range of data reports on many different sources of energy, including petroleum fuels, as well as alternative fuels. One example of available fuel data from DOE can be found at DOE's Alternative Fuels Data Center (http://www.afdc.energy.gov/fuels/fuel_properties.php). A listing of DOE offices, including lab and technology centers, can be found at (http://www.doe.gov/ offices). These lab and technology centers do extensive research on a broad range of topics, including some topics on various fuel sources. Historically, the Auto Alliance North American Fuel Survey has been a valuable source of information about fuels, but has been discontinued. The Alliance of Automobile Manufacturers contributes to a regularly published report, "Worldwide Fuel Charter." This report discusses, among other things, various fuel properties at varying ambient temperatures, along with the various methods used to test fuel samples. The Hart study shows ethanol penetration by state from 2006 through 2009. AEO month-to-month penetrations are projected through 2020. EPA guidance notes that future fuel inputs should reflect state regulations, but does not address the issue further.

4.9.3.4 Tax Records and Compliance Testing

Many states collect data on fuels as part of the Comptroller's Office tax assessment data or part of the state's Department of Weights and Measures compliance programs. Data collected under these programs may include information on one or more of the fuel properties and/or market share information. These data also should be publicly available and may be used to update MOVES inputs to reflect real-world data.

4.9.3.5 Refinery Data

Some state or local agencies may be able to obtain data directly from the refineries supplying fuel to a given area. The refinery certification database contains batch-by-batch refinery gate reports on fuel properties. In 2007, approximately 28,000 batches of conventional gasoline were reported. One advantage of these reports is that locations and volumes are known. Refineries may be able to provide fuel projections and some market share projections. However, some data collected at the refinery does not necessarily reflect what is dispensed at the pump. "Splash" blending of ethanol is a common practice, and name-brand providers also may contribute its own additives to the fuel blend before being delivered to the pumps. These practices can significantly alter some fuel properties, including RVP and aromatics. Some fuel properties are less sensitive to post refinery blending, so may be better candidate for refinery data; one example would be fuel sulfur level.

4.9.4   Sample Data and Tools

Sample data from the fuel formulation and fuel supply tables are shown in Tables 4.9.7 and 4.9.8. These follow the format of the templates provided through the County and Project Data Managers for modification by the user. The data shown are the embedded

data for Travis County, Texas (Austin), for July 2011. As shown, there are two gasoline fuels (an E0 and E10 blend) and one diesel fuel. The market shares sum to 1 across each fuel type, gasoline and diesel. While these sample data are only for July, the fuelSupply table contains market shares of different fuel formulations summing to 1 for each month, to reflect different blends of gasoline across seasons.

Table 4.9.7   Fuel Supply Data Sample

countyID	fuelYearID	monthGroupID	fuelFormulationID	marketShare	Notes (Added Here Only)
48453	2011	7	3508	0.86	Gasoline E10 blend
48453	2011	7	8890	0.14	Gasoline E0 blend
48453	2011	7	20011	1	Diesel

Table 4.9.8   Fuel Formulation Data Sample

fuelFormulationID	fuelSubtypeID	RVP	sulfurLevel	ETOHVolume	MTBEVolume	ETBEVolume	TAMEVolume	aromaticContent	olefinContent	benzeneContent	e200	e300	volToWtPercentOxy	BioDieselEsterVolume	CetaneIndex	PAHContent	T50	T90
3508	12	8.36	30	10	0	0	0	19.8	12.51	0.6615	54.33	87.25	0.35	–	–	–	191	310
8890	10	8.36	30	0	0	0	0	19.8	12.51	0.6615	54.33	87.25	0	–	–	–	191	310
20011	20	0	11	0	0	0	0	0	0	0	0	0	0	–	–	–	–	–

4.9.5   Example – Local Fuel Sampling

The following example shows how local fuel sampling can be used to develop fuel property inputs for MOVES for use in local modeling. This work was conducted for the Texas Commission on Environmental Quality (TCEQ, 2011).

In order to maintain a high confidence level in the fuel parameters used in the development of on-road emission inventories, trend analysis and control strategy analysis, TCEQ has undertaken a program to periodically collect and analyze fuel samples. The program ensures the accuracy of local specific fuel information and provides the best data available for analysis to support Texas SIP and control strategy development. Under these efforts, physical properties and speciation profiles are developed, and laboratory test results for samples of gasoline and diesel fuel collected from retail stations across Texas are reported. Testing of various properties is completed in an approved laboratory which involves speciation of VOC, including oxygenates, determination of RVP, and estimation of sulfur in gasoline, and quantification of aromatics, cetane and sulfur in diesel fuel. Samples of regular, mid-grade, and premium gasoline, and diesel fuel were taken from 92 retail gas stations, from the 25 areas across the state. The 25 areas corresponded to the 25 Texas Department of Transportation Districts (Figure 4.9.1).

The first step in the process was site selection. Background information to help assess the geographic and temporal boundaries for sampling at retail stations was obtained and included:

- The geographic boundaries of the 25 TxDOT districts throughout the state; and

- Surrogates for estimating sales volumes from readily available data, including underground storage tank numbers and sizes (obtained from the TCEQ Petroleum Storage Tank Database).

A sampling plan was developed to specify the number of stations per area, the total number of samples (including number of diesel and gas samples, across gas grades), and the allocation of stations across the different areas. The summer 2011 sampling plan specifications included the following:

- Each fuel sampling region has a minimum of three sample sites;

- Both diesel and gasoline samples are to be collected at each location;

- Regular, mid-grade, and premium gasoline grades are to be sampled; and

- Gasoline and diesel samples are to be collected separately (no compositing).

Figure 4.9.1   TxDOT District Boundaries and Major City Locations
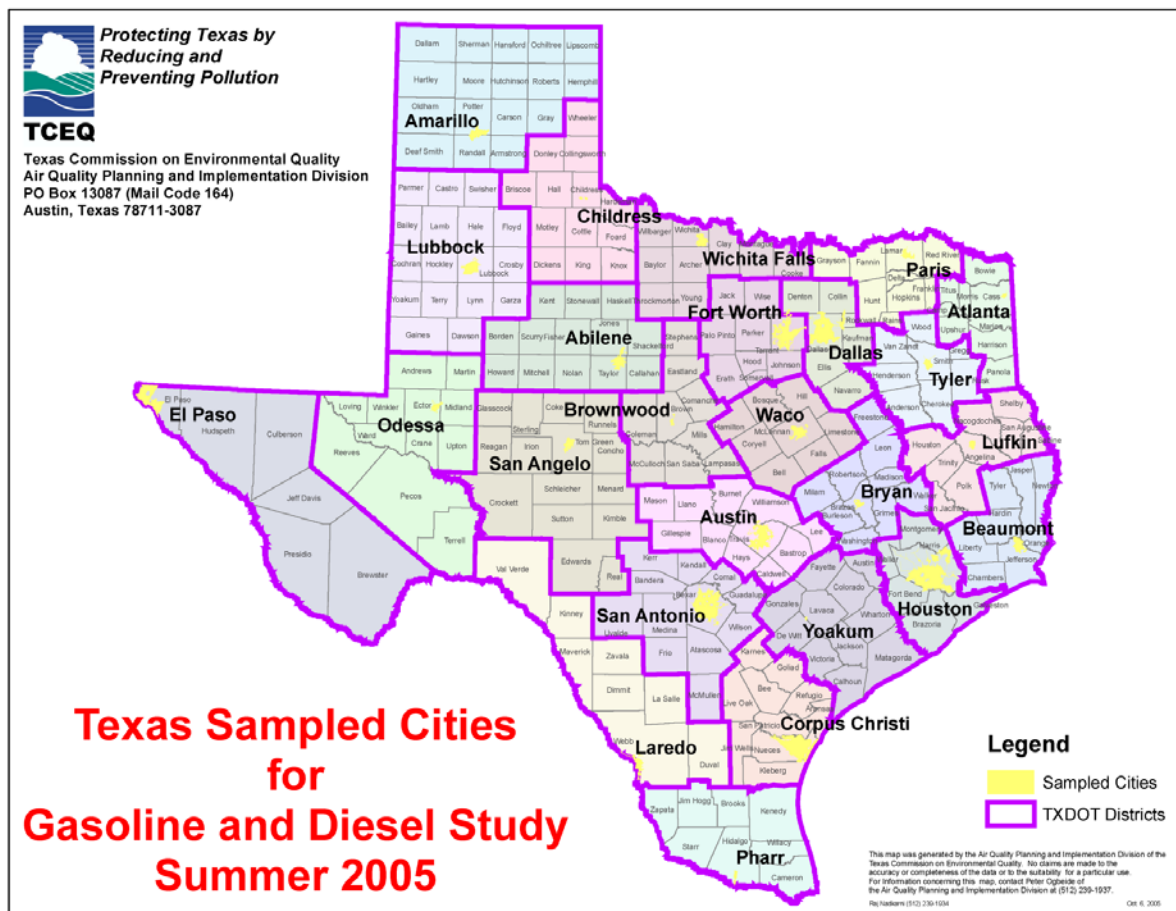
This approach required a lab test of every sample. As a result, it was more costly and limited the total number of stations that could be sampled. However, it did provide an indication of differences within areas that would not be discernable using a compositing approach. Specifically, this approach enabled the determination of minimum, maximum, and average fuel parameter values, instead of just averages for each region. The sampling plan is summarized in Table 4.9.9.

Table 4.9.9 Initial Sampling Plan Summary Table
Summer 2011

TxDOT District	Number of Stations	Area Designation
Abilene	3	Attainment Area
Amarillo	3	Attainment Area
Atlanta	3	Attainment Area
Austin	5	Attainment Area (Former Early Action Compact Area)
Beaumont	5	Beaumont-Port Arthur Nonattainment Area
Brownwood	3	Attainment Area
Bryan	3	Attainment Area
Childress	3	Attainment Area
Corpus Christi	4	Corpus Christi Near Nonattainment Area
Dallas	4	Dallas-Fort Worth Nonattainment Area
El Paso	4	Attainment Area (Maintenance)
Fort Worth	4	Dallas-Fort Worth Nonattainment Area
Houston	7[a]	Houston-Galveston-Brazoria Nonattainment Area
Laredo	3	Attainment Area
Lubbock	3	Attainment Area
Lufkin	3	Attainment Area
Odessa	3	Attainment Area
Paris	3	Attainment Area
Pharr	3	Attainment Area
San Angelo	3	Attainment Area
San Antonio	5	San Antonio Early Action Compact Area
Tyler	5	Northeast Texas Early Action Compact Area
Waco	3	Attainment Area
Wichita Falls	3	Attainment Area
Yoakum	4	Victoria Near Nonattainment Area
Total	92	

[a] These stations were sampled a second time later in the summer.

In order to identify specific fuel stations for sampling, TCEQ's latest Petroleum Storage Tank (PST) Database was used to identify "active" establishments that sold both gasoline and diesel fuels and to ensure that that the larger service stations were sampled. The size of the service station was used as a surrogate for fuel throughput, since actual throughput data is only available at the wholesale level; only those facilities with tank capacities of 10,000 gallons or more were selected. Retail stations with enforcement actions against

them were filtered from the list as well. Each of the remaining stations was assigned to the appropriate TxDOT district based on county designation. From this list, primary and alternate sampling candidates were selected using a weighted random sample where the weights were applied to each station that were directly proportional to the total number of gasoline plus diesel tanks listed for each station in the PST Database. Alternate candidates were selected in case the primary candidates could not be tested (i.e., out of business, temporarily closed, or otherwise inaccessible). The number of candidates selected within each TxDOT district was determined according to the air quality designation for the area, in accordance with the table above.

In addition to the initial round of sampling, a second round of testing was conducted in an attempt to obtain a better understanding of temporal variability of fuel composition within a region. For a small subset of fueling stations (the seven located in the Houston area), a second round of sampling was conducted, ensuring that enough time has elapsed for complete tank turnover (at least four weeks). This second round of sampling was intended to make a preliminary assessment of the temporal variability of fuel parameters at the station level.

Independent contractors working with the approved laboratory acquired fuel samples from retail stations. Each contractor received written instructions, service station sampling procedures, sample containers, and shipping instructions. All contractors were instructed on retail station sample acquisition with special emphasis on sample handling and safe disposal of flushed gasoline. U.S. DOT and International Air Transport Association approved fuel sample containers and shipping cartons were used. Each carton held four aluminum containers. Boxes are assembled at the laboratory by trained staff, and all appropriate shipping materials are provided to the contractor along with DHL-approved instructions for shipment of hazardous materials.

Gasoline testing was performed on individual regular, mid-grade, and premium gasoline samples. There was no compositing of samples.

Key testing methods included:

- Reid vapor pressure (ASTM D5191-10b);
- Sulfur (ASTM D2622-10);
- Distillation (ASTM D86-10a);
- Benzene (ASTM D3606-EPA Method);
- Total aromatics and olefins (ASTM D1319-10);
- Oxygenates (ASTM D5599-00(2010)); and
- Detailed hydrocarbon analysis (ASTM D6729-04-(2009)).

Diesel samples were acquired and tested at all retail fuel sites. Sample testing performed on each sample included:

- Cetane number (ASTM D613-10a);

- Calculated cetane index (ASTM D976-06);

- API gravity (ASTM D4052(2009));

- Sulfur (ASTM D5453-09);

- Nitrogen (ASTM D4629-10);

- Aromaticity (ASTM D1319-10);

- Total aromatic content (ASTM D5186-03(2009));

- Polycyclic aromatic content (ASTM D5186-03(2009));

- Distillation (ASTM D86-10a); and

- Flash point (ASTM D93-10a).

Fuel sample data were used to develop fuel parameter inputs for EPA's MOVES2010 model for Texas. Fuel parameter files were developed for each county in Texas using fuel sample data obtained from the 92 gasoline and diesel retail locations across the State in the summer of 2011. Specific contaminants, as they related to MOVES, were extracted from the data. Since three grades of gasoline were sampled, regular, mid-grad, and premium blend data were extracted separately and data for RVP, fuel sulfur, benzene, ethanol, MTBE, ETBE, and TAME were then averaged by geographic area. For example, benzene for gasoline was averaged for each of the 25 districts, for regular, mid-grade, and pre-mium blends.

The results were used to calculate the required MOVES fuel parameter inputs, weighting across fuel grades using the latest available sales data from the Energy Information Administration. According to EIA data for Texas in 2009, regular gasoline comprised 87.8 percent of the market, mid-grade gasoline comprised 6.5 percent, and premium gasoline comprised 5.7 percent. These weighting factors were applied to each of the geographic areas for each parameter. Such a weighting process can be applied to any of the over 50 chemical compounds evaluated in the analysis.

The resulting weighted MOVES fuel parameter inputs for gasoline included:

- RVP (psi);

- Sulfur (ppm);

- Olefins (% wt);

- Aromatics (% wt);

- Benzene (% wt); and

- Oxygenates (% vol).

Additional MOVES fuel input requirements include lower volatility percentage (E200) and upper volatility percentage (E300). A research laboratory performed distillate analysis, providing the temperatures corresponding to specific sample fractions (e.g., 5, 10, or 20 percent). In order to estimate E200 and E300 fractions as required by the MOVES model, ERG performed a simple interpolation of the lab's distillation data.

Using the TxDOT mappings, each county in the state was assigned to a unique TxDOT district (Figure 4.9.9). The county assignments were identical to those developed for the 2005, 2007, and 2008 sampling studies.

The fuel specifications for the summer sampling results were compiled, processed, and formatted for use as an input file for MOVES. Using the MOVES County Data Manager, the fuel data template was exported as an Excel file. This template file was then updated with the summer fuel sampling data for the following parameters:

1. MonthGroupofAnyYear: Summer months are defined as May through October.

2. FuelSupplyYear: 2011.

3. County: Parameters specified for all 254 counties.

4. FuelSubtype: Included a record for each fuel type found in the dataset (e.g., diesel, conventional gasoline, RFG).

5. FuelFormulation: Existing fuel formulation IDs with the appropriate fuelsubtype IDs were selected for updating (in the future, local fuelFormulations could be defined).

6. FuelSupply: Created a record for each county-year-month combination and mapped it to the correct fuel formulation ID.

This process resulted in populating an Excel file containing the summer fuel data collected by the TCEQ. This file may be edited according to user needs and imported directly into MOVES using the County Data Manager within MOVES. Resulting fuel properties by region are shown in Table 4.9.10.

As shown in Table 4.9.10, there is variability across regions for most of the fuel properties. Though not shown, there are also some considerable differences from default fuel properties contained in the default MOVES2010 database. Examples are aromatic content, where the fuel samples shows values of nearly 42 weight percent versus default maximum of 24 percent; and sulfur content, where the samples data showed a range of 13-43 ppm while the default data was a uniform 30 ppm. These differences between sampled and default can translate to significant emission differences based on recent fuels research.

Table 4.9.10 Gasoline Properties by Region
Summer 2011

Region	RVP	Sulfur (ppm)	Aromatics (% wt)	Olefins (% wt)	Benzene (% wt)	EtOH (% vol)	MTBE (% vol)	ETBE (% vol)	TAME (% vol)	E200 (%)	E300 (%)
Abilene	9.41	23.7	37.50	8.97	0.676	4.898	0.000	0.000	0.000	46.536	82.12
Amarillo	9.55	19.2	32.54	6.28	0.692	8.281	0.000	0.000	0.000	60.139	88.135
Atlanta	7.27	26.3	38.74	6.94	2.156	9.205	0.039	0.000	0.000	47.733	80.959
Austin	7.54	42.6	29.45	12.02	0.605	8.667	0.027	0.000	0.000	51.193	80.365
Beaumont	7.29	27.7	30.03	8.73	1.228	8.855	0.000	0.000	0.000	49.87	81.93
Brownwood	8.19	28.3	30.41	9.19	0.710	4.971	0.037	0.000	0.000	45.68	83.294
Bryan	7.35	24.7	29.67	8.32	0.746	7.877	0.000	0.000	0.000	49.276	82.463
Childress	9.49	19.4	31.57	6.18	0.696	9.078	0.000	0.000	0.000	59.575	87.577
Corpus Christi	7.70	27.8	23.94	10.17	0.528	9.44	0.031	0.000	0.000	49.859	83.442
Dallas	7.13	24.1	24.58	8.89	0.543	8.383	0.000	0.000	0.000	47.49	83.792
El Paso	7.25	26.6	41.80	13.44	0.736	1.988	0.000	0.000	0.000	44.676	81.714
Fort Worth	7.09	22.7	23.26	9.37	0.537	9.054	0.000	0.000	0.000	47.23	83.519
Houston	7.00	24.7	22.14	10.61	0.617	8.851	0.000	0.000	0.000	49.067	83.389
Laredo	8.99	18.5	29.08	7.85	0.363	7.507	0.000	0.000	0.000	55.599	84.94
Lubbock	9.38	25.2	33.09	6.23	0.622	8.229	0.039	0.000	0.000	55.081	85.118
Lufkin	7.29	33.5	36.59	8.57	1.793	8.311	0.003	0.000	0.000	48.627	80.035
Odessa	9.31	24.4	37.08	10.75	0.668	2.595	0.003	0.000	0.000	45.839	82.137
Paris	7.05	17.7	30.09	8.44	1.276	8.267	0.002	0.000	0.000	46.873	82.897
Pharr	9.31	33.9	31.41	11.31	0.62	6.565	0.000	0.000	0.000	52.77	82.535
San Angelo	9.22	24.9	34.26	12.27	0.758	2.575	0.000	0.000	0.000	47.213	82.083
San Antonio	7.56	31.6	31.45	11.04	0.524	7.755	0.000	0.000	0.000	50.308	79.917
Tyler	7.33	12.6	36.75	7.59	2.467	8.828	0.001	0.000	0.000	45.383	82.718
Waco	7.46	34.2	27.93	10.19	0.677	8.563	0.000	0.000	0.000	50.319	82.239
Wichita Falls	8.40	31.3	34.28	8.70	0.788	4.665	0.001	0.000	0.000	43.662	82.209
Yoakum	7.35	35.1	24.36	11.59	0.593	9.027	0.000	0.000	0.000	50.812	81.629
Average	**8.04**	**26.43**	**31.28**	**9.34**	**0.865**	**7.30**	**0.007**	**0.00**	**0.00**	**49.63**	**82.85**
Min	**7.00**	**12.60**	**22.14**	**6.18**	**0.363**	**1.99**	**0.000**	**0.00**	**0.00**	**43.66**	**79.92**
Max	**9.55**	**42.60**	**41.80**	**13.44**	**2.467**	**9.44**	**0.039**	**0.00**	**0.00**	**60.14**	**88.14**
Range	**2.55**	**30.00**	**19.67**	**7.26**	**2.104**	**7.45**	**0.039**	**0.00**	**0.00**	**16.48**	**8.22**
Std. Deviation	**0.96**	**6.56**	**5.16**	**1.97**	**0.526**	**2.28**	**0.014**	**0.00**	**0.00**	**4.26**	**1.98**

■ 4.10 Inspection and Maintenance Programs

4.10.1 Description and Format

The modeling of Inspection and Maintenance program benefits has been a core element of EPA's mobile source emission models since MOBILE1. I/M programs were required in areas out of attainment with National Ambient Air Quality Standards, and other states have adopted programs as part of local air quality control programs. User inputs for MOVES reflect the myriad of implementation options that states have adopted to strike the balance between emission reduction, cost effectiveness, and program efficiency. Local program information is also required for official SIP and conformity analyses, and users can specify the type of program, define vehicle and model year coverage, and specify how effective a given program is. The same I/M input data apply for county- or project-scale runs.

User data for I/M programs is provided through the IMCoverage table via the County or Project Data Manager (Table 4.10.1). This table defines the scope of the I/M programs for specific counties and calendar years, including the type of program and the pollutants, vehicle classes and model years covered; and accounts for the rate of compliance with the program. Because the I/M program scope is well defined, the principal input is this latter element, known as ComplianceFactor. ComplianceFactor attempts to represent a particular I/M program's ability to achieve theoretical design benefits for their program. It may vary from 0 to 100, where zero would represent a program with no benefits and 100 a program with the full benefits available given the other program parameters entered. Factors which tend to reduce program effectiveness are the systematic waiver of failed vehicles from program requirements, the existence of large numbers of motorists who completely evade the program requirements, technical losses from improperly functioning equipment, or inadequately trained technicians. Whereas MOBILE6 allowed user input for a number of these factors (e.g., technician training), for the sake of simplicity MOVES has focused ComplianceFactor on quantifying the effects of program evasion and waivers, which are easier to track.

Table 4.10.1 I/M Coverage Data Table

Parameter	Description
stateID	2-digit FIPS code identifying the state
countyID	Code identifying the county being modeled. It is 4 or 5 digits and is a concatenation of the FIPSstateID followed by the FIPScountyID.
polProcessID	MOVES estimates emission reductions from I/M programs for hydrocarbons, NO_x, and CO. For exhaust emissions, I/M programs can affect both running and start emissions. For evaporative emissions, I/M programs affect hydrocarbon emissions from fuel vapor venting and fuel leaks.
yearID	Calendar year of the operating I/M program.
sourceTypeID	Source (vehicle) type included in the I/M program.
fuelTypeID	Fuel type included in the I/M program. MOVES currently calculates I/M program benefits only for gasoline vehicles.
IMProgramID	An arbitrary number that serves as a substitute for unique combinations of test standard, test frequency, begin model year, and end model year. The same IMProgramID can be associated with multiple source types and pollutant processes, but not with different test standards, frequencies, or model year ranges.
inspectFreq	MOVES allows users to enter either annual or biennial test frequency. MOVES also includes an option for continuous I/M; however, there are currently no emission benefits assigned to this option in MOVES.
testStandardsID	MOVES allows users to choose between 13 exhaust emission tests and 7 evaporative emission tests. These are listed in Table 4.10.2.
begModelYearID	MOVES uses the variable to specify the beginning model year affected by a particular I/M program.
endModelYearID	MOVES uses the variable to specify the ending model year affected by a particular I/M program.
useIMyn	Yes/No toggle that allows the user to turn off the I/M program for a given row of the input table. This is useful for turning off the default I/M parameters and entering program-specific I/M information and toggling this parameter to "Y."
complianceFactor	MOVES uses the compliance factor input to account for I/M program compliance rates, waiver rates, and adjustments needed to account for the fraction of vehicles within a source type that are covered by the I/M program.

The majority of inputs in IMCoverage define the scope of the program (vehicles, model year, etc.) and are straightforward to enter according to the parameters of the local I/M program. Users can run "what-if" cases to evaluate the benefits of different model year coverage, different vehicle classes etc. Beyond this, there is little variability in inputs. Discussion of data source options will therefore focus on ComplianceFactor. ComplianceFactor defines the fraction of a given source type that actually receives the benefit of the I/M program benefit. This is not usually 100 percent, because of three factors:

- **Waiver Rate** accounts for a certain fraction of vehicles that fail an initial test and are then given a waiver from the program. This is different from model years exceptions –

vehicles given waivers are subject to the program initially, but are allowed to skip a retest due to high cost of repair or other reasons.

- **Compliance Rate.** Beyond allowed waivers, the reality of I/M programs is that not all vehicles that should successfully complete the program do. Multiple studies of I/M program compliance confirm that a certain fraction of vehicles manage to avoid tests (in part because a certain number of vehicles are unregistered). Of the population that should complete the program, compliance rate is the fraction of vehicles that actually do.

- **Regulatory Class Coverage**. The I/M program may only apply to a subset of vehicles within a source type; this is more applicable to the passenger truck and light commercial truck source types, which include vehicles from heavier regulatory classes that are typically not subject to I/M programs (i.e., over 8,500 pounds gross vehicle weight rating). The MOVES SIP and Conformity Guidance contains estimates of regulatory class coverage values for the different source types that can be used in the absence of location-specific data. The values are located in Table A.3, and provide an estimate of the breakdown of percentages of each MOBILE6 vehicle class description within each MOVES source type.

EPA's guidance lays out the method for calculating ComplianceFactor accounting for these three effects. This is an "off-model" calculation to be performed by the user, with the resulting ComplianceFactor entered into the IMCoverage table:

Compliance factor = compliance rate x (1 – waiver rate) x regulatory class coverage

Compliance rate, waiver rate, and class coverage are expressed in fractions (e.g., 0.90) and the resulting compliance factor is multiplied by 100 for entry in the IMCoverage table. Underlying tables in the MOVES database contain fundamental information on I/M programs. These are not accessible through the data managers, and EPA guidance does not suggest that users make changes to these; but they are helpful to be aware of to understand how I/M works in MOVES. Among these, the IMTestStandards table defines the menu of tests users can choose through IM Coverage (Table 4.10.2). The IMFactor table contains information about the overall effectiveness of an I/M program relative to the baseline IM240 program used to develop I/M benefits – in essence, it defines the maximum amount of benefit for a given I/M test type, which is then adjusted according to ComplianceFactor provided by the user.

The remainder of this section will focus on the IMCoverage table, since it is the only I/M-related table in the County and Project data managers.

Table 4.10.2 I/M Emission Test Types

Test Standards ID	Test Standards Description	Description
11	Unloaded Idle Test	Test performed while vehicle idles in Park or Neutral
12	Two-mode, 2500 RPM/Idle Test	Test performed while vehicle idles and at 2500 rpm
13	Loaded/Idle Test	Test performed while vehicle operates on a chassis dynamometer at constant load
21	ASM 2525 Phase-in Cutpoints	Test performed on a dynamometer, under load, through a defined "steady state" driving cycle at 25 mph and 25% load, at phase-in cutpoints.
22	ASM 5015 Phase-in Cutpoints	Test performed on a dynamometer, under load, through two defined "steady state" driving cycles at 25 mph and 25% load, and 15 mph and 50% load, at phase-in cutpoints.
23	ASM 2525/5015 Phase-in Cutpoints	Test performed on a dynamometer, under load, through two defined "steady state" driving cycles at 25 mph and 25% load, and 15 mph and 50% load, at phase-in cutpoints.
24	ASM 2525 Final Cutpoints	Test performed on a dynamometer, under load, through a defined "steady state" driving cycle at 25 mph and 25% load, at final cutpoints.
25	ASM 5015 Final Cutpoints	Test performed on a dynamometer, under load, through a defined "steady state" driving cycle at 15 mph and 50% load, at final cutpoints.
26	ASM 2525/5015 Final Cutpoints	Test performed on an inertia-weighted dynamometer through two defined "steady state" driving cycles at 25 mph and 25% load, and 15 mph and 50% load, at final cutpoints.
31	IM240 Phase-in Cutpoints	Test performed on a dynamometer, under load, through a predefined "transient" driving cycle of up to 240 seconds at phase-in cutpoints.
33	IM240 Final Cutpoints	Test performed on a dynamometer, under load, through a predefined "transient" driving cycle of up to 240 seconds.
41	Evaporative Gas Cap Check	A test conducted by pressurizing the gas cap for the purpose of identifying leaks in the gas cap.
42	Evaporative System Pressure Check	A test conducted by pressuring the evaporative system by way of the fuel tank's fillneck and sometimes referred to as the fillneck pressure (FP) test.
43	Evaporative System OBD Check	Test of the evaporative emission-related systems and components performed by visual check of the MIL and scan of the OBD computer system for readiness, MIL status, and stored trouble codes, on 1996 and newer, OBD-equipped vehicles.
44	Evaporative Gas Cap and Pressure Check	A pair of tests to identify leaks in the gas cap (GC) and the rest of the vehicle's evaporative system. The latter test is conducted by pressuring the evaporative system by way of the fuel tank's fillneck and is referred to as the fillneck pressure (FP) test.
45	Evaporative Gas Cap and OBD Check	The evap OBD test performed in conjunction with a separate check of the gas cap (GC) for the purpose of identifying leaks in the gas cap not otherwise identified by the evap OBD check. This combination of tests can only be conducted on 1996 and newer, OBD-equipped vehicles.
46	Evaporative Pressure and OBD Check	The evap OBD test performed in conjunction with a separate fillneck pressure test.
47	Evaporative Gas Cap, Pressure and OBD Check	The evap OBD test performed in conjunction with a separate fillneck pressure test and gas cap test.
51	Exhaust OBD Check	Test of exhaust-related systems and components performed by visual check of Malfunction Indicator Light (MIL) and scan of on-board (OBD) computer for system readiness, MIL status and stored trouble codes, on 1996 and newer OBD-equipped vehicles only

Source: EPA SIP and Conformity Guidance

4.10.2 Source of Embedded Data and EPA Guidance

EPA provides an embedded table of I/M inputs by county, but MOVES guidance states that this should be used as a starting point only and that local information on individual programs will clearly provide more accurate and representative results. Relevant guidance document sections include:

- MOVES2010b User Guide – Section 2.3.3.4.16, I/M Programs Importer (p. 81);
- MOVES SIP and Conformity Guidance: Section 4.11, Inspection and Maintenance Programs (p. 49); and
- Data tables: IMCoverage, ComplianceFactor.

The database embedded with MOVES2010b contains a fully populated IMCoverage table, covering every county with an I/M program in the U.S. Embedded inputs for IMCoverage were based on state-submitted inputs used in the 2005 National Emissions Inventory (U.S. EPA, 2010). State program parameters define all of the fields in IMCoverage except for ComplianceFactor. Embedded ComplianceFactor entries were estimated based on results of I/M program evaluations conducted by state and/or their contractors. These evaluations track basic statistics on programs such as the number of vehicles undergoing the I/M test, fraction of vehicles failing their initial test, number of failing vehicles receiving waivers, number ultimately passing, etc. These statistics are used to develop estimates of ComplianceFactor for MOVES. Updates to MOVES2014 take advantage of state data submitted as part of the NEI.

I/M program data are generally readily available from the agencies operating the program, but MOVES users can find it challenging to put it into the format needed for MOVES. Other issues, such as aggregating or disaggregating compliance factors by source type and model year, also can be difficult for new users.

EPA recommends that users modeling an existing I/M program in MOVES begin by examining the embedded I/M program description included in MOVES for the particular county in question. The embedded I/M data can be reviewed by selecting the Export Default Data button in the I/M tab of the County Data Manager. Users should review the details of the embedded I/M program and make any necessary changes to match the actual local program. In particular, users should note that any grace periods or exemption ages in an I/M program need to be included in the beginning and ending model years based on the calendar year of evaluation. The embedded I/M files do not incorporate grace periods or exemption ages.

Forecast year data. Forecast year data may differ from base-year data if changes are planned to the I/M program. An example would be where a new inspection program is planned, such as an on-board diagnostics (OBD)-based program, or increased vehicle coverage.

4.10.3 Data Sources, Procedures and Methods

Table 4.10.3 provides an overview of data source options for the ComplianceFactor table.

Table 4.10.3 Options for Data Sources – ComplianceFactor

Data Source or Procedure	Current Use	Uses and Advantages	Limitations
MOVES embedded data	Common	Easiest option.	Not updated regularly.
MOBILE6 input files	Common	Existing basis for program data.	Assumes I/M program parameters have remained the same since MOBILE6 last updated; requires calculation of ComplianceFactor.
Waiver data	Common	Program-specific data supports development of waiver rate input.	
Analysis of I/M versus registration data	Common	Straightforward analysis for identifying program compliance.	Will not include unregistered vehicles.
I/M program evaluations	Limited	Observed data from program effectiveness studies/	May not be available for all states; may not include unregistered vehicles.
Parking lot studies	Limited	Can supplement I/M program data.	Labor-intensive, only smaller samples feasible; requires IM sticker.
Remote sensing/license plate recognition	Experimental	Can supplement I/M program data with larger sample.	Requires deployment of equipment at roadside sites.
Remote OBD	Experimental	Less intrusive.	Only covers OBD-equipped vehicles, potential bias.
Roadside testing	Experimental	Unbiased approach to measuring compliance.	Resource-intensive, low political viability.

The primary variables in ComplianceFactor are waiver rate and compliance rate. All but the first data source listed below focus on compliance rate.

4.10.3.1 Waiver Data

Waiver rate is the fractional value that represents the portion of the fleet that failed an initial test and do not pass a retest, but received a waiver from meeting the I/M requirement. This value is typically tracked by programs each year and reported to EPA. In the first year of a program, this rate could be estimated using an existing program's waiver data by model year and scaling it so that the vehicle age distribution is similar to the user's age distribution. Based on state averages and the values that EPA has approved over the years, the typical waiver rate is usually less than 2 percent of the fleet tested.

4.10.3.2 Analysis of I/M versus Registration Data

Compliance rate can be estimated by comparing I/M data on the number of vehicles successfully completing a test, with total vehicles registered. This does not include unregistered vehicles, but is still a best-practice approach to generating a local compliance rate.

4.10.3.3 Program Evaluation

Program evaluations conducted by states are a much more detailed examination of I/M program effectiveness. They often include the compliance rate calculation (completions versus registrations) discussed above. Evaluations may not be conducted every year, however, and the level of detail will vary by state.

4.10.3.4 Parking Lot Surveys

For many years, parking lot surveys were the preferred method of estimating program compliance. In this approach, individuals survey parking lots and manually record license plate information. If the I/M program has a separate sticker or is tied to a registration sticker, then I/M program compliance can be estimated by dividing the number of vehicles with a valid sticker by the total number of vehicles surveyed. However, if there is not a sticker enforced requirement, then the license plate must checked against the state's vehicle I/M database to determine which vehicles have met their I/M test requirement. The compliance rate would then be the ratio of those surveyed vehicles that have met their I/M testing requirement and the total number of vehicles surveyed. A typical parking lot survey effort may generate in the range of 15,000-20,000 vehicles at a cost in the range of $40,000-$50,000. This is considered to be expensive compared to using remote sensing, as it only provides compliance estimate based on a fairly small vehicle sample.

4.10.3.5 Remote Sensing/Automatic License Plate Recognition

As automatic license plate recognition software has improved the use of remote sensing devices (RSD), which can measure pollutants emitted from vehicle exhaust, to estimate program compliance has become more common. Many I/M programs routinely collect RSD data to use as part of their program evaluation efforts or as a fleet characterization tool. Typically in the range of one million records are already available, so the only additional cost is to match the RSD records to the I/M test record database to determine which vehicles have met their I/M requirements. This last step is essentially the same as in the parking lot survey method; given the much larger sample size, however, using RSD data to estimate compliance is increasingly preferred over parking lot surveys.

4.10.3.6 Roadside Testing

Some states perform roadside testing of vehicles as part of their program evaluation process. For those that do, the resulting data also can be used to estimate program compliance. The general method would be the same as those outlined above. Those vehicles that receive a roadside test would be logged and then compared to the I/M database to determine what percentage of the roadside-tested vehicles have met the I/M program requirements. As in the RSD scenario, the compliance data are again free. However, the overall cost to obtain the data is much higher from a labor standpoint and the assistance of law enforcement is often required to pull vehicles over to receive the roadside test.

4.10.3.7 Remote OBD

Remote on-board diagnostics testing involves having an OBD transponder installed on a vehicle. During the course of routine driving, the owner would choose to activate the OBD transponder and drive past a data collection point. The vehicle's OBD status would then be transferred to the state's I/M database and the I/M program could then communicate the results to the owner by mail or electronically. This information would allow a compliance rate to be estimated in the same way used for the other methods, and the cost would also be minimal since the data collection is part of the remote OBD process. The main drawback is that it seems highly unlikely an owner that had not met the I/M program requirements would willingly turn on the OBD transponder and broadcast this to the state's I/M program. For that reason, using remote OBD to estimate program compliance is likely to over-estimate the program's true compliance rate.

4.10.4 Sample Data and Tools

Table 4.10.4 is an extract of an Excel file that was used as the basis for creating the IMCoverage table needed to perform a MOVES run. This figure is just a small part of the actual file that is over 1,500 rows; however, all of the categories listed in Table 4.10.1 can be seen.

Table 4.10.4 Sample IMCoverage Data

polProcessID	stateID	countyID	yearID	sourceTypeID	fuelTypeID	IMProgramID	inspectFreq	testStandardsID	begModelYearID	endModelYearID	uselMyn	complianceFactor
101	24	24003	2017	21	1	1	2	11	1977	1983	N	83.52
102	24	24003	2017	21	1	1	2	11	1977	1983	N	83.52
201	24	24003	2017	21	1	1	2	11	1977	1983	N	83.52
202	24	24003	2017	21	1	1	2	11	1977	1983	N	83.52
101	24	24003	2017	31	1	1	2	11	1977	1983	N	83.52
102	24	24003	2017	31	1	1	2	11	1977	1983	N	83.52
201	24	24003	2017	31	1	1	2	11	1977	1983	N	83.52
202	24	24003	2017	31	1	1	2	11	1977	1983	N	83.52
101	24	24003	2017	32	1	1	2	11	1977	1983	N	83.52
102	24	24003	2017	32	1	1	2	11	1977	1983	N	83.52
201	24	24003	2017	32	1	1	2	11	1977	1983	N	83.52
202	24	24003	2017	32	1	1	2	11	1977	1983	N	83.52
101	24	24003	2017	52	1	1	2	11	1977	1983	N	83.52
102	24	24003	2017	52	1	1	2	11	1977	1983	N	83.52
201	24	24003	2017	52	1	1	2	11	1977	1983	N	83.52
202	24	24003	2017	52	1	1	2	11	1977	1983	N	83.52
101	24	24003	2017	21	1	6	2	33	1984	1995	N	83.52
101	24	24003	2017	21	1	21	2	11	1977	1995	Y	87.84
102	24	24003	2017	21	1	21	2	11	1977	1995	Y	87.84
201	24	24003	2017	21	1	21	2	11	1977	1995	Y	87.84
202	24	24003	2017	21	1	21	2	11	1977	1995	Y	87.84
101	24	24003	2017	31	1	21	2	11	1977	1995	Y	87.84
102	24	24003	2017	31	1	21	2	11	1977	1995	Y	87.84
201	24	24003	2017	31	1	21	2	11	1977	1995	Y	87.84
202	24	24003	2017	31	1	21	2	11	1977	1995	Y	87.84
101	24	24003	2017	32	1	21	2	11	1977	1995	Y	87.84
102	24	24003	2017	32	1	21	2	11	1977	1995	Y	87.84
201	24	24003	2017	32	1	21	2	11	1977	1995	Y	87.84
202	24	24003	2017	32	1	21	2	11	1977	1995	Y	87.84
101	24	24003	2017	52	1	21	2	11	1977	2015	Y	43.04
102	24	24003	2017	52	1	21	2	11	1977	2015	Y	43.04

It can be seen that the complianceFactor varies depending on sourceTypeID and testStandardID; however, it should be noted that MOVES only calculates I/M benefits for gasoline vehicles less than 8,501 pounds GVWR even if nongasoline fueled vehicles over 8,500 pounds GVWR are included in the IMCoverage table.

4.10.5 Example

This example shows the calculation of ComplianceFactor, based on an evaluation of the Connecticut I/M program (Connecticut Department of Environmental Protection, 2009). The example is based on one contained in EPA guidance, but with data from the Connecticut program evaluation.

The example shows how Compliance Rate, Waiver Rate, and Regulatory Class Coverage are derived, and the calculation of ComplianceFactor to be entered in the IMCoverage table.

Compliance rate is calculated as the fraction of vehicles with valid final passing tests (925,830) compared to the total number of vehicles subject to the program, derived from registration data. In 2008, this rate was 96.9 percent. This rate does not account for unregistered vehicles; a more precise estimate of compliance rate would account for vehicles on the road that are not registered, but identifying and quantifying these vehicles would require supplemental study not performed for this program evaluation.

Waivers were given to 472 of 79,470 vehicles that failed their I/M test, resulting in a waiver rate of 0.6 percent.

Regulatory class coverage is replicated from the EPA guidance example; in general the values provided in the guidance should be used, rather than user-supplied values. An I/M program that applies to light trucks (less than 8,501 pounds GVWR, LDT regulatory class) would overlap with two MOVES source types: passenger trucks (sourcetype 31) and light commercial trucks (sourcetype 32). According to the factors in EPA guidance (Appendix 3), the LDT regulatory class comprises 94 percent of passenger trucks and 88 percent of light commercial trucks.

ComplianceFactor is calculated according to the following equation:

Compliance factor = compliance rate x (1 – waiver rate) x regulatory class coverage

For Passenger Trucks, the calculation is:

ComplianceFactor = 0.969 x (1-0.006) x 0.94 = 0.905

For Light Commercial Trucks, the calculation is

ComplianceFactor = 0.969 x (1-0.006) x 0.88 = 0.848

These values (multiplied by 100 to be expressed in percent, e.g., 90.5) would be entered into the IMCoverage table for these source types. By comparison, the embedded ComplianceFactor for both source types is 0.93.

5.0 Examples

Two in-depth examples are provided in this section to make a comprehensive illustration of how MOVES inputs might be developed. These examples include:

1. Regional (county-scale) analysis with limited data available, such as might be encountered in a rural area not covered by a travel demand model and with limited traffic monitoring; and

2. Regional (county-scale) analysis with more extensive data available, such as an urban area with a travel demand model and more extensive traffic monitoring networks.

A discussion of the general context of each example is first provided, followed by a step-by-step illustration for each input. The examples are fictional but are constructed based on real-world data. The data sources and processing procedures used in the examples are intended to be typical or appropriate for these types of applications, but other data sources and processing procedures may be used if available and appropriate. When developing inputs for regulatory purposes (SIP development, regional or hotspot conformity analysis), users should be sure to follow all applicable EPA guidance and consult on data sources and methods as needed. Presentation of a data source or method in this document does not constitute its acceptance for regulatory purposes.

The complete sample data files for each example can be found in a Microsoft Excel workbook, "MOVES Input Examples," accompanying this handbook.

■ 5.1 Example #1: Regional Analysis with Limited Data

5.1.1 Overview

This example illustrates the development of MOVES inputs at the county-scale of analysis using the County Data Manager. This example illustrates how inputs might be created when data sources are limited. For example, the area might be a rural area in a state without a travel demand forecasting model, or a "donut" portion of an urban area that is not covered by the MPO model. Similarly, there is a very limited amount of observed data on vehicle activity from traffic counts. The example is constructed using data from various real-world sources from different locations in the U.S.

5.1.2 Uses

Uses of MOVES in this context might include:

• National Emissions Inventory submissions;

- Setting budgets for the State Implementation Plan;

- Regional conformity analysis;

- Greenhouse gas inventory and forecast development; or

- Obtaining emission rates for off-model project or program evaluation.

5.1.3 Run Specifications

Some of the run specifications (runspecs) will vary depending upon the particular use of the model. The input requirements are generally unaffected. Typical runspecs for the applications listed above would include:

Scale: County level.

Calculation type: All inputs in this example are prepared to allow the use of either inventory mode or emission rate mode.

Time span: All inputs in this example are prepared to allow the use of the "hour" time aggregation level (finest detail) as required by EPA for SIP/conformity analysis. Inputs are prepared for a current year (2010) and a future year (2040). All inputs in this example are prepared for an annual run that includes all months of the year, weekdays, and week-ends, and all 24 hours of the day. The same inputs also could be used for a seasonal run, such as summer or winter that only includes a limited number of months. In this case MOVES would import all of the data, but ignore the months that are not needed for that run.

Geographic bounds: The countyID for Washtenaw County, MI (26161) is included in all inputs for this example to allow for a new MOVES user to practice conducting an actual MOVES run with the example input files provided; however, the example is constructed for a fictional county using data from various real-world sources.

Vehicles: All inputs in this example are intended for a run with all 13 source types.

Road types: All inputs in this example are intended for a run with all five road types.

Pollutants and processes: All inputs in this example are prepared for MOVES runs of any of the pollutants/processes available. As noted above, MOVES would ignore the months of data that are not needed for a seasonal run, such as a summer ozone (NO_x and VOC) run or winter carbon monoxide (CO) run.

5.1.4 Overview of Input Data Sources

Table 5.1.1 provides an overview of the data source for each required input.

Table 5.1.1   Data Sources for Example 5.1

Input	Approaches to Developing Current Year Input	Approaches to Developing Future Year Input
Age distribution by source type	MOVES default distributions for current year all source types	MOVES default distributions for future year all source types
Source (vehicle) type population	Regional VMT by HPMS type combined with MOVES default miles/vehicle for all source types	Projected from current year values based on human population forecast
VMT by vehicle class	VMT by county from traffic counts (HPMS); apportioned to 6 vehicle types by regional or statewide VMT fractions from classification counters	Projected from current year VMT based on human population forecast
Road type distribution	From HPMS, with source type-specific adjusted by statewide VMT fractions by road type/source type	Same as current year distribution
Temporal adjustments (month VMT fractions)	MOVES defaults	Same as current year distribution
Temporal adjustments (day VMT fractions)	MOVES defaults	Same as current year distribution
Temporal adjustments (hour VMT fractions)	MOVES defaults	Same as current year distribution
Ramp fraction	MOVES default (8%)	MOVES default (8%)
Average speed distribution	Current year observed speeds, from ATRs	Same as current year distribution
Meteorology data	Local data from NCDC	Same as current year
Fuel formulation and supply	MOVES defaults	Local knowledge of future regulations or MOVES defaults
I/M programs	State agency program web site	Same as current year program, but change model years to correspond to future year being modeled

5.1.5 Age Distribution

Source:

* The data source for all source types is the MOVES default database. It is available at: http://www.epa.gov/otaq/models/moves/tools.htm. A sample screenshot is shown in Figure 5.1.1.

Figure 5.1.1   MOVES Default Age Distributions on EPA Web Site
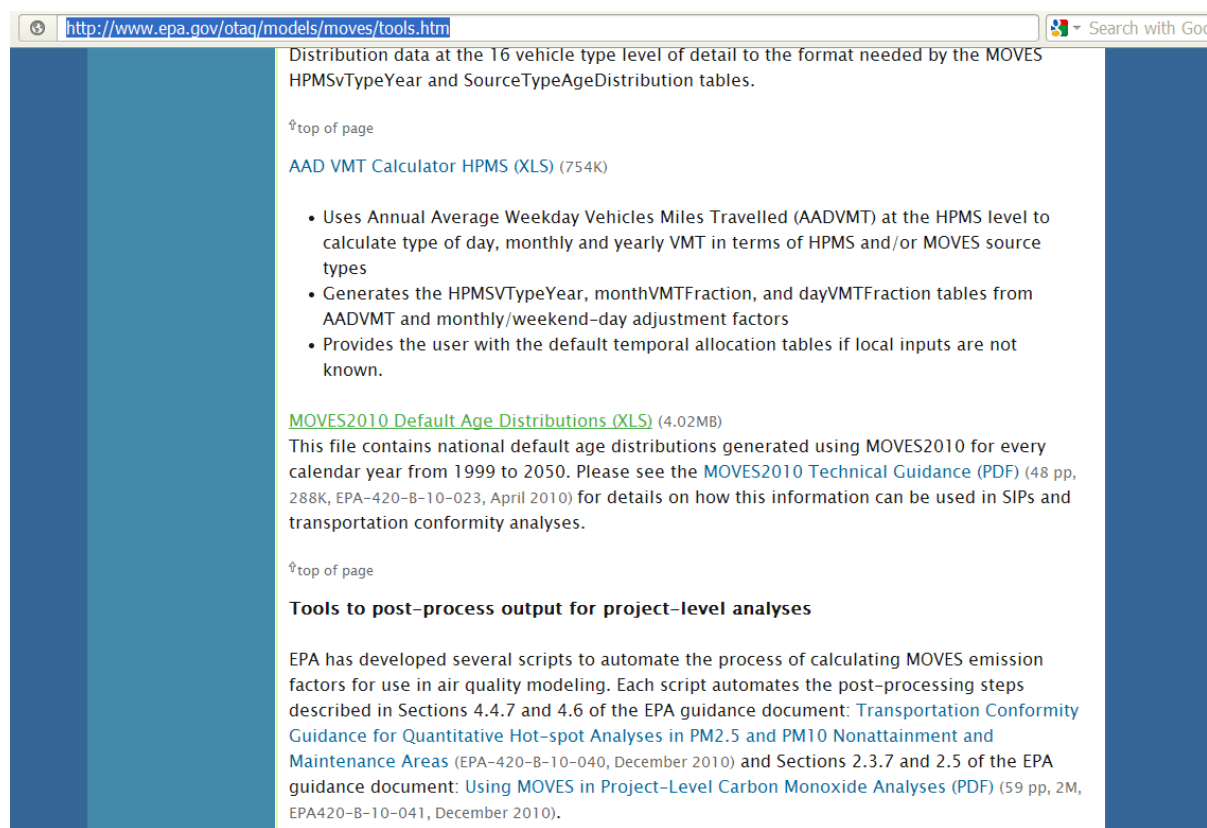
- This dataset contains estimates of national age distributions for all source types for each year from 1999 to 2050. For these examples, we use the 2010 and 2040 tabs of the spreadsheet. The data can be pasted directly into a template from the MOVES County Data Manager for age distributions.

Year(s):

- 2010 and 2040.

Source data format:

- The data file obtained from the EPA web site is an Excel spreadsheet file. It has separate tabs for each year.

Processing steps required:

1. Download the EPA's age distribution estimates.

2. Extract the desired years and paste the values into a template from the County Data Manager.

Input data example:

An excerpt of a sample input file is shown in Table 5.1.2. The full data file can be found in the MOVES Input Examples workbook.

Table 5.1.2   Example Input File: Age Distribution

sourceTypeID	yearID	ageID	ageFraction
11	2010	0	0.1974
11	2010	1	0.1972
11	2010	2	0.1687
11	2010	3	0.1298
11	2010	4	0.1054
11	2010	5	0.0771
…	…	…	…

Alternative sources and methods:

- State registration data also could be used to determine the age distributions for some or all source types. This is shown further in the example for which more extensive data is available (Section 5.2). Also, if registration data are difficult to obtain or work with, I/M program data may serve as a substitute in states or regions that operate I/M programs.

5.1.6 Source Type Population

Source:

- The sources for the county vehicle population in this example are taken from the HPMS estimates of yearly VMT within the county as well as MOVES national-level estimates of average yearly VMT per vehicle. The HPMS data are tabulated by HPMS vehicle type, not MOVES vehicle type, so calculations must be performed in order to convert between the two types. Along with the county VMT, the MOVES estimates of yearly VMT per vehicle are used to estimate the total population of vehicles operating in the county (number of vehicles = total vehicle-miles/miles per vehicle). Walker County, GA, is used in this example, for consistency with the data used in the "VMT by Vehicle Type" section below.

Year(s):

- This example provides data for 2010 and 2040, and draws data for both of those two years from the MOVES national-database default VMT as well as the HPMS estimates and projections.

Source data format:

- The MOVES default VMT can be extracted in spreadsheet form from a national-run MOVES output. ActivitytypeID 1 can be summed for the various road types to get estimates of total distance traveled (activitytypeID 1), and total vehicle population (activitytypeID 6) can be taken for each source type.

- The HPMS data is obtained from the state department of transportation as described under the next input, "VMT by Vehicle Class." It includes the total annual miles traveled within the county by road type and is combined with Highway Statistics Table VM-4 to produce the total VMT by six HPMS vehicle types within the county.

Processing steps required:

1. Annual VMT for the county by six HPMS vehicle types is calculated in the next section "VMT by Vehicle Class" based on state HPMS reporting and Highway Statistics Table VM-4. Table 5.1.3 shows the values used for this example.

Table 5.1.3   VMT Fractions from HPMS Data

HPMS Vehicle Type	HPMS ID	Year	HPMS VMT
Motorcycle	10	2010	5,402,402
Passenger Car	20	2010	352,806,080
Light Truck	30	2010	135,122,781
Buses	40	2010	5,601,436
Single Unit Truck	50	2010	35,039,781
Combination Truck	60	2010	27,762,521

2. For motorcycles and passenger cars, it is straightforward to convert from HPMS vehicle type to MOVES source type as they describe the same group of vehicles. For source types that are subsets of HPMS vehicle types, the MOVES embedded VMT fraction by source type (at the national level) is used to allocate the VMT by HPMS type to source types. For example, the total HPMS VMT for light trucks is divided between source types 31 and 32 using the ratio of type 31 to type 32 VMT found in the MOVES embedded VMT values. The national level MOVES VMT values are approximately:

   Source type 31: 8.394×10^{11}

   Source type 32: 2.804×10^{11}

3. Source type 31 is about 75 percent of the total, and 32 is about 25 percent of the total for light trucks. Taking the exact percentages, multiplied by the total light truck VMT in the table above, produces 101,285,147 VMT for source type 31, and 33,837,634 VMT for source type 32. This process is repeated for the other vehicle types with subdivisions (41-43, 51-54, and 61-62). Table 5.1.4 shows an example of the resulting VMT fractions and estimates ("New VMT").

4. The national MOVES run also is used to extract the average miles per year driven by each source type (Table 5.1.4). For the output of the run, the user must select distance traveled and population (activityIDs 1 and 6, as described above). The user sums the distance traveled for each source type over the various roadtypeIDs. The user then takes the total population for each source type (it is not presented by roadtypeID, so there is no need to sum). Dividing miles per year by the population yields an estimate of the average yearly miles traveled by each source type.

5. "New VMT" is divided by the average annual miles per vehicle to obtain the estimated population of each source type (Table 5.1.4). For example, for source type 31, 101,285,147 VMT / 9,890 miles/vehicle = 10,241 vehicles.

Table 5.1.4 Sample VMT and Population Data by Source Type

Source Type ID	Source Type	Year	VMT Fraction	New VMT	Miles/ Vehicle	Vehicle Population
11	Motorcycle	2010	0.0053	5,402,402	1,761	3,069
21	Passenger Car	2010	0.5442	352,806,080	13,917	25,350
31	Passenger Truck	2010	0.2832	101,285,147	9,890	10,241
32	Light Commercial Truck	2010	0.0946	33,837,634	9,890	3,421
41	Intercity Bus	2010	0.0009	2,296,220	21,115	109
42	Transit Bus	2010	0.0003	717,445	11,764	61
43	School Bus	2010	0.001	2,587,771	3,505	738
51	Refuse Truck	2010	0.0006	555,462	16,857	33
52	Single Unit Short-Haul Truck	2010	0.0218	28,914,453	12,821	2,255
53	Single Unit Long-Haul Truck	2010	0.0037	3,921,282	13,529	290
54	Motor Home	2010	0.0013	1,648,584	3,161	522
61	Combination Short-Haul Truck	2010	0.0163	11,514,109	44,778	257
62	Combination Long-Haul Truck	2010	0.0267	16,248,412	52,819	308

6. For 2040, Steps 1-5 are repeated using the projected 2040 VMT by six HPMS vehicles in place of the 2010 VMT by six HPMS vehicle types. The 2040 VMT projections are based on the 2040 human population forecast for Walker County, GA of 84,038 people as described in the "VMT by Vehicle Class" below. The MOVES national defaults used in Steps 2 and 4 above are different for 2040 and 2010.

Input data example:

Table 5.1.5 shows the estimated source type population for both 2010 and 2040 in MOVES input format.

Table 5.1.5   Example Input File: Source Type Population

yearID	sourceTypeID	sourceTypePopulation
2010	11	3,069
2010	21	25,350
2010	31	10,241
2010	32	3,421
2010	41	109
2010	42	61
2010	43	738
2010	51	33
2010	52	2,255
2010	53	290
2010	54	522
2010	61	257
2010	62	308
2040	11	5,513
2040	21	28,392
2040	31	11,539
2040	32	3,855
2040	41	138
2040	42	67
2040	43	910
2040	51	13
2040	52	2,664
2040	53	430
2040	54	638
2040	61	203
2040	62	297

Alternative sources and methods:

• State registration data also could be used to determine the source type populations for some or all vehicle types if available. However, state databases may not always include fleet vehicles (school buses, transit buses, refuse trucks). Information on those vehicle types may be available from other sources, though, such as transit agencies and departments of education. Also, state registrations may not be a good representation of the population of long-haul trucks, which are often registered in other states.

See Section 5.2 for a more detailed example of the development of source type popu-
lation from registration data.

- If registration data are difficult to obtain or work with, I/M program data also may
  serve as a substitute for some vehicle types in order to estimate a countywide vehicle
  population.

5.1.7 VMT by Vehicle Class

Source:

- HPMS VMT data by road type are used for the current year (2010) and combined with
  Highway Statistics Table VM-4 to divide VMT by the six HPMS vehicle types. In this
  example, HPMS VMT data are obtained from the Georgia DOT for Walker County,
  GA. It is the equivalent of using travel demand model output for the base year since
  HPMS adjustment factors are used for SIP/conformity purposes. The Highway
  Statistics Table VM-4 was submitted to FHWA by Georgia DOT and is based on
  statewide classification count data. The Highway Statistics Excel tool produced for
  this research project and made available with this report is used to combine the data,
  although the steps completed by the tool are described below.

- VMT for the future year (2040) is projected using historical per capita VMT infor-
  mation (based on U.S. Census population estimates and HPMS VMT) combined with
  official 2040 population forecasts for Walker County, GA obtained from the
  Chattanooga/North Georgia Transportation Planning Organization (TPO). While
  trends prior to 2000 showed increasing VMT per capita, trends since that time show a
  leveling off of VMT per capita, and perhaps even a slight decline, although that may
  be due to temporary economic conditions. Therefore, a projection of constant VMT
  per capita is used in this example, but other methods (such as projecting a 10-year
  trend in VMT per capita) also could be appropriate.

Year(s):

- The 2010 input is created using 2010 HPMS VMT and the 2010 version of Highway
  Statistics Table VM-4.

- The 2040 input is created using a projection method based on the 2040 population fore-
  cast and historical VMT per capita from 2001 to 2010. The 2010 version of Highway
  Statistics Table VM-4 is also used.

Source data format:

- HPMS VMT are obtained from GDOT's 445 Reports[30] which are in PDF or Excel file
  tabular form with rows denoting different roadway functional classes (rural interstate,

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[30] http://www.dot.ga.gov/informationcenter/statistics/RoadData/Pages/445Archives.aspx.

urban principal arterial, etc.). An example is shown in Figure 5.1.2. Only the far right hand column for total VMT in thousands is used (the other columns that are not used report mileage and lane mileage and specify ownership – state, county, or city). A separate table is available for each county in the state and new information is published annually.

Figure 5.1.2   Sample VMT Data From State Reporting

Georgia Department of Transportation
Office Of Transportation Data
Mileage by Route and Road System Report 445
for 2010

County: WALKER

Road System Type	State Route			County Road			City Streets			Totals		
	Mileage	Lane Mileage	VMT	Mileage	Lane Mileage	VMT	Mileage	Lane Mileage	VMT	Mileage	Lane Mileage	VMT
Rural Interstate	0.00	0	0	0.00	0	0	0.00	0	0	0.00	0	0
Rural Principal Arterial	17.63	66	173	0.00	0	0	0.00	0	0	17.63	66	173
Rural Minor Arterial	29.85	60	72	0.37	1	1	0.00	0	0	30.22	61	74
Rural Major Collector	84.63	169	131	47.08	94	38	0.00	0	0	131.71	263	169
Rural Minor Collector	0.00	0	0	28.47	57	12	0.00	0	0	28.47	57	12
Rural Local	0.00	0	0	367.81	736	220	0.12	0	0	367.93	736	220
Rural Totals	132.11	295	376	443.73	888	271	0.12	0	0	575.96	1,183	648
Small Urban Interstate	0.00	0	0	0.00	0	0	0.00	0	0	0.00	0	0
Small Urban Freeway	0.00	0	0	0.00	0	0	0.00	0	0	0.00	0	0
Small Urban Principal Arterial	8.81	28	78	0.00	0	0	0.00	0	0	8.81	28	78
Small Urban Minor Arterial	7.18	14	34	0.38	1	2	3.50	7	14	11.06	22	50
Small Urban Collector	0.00	0	0	4.42	9	6	7.10	14	8	11.52	23	14
Small Urban Local	0.00	0	0	10.53	21	12	45.06	90	49	55.59	111	61
Small Totals	15.99	42	112	15.33	31	19	55.66	111	72	86.98	184	203
Urbanized Interstate	0.00	0	0	0.00	0	0	0.00	0	0	0.00	0	0
Urbanized Freeway	0.00	0	0	0.00	0	0	0.00	0	0	0.00	0	0
Urbanized Principal Arterial	11.76	46	163	0.00	0	0	0.00	0	0	11.76	46	163
Urbanized Minor Arterial	14.40	28	65	12.44	25	61	7.93	15	35	34.77	68	160
Urbanized Collector	0.00	0	0	25.76	51	42	4.52	9	7	30.28	60	49
Urbanized Local	0.00	0	0	138.07	276	237	45.47	90	79	183.54	366	316
Urbanized Totals	26.16	74	228	187.94	352	340	57.92	114	122	260.35	540	689
County Totals	174.26	411	717	635.33	1,271	630	113.70	225	193	923.29	1,907	1,540

NOTE: Excludes Ramps, Private and Public Roads.
Includes State Routes, County Roads, and City Streets Type Roads From the GDOT Road Characteristics Database.
Projected Roads (unbuilt roads)are excluded.
Only Sections that are "open to traffic" are used to calculate mileage and VMT.
Road Inventories are normally collected on a 3-5 year cycle
Vehicle Miles Traveled (VMT) is calculated by multiplying the Annual Average Daily Travel* the Section Length
for each section and summarizing.
NOTE: VMT is denoted in Thousands

Source: Georgia DOT.

- Highway Statistics Table VM-4 is in PDF or Excel file tabular form with a separate row for every state. Each state has three percent distributions of VMT by six vehicle types reported that each sum to 100 percent. The columns show the six HPMS vehicle types (motorcycles, passenger trucks, light trucks, buses, single unit trucks, and combination trucks) and three road types (Interstate, other arterials, other).

- U.S. Census Population Estimates are in Excel or CSV file tabular form with a separate file available for each state. These tables have a separate row for each county in a state and a column for each of ten years in a decade.

Processing steps required:

<u>2010 VMT</u>

Note: Steps 1-4 are the same for the VMT by vehicle class MOVES input and Road Type Distribution MOVES input.

1. Convert *annual average daily VMT* provided in the HPMS report to *annual VMT* by multiplying by 365.

2. Aggregate HPMS VMT by the road types found in Highway Statistics VM-4. The GDOT HPMS reports contain 18 road types (six road types for three area types – rural, small urban, and urbanized) which must be aggregated into the six road types from Table VM-4. The table below shows the road type mapping used to complete the aggregation.

3. For each of the Table VM-4 road types multiply the VMT by the percentages found in Table VM-4 for each of the six HPMS vehicle types. This provides 36 VMT numbers (six road types times six vehicle types).

4. Convert to MOVES road types. For each vehicle type sum the "Rural Other Arterial" and "Rural Other" to produce "Rural Unrestricted Access." For each vehicle type sum the "Urban Other Arterial" and "Urban Other" to produce "Urban Unrestricted Access." The restricted access MOVES road types correspond directly to "Interstate System"; therefore, no operations are needed. This provides 24 VMT numbers (four road types times six vehicle types). The correspondence between HPMS, VM-4, and MOVES road types is shown in Table 5.1.6.

5. For each of the six HPMS vehicle types aggregate VMT over the four MOVES road types. This provides the six VMT numbers required for the VMT by vehicle class input.

Table 5.1.6   Road Type Correspondences

HPMS Report Road Types	Table VM-4 Road Types	MOVES Road Types
Rural Interstate	Rural Interstate System	Rural Restricted Access
Rural Principal Arterial	Rural Other Arterials	Rural Unrestricted Access
Rural Minor Arterial		
Rural Major Collector	Rural Other	
Rural Minor Collector		
Rural Local		
Small Urban Interstate	Urban Interstate System	Urban Restricted Access
Small Urban Freeway		
Small Urban Principal Arterial	Urban Other Arterials	Urban Unrestricted Access
Small Urban Minor Arterial		
Small Urban Collector	Urban Other	
Small Urban Local		
Urbanized Interstate	Urban Interstate System	Urban Restricted Access
Urbanized Freeway		
Urbanized Principal Arterial	Urban Other Arterials	Urban Unrestricted Access
Urbanized Minor Arterial		
Urbanized Collector	Urban Other	
Urbanized Local		

<u>2040 VMT</u>

1. Calculate Walker County, GA's VMT per capita for 10 historic years. Obtain 2001 to 2010 VMT from GDOT 445 Reports for each of the 10 years. Obtain 2001 to 2010 population estimates from the U.S. Census Bureau.[31] Convert *annual average daily VMT* to *annual VMT* by multiplying by 365. Calculate VMT per capita by dividing annual VMT by the population estimate for each year.

2. Average the 10 years of historic VMT per capita to obtain a single VMT per capita number to apply to 2040. Table 5.1.7 shows the 10 years of data and the average calculated for Walker County, GA.

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[31] U.S. Census Bureau. Intercensal Estimates of the Resident Population for Counties: April 1, 2000 to July 1, 2010. Available: http://www.census.gov/popest/data/intercensal/county/CO-EST00INT-01.html

Table 5.1.7   10-Year VMT, Population, and VMT per Capita (Example)

Year	Annual Average Daily VMT	Population Estimate	Annual VMT/capita
2001	1,671,244	62,109	9,822
2002	1,557,806	62,841	9,048
2003	1,558,022	63,478	8,959
2004	1,496,681	64,228	8,505
2005	1,639,421	65,160	9,183
2006	1,618,304	66,343	8,903
2007	1,595,362	67,405	8,639
2008	1,512,000	68,103	8,104
2009	1,602,000	68,612	8,522
2010	1,539,000	68,761	8,169
Average VMT per capita:			8,785

3. Obtain the 2040 population forecast from the local MPO or state sources. For this example, the Walker County population forecast of 84,038 people was obtained from the Chattanooga/North Georgia TPO.

4. Estimate 2040 annual VMT by multiplying the average VMT per capita (8,785) by the 2040 population forecast (84,038). This results in a 2040 VMT estimate of 738,314,631.

5. Calculate the 2010 to 2040 VMT growth rate: (2040 VMT – 2010 VMT)/2010 VMT = (738,314,631 – 561,735,000)/561,735,000 = 31.43%.

6. Apply the growth rate to each of the six vehicle type VMT numbers calculated for 2010 to produce the 2040 VMT by vehicle class input. For example, for motorcycles, 5,402,402 * 1.3143 = 7,100,629.

Input data example:

The resulting sample input files for 2010 and 2040 are shown in Tables 5.1.8 and 5.1.9. They also can be found in the Examples workbook.

Table 5.1.8   Example Input File: 2010 VMT

HPMSVtypeID	yearID	HPMSBaseYearVMT	baseYearOffNetVMT
10	2010	5,402,402	
20	2010	352,806,080	
30	2010	135,122,781	
40	2010	5,601,436	
50	2010	35,039,781	
60	2010	27,762,521	

Table 5.1.9   Example Input File: 2040 VMT

HPMSVtypeID	yearID	HPMSBaseYearVMT	baseYearOffNetVMT
10	2040	7,100,629	
20	2040	463,709,562	
30	2040	177,598,202	
40	2040	7,362,230	
50	2040	46,054,426	
60	2040	36,489,582	

Alternative sources and methods:

- A number of variations to the VMT projection method described in this example could be used. For example, more than 10 years of historical data could be used to calculate the VMT per capita. Also, a linear trend for the VMT per capita could be created to predict the VMT per capita in 2040. Finally, the use of population forecasts could be abandoned all together and VMT trends based only on historical VMT data could be created. However, this method would ignore socioeconomic conditions as the main driver of VMT. Example 4.3.2 in Section 4.0 of this document explores some of these variations.

- Growth factors from nearby areas with a travel demand model could be obtained from that model and applied to HPMS VMT.

- To account for the difficulty that vehicle classification counters have in distinguishing HPMS types 20 (passenger cars) and 30 (passenger trucks), the VMT for these vehicle types could be combined and resplit based on MOVES defaults as explained in Example 5.2.

5.1.8 Road Type Distribution

Source:

- HPMS VMT data by road type are used for the current year (2010) and combined with Highway Statistics Table VM-4 to allocate VMT among the six HPMS vehicle types. In this example, HPMS VMT data is obtained from Georgia DOT for Walker County, GA. It is the equivalent of using travel demand model output for the base year since HPMS adjustment factors are used for SIP/conformity purposes. The Highway Statistics Table VM-4 was submitted to FHWA by Georgia DOT and is based on statewide classification count data. The Highway Statistics Excel tool produced as part of this project and made available with this report is used to combine the data, although the steps completed by the tool are described below.

Year(s):

- The 2010 input is created using 2010 HPMS VMT and the 2010 version of Highway Statistics Table VM-4.

- The 2010 road type distribution is also applied to 2040 since the VMT projection method used in this example does not consider different VMT growth rates on different road types.

Source data format:

- HPMS VMT are obtained from GDOT's 445 Reports which are in PDF or Excel file tabular form with rows denoting different roadway functional classes (rural interstate, urban principal arterial, etc.). An example is shown in Figure 5.1.2. Only the far right hand column for total VMT in thousands is used (the other columns that are not used report mileage and lane mileage and specify ownership – state, county, city). A separate table is available for each county in the state and new information is published annually.

- Highway Statistics Table VM-4 is in PDF or Excel file tabular form with a separate row for every state. Each state has three percent distributions of VMT by six vehicle types reported that each sum to 100 percent. The columns show the six HPMS vehicle types (motorcycles, passenger trucks, light trucks, buses, single unit trucks, and combination trucks) and three road types (interstate, other arterials, other).

Processing steps required:

Note: Steps 1-4 are the same for the VMT by vehicle class MOVES input and Road Type Distribution MOVES input.

1. Convert *annual average daily VMT (AADVMT)* provided in the HPMS report to *annual VMT* by multiplying by 365. For example:

> AADVMT for rural principal arterial = 173,00 vehicle-miles/day * 365 days/year = 63,145,000 vehicle-miles/year
>
> AADVMT for rural minor arterial = 74,00 vehicle-miles/day * 365 days/year = 27,010,000 vehicle-miles/year

2. Aggregate HPMS VMT by the road types found in Highway Statistics VM-4. The GDOT HPMS reports contain 18 road types (six road types for three area types – rural, small urban, and urbanized) which must be aggregated into the six road types from Table VM-4. The table in the VMT by vehicle class section shows the road type mapping used to complete the aggregation. For example, rural principal arterial and rural minor arterial are combined into "rural other arterials" as shown in this calculation:

> Annual VMT for Rural Other Arterials = 63,145,000 + 27,010,000 = 90,155,000

3. For each of the Table VM-4 road types multiply the VMT by the percentages found in Table VM-4 for each of the six HPMS vehicle types. This provides 36 VMT numbers (six road types times six vehicle types). For example, VMT for Rural Other Arterials (90,155,000) is multiplied by the following percentages by vehicle type:

> Rural Other Arterial Motorcycles = 90,155,000 * 1.25% = 1,126,938
>
> Rural Other Arterial Passenger Cars = 90,155,000 * 57.46% = 51,803,063
>
> Rural Other Arterial Light Trucks = 90,155,000 * 24.44% = 22,033,882
>
> Rural Other Arterial Buses = 90,155,000 * 1.28% = 1,153,984
>
> Rural Other Arterial Single-Unit Trucks = 90,155,000 * 8.21% = 7,401,726
>
> Rural Other Arterial Combination Trucks = 90,155,000 * 7.36% = 6,635,408

4. Convert to MOVES road types. For each vehicle type sum the "Rural Other Arterial" and "Rural Other" to produce "Rural Unrestricted Access." For each vehicle type sum the "Urban Other Arterial" and "Urban Other" to produce "Urban Unrestricted Access." The restricted access MOVES road types correspond directly to "Interstate System"; therefore, no operations are needed. This provides 24 VMT numbers (four road types times six vehicle types). For example, the following calculations show Rural Unrestricted Access Motorcycles VMT, which is the sum of Rural Other Arterial VMT (shown in step 3 above) and Rural Other (also calculated in step 3, but not shown):

> Rural Unrestricted Access Motorcycles = 1,126,938 + 1,053,828 = 2,180,766

5. Calculate the road type distribution for each of the six HPMS vehicle types. For a particular HPMS vehicle type take VMT on a single road type divided by VMT on all four road types. Repeat for each of the four road types to get a percent distribution that sums to 100 percent. Repeat for the other five HPMS vehicle types. Apply the

same distribution to all MOVES source types within an HPMS vehicle type (the first digit of the MOVES source type codes denotes the HPMS vehicle type). MOVES road type 1 (off-network) is not used; therefore, it appears with zeros in the example table. It should be noted that there are no restricted access roadways in Walker County, GA; therefore, road types 2 and 4 are zero throughout the example table. The following calculations are an example of calculating the road type distribution for motorcycles:

Rural Restricted Access = 0/5,402,402 = 0.0

Rural Unrestricted Access = 2,180,766/5,402,402 = 0.4037

Urban Restricted Access = 0/5,402,402 = 0.0

Urban Unrestricted Access = 3,221,636/5,402,402 = 0.5963

Input data example:

A portion of the resulting sample input file is shown in Table 5.1.10. The full input file for all source types can be found in the Examples workbook.

Table 5.1.10 Example Input File: Road Type Distribution

sourceTypeID	roadTypeID	roadTypeVMTFraction
11	1	0
11	2	0
11	3	0.403666
11	4	0
11	5	0.596334
21	1	0
21	2	0
21	3	0.363886
21	4	0
21	5	0.636114
31	1	0
31	2	0
31	3	0.484776
31	4	0
31	5	0.515224
32	1	0
32	2	0
32	3	0.484776
32	4	0
32	5	0.515224
…	…	..

Alternative sources and methods:

- Use classification counts to produce a table to use in place of Highway Statistics Table VM-4. Table VM-4 is derived from classification counts, but there is a multiyear lag before this table becomes available on the Highway Statistics web site. Using the classification count data directly also may allow a more detailed calculation method if it provides vehicle type distributions for more than six road types. It also could allow for the selection of count stations from a geographic area more specific than statewide and allow the use of local classification counts that may not be included in the State DOT's submittal to FHWA.

- A simpler method than the one shown in this example would be to use HPMS VMT by road type directly without using Table VM-4 or classification counts. This would produce a single road type distribution that would be used for all MOVES source types.

5.1.9 Temporal Adjustments

Source:

- For this limited data example MOVES defaults are used for the three temporal adjustment inputs: month VMT fraction, day VMT fraction, and hour VMT fraction.

Year(s):

- 2010 MOVES defaults are used for the current year (2010).

- 2040 MOVES defaults are used for the future year (2040). The day VMT fraction and hour VMT fraction are the same for 2010 and 2040, but the month VMT fraction differs since 2040 is a leap year and 2010 is not.

Source data format:

- The MOVES default inputs are tabular files that can be saved from the MOVES County Data Manager as an Excel file. They are already in the exact format needed by MOVES.

Processing steps required:

1. After selecting the year 2010 and a county in the runspec creator, open the County Data Manager, select the Vehicle Type VMT tab, and hit the "export default data" button and save as an Excel file.

2. The resulting file will have multiple tabs, including the month VMT fraction, day VMT fraction, and hour VMT fraction with default values. The day and hour VMT fraction tables can be used for both 2010 and 2040 since selecting a different year and reexporting default values would result in a table with the same values. The month VMT fraction table has a field to indicate whether or not the information is for a leap year. Since 2010 is not a leap year but 2040 is, the user should change the year in the runspec

creator to 2040 and reexport the default values to get a new month VMT fraction table with isLeapYear set to "yes" and with different values in it.

3. The resulting files can be used directly in the MOVES runs without any manipulation.

Input data example:

Tables 5.1.11 and 5.1.12 show sample month VMT fraction input file excerpts for 2010 and 2040, respectively. Tables 5.1.13 and 5.1.14 show day and hour VMT fraction input file excerpts, with the same data for 2010 and 2040.

Table 5.1.11 Example Input File: 2010 Month VMT Fraction

sourceTypeID	isLeapYear	monthID	monthVMTFraction
11	N	1	0.073086
11	N	2	0.069713
11	N	3	0.081732
11	N	4	0.082302
11	N	5	0.087503
11	N	6	0.088272
11	N	7	0.092325
11	N	8	0.09343
11	N	9	0.084681
11	N	10	0.086516
11	N	11	0.080228
11	N	12	0.080214
…	…	…	…

Table 5.1.12   Example Input File: 2040 Month VMT Fraction

sourceTypeID	isLeapYear	monthID	monthVMTFraction
11	Y	1	0.072904
11	Y	2	0.072023
11	Y	3	0.081529
11	Y	4	0.082098
11	Y	5	0.087286
11	Y	6	0.088052
11	Y	7	0.092096
11	Y	8	0.093198
11	Y	9	0.08447
11	Y	10	0.086301
11	Y	11	0.080029
11	Y	12	0.080015
…	…	…	…

Table 5.1.13   Example Input File: 2010 and 2040 Day VMT Fraction

sourceTypeID	monthID	roadTypeID	dayID	dayVMTFraction
11	1	1	2	0.237635
11	1	1	5	0.762365
11	1	2	2	0.27882
11	1	2	5	0.72118
11	1	3	2	0.27882
11	1	3	5	0.72118
11	1	4	2	0.237635
11	1	4	5	0.762365
11	1	5	2	0.237635
11	1	5	5	0.762365
…	…	…	…	…

Table 5.1.14   Example Input File: 2010 and 2040 Hour VMT Fraction

sourceTypeID	roadTypeID	dayID	hourID	hourVMTFraction
11	1	2	1	0.021474
11	1	2	2	0.014443
11	1	2	3	0.010968
11	1	2	4	0.007495
11	1	2	5	0.006839
11	1	2	6	0.010359
11	1	2	7	0.01843
11	1	2	8	0.026812
11	1	2	9	0.036385
11	1	2	10	0.047541
11	1	2	11	0.057466
11	1	2	12	0.065079
11	1	2	13	0.071323
11	1	2	14	0.071492
11	1	2	15	0.071723
11	1	2	16	0.072006
11	1	2	17	0.071149
11	1	2	18	0.067887
11	1	2	19	0.061772
11	1	2	20	0.051688
11	1	2	21	0.042866
11	1	2	22	0.03803
11	1	2	23	0.032207
11	1	2	24	0.024568
…	…	…	…	…

Alternative sources and methods:

- Travel demand model information about the split of VMT over various time periods can be combined with MOVES default hour VMT fractions.

- Traffic count data (either classified or unclassified) can be used to create the three temporal adjustment inputs as shown in the more extensive data example (Section 5.2).

5.1.10 Ramp Fraction

Source:

- For this limited data example MOVES defaults are used for the ramp fraction input. Note that the ramp fraction value refers to the fraction of vehicle-*hours* of travel, not vehicle-miles of travel.

Year(s):

- The MOVES defaults for ramp fraction are the same for both 2010 and 2040.

Source data format:

- The MOVES default input is a tabular file that can be saved from the MOVES County Data Manager as an Excel file. It is already in the exact format needed by MOVES.

Processing steps required:

1. After selecting a county in the runspec creator, open the County Data Manager, select the ramp fraction tab, and hit the "export default data" button and save as an Excel file.

2. The resulting file will have a tab called roadType that has a simple table with road type 2 and 4. The MOVES 2010 default ramp fraction values are 0.08 for both road type 2 (rural restricted access) and road type 4 (urban restricted access).

3. The resulting file can be used directly in the MOVES runs without any manipulation.

Input data example:

The resulting sample input file is shown in Table 5.15.

Table 5.1.15   Example Input File: Ramp Fraction

roadTypeID	rampFraction
2	0.08
4	0.08

Alternative sources and methods:

- Travel demand model outputs can be used to calculate the ramp fraction as shown in the more extensive data example (Section 5.2).

5.1.11 Average Speed Distribution

Source:

- Speed data from nine rural automatic traffic recorder stations in four north Florida Counties (Madison, Hamilton, Columbia, and Baker) are used to create the average speed distribution input. Data from ATRs are used to show how real world speed data can be used in rural areas without a travel demand model to provide speed information. Five out of the nine stations are on rural unrestricted access roadways (MOVES road type 3) and two of the stations are on urban unrestricted access road-ways (MOVES road type 5). The two remaining stations are on rural restricted access roadways (MOVES road type 2). The data from these two stations are used for the speed distributions on both road type 2 and 4; however, MOVES will ignore the speed distributions on these two road types if used with the road type distribution input from this example since it reports zero VMT on these two road types. A month's worth of data from May 2012 were used that includes both weekdays and weekends and details by the 24 hours of the day.

Year(s):

- The May 2012 speed data are used to represent both the current year (2010) and future year (2040).

Source data format:

- The source ATR data are in CSV format with rows for each combination of ATR station (site), date, direction, and hour. There are 15 speed bin columns that list traffic volumes by speed bin, plus a total volume column. An example of a few rows of the source data is shown in Table 5.1.16. Only the first six speed bins are shown. The speed bins are defined in the Table 5.1.17, along with the closest corresponding MOVES speed bins.

Table 5.1.16 Sample Data from ATR Speed File

COUNTY	SITE	BEGDATE	DIR	HOUR_IND	SP01	SP02	SP03	SP04	SP05	SP06
1	228	5/2/2012	E	10	0	0	0	0	2	14
1	228	5/2/2012	E	11	0	0	0	0	1	10
1	228	5/2/2012	E	12	0	0	0	1	0	20
1	228	5/2/2012	E	13	0	0	0	0	1	15

Table 5.1.17   Speed Bins in ATR File and MOVES

Florida ATR Speed Bins		MOVES Speed Bins		
		1	2.5	speed < 2.5mph
		2	5	2.5mph <= speed < 7.5mph
		3	10	7.5mph <= speed < 12.5mph
		4	15	12.5mph <= speed < 17.5mph
SP01	<=20 mph	5	20	17.5mph <= speed <22.5mph
SP02	21-25 mph	6	25	22.5mph <= speed < 27.5mph
SP03	26-30 mph	7	30	27.5mph <= speed < 32.5mph
SP04	31-35 mph	8	35	32.5mph <= speed < 37.5mph
SP05	36-40 mph	9	40	37.5mph <= speed < 42.5mph
SP06	41-45 mph	10	45	42.5mph <= speed < 47.5mph
SP07	46-50 mph	11	50	47.5mph <= speed < 52.5mph
SP08	51-55 mph	12	55	52.5mph <= speed < 57.5mph
SP09	56-60 mph	13	60	57.5mph <= speed < 62.5mph
SP10	61-65 mph	14	65	62.5mph <= speed < 67.5mph
SP11	66-70 mph	15	70	67.5mph <= speed < 72.5mph
SP12	71-75 mph	16	75	72.5mph <= speed
SP13	76-80 mph			
SP14	81-85 mph			
SP15	>=86 mph			

Processing steps required:

1. Determine MOVES road types for the ATR stations and add a column to the source data to denote it. For this example, since there were only nine stations, a map of the station locations (shown in Figure 5.3) was examined to determine the MOVES road types. For a larger analysis with hundreds of stations an automated GIS process could be developed.

Figure 5.1.3 Map of ATR Station Locations Used in Example
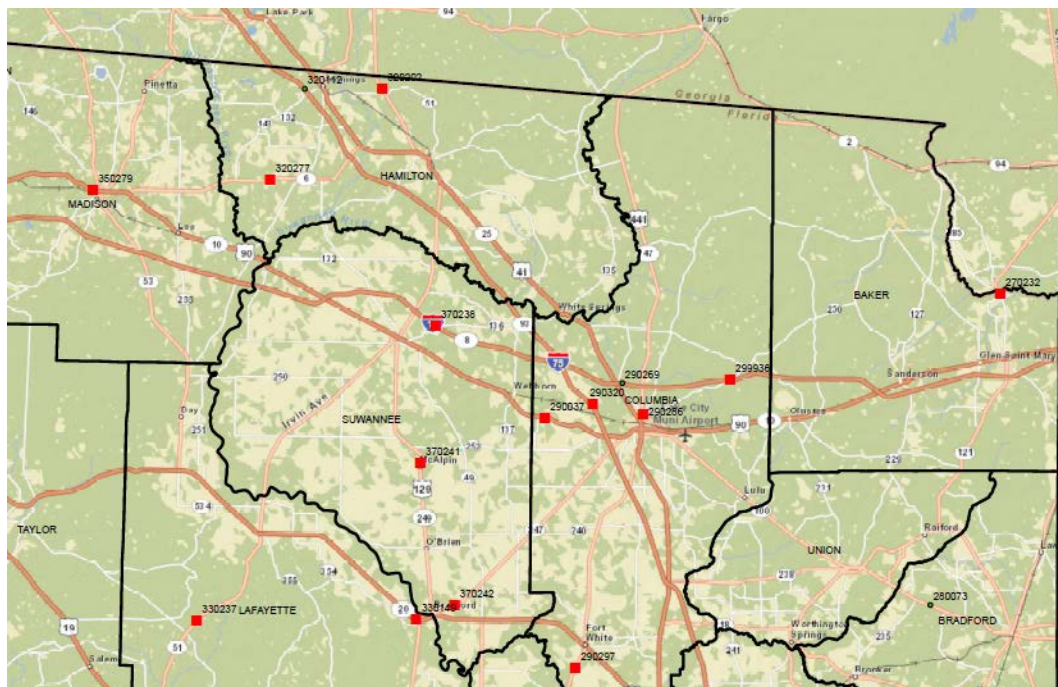
Source: Florida DOT.

2. Add two columns to the source data file after the date, the first to denote the day of the week and the second to denote the MOVES DayID. The Excel WEEKDAY function can be used to convert the date into a number from one to seven that denotes the day of the week. An IF statement can be used to mark Sundays (1) and Saturdays (7) as DayID 2 and all other days as DayID 5.

3. As seen in the table above, the ATR speed bins do not exactly line up with the MOVES speeds bins. Add 16 columns to the source data table for the 16 MOVES speed bins. Write formulas to reassign the volumes from ATR speed bins to MOVES speed bins. For example, MOVES speed bin 7, which represents 27.5 to 32.5 mph, are populated by taking one-half the volume from ATR speed bin 2 (21 to 25 mph) and one-half the volume from speed bin 3 (26 to 30 mph). Since the data in this example are from rural and very small urban areas it is assumed that MOVES speed bin 0-4 are zero. If conducting the analysis for areas that are expected to have lower speeds, one could distribute the <=20 mph ATR bin using MOVES defaults. MOVES speed bin 5 is assumed to be all of ATR bin 1 plus one-half of ATR bin 2. MOVES speed bin 16 is assumed to be one-half of ATR bin 12 and all of ATR bins 13-15.

4. MOVES requests the speed distributions as a distribution of vehicle **hours** traveled, instead of vehicle **miles** traveled. Therefore, the volume results from the previous step should be divided by the midpoint speed of each MOVES speed bin to produce VHT. For example, volumes for MOVES speed bin 5 are divided by 20 mph, volumes for MOVES speed bin 6 are divided by 25 mph, etc. This can be done within the same formulas written for the previous step.

5. Use an Excel pivot table to sum the VHT over all stations by MOVES speed bins as rows and three column types: MOVES Day ID, MOVES road type, and hour. Sum the VHT for all 16 MOVES speed bins in each column (each combination of MOVES Day ID, MOVES road type, and hour). Divide the VHT in each cell of the pivot table by the corresponding sum of VHT at the bottom of each column. This will produce a speed distribution for each column (each combination of MOVES Day ID, MOVES road type, and hour).

6. Cut and paste the speed distributions into the MOVES average speed distribution input format. For this example, the speed distributions for MOVES road type 2 are used for both road type 2 and 4.

Input data example:

A portion of the resulting sample input file is shown in Table 5.1.18. The full input file for all source types can be found in the Examples workbook. Figure 5.1.4 illustrates all speed distributions found in the full input file. The road types can be easily distinguished: the group that peaks to the left around speed bin 9 is road type 5 (urban unrestricted access), the group that peaks in the middle around speed bin 13 is road type 3 (rural unrestricted access), and the group that peaks to the far right at speed bin 16 is road type 2 (rural restricted access). The individual lines within each group are the individual hours and days.

Table 5.1.18 Example Input File: Average Speed Distribution

sourceTypeID	roadTypeID	hourDayID	avgSpeedBinID	avgSpeedFraction
11	2	15	1	0
11	2	15	2	0
11	2	15	3	0
11	2	15	4	0
11	2	15	5	0.00084863
11	2	15	6	0.001789839
11	2	15	7	0.0014401
11	2	15	8	0.000484932
11	2	15	9	0.000578612
11	2	15	10	0.001302948
11	2	15	11	0.003641396
11	2	15	12	0.013970842
11	2	15	13	0.066373187
11	2	15	14	0.203600093
11	2	15	15	0.298585662
11	2	15	16	0.407383759
…	…	…	…	…

Figure 5.1.4   Speed Distributions (Illustration)
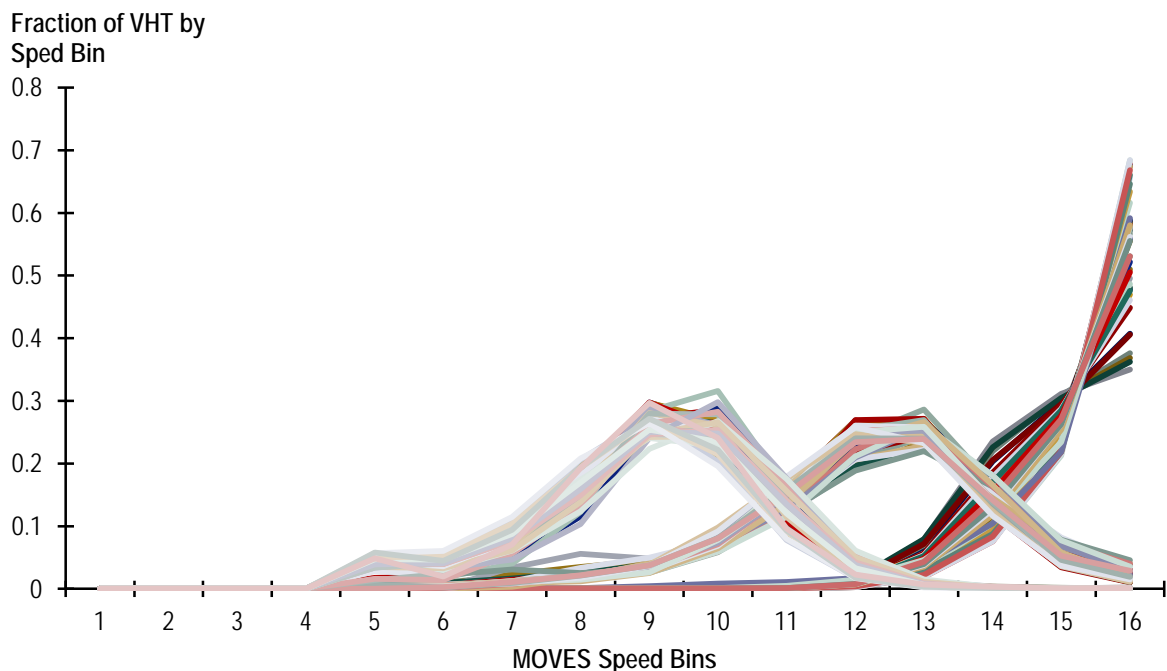
Alternative sources and methods:

- MOVES default speed distributions could be used instead.

- Travel demand model outputs can be used either directly or with post processing applied as described in Example #2 with more extensive data.

- Observed speed data based on GPS units, cell phones, or Bluetooth could be acquired from private sources.

5.1.12 Meteorology Data

Source:

- The meteorology data are sourced from the National Oceanographic and Atmospheric Administration's (NOAA's) National Climatic Data Center (NCDC). This is available at: http://www.ncdc.noaa.gov/IPS/lcd/lcd.html. Figure 5.1.5 shows a sample screenshot. In this example, data are selected in order to represent Washtenaw County, MI.

Figure 5.1.5   National Climatic Data Center Screen Shot
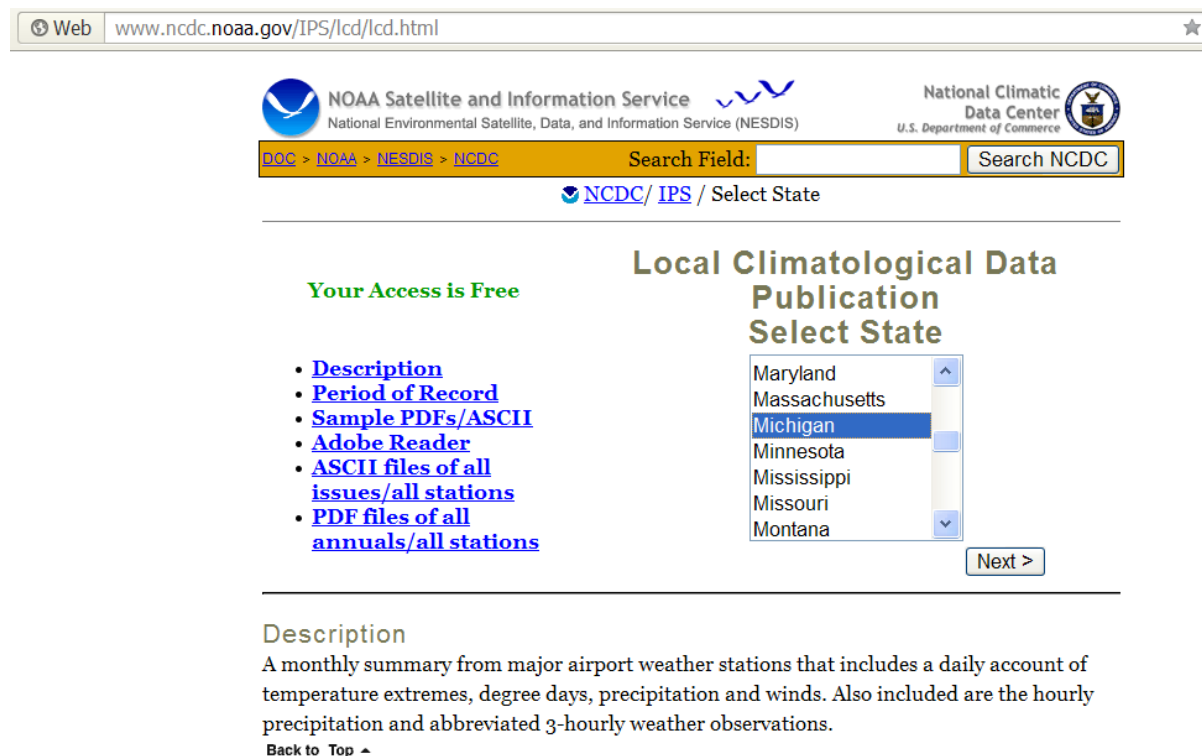
Year(s):

- Actual meteorological data for 2010 are acquired to develop the 2010 MOVES inputs. The same data are used for 2040 since forecast meteorological data are not available. Note that SIPs require set years for meteorological data.

Source data format:

- The data can be downloaded from the NCDC as either a PDF or an ASCII text file. The text file is easier to convert into the MOVES input format, but the data do not contain header labels describing the contents of each column. Downloading the PDF file is helpful because the PDF contains data headers that can be used to cross reference and label the data. For input to MOVES, the user should take the data from the final (bottom) section of data, which is the average monthly summary by hour, starting online 326 of the downloaded text file. It is comma delimited, and has 24 rows for each hour of the day. The column headers as read from the left are hour (Local Standard Time), <blank>, <blank>, dry bulb temperature (F), dew point (F), wet bulb temperature (F), relative humidity (%), actual barometric pressure (inHg), corrected barometric pressure (inHg), visibility (miles), wind speed (mph), resultant wind speed (mph), and resultant wind direction. Note that the first two columns after hour are blank in the average monthly summary, as they represent variables that cannot be averaged.

Processing steps required:

1. Create a Meteorology template file from the MOVES County Data Manager. If the correct months are selected in the runspec, the template will contain rows for all of the necessary data.

2. Download the text data for each desired month/year from the NCDC web site.

3. If using Microsoft Excel, convert the ASCII comma-separated NCDC data into tabular form using the Text-to-Columns feature with comma as the delimiter.

4. Copy columns A and G, rows 326 to 349 into the Meteorology template. Copy the 24 rows representing each hour into the appropriate rows in the template for month and hour.

5. Repeat for other months as necessary, completely populating the Meteorology template.

6. In this example, we assume that the weather will be equivalent in 2010 and 2040, so carry the data from the 2010 input file to the 2040 file.

Input data example:

An excerpt of the data available from NCDC is presented in the Table 5.1.19 for Detroit Wayne Airport (DTW), for December 2010. DTW is the closest location with complete data to Washtenaw County that is available from NCDC.

Table 5.1.19   Example of NCDC Data

Hour	<blank>	<blank>	Dry Bulb Temp (F)	Dew Point	Wet Bulb Temp (F)	Relative Humidity	Actual Pressure (inHg)	<Various other data -> >
1			24	18	22	78	29.31	
2			24	18	22	79	29.31	
3			24	19	22	80	29.32	
4			24	18	22	81	29.31	
5			24	18	22	80	29.3	
6			23	18	22	82	29.31	
7			23	18	22	83	29.31	
8			23	18	22	82	29.32	
…								

Alternative sources and methods:

- MOVES contains default weather data that can be used instead of downloaded data from the NCDC. The MOVES default data are based on a multiple-year average of

historical NCDC data. If the user wants to model a particular historical year, the NCDC data are likely to be more accurate. For a general MOVES run, however, the MOVES defaults may be more representative of typical weather conditions.

5.1.13 Inspection and Maintenance Programs

Source:

- When generating a new I/M program input for MOVES, using the MOVES default for a given county is a convenient way to get started with a template for editing. This can then be updated and altered to more accurately reflect the I/M program in the county being modeled. For the purposes of illustration in this example, Hartford County, Connecticut will be modeled. The source for verifying many of the values in the MOVES default database will be the Connecticut Emissions Program; Figure 5.1.6 provides an example screenshot of the program web site.

Figure 5.1.6   Example of I/M Program Web Site
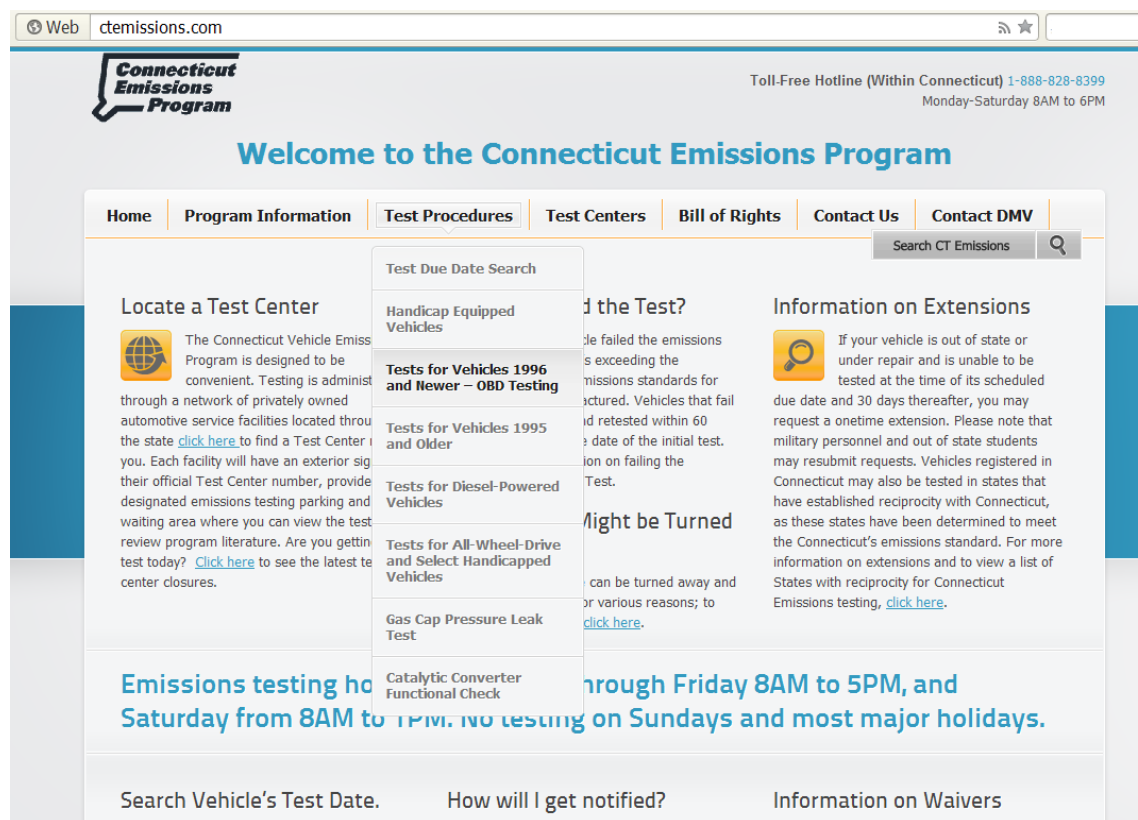
Source: Connecticut Emissions Program, ctemissions.com.

- In addition to published program attributes such as required testing frequency and model years of vehicles subject to testing, the compliance factor must be estimated. Compliance factor will be estimated using the values given in the example in Section 4.10.5.

Year(s):

- For the 2010 example, data will be taken from the most recent program information available. Model years will be adjusted to reflect any vehicle-age related aspects of the program, primarily new-vehicle exemptions and classic/antique vehicle exemptions. These model year dependencies will be performed for both the 2010 and 2040 cases.

Source data format:

- The MOVES default database can be extracted as an Excel spreadsheet. The default data may not be updated regularly and, as such, may not have model year cutoffs that are accurate to the scenario being modeled. It is likely that the values will need to be updated for this purpose. The Connecticut Emissions Program web site presents the various program requirements as text on their web site. The user must convert this text into the format used by the County Data Manager.

- The IMCoverage table used by the County Data Manager takes the format of Table 5.1.20. An excerpt of the default data upon exporting the IMCoverage table is shown in the table.

Table 5.1.20   I/M Coverage Table Example

polProcessID	stateID	countyID	yearID	sourceTypeID	fuelTypeID	IMProgramID	inspectFreq	testStandardsID	begModelYearID	endModelYearID	useIMyn	complianceFactor
101	8	9003	2010	21	1	4	1	24	1968	1980	Y	93.12
102	8	9003	2010	21	1	10	2	51	1996	2008	Y	93.12
201	8	9003	2010	21	1	4	1	24	1968	1980	Y	93.12
202	8	9003	2010	21	1	10	2	51	1996	2008	Y	93.12
101	8	9003	2010	31	1	4	1	24	1968	1980	Y	93.12
102	8	9003	2010	31	1	10	2	51	1996	2008	Y	93.12
201	8	9003	2010	31	1	4	1	24	1968	1980	Y	93.12
202	8	9003	2010	31	1	10	2	51	1996	2008	Y	93.12
101	8	9003	2010	32	1	4	1	24	1968	1980	Y	93.12
102	8	9003	2010	32	1	10	2	51	1996	2008	Y	93.12

Processing steps required:

1. After selecting the county in the runspec creator, open the County Data Manager and export the default I/M Program database for that county.

2. Find information about the I/M program for that county. For this example, information is taken from the program's web site, ctemissions.com. Almost all program web sites contain the information that is required to update the IMCoverage table.

3. If the default data need to be updated, users need to be aware that there is a process that must be followed that is easily prone to error. In particular, it is necessary to change the useIMyn field to "N" for existing records in the IM table, and alter the IMProgramID field for any new or updated records. The easiest method to do this is to change the useIMyn field to "N" for each row of the default data, and then duplicate these rows again in the table, changing the IMProgramID to a new value and the useIMyn back to "Y." The other values in these rows can then be updated without causing errors in the model run.

4. The next steps involve updating the values in the newly copied rows to accurately match those given in the program description. First, ensure that the yearID in all rows matches the year to be modeled.

5. For each desired pollutant process ID, match each set of rows to the vehicle type, test type, and applicable years as given by the program description. The following steps describe the updates necessary in the excerpt to the table given above:

   a. The inspectFreq value should be 2 for all rows of the excerpt. All vehicles that are subject to testing are subject once every two years.

   b. According to the web site, all vehicles older than 25 years are exempt. The begModelYearID for the pre-OBD model years should be 1985, not 1968. There should be no begModelYearID older than 1985 in this example as those vehicles are all exempt from testing.

   c. The OBD cutoff is 1996. The endModelYearID for pre-OBD vehicles should be 1995, not 1980 as in the default, and the begModelYearID for OBD vehicles should be 1996 (correct in the default).

   d. The web site indicates that vehicles under four years old are exempt from testing. For this reason, the endModelYearID for OBD vehicles should be 2007.

   e. The teststandardsID's given in the excerpt, 24 and 51, are accurate for the ASM test and the OBD test. According to the web site, all vehicle types that receive ASM tests also should receive gas cap pressure tests, so all rows for these vehicle types should be duplicated with a teststandardsID of 41 as well. (This was accurately shown outside of the excerpted area in the MOVES default.)

   f. The compliance factor should be updated to the most accurate estimate possible for each vehicle type. In this case, compliance factors of 90.5 for passenger cars and trucks and 84.8 for light commercial trucks are used (see Section 4.10.5).

   g. Though the excerpt does not show it, the data rows need to be repeated for diesel fuel if appropriate. In this case, the MOVES default does not contain any infor-

mation about diesel fueled vehicles (fuelTypeID = 2), but the Connecticut program does subject 1997 and newer diesel-powered vehicles to OBD testing.

6. In this example, the same patterns are used for the 2040 data. Because all vehicles, both gasoline and diesel powered, less than 25 years of age will be OBD compliant, the rows representing the ASM tests can be removed. The model year ranges for all vehicles subject to testing will then be 2015 to 2037. In this example, no change is assumed in the compliance factor over this period.

Input data example:

Table 5.1.21 represents the same rows as given in the excerpt from the MOVES default data, but with values updated to reflect the program information as found in the processing steps described above. Values in bold are those that were changed from the default. The table depicts those values used in the modeling of the 2010 case. Because the values are going to be entered for Washtenaw County, Michigan, there were no default data to be left in the table with useIMyn marked as "N." This is because Michigan does not have an I/M program.

Table 5.1.21 Example Input Data: I/M Program

polProcessID	stateID	countyID	yearID	sourceTypeID	fuelTypeID	IMProgramID	inspectFreq	testStandardsID	begModelYearID	endModelYearID	useIMyn	complianceFactor
101	8	9003	2010	21	1	4	**2**	24	**1985**	**1995**	Y	90.5
102	8	9003	2010	21	1	10	2	51	1996	**2007**	Y	90.5
201	8	9003	2010	21	1	4	**2**	24	**1985**	**1995**	Y	90.5
202	8	9003	2010	21	1	10	2	51	1996	**2007**	Y	90.5
101	8	9003	2010	31	1	4	**2**	24	**1985**	**1995**	Y	90.5
102	8	9003	2010	31	1	10	2	51	1996	**2007**	Y	90.5
201	8	9003	2010	31	1	4	**2**	24	**1985**	**1995**	Y	90.5
202	8	9003	2010	31	1	10	2	51	1996	**2007**	Y	90.5
101	8	9003	2010	32	1	4	**2**	24	**1985**	**1995**	Y	84.8
102	8	9003	2010	32	1	10	2	51	1996	**2007**	Y	84.8

Alternative sources and methods:

There are private web sites that attempt to catalog the I/M programs of various states and counties. For example, the OBD clearinghouse maintains a list of I/M programs and can be used to populate the IMCoverage table.[32]

5.1.14 Fuel Formulation and Supply

Source:

- For the limited data example, fuel information will be taken from the MOVES defaults.

Year(s):

- The MOVES defaults are appropriate estimates for 2010. Because long-term projections or estimations of future fuel properties into the future are not available, the same data will be used for 2040 as well.

Source data format:

- The data can be extracted for review from the MOVES County Data Manager. The data can be extracted into spreadsheet form, and read back into the input database in the same format.

Processing steps required:

1. After selecting the year 2010 and the desired county in the runspec creator, open the County Data Manager, select the Fuel tab, click the "export default data" button, save as an Excel file.

2. The resulting file will have multiple tabs, including FuelSupply and FuelFormulation, containing default values. This file can be used directly in the MOVES runs without any manipulation.

Input data example:

An excerpt of the MOVES default values for the Harris County (countyID 48201) fuel supply appears in Table 5.1.22. The values must be repeated or added for the other desired months.

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[32] www.obdclearinghouse.com/index.php?body=programstatus.

Table 5.1.22   Sample Input Table: Fuel Supply

countyID	fuelYearID	monthGroupID	fuelFormulationID	marketShare	marketshareCV
48201	2010	1	8894	0.12709	0.5
48201	2010	1	3512	0.879291	0.5
48201	2010	1	20011	1	0.5
48201	2040	1	8894	0.12709	0.5
48201	2040	1	3512	0.879291	0.5
48201	2040	1	20011	1	0.5

The fuel formulationID tab must reflect the fuelformulationIDs represented in the fuel supply table. For this example, those IDs are 8894, 3512, and 20011. The fuelformulationIDs for this example are presented in Table 5.1.23. Note that the fuel formulation table differs between MOVES 2010a and 2010b. For 2010b, the table includes T50 and T90, which are different measures of fuel evaporative characteristics that override the values listed for E200 and E300. Because MOVES will only use one pair of values, the user needs only to enter one set of values depending on the available data, with zeros entered in the unused columns.

Table 5.1.23   Sample Input Table: Fuel Formulation

fuelFormulationID	fuelSubtypeID	RVP	sulfurLevel	ETOHVolume	MTBEVolume	ETBEVolume	TAMEVolume	aromaticContent	olefinContent	benzeneContent	e200	e300	BioDieselEsterVolume	CetaneIndex	CetaneIndex	T50	T90
8894	11	11.71	30	0	0	0	0	19.492	11.729	0.55	56.07	86.98	0	0	0	187.4	311.3
4062	12	11.71	30	10	0	0	0	19.492	11.729	0.55	56.07	88.98	0	0	0	187.4	311.3
20011	20	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Alternative sources and methods:

- States may conduct fuel surveys in support of emissions estimates. The results of these surveys are generally publicly available, either directly from agency web sites or from records requests. The example provided in Section 5.2 includes inputs from a state fuel survey. Other previously conducted survey data may be available for some areas from either the U.S. Department of Energy or EPA. While not released at the time of this writing, it is also likely that EPA will release the complete findings of the 2011 National Emissions Inventory. This may include fuel data from a wide range of

states and counties. The NEI data is also likely to be the source of the default fuel properties data in MOVES2014. Finally, fuel data may be available from refiners. Refiners may be able to provide fuel properties by batch, though these data may not reflect what is actually delivered at the pump due to the effects of splash blending or fuel weathering.

■ 5.2 Example #2: Regional Analysis with More Extensive Data

5.2.1 Overview

This example illustrates the development of MOVES inputs at the county-scale of analysis using the County Data Manager. This example illustrates how inputs might be created when more extensive local data sources are available. For example, the area might be a metropolitan area with a travel demand forecasting model as well as other regional data collection systems. The example is constructed using data from various real-world sources from different locations in the U.S.

5.2.2 Uses

Uses of MOVES in this context might include:

- National Emissions Inventory submissions;

- Setting budgets for the State Implementation Plan;

- Regional conformity analysis;

- Greenhouse gas inventory and forecast development; or

- Obtaining emission rates for off-model project or program evaluation.

The inputs provided here are illustrative. If the model is used for regulatory purposes (SIP development or conformity analysis), users should be sure to follow all applicable EPA guidance and consult on data sources as needed.

5.2.3 Run Specifications

Some of the run specifications (runspecs) will vary depending upon the particular use of the model. The input requirements are generally unaffected. Typical run specs for the applications listed above would include:

Scale: County level.

Calculation type: All inputs in this example are prepared to allow the use of either inventory mode or emission rate mode.

Time span: All inputs in this example are prepared to allow the use of the "hour" time aggregation level (finest detail) as required by EPA for SIP/conformity analysis. Inputs are prepared for a current year (2010) and a future year (2040). All inputs in this example are prepared for an annual run that includes all months of the year, weekdays and weekends, and all 24 hours of the day. The same inputs also could be used for a seasonal run, such as summer or winter that only includes a limited number of months. In this case MOVES would import all of the data, but ignore the months that are not needed for that run.

Geographic bounds: The countyID for Washtenaw County, MI (26161) is included in all inputs for this example to allow for a new MOVES user to practice conducting an actual MOVES run with the example input files provided; however, the example is constructed for a fictional county using data from various real-world sources.

Vehicles: All inputs in this example are intended for a run with all 13 source types.

Road types: All inputs in this example are intended for a run with all five road types.

Pollutants and processes: All inputs in this example are prepared for MOVES runs of any of the pollutants/processes available. As noted above, MOVES would ignore the months of data that are not needed for a seasonal run, such as a summer ozone (NO_x and VOC) run or winter carbon monoxide (CO) run.

5.2.4 Overview of Input Data Sources

Table 5.2.1 provides an overview of the data source for each required input.

Table 5.2.1 Data Sources for Example 5.2

Input	Approaches to Developing Current Year Input	Approaches to Developing Future Year Input
Age distribution by source type	Light-duty vehicles (source types 11-32), transit buses (42), and short-haul heavy-duty vehicles (types 51, 52, 61): State vehicle registration data	Same as current year distribution
	School buses: State school bus database (43)	Same as current year distribution
	Long-haul heavy-duty vehicles (source types 41, 53, 54, 62): MOVES default distributions for current year	MOVES default distributions for future year
Source (vehicle) type population	Light-duty vehicles (source types 11-32), transit buses (42), and short-haul heavy-duty vehicles (types 51, 52, 61): State vehicle registration data	Apply human population forecast to grow current year vehicle population
	School buses: State school bus database (43)	Apply human population forecast to grow current year vehicle population
	Long-haul heavy-duty vehicles (source types 41, 53, 54, 62): Regional VMT by HPMS type combined with MOVES default miles/vehicle	Use future year VMT from TDFM as basis for calculation
VMT by vehicle class	VMT by county from traffic counts (HPMS) for current year; apportioned to 6 vehicle types by regional or statewide VMT fractions from classification counts	Use TDFM to get future year VMT; apply VMT fractions by vehicle type from current year classification count data
Road type distribution	From TDFM, with source type-specific adjusted by statewide VMT fractions by road type/source type from classification counts	Use TDFM to get future year VMT by road type; apply current classification count data
Temporal adjustments (month VMT fractions)	Statewide unclassified counts	Same as current year distribution
Temporal adjustments (day VMT fractions)	Statewide vehicle classification counts by six HPMS vehicle types	Same as current year distribution
Temporal adjustments (hour VMT fractions)	Weekday: Statewide vehicle classification counts by six HPMS vehicle types using weekday data, adjust to four time-of-day periods from TDFM Weekend: Statewide vehicle classification counts by six HPMS vehicle types using weekend data, no TDFM adjustments	Weekday: Use current year vehicle classification counts and future year TDFM to adjust to four times of day Weekend: same as current year distribution
Ramp fraction	TDFM for current year	TDFM for future year
Average speed distribution	From TDFM for current year, with postprocessing and validation	From TDFM for future year, with postprocessing
Meteorology data	Local data from NCDC	Same as current year meteorology data
I/M programs	State agency overseeing program	Same as current year program, but change model years to correspond to future year being modeled
Fuel formulation and supply	Local fuel survey	Same as current year

5.2.5 Age Distribution

Source:

- For light-duty vehicles (source types 11-32) and local and most short-haul heavy-duty vehicles (types 42, 51, 52, 61), age distribution is obtained from state vehicle registration data as obtained from the Department of Motor Vehicles or state Department of Transportation. In this example, we will use Texas DOT registration data covering vehicles registered in the Houston area.

- For school buses (type 43), in this example, the Massachusetts Department of Environmental Protection maintains a database of all school buses operating in the state, including their age and other pertinent information.

- For long-haul and intercity heavy-duty vehicles (source types 41, 53, 54, 62), the default MOVES age distributions are used. This is because these vehicles are likely to operate within counties that they are not necessarily registered in while performing their long-haul functions.

Year(s):

- Registration data from 2009/2010 are used for age distributions of the vehicle types using registration data, and these data are carried over unchanged for 2040.

- For the school buses, the data are for 2014. These data will be used unchanged for 2010 and 2040.

- For the vehicle types for which the MOVES default distribution is used, the distribution will be extracted for 2010 and 2040 from the default data.

Source data format:

- The data file obtained from the DMV is a listing of all registered vehicles. Fields are included for vehicle make, model, model year, and vehicle type (body style). Vehicles are not usually categorized the same way in registration data as they are within MOVES. The vehicle entries must be categorized by appropriate vehicle source types. This can be done by creating or using an automated algorithm to assign each vehicle to a MOVES source type.

- For school buses, the data are provided in ASCII text file format. The file is a list of all buses in the state. The entry for each bus contains information such as model year and fuel type.

- The MOVES default age distribution file is available in spreadsheet form. Its contents can be directly copied into an age distribution template drawn from the MOVES County Data Manager.

Processing steps required:

For registration data:

1. The MOVES source type for each vehicle must be determined. This may be done using a vehicle identification number decoder or other algorithm that considers the make, model, gross vehicle weight, or body style of the vehicle. This is described further later in this example.

2. Source types for which MOVES default age distribution data are used are excluded from the registration dataset.

3. Within each remaining source type, scripts are used to sum the total number of vehicles by model year. The fraction of each model year of the total population of that source type is calculated.

4. Model years are associated with a vehicle age. For example, the most recent model year found in the data would be age 0. This is typically one-year newer than the calendar year, as vehicle model years can be released early by up to one calendar year.

5. The population fractions by age and source type are used to construct the MOVES input table.

For the school bus data:

1. A script is used to sum the total number of vehicles by model year. The fraction of each model year of the total population of school buses is calculated.

2. Model years are associated with a vehicle age. For example, the most recent model year would be age 0.

3. The population fractions by age and source type are used to construct the MOVES input table.

The remaining vehicles (primarily long-haul heavy-duty vehicles) use the MOVES default distribution. The procedure is the same as that given in the limited data example. The values for these source types are inserted into the appropriate source type groups within the template for age distribution in the County Data Manager.

Input data example:

For the light-duty vehicles and those for which age distributions are taken from registration data, the registration database for vehicles from Harris County, Texas is used in this example. Table 5.2.2 provides an example of how MOVES source types can be defined based on data in the database. The relevant values from that spreadsheet are the registration class, owner county, vehicle model year, vehicle classification, and gross weight. For each source type and sourcetypeID, the following values in the Texas registration database can be used to associate the source types with the registration data. Values marked with "–" imply that the vehicle is adequately described by the values in the other columns

without the need for any specific value in for the given column. Given that the registration data are not specifically designed for this purpose, there will be some errors when assigning vehicles to source types in this fashion. Note in this example that there is no specific way to discern intercity buses from school buses in the registration. In this example, school bus data are provided from an outside source, while "not 40" registration class and "bus" vehicle classification is used to represent intercity buses. However the accuracy of data on intercity buses will be reduced because some school buses are likely to be included.

Table 5.2.2 Example of Registration Data with MOVES Source Type Added

Source Type	sourceTypeID	Registration Class	Vehicle Classification	Body Style	Gross Weight (lbs.)
Motorcycle	11	–	MTRCYCLE	–	–
Passenger Car	21	–	PASS	–	< 6,000
Passenger Truck	31	–	PASS-TRK	–	< 8,500
Light Commercial Truck	32	–	PASS-TRK	–	> 8,500
Intercity Bus[a]	41	Not 40	BUS	–	–
Transit Bus	42	40	BUS	–	–
School Bus[a]	43	Not 40	BUS	–	–
Refuse Truck	51	–	–	GG	–
Single Unit Short-Haul Truck	52	Not 10,34	TRK>1[b]	Not TF,TR, or GG	> 10,000
Single Unit Long-Haul Truck	53	6	TRK>1	Not TF TR, or GG	> 10,000
Motor Home	54	–	–	MH	> 8,500
Combination Short-Haul Truck	61	10, 34	TRK>1 or TRACTOR	TF or TR	> 10,000
Combination Long-Haul Truck	62	6	TRK>1 or TRACTOR	TF or TR	> 10,000

[a] It is not directly possible to differentiate between intercity buses and school buses in the registration data

[b] TRK>1 includes all trucks over 1 ton gross weight.

Registration Classes: 6 = Apportioned Truck/Tractor, 10 = Combination Truck, 34 = Tractor, 40 = City Bus

Body Styles: GG = Refuse Truck, TF & TR = Combination Tractor, MH = Motorhome

Filtering the registration data for a given county by using the above data allows almost all registration entries to be associated with a given source type. Once the source type has been determined, the user calculates each vehicle's age based on model year, and then finds the fraction of vehicles with each age value. This is tallied and used to generate the age distribution table. An excerpt for the Harris County data is shown in Table 5.2.3.

Table 5.2.3 Sample Input Table: Age Distribution

sourceTypeID	yearID	ageID	ageFraction
11	2010	0	0.065
11	2010	1	0.113
11	2010	2	0.135
11	2010	3	0.113
11	2010	4	0.088
11	2010	5	0.063
…	…	…	…

Alternative sources and methods:

State registration data also could be used to determine the age distributions for long-haul heavy-duty vehicles. This may be appropriate for larger states which see a substantial number of interstate truck registrations. For smaller states, or states that see few registrations, use of a national average is probably more appropriate for characterizing the fleet, including traffic from other states.

If registration data are difficult to obtain or work with, I/M program data may serve as a substitute.

5.2.6 Source Type Population

Source:

- For light-duty vehicles and short-haul heavy-duty vehicles (source types 11 – 32, 42, 51, 52, and 61), source type population is determined directly from state vehicle registration data as obtained from the Department of Motor Vehicles.

- For school buses (sourcetype 43), the population data are extracted from the same Massachusetts Department of Environmental Protection bus inventory as was used for the age distribution.

- For the remaining heavy-duty vehicles (source types 41, 53, 54, and 62), source type populations are estimated from VMT by vehicle type estimated from state HPMS traffic reporting, and average mileage accumulation by vehicle type from MOVES. This approach is similar to that used for populations of all source types in Example 5.1.

- For the future year (2040), regional population growth projections obtained from the region's MPO were used to inflate populations of locally registered vehicles (light-

duty vehicles, short-haul trucks, and transit and school buses). National human population projections from the U.S. Census Bureau[33] were used to develop future estimates of long-haul source types. Table 1 of the "Middle Series" was chosen to be generally representative in this case. The ratio of the 2040 population estimate to the 2010 population was used as the factor to grow the number of vehicles from the 2010 case. In this example, we find that both the metropolitan and U.S. population are expected to grow by 19.9 percent during this time.

Year(s):

- For light-duty and short-haul heavy-duty vehicles, the registration data from the closest available year to 2010 (in this case, 2009/2010) will be used for the current population. For 2040, the current population will be multiplied by the regional population forecast growth percentage.

- The available school bus distribution data will be used for current year estimates. For 2040, the current population will be multiplied by the regional population forecast growth percentage.

- For long-haul heavy-duty vehicles, population will be estimated using regional VMT from HPMS combined with MOVES default miles/vehicle for long-haul heavy-duty vehicles to yield population. This will be performed in a similar fashion to the population estimate in the limited data example presented previously.

Source data format:

- Both the MOVES default distribution, as well as the school bus inventory, were provided in spreadsheet form with entries for vehicle type and model year.

- The MOVES default VMT per vehicle can be extracted in spreadsheet form from a national-run MOVES output. ActivitytypeIDs 1 and 6 can be summed for the various road types to obtain estimates of distance traveled (activitytypeID 1) and vehicle population (activitytypeID 6).

- The HPMS data are obtained from the state DOT HPMS web site and placed in spreadsheet form. The data that are obtained include total annual VMT within the county, and total VMT by vehicle type at the state level.

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[33] http://www.census.gov/population/projections/data/national/2012/summarytables.html.

Processing steps required:

<u>Light-duty and short-haul vehicles:</u>

1. The MOVES source type for each vehicle must be determined. This may be done using a VIN decoder or other algorithm that considers the make, model, or body style of the vehicle. In this case, the same process as described above is used for the age distribution calculations.

2. Source types for which MOVES embedded data are used are excluded from the dataset, along with vehicles based outside the county of interest (if present).

3. Within each remaining source type, the total number of vehicles is summed.

4. For the 2040 case, the number of vehicles in each source type category is multiplied by the ratio of 2040 to 2010 human population.

<u>School buses:</u>

1. The total number of vehicles in the state is summed.

2. Because county of operation is not given in the bus inventory, assumptions must be made in order to calculate the county school bus population. In this example, Hampden County is modeled. The percentage of statewide school buses that operate in this county is assumed equal to the percentage of total Massachusetts residents that live in Hampden County. A MOVES user could refine this approach if better data were available to estimate school buses per capita.

   Number of residents of Hampden County: 463,490[34]
   Number of residents of Massachusetts: 6,547,629
   Percentage in Hampden County: 7.1 percent
   So, of the 11,278 school buses in the state, we assume that 798 operate within the county.

3. For the future year estimates, the number of buses is multiplied by the ratio of 2040 to 2010 population.

<u>Heavy-duty vehicles:</u>

The heavy vehicle process is similar to the procedure used in the limited data example (Section 5.1) described previously. In this case, however, the HPMS VMT data comes from the source described for VMT in the next section of this example and uses only the long-haul heavy-duty source types.

Input data example:

Table 5.2.4 provides an example of source type population input table.

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[34] http://www.naco.org/Counties/Pages/FindACounty.aspx.

Table 5.2.4   Example Input Table: Source Type Population

yearID	sourceTypeID	sourceTypePopulation
2010	11	49,862
2010	21	1,791,436
2010	31	596,392
2010	32	198,812
2010	41	67
2010	42	535
2010	43	798
2010	51	754
2010	52	39,601
2010	53	689
2010	54	1,240
2010	61	17,455
2010	62	3,422
2040	11	59,760
2040	21	2,147,056
2040	31	714,783
2040	32	238,278
2040	41	86
2040	42	641
2040	43	956
2040	51	904
2040	52	47,462
2040	53	1,050
2040	54	1,557
2040	61	20,920
2040	62	3,334

Alternative sources and methods:

State registration data also could be used to determine the source type populations for heavy-duty vehicle types 41-43, 51, and 54 if available. However, state databases may not always include fleet vehicles (school buses, transit buses, and refuse trucks), and they may not accurately represent the in-state population of long-haul trucks.

5.2.7 VMT by Vehicle Class

Source:

- HPMS VMT data by road type are used for the current year (2010) and combined with Highway Statistics Table VM-4 to allocate VMT among the six HPMS vehicle types. In this example, HPMS VMT data are obtained from Tennessee DOT for Hamilton County, TN. It is the equivalent of using travel demand model output for the base year since HPMS adjustment factors are used for SIP/conformity purposes. The Highway Statistics Table VM-4 was submitted to FHWA by Tennessee DOT and is based on statewide classification count data. The Highway Statistics Excel tool produced as part of as part of this project and made available with this report is used to combine the data, although the steps completed by the tool are described below.

- Travel demand model output data are used for the future year (2040) VMT and combined with Highway Statistics Table VM-4 for 2010 to allocate VMT among the six HPMS vehicle types. In this example, the Chattanooga travel demand model is used to provide VMT by road type for Hamilton County, TN. The Highway Statistics Excel tool was again used to combine the VMT by road type with vehicle classification data by road type.

Year(s):

- The 2010 input is created using 2010 HPMS VMT and the 2010 version of Highway Statistics Table VM-4.

- The 2040 input is created using 2040 travel demand model output and the 2010 version of Highway Statistics Table VM-4.

Source data format:

- HPMS VMT are obtained from TDOT's HPMS reports[35] which are in PDF tabular form with rows for each county in the state and columns for each of the 13 road types. The reports are made available annually.

- Highway Statistics Table VM-4 is in PDF or Excel file tabular form with a separate row for every state. Each state has three percent distributions of VMT by six vehicle types reported that each sum to 100 percent. The columns show the six HPMS vehicle types (motorcycles, passenger trucks, light trucks, buses, single unit trucks, and combination trucks) and three road types (Interstate, other arterials, other).

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[35] Tennessee DOT: 2010 HPMS DVMT Rural and Urban by County.
http://www.tdot.state.tn.us/hpms/.

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Processing steps required:

2010 VMT

Note: Steps 1-4 are the same for the VMT by Vehicle Class MOVES input and Road Type Distribution MOVES input.

1. Convert *annual average daily VMT* provided in the HPMS report to *annual VMT* by multiplying by 365.

2. Aggregate HPMS VMT by the road types found in Highway Statistics VM-4. The TDOT HPMS reports contain 13 road types which must be aggregated into the six road types from Table VM-4. A road type mapping was used similar to that shown in the limited data example VMT by Vehicle Class section.

3. For each of the Table VM-4 road types, multiply the VMT by the percentages found in Table VM-4 for each of the six HPMS vehicle types. This provides 36 VMT numbers (six road types times six vehicle types).

4. Convert to MOVES road types. For each vehicle type sum the "Rural Other Arterial" and "Rural Other" to produce "Rural Unrestricted Access." For each vehicle type sum the "Urban Other Arterial" and "Urban Other" to produce "Urban Unrestricted Access." The restricted access MOVES road types correspond directly to "Interstate System"; therefore, no operations are needed. This provides 24 VMT numbers (four road types times six vehicle types).

5. For each of the six HPMS vehicle types, aggregate VMT over the four MOVES road types. This provides the six VMT numbers required for the VMT by vehicle class input.

6. Adjust the VMT for HPMS vehicle types 20 (passenger car) and 30 (light truck) to redistribute based on MOVES defaults, since vehicle classification counters do not distinguish these vehicle types very well. Obtain MOVES defaults by conducting a national scale run for 2010 that includes activity type ID=1 (distance traveled) source type. Add VMT for HPMS vehicle types 20 and 30 and redistribute based on the MOVES defaults.   Example 4.3.1 in Section 4.0 includes a discussion entitled "Refinement for Passenger Car/Light Truck Split" with numerical examples.

2040 VMT

The same steps used to create the 2010 VMT by vehicle class are followed, except the 2010 HPMS VMT is replaced with 2040 VMT from the travel demand model output adjusted using HPMS adjustment factors. Also, a 2040 MOVES national scale run (instead of 2010) is used to obtain the MOVES default split between HPMS vehicle types 20 and 30.

Input data example:

The resulting sample input files for 2010 and 2040 are shown in Tables 5.2.5 and 5.2.6.

Table 5.2.5   Sample Input File: 2010 VMT

HPMSVtypeID	yearID	HPMSBaseYearVMT	baseYearOffNetVMT
10	2010	24,621,456	
20	2010	1,854,987,441	
30	2010	1,289,081,840	
40	2010	3,464,209	
50	2010	83,286,277	
60	2010	308,810,421	

Table 5.2.6   Sample Input File: 2040 VMT

HPMSVtypeID	yearID	HPMSBaseYearVMT	baseYearOffNetVMT
10	2040	34,209,056	
20	2040	3,033,765,463	
30	2040	1,223,078,784	
40	2040	4,573,924	
50	2040	112,438,862	
60	2040	409,225,979	

Alternative sources and methods:

- VMT output taken directly from the travel demand model could be used in place of HPMS VMT for the current year and in place of HPMS adjusted VMT for the future year. Careful validation of the travel model outputs should be performed by road type if this method is used.

- In areas that have confidence that their vehicle classification counter technology can distinguish HPMS vehicle types 20 (passenger cars) and 30 (light trucks), the adjustments to VMT for these vehicle types based on MOVES defaults could be eliminated.

5.2.8 Road Type Distribution

Source:

- HPMS VMT data by road type are used for the current year (2010) and combined with Highway Statistics Table VM-4 to allocate VMT by the six HPMS vehicle types. In this example, HPMS VMT data is obtained from Tennessee DOT for Hamilton County, TN. It is the equivalent of using travel demand model output for the base year since HPMS adjustment factors are used for SIP/conformity purposes. The Highway Statistics Table VM-4 was submitted to FHWA by Tennessee DOT and is based on statewide

classification count data. The Highway Statistics Excel tool produced as part of this project and made available with this report is used to combine the data, although the steps completed by the tool are described below.

- Travel demand model output data are used for the future year (2040) VMT and combined with Highway Statistics Table VM-4 for 2010 to allocate VMT by the six HPMS vehicle types. In this example, the Chattanooga travel demand model is used to provide VMT by road type for Hamilton County, TN. The Highway Statistics Excel tool was again used to combine the VMT by road type with vehicle classification data by road type.

Year(s):

- The 2010 input is created using 2010 HPMS VMT and the 2010 version of Highway Statistics Table VM-4.

- The 2040 input is created using 2040 travel demand model output and the 2010 version of Highway Statistics Table VM-4.

Source data format:

- HPMS VMT are obtained from TDOT's HPMS reports[36] which are in PDF tabular form with rows for each county in the state and columns for each of the 13 road types. The reports are made available annually.

- Highway Statistics Table VM-4 is in PDF or Excel file tabular form with a separate row for every state. Each state has three percent distributions of VMT by six vehicle types reported that each sum to 100 percent. The columns show the six HPMS vehicle types (motorcycles, passenger trucks, light trucks, buses, single unit trucks, and combination trucks) and three road types (interstate, other arterials, other).

Processing steps required:

2010 Road Type Distribution

Note: Steps 1-4 are the same for the VMT by Vehicle Class MOVES input and Road Type Distribution MOVES input.

1. Convert *annual average daily VMT* provided in the HPMS report to *annual VMT* by multiplying by 365.

2. Aggregate HPMS VMT by the road types found in Highway Statistics VM-4. The TDOT HPMS reports contain 13 road types which must be aggregated into the six

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[36] Tennessee DOT, 2010 HPMS DVMT Rural and Urban by County.
   http://www.tdot.state.tn.us/hpms/

road types from Table VM-4. A road type mapping similar to that shown in the Limited Data example (section 5.1) VMT by Vehicle Class section is used.

3. For each of the Table VM-4 road types, multiply the VMT by the percentages found in Table VM-4 for each of the six HPMS vehicle types. This provides 36 VMT numbers (six road types times six vehicle types).

4. Convert to MOVES road types. For each vehicle type sum the "Rural Other Arterial" and "Rural Other" to produce "Rural Unrestricted Access." For each vehicle type sum the "Urban Other Arterial" and "Urban Other" to produce "Urban Unrestricted Access." The restricted access MOVES road types correspond directly to "Interstate System"; therefore, no operations are needed. This provides 24 VMT numbers (four road types times six vehicle types).

5. Adjust the VMT for HPMS vehicle types 20 (passenger car) and 30 (light truck) to redistribute based on MOVES defaults since vehicle classification counters do not distinguish these vehicle types very well. Obtain MOVES defaults by conducting a 2010 national scale run that includes activity type ID=1 (distance traveled) by road type and source type. Using road type specific VMT numbers from steps 1-4, add VMT for HPMS vehicle type 20 and 30 one road type at a time and then redistribute based on the MOVES default for that split for that road type. The result is still 24 VMT numbers (four road types times six vehicle types), but the eight VMT numbers for HPMS vehicle types 20 and 30 have been adjusted. Example 4.3.1 in Section 4.0 includes a discussion entitled "Refinement for Passenger Car/Light Truck Split" with numerical examples.

6. Calculate the road type distribution for each of the six HPMS vehicle types. For a particular HPMS vehicle type, divide VMT on a single road type y VMT on all four road types. Repeat for each of the four road types to obtain a percent distribution that sums to 100 percent. Repeat for the other five HPMS vehicle types. Apply the same distribution to all MOVES source types within an HPMS vehicle type (the first digit of the MOVES source type codes denotes the HPMS vehicle type). MOVES road type 1 (off-network) is not used; therefore, it appears with zeros in the example table.

2040 Road Type Distribution

The same steps used to create the 2010 road type distribution are followed, except the 2010 HPMS VMT is replaced with 2040 VMT from the travel demand model and a 2040 national scale MOVES run is used to obtain the MOVES default split between HPMS vehicle types 20 and 30.

Input data example:

A portion of the resulting sample input files is shown in Tables 5.2.7 and 5.2.8 for 2010 and 2040. The full input files for all source types can be found in the Examples workbook.

Table 5.2.7 Sample Input File: 2010 Road Type Distribution

sourceTypeID	roadTypeID	roadTypeVMTFraction
11	1	0
11	2	0.054503
11	3	0.083045
11	4	0.220846
11	5	0.641606
21	1	0
21	2	0.007306
21	3	0.049151
21	4	0.349135
21	5	0.594408
31	1	0
31	2	0.007588
31	3	0.053209
31	4	0.346461
31	5	0.592741
32	1	0
32	2	0.007588
32	3	0.053209
32	4	0.346461
32	5	0.592741
…	…	…

Table 5.2.8 Sample Input File: 2040 Road Type Distribution

sourceTypeID	roadTypeID	roadTypeVMTFraction
11	1	0
11	2	0.071552
11	3	0.086922
11	4	0.204158
11	5	0.637368
21	1	0
21	2	0.00989
21	3	0.053321
21	4	0.33095
21	5	0.605839
31	1	0

Table 5.2.8   Sample Input File: 2040 Road Type Distribution (continued)

sourceTypeID	roadTypeID	roadTypeVMTFraction
31	2	0.010266
31	3	0.057692
31	4	0.328236
31	5	0.603806
32	1	0
32	2	0.010266
32	3	0.057692
32	4	0.328236
32	5	0.603806
…	…	…

Alternative sources and methods:

- Classification counts can be used to produce a table for use in place of Highway Statistics Table VM-4. Table VM-4 is derived from classification counts, but there is a multiyear lag before this table becomes available on the Highway Statistics web site. Using classification count data obtained directly from a state or local source also may allow a more detailed calculation method if it provides vehicle type distributions for more than six road types. It also could allow for the selection of count stations from a geographic area more specific than statewide and allow the use of local classification counts that may not be included in the State DOT's submittal to FHWA.

- A simpler method than the one shown in this example would be to use HPMS VMT by road type directly without using Table VM-4 or classification counts. This would produce a single road type distribution that would be used for all MOVES source types.

5.2.9   Temporal Adjustments

Source:

- For the dayVMTFraction and hourVMTFraction input, several months of statewide vehicle classification count data are used. In this example, the data are from 225 classification count locations in Florida obtained from FHWA's Vehicle Travel Information System, which was analyzed and placed into the VTRIS Excel spreadsheet tool developed for this project and made available with this report. This type of information was deemed to be better than what could be obtained from a travel demand model since it is by six vehicle types instead of two, weekends and weekdays instead of just weekdays, and by 24 hours of the day instead of four time periods.

- For the monthVMTFraction input, an entire year's worth of statewide vehicle classification counts covering all four road types are not available for any state from

the 2012 VTRIS data included in the Excel tool. (Not all states report classification data to FHWA.) Therefore, Tennessee DOT's monthly variation factors are used, which are derived from the statewide system of continuous traffic counters. Tennessee DOT normally uses these factors to calculate AADT for coverage count locations with only a few days count data; however, they are also useful to calculate the month VMT fraction input for MOVES since they are based on the same type of underlying data that were not available for a full year from VTRIS.

Year(s):

- The Florida VTRIS data are from September to December 2012 and are used to represent both the current year (2010) and future year (2040).

- The TNDOT data are from the 2008, 2009, and 2010 versions of a table called "5-YEAR-AVERAGE MONTHLY VARIATION FACTORS, BY DAY OF WEEK." Therefore, it can be assumed that the count data behind these tables is from the years 2004 to 2010. They are used to represent both the current year (2010) and future year (2040).

Source data format:

- The VTRIS classification count table is in tabular form in CSV file format. There is a separate row for each combination of station ID, direction of travel, lane, year, month, day, and hour as shown in the table below. There is a total volume column plus 15 columns for volume by FHWA vehicle class (Class 1 and 2 are shown in Table 5.2.9).

Table 5.2.9   Example of Classified Traffic Count Data from VTRIS

Station ID	Direction of Travel	Lane	Year	Month	Day	Hour	Total	Class 1	Class 2
000586	3	3	12	10	21	13	235	4	212
000604	3	1	12	10	21	13	352	8	277
000593	5	1	12	10	21	13	434	0	426
000593	1	3	12	10	21	13	557	0	548

- Tennessee DOT's monthly variation factor sheets are available as Excel files with tables similar to the partial example shown in Table 5.2.10. The variation factors show how much above or below the AADT the volume on a single day can be expected to vary. A factor of 1.00 would indicate that the volume from a single day can be expected to be equal to the AADT. The factors are provided by the seven days of the week, 12 months of the year, and for three area/road types: rural Interstate, rural other, and urban. Since different factors are available for different area/road types, statewide VMT for those area/road types are also obtained to provide the proper weighting. Table 5.2.11 shows an example of this data for rural road types. Urban road types are also available.

Table 5.2.10 Example of Monthly Variation Factors

2008	JAN.	FEB.	MAR.	APR.	…
Rural Interstate					
Sunday	1.32	1.24	1.02	1.01	…
Monday	1.17	1.17	1.08	1.07	…
Tuesday	1.13	1.12	1.04	1.04	…
Wednesday	1.10	1.09	1.00	1.00	…
Thursday	1.08	1.05	0.94	0.94	…
Friday	1.00	0.94	0.82	0.86	…
Saturday	1.22	1.18	0.97	0.99	…
…	…	…	…	…	

Table 5.2.11 Example of VMT Data for Rural Road Types

FUNCTIONAL SYSTEM	DAILY (1000)
Rural Interstate	23,716
Rural Other Freeway	0
Rural Principal Arterial	15,091
Rural Minor Arterial	13,902
Rural Collector	16,400
Rural Local	8,706

Processing steps required:

Day and Hour VMT Fraction

Note: Steps 1-4 were performed already for the VTRIS data analysis described in the NCHRP 25-38 Final Report. If using 2012 data from the VTRIS Excel tool these steps do not need to be performed again. In that case step 5 will be the first step. If analyzing raw classification data from another year of VTRIS data or if analyzing other classification data, such as from a State DOT, all steps below should be completed.

1. Filter the classification data to only use the records with at least the six HPMS vehicle types. For the VTRIS data this meant using only the records with (FHWA Scheme F) 13 classes or greater. While those records with 14 and 15 vehicle classes were selected, the actual reporting for vehicle classes 14 and 15 was not used. These classes represent "not available" or "not applicable."

2. Filter the classification data to only use the records with a complete day of count data. This means that for a particular count station, 24 hours of data on the same day are required to ensure the appropriate data are used to produce the hour VMT fraction input for MOVES. Another filter could be applied to use only records with a complete week of count data (for calculating the day VMT fractions); however, this was not done for the VTRIS analysis. A third filter could be applied to use only records with a complete year of count data (for calculating month VMT fractions). When this filter was applied to the VTRIS data all records were filtered out except for stations on Maine's rural restricted access and rural unrestricted access roadways. These data are not useful for creating the month VMT fraction input since data representative of all road types need to be used (since road type is not a column in the month VMT fraction input).

3. Assign MOVES road types to station IDs by using the roadway functional class of the station.

4. Sum the classified volumes by State, MOVES road type, Year, Month, Day, and Hour. Combine FHWA vehicle classes into the appropriate HPMS vehicle classes as shown in Table 5.2.12

Table 5.2.12   FHWA "Scheme F" to HPMS Vehicle Mapping

FHWA Vehicle Class	Description of Class	HPMS Vehicle Type Code	HPMS Vehicle Type Description
Class1	Motorcycles	10	Motorcycles
Class2	Passenger Cars	20	Passenger Cars
Class3	Other Two-Axle, Four-Tire Single Unit Vehicles	30	Light Trucks
Class4	Buses, passenger-carrying buses with two axles and six tires or three or more axles	40	Buses
Class5	Two-Axle, Six-Tire, Single-Unit Trucks	50	Single Unit Trucks
Class6	Three-Axle Single-Unit Trucks		
Class7	Four or More Axle Single-Unit Trucks		
Class8	Four or Fewer Axle Single-Trailer Trucks	60	Combination Trucks
Class9	Five-Axle Single-Trailer Trucks		
Class10	Six or More Axle Single-Trailer Trucks		
Class11	Five or fewer Axle Multi-Trailer Trucks		
Class12	Six-Axle Multi-Trailer Trucks		
Class13	Seven or More Axle Multi-Trailer Trucks		
Class14	Vendor Defined 1 Typically Unavailable	Not Used	
Class15	Vendor Defined 2 Typically Unclassifiable	Not Used	

Note: If using the VTRIS Excel tool the "12VTRIS HrVOL by FC,State,DOW" tab represents the result of Steps 1-4 and the user can start by working with this tab for Step 5.

5. Convert the date information into the MOVES day ID. Add three columns to the table from the previous step. The first should combine the month, day, and year to create an actual date, such as 4/23/2012. The second column should denote the day of the week (Sunday through Saturday or 1-7). The Excel WEEKDAY function can be used to convert the date into a number from one to seven. The third column should record the MOVES day ID by using an IF statement to mark Sundays (1) and Saturdays (7) as dayID 2 and all other days as dayID 5.

6. Use an Excel pivot table to filter to the appropriate state, arrange the data, and calculate the percent distributions over the 24 hours of the day. For this example, state was placed in the report filter and Florida was selected. MOVES road type, dayID, and Hour were placed in the row labels. Volumes for HPMS vehicle types 10-60 were placed in the values, one column per HPMS vehicle type. The value field settings for each of these were changed to show value as a percent of the parent row total. This converts the volumes for individual hours to a percent of all 24 hours. Each column has 192 rows for the fourMOVES road types, two day types, and 24 hours. Copy and paste each column from the pivot table to the hour VMT Fraction MOVES input table. For HPMS vehicle types with multiple MOVES source types repeat the paste several times. For example, HPMS vehicle type 40 would be pasted three times (for source types 41, 42, and 43).

7. Use an Excel pivot table to filter to the appropriate state, arrange the data, and calculate the percent distributions between weekend and weekday. For this example, state was placed in the report filter and Florida was selected. MOVES road type and Day ID were placed in the row labels. Volumes for HPMS vehicle types 10-60 were placed in the values one column per HPMS vehicle type. The value field settings for each of these were changed to show value as a percent of the parent row total. This converts the volumes for individual day IDs to a percent of volume for the whole week. Each column has eight rows for the four MOVES road types and two day types. These are copied 12 times for the 12 months of the year since the information was not available by month. This produced 96 values in each column. Copy and paste each column to the day VMT Fraction MOVES input table. For HPMS vehicle types with multiple MOVES source types repeat the paste several times. For example, HPMS vehicle type 40 would be pasted three times (for source types 41, 42, and 43).

<u>Month VMT Fraction</u>

1. Calculate the daily VMT associated with each monthly variation factor from the Tennessee DOT table. Three annual average daily VMT values for rural Interstate, rural other, and urban are associated with the three groups of monthly variation factors. The factors are usually multiplied by a specific day's VMT to get annual average daily VMT; however, since the annual average daily VMT is already known, the factors should be divided by the annual average daily VMT to get a specific day VMT.

2. Repeat Step 1 for all years of data. This example has three years of data: 2008 to 2010.

3. Sum the 45 specific weekday VMTs for each month (5 days x 3 area/road types x 3 years of data) and then divide by 15 (5 days x 3 years of data) to get the average

weekday VMT for each month. This results in 12 average weekday VMT numbers, one for each month of the year.

4. Sum the 18 specific weekend day VMTs for each month (2 days x 3 area/road types x 3 years of data) and then divide by 6 (2 days x 3 years of data) to get the average weekend day VMT for each month. This results in 12 average weekend day VMT numbers, one for each month of the year.

5. Calculate the monthly VMT using assumptions from MOVES' internal calculations (the number of weekdays in a month equals 5/7 times the number of days in a month, the number of weekend days in a month equals 2/7 times the number of days in a month). Use the following equation to calculate the monthly VMT for each month of the year using the average weekday VMT and average weekend day VMT from Steps 3 and 4.

$$Monthly\ VMT_i = Avg.\ Weekday\ VMT_i * \frac{5}{7} * D_i + Avg.\ Weekend\ Day\ VMT_i * \frac{2}{7} * D_i$$

Where: D_i = Number of Days in Month i

6. For this example month VMT fractions for 2040 are needed, which is a leap year. Repeat Step 5 using 29 days for February instead of 28.

7. Calculate the month VMT fractions by dividing each monthly VMT by the total VMT for all 12 months. Repeat for the leap set of leap year monthly VMT.

Input data example:

A portion of the resulting sample input files is shown here for hour VMT fraction (Table 5.2.13), day VMT fraction (Table 5.2.14), and month VMT fraction (Table 5.2.15). The future year (2040) inputs are the same as the current year (2010) inputs, except for month VMT fraction which is slightly different for 2040 since it is a leap year. The full input files for all source types can be found in the Examples workbook. Figures 5.2.1, 5.2.2, and 5.2.3 illustrate the hour VMT fraction and day VMT fraction data from the full input files.

Table 5.2.13   Example Input File: Hour VMT Fraction

sourceTypeID	roadTypeID	dayID	hourID	hourVMTFraction
11	2	2	1	0.01384
11	2	2	2	0.009912
11	2	2	3	0.007625
11	2	2	4	0.007856
11	2	2	5	0.008572
11	2	2	6	0.010189
11	2	2	7	0.016404
11	2	2	8	0.025669
11	2	2	9	0.040249
11	2	2	10	0.059379
11	2	2	11	0.076962
11	2	2	12	0.084125
11	2	2	13	0.083639
11	2	2	14	0.08223
11	2	2	15	0.07925
11	2	2	16	0.079619
11	2	2	17	0.073543
11	2	2	18	0.062013
11	2	2	19	0.052009
11	2	2	20	0.038493
11	2	2	21	0.030683
11	2	2	22	0.025623
11	2	2	23	0.017791
11	2	2	24	0.014325
…	…	…	…	…

Figure 5.2.1   Illustration of Weekday Hour VMT Fractions
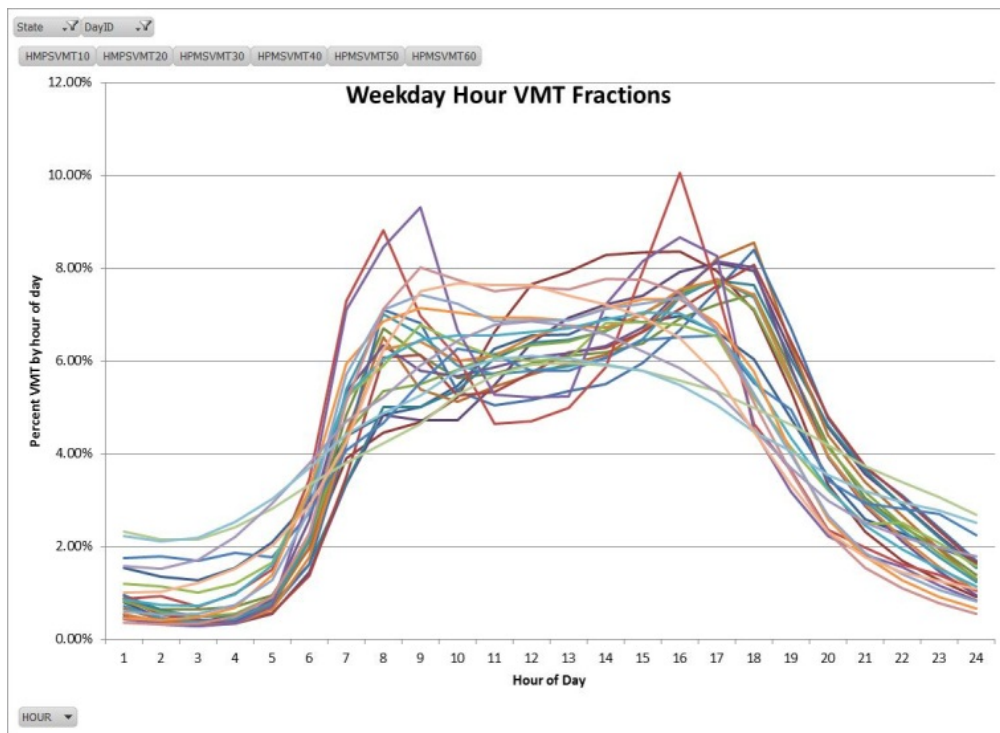
Figure 5.2.2   Illustration of Weekend Hour VMT Fractions
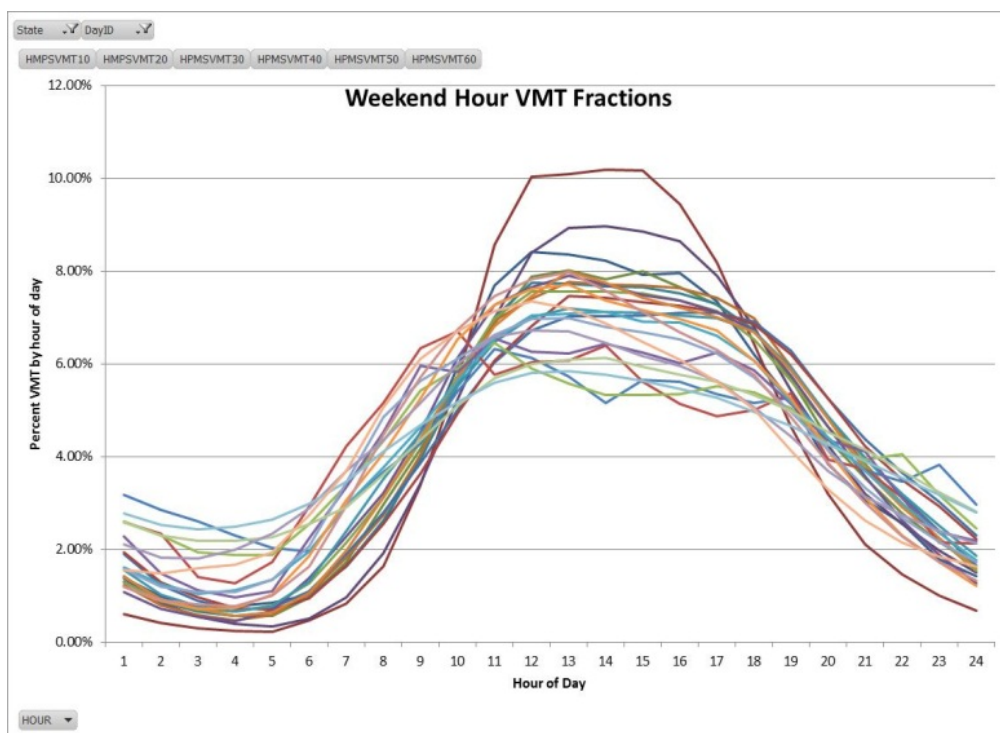
Table 5.2.14   Example Input File: Day VMT Fraction

sourceTypeID	monthID	roadTypeID	dayID	dayVMTFraction
11	1	2	2	0.302633
11	1	2	5	0.697367
11	1	3	2	0.378731
11	1	3	5	0.621269
11	1	4	2	0.284145
11	1	4	5	0.715855
11	1	5	2	0.341116
11	1	5	5	0.658884
…	…	…	…	…

Figure 5.2.3   Illustration of Day Fraction Inputs
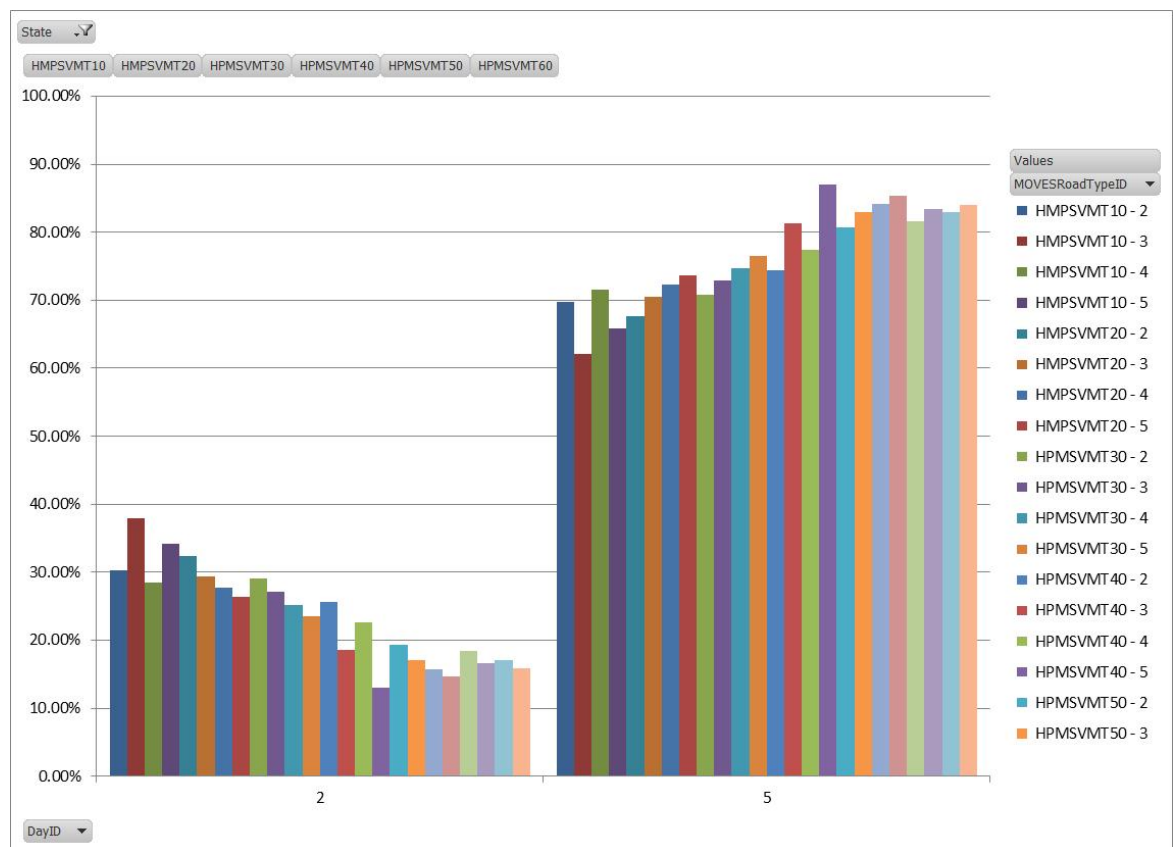
Table 5.2.15   Example Input File: Month VMT Fraction

sourceTypeID	isLeapYear	monthID	monthVMTFraction
11	N	1	0.078509
11	N	2	0.07323
11	N	3	0.085817
11	N	4	0.084137
11	N	5	0.086696
11	N	6	0.085045
11	N	7	0.087363
11	N	8	0.087254
11	N	9	0.082206
11	N	10	0.085959
11	N	11	0.08169
11	N	12	0.082093
…	…	…	…

Alternative sources and methods:

- Travel demand model output combined with MOVES defaults may be used to determine hour VMT fractions. The model output will provide VMT by up to four time periods, and those are broken down into 24-hour VMT fractions using MOVES default hourly distributions within each time period.

- MOVES defaults may be used for month, day, and hour VMT fractions.

5.2.10 Ramp Fraction

Source:

- The information necessary to calculate ramp fraction is obtained from a travel demand model. For this example, the Chattanooga travel demand model data is used.

Year(s):

- The Chattanooga travel demand model output data used in this example is from a 2007 model. It is applied to both the current year (2010) and the future year (2040). If the user has travel demand model output from both a base and future year they could use different information for each year.

Source data format:

- In this example, the MOVES user has a travel demand model with VHT as a field in the table of links. If a field for VHT is not available it could be calculated for each link by dividing VMT by speed (in miles per hour).

Processing steps required:

1. Aggregate VHT from the travel demand model urban/rural ramps and urban/rural restricted access roadways. Table 5.2.16 shows an example of these results from the Chattanooga travel demand model. The AB and BA designations are for separate directions when both directions are modeled on the same link; however, only the total is used to calculate the ramp fraction.

Table 5.2.16   VHT from Travel Demand Model

	Ramp Links			Restricted Access Links			
	AB	BA	Total	AB	BA	Total	Ramp Fraction
Rural Links	724	93	817	24,845	10,747	35,592	2.29%
Urban Links	2,466	481	2,948	52,905	12,633	65,538	4.50%

2. Divide total VHT for rural ramps by total VHT for rural restricted access roadways to obtain the ramp fraction for road type 2. Divide total VHT for urban ramps by total VHT for urban restricted access roadways to obtain the ramp fraction for road type 4. The following calculations use the example numbers from Table 4.6.3:

    Ramp Fraction for MOVES Road Type 2 = 817/35,592 = 2.29%

    Ramp Fraction for MOVES Road Type 4 = 2,948/65,538 = 4.50%

Input data example:

The resulting sample input file is shown in Table 5.2.17.

Table 5.2.17   Example Input File: Ramp Fraction

roadTypeID	rampFraction
2	0.0229
4	0.045

Alternative sources and methods:

- If ramp count information is available it should be used to validate the base-year ramp volumes output by the travel demand model.

- The MOVES default ramp fraction is 8 percent. EPA allows the use of this value in areas without good local data. Some areas have found that their travel demand model data produce a ramp fraction very close to 8 percent so they just use the MOVES default value. High-density urban areas can expect a higher ramp fraction and low-density rural areas can expect a lower ramp fraction.

5.2.11 Average Speed Distribution

Source:

- For weekday speed distributions, travel demand model outputs that are postprocessed to develop speeds by hour of the day are used. In this example, data from the Atlanta travel demand model are used. Local traffic counts are used to proportion VMT from the four model time periods into 24 hours of the day.

- For weekends, travel demand model output specific to weekend conditions is not available. Speed monitoring data could be used if available, or data from representative weekday modeled time periods could be used. In this example, the modeled weekday midday speed distribution is repeated for the weekend.

Year(s):

- The Atlanta travel demand model output data used in this example is from a 2010 model. It is applied to both the current year (2010) and the future year (2040). If the user has travel demand model output from both a base and future year they could use different information for each year.

Source data format:

- In this example, the MOVES user has a travel demand model with VMT, speed, and capacity as fields in the table of links. A simple example is shown in Table 5.2.18 with three links for the a.m. peak period. The first two columns show the start and end nodes for each link. Facility type is a local classification that was recoded into MOVES road type (4 = urban restricted). A.M. VMT is the morning peak period VMT on that link. Freeflow (FF) speed and capacity (in vehicles per lane per hour or vplph) are attributes of the link or facility type. Number of lanes is an attribute of the link. "Cong. speed" is the congested speed initially calculated by the model. Similar data are available for three other time periods (midday, p.m. peak, and overnight), for all links in the network.

- The user also has a table of hour VMT fractions (Table 5.2.19), which can be obtained as described in the "Temporal Adjustments" section.

-

Table 5.2.18   Example of Travel Demand Model Data

A Node	B Node	Facility Type	MOVES Road Type	A.M. VMT	Length (mi)	FF Speed (mph)	Capacity (vplph)	Lanes	Cong. Speed (mph)
23120	23488	75	4	8754	0.35	65	2000	2	44.74
23488	23911	75	4	7111	0.27	65	2000	2	47.84
23911	23953	71	4	14256	0.24	65	2000	3	43.25

Table 5.2.19   Example Data for Hour VMT Adjustments

Hour	VMT Fraction
1	0.009862
…	…
7	0.045957
8	0.069644
9	0.060828
10	0.050286
11	0.049935
…	…
24	0.017907

Processing steps required:

1. For each link in the network, determine the volume for each hour of the day based on the time period volumes produced by the model and the fraction of VMT by hour from the local traffic counts.   In this example, the volume on the first link in Table 5.2.18 (8754 vehicles) is divided among the three hours corresponding to the a.m. time period using the VMT fractions shown in Table 5.2.19. For example:

    VMT (hr 8) = 8754 * (0.069644/(0.069644 + 0.060828 + 0.050286)) = 8754 * 0.385 = 3373

2. Compute free-flow travel time for each link by dividing link length by the free-flow speed coded in the model's highway network. For example: $t_0 = 0.35$ mi $/ 65$ mi/hr $= 0.005385$ hrs.

3. Compute the congested travel time for each link and hour using the BPR volume delay function shown in equation (1).

$$t_c = t_0 \left(1 + \alpha \left(\tfrac{V}{C}\right)^{\beta}\right) \tag{1}$$

Where:

t_c = Congested travel time

t_0 = Free-flow travel time

α, β = Constants (coded in the model or a lookup table by facility type; in this example, $\alpha=0.45$ and $\beta=6.75$ are used as the freeway coefficients from the Jacksonville model)

V = Hourly traffic flow

C = Hourly capacity

For example:

$$t_c = 0.005385 \left(1 + 0.45 \left(\tfrac{3353}{4000}\right)^{6.75}\right) = 0.006151 \tag{1}$$

4. Compute the congested travel speed (S_c) by dividing link length by the congested travel time. For example: S_c = 0.35 mi / 0.006151 hr = 56.90 mph.

5. Assign the link/hour to a MOVES speed bin based on the congested speed. For example, 56.90 mph falls in speed bin 12 (52.5-57.5 mph).

6. Compute vehicle-hours of travel (VHT) = VMT/congested speed. For example: VHT = 3373 / 56.90 mph = 44.46 hrs. The various intermediate values from steps 2 to 6 are shown in Table 5.2.20.

Table 5.2.20 Sample Link Speed Calculation Data

A Node	B Node	Hour ID	Hour VMT	t_0 = Free-Flow TT (hrs)	t_c = Cong. TT (hrs)	Cong. Speed (mph)	Speed Bin	VHT
23120	23488	8	3373	0.005385	0.006151	56.90	12	44.46
23120	23488	9	2946	0.005385	0.005692	61.49	13	41.14
23120	23488	10	2435	0.005385	0.005470	63.99	14	39.54
23488	23911	8	2740	0.004154	0.004299	62.80	14	40.28
23488	23911	9	2393	0.004154	0.004212	64.10	14	39.47
23488	23911	10	1978	0.004154	0.004170	64.75	14	39.07
23911	23953	8	5493	0.003692	0.004608	52.09	11	48.57
23911	23953	9	4797	0.003692	0.004059	59.12	13	42.79
23911	23953	10	3966	0.003692	0.003794	63.26	14	39.99

7. For each hour, calculate the average speed distribution across all links. To do this, for each speed bin, sum the total VHT for the links in that speed bin and divide by total VHT across all links. In the simple example shown above, for hour 8, the speed fractions are as follows:

avgSpeedFraction (bin 11) = 48.57 / (44.46 + 40.28 + 48.57) = 0.3643

avgSpeedFraction (bin 12) = 44.46 / (44.46 + 40.28 + 48.57) = 0.3335

avgSpeedFraction (bin 14) = 40.28 / (44.46 + 40.28 + 48.57) = 0.3022

Speed fractions for all other bins for hour 8 are zero.

Input data example:

Table 5.2.21 shows the resulting example speed distribution for passenger cars, on urban freeways, for the 7:00-8:00 a.m. weekday time period. The same distribution would be repeated for all 13 source types, since separate speed information is not available by source type. Different distributions would be computed for each hour. Also, different distributions would be computed for each road type using the links associated with that road type. Unless a local source of monitored speed data is available, weekday speed distributions from appropriate hour(s) of the model (dayID = 5) could be used to represent weekend speed distributions (dayID = 2).

Table 5.2.21   Example Input File: Average Speed Distribution

sourceTypeID	roadTypeID	hourDayID	avgSpeedBinID	avgSpeedFraction
21	4	85	1	0
21	4	85	2	0
21	4	85	3	0
21	4	85	4	0
21	4	85	5	0
21	4	85	6	0
21	4	85	7	0
21	4	85	8	0
21	4	85	9	0
21	4	85	10	0
21	4	85	11	0.3643
21	4	85	12	0.3335
21	4	85	13	0
21	4	85	14	0.3022
21	4	85	15	0
21	4	85	16	0

Alternative sources and methods:

- Observed speed monitoring data, for example from an ITS archive or a private source, could be used to directly develop speed distributions. The data may come in different formats. If acquired from a private vendor, it is likely to be in the form of average speed by link by hour of the day (and possibly day of week). In this case, the links need to be associated with a traffic volume so that they can be weighted appropriately. If from an ITS archive, it is likely to be in 5- or 15-minute time intervals by link and must be aggregated to the hourly level and across days of the year. See Section 4.7 of this document as well as Section 7.0 of the Final Report for a discussion of some of the issues associated in working with speed data.

- Alternative volume-delay functions or coefficients also could be used to postprocess model output. See Section 4.7 for a discussion of methods.

5.2.12 Meteorology Data

For this example, the Meteorology input will use the same data as was generated for the Limited Data case (Example 5.1). This was taken from the NCDC data for Detroit/Wayne County airport in Michigan.

5.2.13 I/M Programs

For this example, the I/M inputs will use the same data as were generated for the Limited Data case (Example 5.1). This was based on data for Hartford County, CT.

5.2.14 Fuel Formulation and Supply

Source:

- Fuel information will be taken from the results of a fuel sampling study undertaken by the Texas Council on Environmental Quality (TCEQ) in 2011. This sampling was performed in order to improve inputs to various air quality models, including MOVES, by surveying actual public sources of fuels. The data are available by open records requests to TCEQ (www.tceq.state.tx.us).

Year(s):

- The survey was conducted in June, 2011, and these data are used for the 2010 estimate. Because the fuel surveys do not include any projections or estimations of future fuel properties, the same data will be used for 2040 as well.

Source data format:

- The data are available in spreadsheet form, with separate Fuel Supply and Fuel Formulation tabs that are ready to be loaded into the CDM.

Processing steps required:

The steps required to convert fuel survey data into MOVES inputs are described in Section 4.9. By using the open records request at the TCEQ web site, it is not necessary for the user to perform all those tasks again. The user should request the electronically submitted attachments to the report entitled *Sampling and Laboratory Analysis of Retail Gasoline and Diesel Fuel for Selected Texas Cities – Summer 2011.*

1. The relevant data will be in the Fuel Supply and Fuel Formulation tabs. The user can filter the data down to only a single county, if desired, though MOVES will only use the needed data if multiple counties are present.

2. Change or filter the years as appropriate so that the fuel is appropriate for the modeled years.

3. Change or filter monthgroupID to reflect modeled months, so that fuel is considered appropriate for the modeled months.

Input data example:

The fuel supply for Harris county (countyID 48201), as extracted from the TCEQ data, appears in Table 5.1.22.

Table 5.2.22 Sample Input Table: Fuel Supply

countyID	fuelYearID	monthGroupID	fuelFormulationID	marketShare	marketshareCV
48201	2010	5	20300	1	0.5
48201	2010	5	4062	1	0.5
48201	2040	5	20300	1	0.5
48201	2040	5	4062	1	0.5

The fuel formulationID tab must reflect the fuelformulationIDs represented in the fuel supply table. For this example, those IDs are 20300 and 4062. The fuelformulationIDs for this example are presented in Table 5.1.23. Note that the fuel formulation table differs between MOVES 2010a and 2010b. For 2010b, the table includes T50 and T90, which are different measures of fuel evaporative characteristics that override the values listed for E200 and E300. Because MOVES will only use one or the other pair of values, the user needs only to enter one set of values or the other depending on the available data, with zeros entered in the for the unused columns.

Table 5.2.23   Sample Input Table: Fuel Formulation

fuelFormulationID	fuelSubtypeID	RVP	sulfurLevel	ETOHVolume	MTBEVolume	ETBEVolume	TAMEVolume	aromaticContent	olefinContent	benzeneContent	e200	e300	BioDieselEsterVolume	CetaneIndex	CetaneIndex	T50	T90
20300	20	0	6.043	0	0	0	0	34.075	2.39	0	0	0	0	0	0	218	329
4062	11	7	24.7	8.85	0	0	0	22.136	10.61	0.62	0	0	0	0	0	199.8	329.4

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7.0 List of Acronyms

AADT	Average annual daily traffic
AADVMT	Annual average daily vehicle miles of travel
AEO	Annual Energy Outlook
ALPR	Automatic license plate recorder
ATR	Automated traffic recorders
AVI	Automatic vehicle identification
BPR	Bureau of Public Roads
CDM	County Data Manager
CO	Carbon monoxide
CRC	Coordinating Research Council
CT	Combination truck
DOE	Department of Energy
DOT	Department of Transportation
EPA	Environmental Protection Agency
ERG	Eastern Research Group
EVR	Electronic Vehicle Registration
FAF	Freight Analysis Framework
FHWA	Federal Highway Administration
FIPS	Federal Information Processing Standards
FMCSA	Federal Motor Carrier Safety Administration
FTA	Federal Transit Administration
GHG	Greenhouse gas
GIS	Geographic information systems
GPS	Global positioning systems
GUI	Graphical user interface
GVWR	Gross vehicle weight rating
HCM	Highway Capacity Manual
HDT	Heavy-duty truck
HERS	Highway Economic Requirements System
HIVIS	Highway Visibility System
HPMS	Highway Performance Monitoring System

I/M	Inspection and maintenance
ITS	Intelligent transportation systems
LCD	Local climatological data
LDT	Light-duty truck
LOS	Level of service
MAR	Mileage accumulation rate
MCMIS	Motor Carrier Management Information System
MOVES	Motor Vehicle Emission Simulator Model
MPO	Metropolitan Planning Organization
NCDC	National Climatic Data Center
NCHRP	National Cooperative Highway Research Program
NEI	National Emissions Inventory
NMIM	National Mobile Inventory Model
NOx	Oxides of nitrogen
NTD	National Transit Database
OBD	On-board diagnostics
PC	Passenger car
PM	Particulate matter
RFG	Reformulated gasoline
RFID	Radio frequency identification
RMSE	Root mean square error
RSD	Remote sensing device
RVP	Reid vapor pressure
SIP	State Implementation Plan
TCEQ	Texas Council on Environmental Quality
TDFM	Travel demand forecasting model
TRB	Transportation Research Board
TTI	Texas Transportation Institute
v/c	Volume-to-capacity
VDF	Volume-delay function
VHT	Vehicle-hours traveled
VIN	Vehicle Identification Number
VIUS	Vehicle Inventory and Use Survey
VMT	Vehicle miles of travel
VTRIS	Vehicle Travel Information System
WIM	Weigh-in-motion