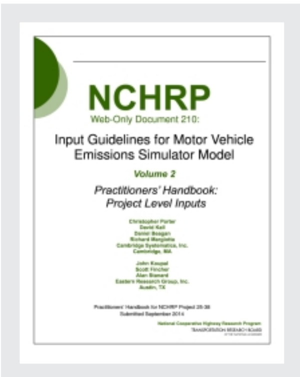

Input Guidelines for Motor Vehicle Emissions Simulator Model, Volume 2: Practitioners' Handbook: Project Level Inputs

DETAILS

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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, or 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 MOVES2010b 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, greenhouse gas (GHG) analysis, and particulate matter (PM) 2.5 and carbon monoxide (CO) hot-spot analysis;[2] and
- Data processing tools, such as MOBILE6 to MOVES data converters, already developed by EPA. These are available on EPA's web site.[3]

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

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[1] The most recent version at the time of preparation of this document 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 versions of the PM and CO guidance at the time of preparation of this document were: U.S. Environmental Protection Agency (2013). *Transportation Conformity Guidance for Quantitative Hot-Spot Analyses in PM2.5 and PM10 Nonattainment and Maintenance Areas.* EPA-420-B-13-053; and, *U.S. Environmental Protection Agency (2010). Using MOVES in Project-Level Carbon Monoxide Analyses. EPA-420-B-10-041.* These documents are referred to as "PM Hot-Spot Analysis Guidance" and "CO Analysis Guidance," respectively, throughout this report.

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

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 on 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 an example illustrating the development of a complete set of MOVES inputs for project-level application.

- **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 **Project 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 four categories: 1) fleet inputs (characteristics of the vehicle fleet); 2) link-level inputs (vehicle activity and geometry); 3) off-network characteristics (vehicle activity); and 4) "other" inputs including meteorology, fuels, and emissions control programs.

Table 2.1 MOVES Project-Level Inputs

Category	No.	MOVES Input	MOVES Input Table	Description	EPA Guidance
Fleet	1	Age distribution by vehicle class	sourceTypeAgeDistribution	Fraction of vehicle population by age (years) for 13 source types	Recommends latest state or local age distribution assumptions from SIP or conformity regional analysis, or project-specific data for a project serving a fleet operating only locally
	2	Source (vehicle) type population	SourceTypeHourFraction	Fraction of vehicle-hours of travel by 13 source types, for each link	Project-specific data, or consistent with regional source type fractions for the project road type, if traffic on road is determined to be similar to regional mix
Link	3	Traffic volume	Link	Total traffic volume for analysis period, for each link	Project-specific data
	4	a. Operating mode distributions OR b. Drive cycles OR c. Average speeds	opModeDistribution driveScheduleSecondLink	a. Percent of time spent in each operating mode bin, by link b. Speed and acceleration by one-second time slice, by link c. Average speed, by link	Drive schedules or operating mode distributions from field surveys or modeling are preferred if available
	5	Link length	Link	Length of each link (miles)	Not specified
	6	Grade	Link	Average grade of each link (percent)	Not specified
Off-Network	7	Source type population	offNetwork	Fraction of vehicle population using facility by 13 source types	Data from existing project documentation and/or similar projects
	8	Start fraction	offNetwork	Fraction of total vehicles that start in each hour of the day	
	9	Extended idle fraction	offNetwork	Fraction of time spent in extended idle mode by hour (long-haul combo trucks)	
	10	Parked fraction	offNetwork	Fraction of time vehicles spend parked in an hour	
Other	1	Weather – meteorology data	zoneMonthHour	Ambient temperature and relative humidity for each hour in the modeling scenario	Consistent with data used in SIP and conformity analysis and dispersion modeling
	2	Inspection and maintenance programs	IMCoverage ComplianceFactor	Various data describing local I/M program characteristics	Recommends review of default data, and substitution of local data if more accurate or recent data are available
	3	Fuel formulation and supply	fuelFormulation fuelSupply	Various data describing local fuel supply	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),[4] EPA staff,[5] and the Coordinating Research Council (CRC),[6] 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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[4] 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.

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

[6] 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	NO_x	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	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%)
Project-Level Inputs						
Project-Level Link Activity	Volpe/FHWA		TBD			
Off-Network Data	Volpe/FHWA		TBD			

Table 3.2 Combined Sensitivity Analysis Results (continued)

MOVES Input	Source[a]	Base Case	Comparison Made	VOC	NO_x	PM
Project-Level Inputs (continued)						
Link Characteristics: Grade	CS/ERG	0% Grade, Urban Restricted and Unrestricted Road Types, 30 mph	-6%, -4%, -2%, +2%, +4%, +6% grade	2%: Substantial (-15% to +22%) 6%: Substantial to very substantial (-36% to +92%)	2%: Substantial (-26% to +33%) 6%: Substantial to very substantial (-58% to +118%)	2%: Substantial (-27% to +41%) 6%: Very substantial (-55% to +175%)
Link Source Types (Hour Fraction)			TBD			
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% (NO_x 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%)
	EPA	75º F	-40º F to 120º F in 10º increments; Calendar years 2005, 2015, and 2025	Very substantial for 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 percent; Moderate = 5-15 percent; Substantial = 15-50 percent; Very Substantial = >50 percent.

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 project-level analysis. The inputs and their respective section numbers are shown below:

1. Age distribution;
2. Link source types;
3. Link characteristics: traffic volumes;
4. Link characteristics: length and grade;
5. Link characteristics: average speed;
6. Operating mode distributions and drive schedules;
7. Off-network data;
8. Meteorology;
9. Fuel formulation and supply; and
10. Inspection and maintenance programs.

For each input, the following information is provided:

- Description and format;
- Source of data embedded in MOVES;
- Data sources, procedures, and methods;
- Sample data and tools; and
- Examples.

For some inputs, including meteorology, inspection and maintenance (I/M) programs, fuels, and most likely age distribution, MOVES users will use the same data developed for MOVES application at a regional scale. These inputs are also discussed in Volume 1 of this handbook, but the discussion is repeated here for ease of reference.

Overview of Project-Scale Inputs

The data tables listed in Table 4.0.1 are populated through the Project Data Manager (PDM) for project-scale analysis. Whether populated tables are required or optional are noted, as this depends on the project definition and approach. The corresponding section(s) in which the input is discussed is noted in the last column of the table.

Table 4.0.1 Project-Scale Analysis Inputs

Table Name	Description	Required?	Unique to Project Scale?	Section in This Report
link	Defines on-network links and activity	Yes	Yes	3, 4, 5
linkSourceTypeHour	Source type fractions	Yes	Yes	2
offNetworkLink	Defines off-network links and activity	Only for off-network	Yes	6
sourceTypeAgeDistribution	Age distribution	Yes	No	1
opModeDistribution	Distribution of activity by operating modes	Only for off-network	Yes	6
driveScheduleSecondLink	Vehicle trajectory	No	Yes	6
fuelFormulation	Fuel properties	Yes	No	9
fuelSupply	Market share of fuels	Yes	No	9
avft	Diesel sales fractions	No	No	9
imCoverage	I/M program parameters	Only with I/M Program	No	10
zoneMonthHour	Meteorology	Yes	No	8

"Link" is a project-scale input table that allows the MOVES user to define characteristics of individual links. A link is a segment of road or an "off-network" location on which a common type of vehicle activity occurs. EPA CO and PM Hot-Spot Analysis Guidance recommends using data from project documentation for these inputs. The guidance also provides information on how to define links for the purposes of emissions modeling. Links may be running links consisting of roadway, ramp, or intersection segments, or they may be off-network (with starts and extended idling). Links can be defined as subsections of physical road segments to capture unique operation (e.g., cruise, acceleration, deceleration and idle), and traffic direction. If a drive cycle is defined, a roadway link must include at least three seconds of vehicle operation.

A link input table consists of the following elements:

- LinkID: Each link in the project must be entered;
- CountyID: Five-digit code;
- ZoneID: County ID with zero at the end;
- RoadTypeID: Each link is associated with a MOVES road type;

- Link Length: Distance in miles;
- Link Volume: Total traffic volume in one hour;
- Link Average Speed: Speed in mph;
- Link Description: Optional text field; and
- Link Grade: Grade in percent grade (100 percent = 45 degree slope).

An example data table of link characteristics is shown in Table 4.0.2. Note that link 5 represents an idling vehicle link as the average speed is zero.

Table 4.0.2 Example of Link Input Characteristics

linkID	countyID	zoneID	roadTypeID	linkLength	linkVolume	linkAvgSpeed	linkDescription	linkAvgGrade
1	26161	261610	5	0.5	1,000	25		0
2	26161	261610	5	0.5	800	35		0
3	26161	261610	5	0.25	400	15		0
4	26161	261610	5	0.25	200	15		0
5	26161	261610	1	0	800	0		0

As an alternative to providing average speed, an operating mode distribution or vehicle drive cycles (schedules) can be provided. For project-level analysis, providing this finer level of detail can improve the resolution of model output, particularly when assessing the impact of a project on traffic flow. EPA guidance provides several potential data sources for operating mode distribution or drive schedules, including instrumented vehicles or traffic microsimulation models. The user chooses an activity approach based on needed level of resolution and available data, and puts the data in the appropriate table. Entries for average speed always needs to be provided even if operating mode distributions or drive cycles are used, although the average speed data are not used in such cases.

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 have also 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 can also 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 increasingly 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 (see Volume 1, Section 4.1.1 of this resource document). For project-scale runs, MOVES does not calculate travel fraction; age distribution is used directly to apportion activity within the project domain. This is an important distinction when considering different sources of data for age distribution, and at what scale the data would be applied. While age distribution characterizes the distribution of all vehicles in an area, travel fraction characterizes the distribution of vehicles (or probability) observed on the road. Data sources based on roadside observation can therefore be applied for project-scale analysis, but would require adjustment to be used to characterize age distribution at the county scale.

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);
- PM Hot-Spot Analysis Guidance: Section 4.5.2, Age Distribution (p. 43);
- CO Analysis Guidance: Section 2.4.2, Age Distribution (p. 22); 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.

For MOVES2010, EPA generated base year age distributions by source type from multiple data sources, making updates 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. 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** contains information on transit buses collected by the Federal Transit Administration 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 on-line at SchoolBusFleet.com.

EPA guidance CO and PM hot-spot analysis suggests three options for age distribution data:

1. The latest state or local age distribution assumptions from SIP or conformity regional analysis;

2. Project-specific fleet age distribution data for a project serving a fleet operating only locally, such as a drayage yard or bus terminal; or

3. The MOVES default distribution if no state or local distribution is available.

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

Table 4.1.2 Sources of Embedded Data (continued)

SourceType	MOVES2010 (1999 Base Year)	MOVES2014 (2011 Base Year)
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

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.[7]

4.1.3 Data Sources, Procedures, and Methods

Although local registration data are the recommended state-of-the-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 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.

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

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 through 2050.	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 pre-processing 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 HPMS types. Vehicle Identification Number (VIN) decoding software can also be used in conjunction with the registration database to derive vehicle type and model year (other information can also 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 SUVs or crossover vehicles. Nonpassenger trucks may be classified by body style, truck purpose, or gross vehicle weight, and each has the potential for mis-categorization 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 sport-utility vehicles 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 mis-categorization, 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 are also mapped based on weight. No mapping is 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 <= 8,500 pounds GVWR
Single-unit Truck (52,53)	Diesel > 8,500, Diesel > 10,000, Diesel > 14,000, Diesel > 16,000
Combination Truck (61,62)	Diesel > 19,500, Diesel > 26,000, Diesel > 33,000, Diesel > 60,000

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 half of the vehicles were registered in the area. Of the remaining vehicles, about 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 can also 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 programs maintain a detailed database 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.

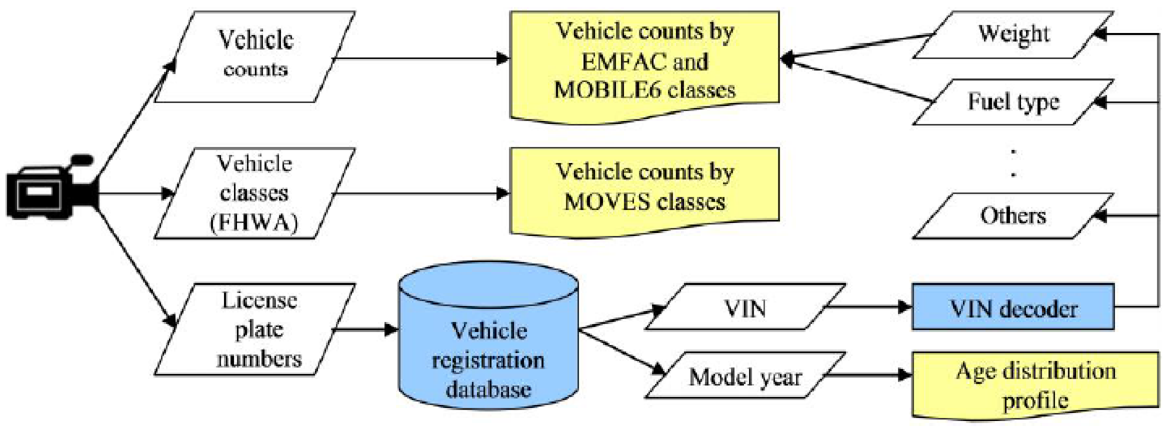
4.1.3.3 Fleet Databases

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 are also 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 Federal Transit Administration (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 registration 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 registration databases from corresponding states to determine vehicle classifications and model years, which can translate to MOVES inputs for vehicle population mix and age distribution. As with any use of the registration database, VIN decoding software can also be used in conjunction with ALPR systems to help derive vehicle type and model year. This process is shown in the diagram in Figure 4.1.1. 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 4.1.1 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. Such an approach would be suitable for project-scale analysis. 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.

4.1.3.5 *Electronic Vehicle Registration*

Several areas in the U.S. now use electric 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.

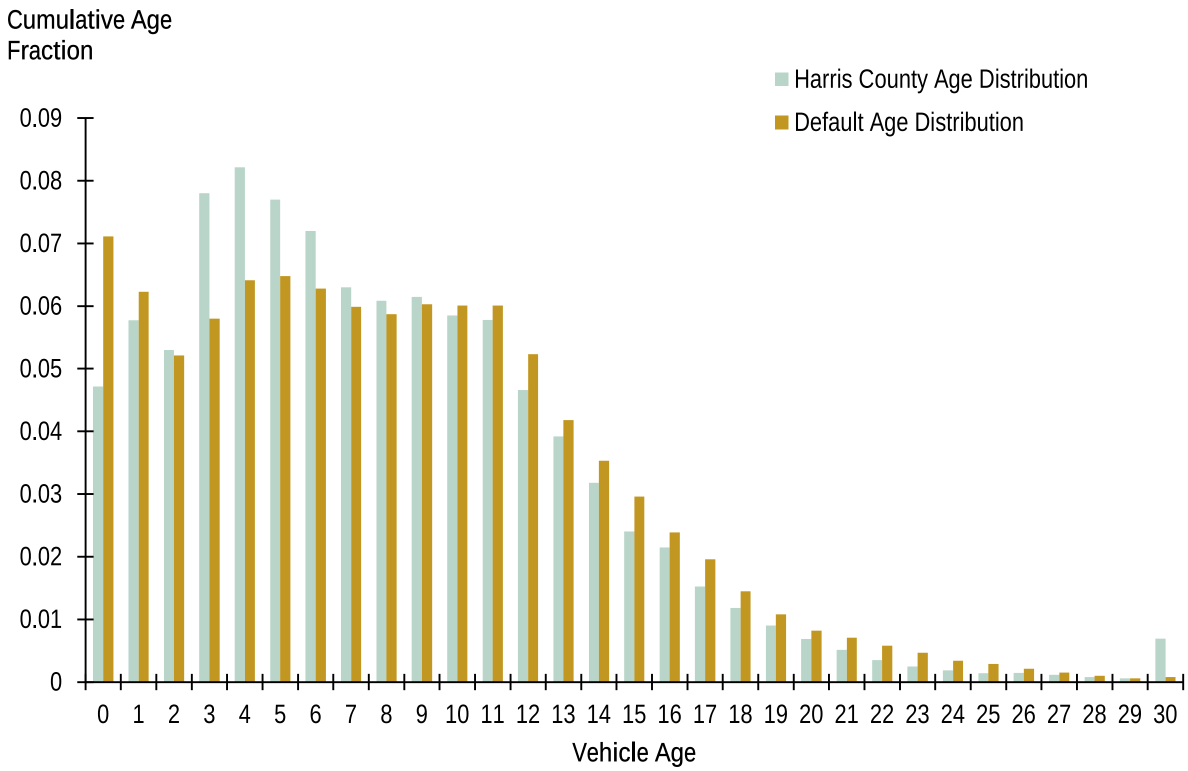
4.1.4 Sample Data and Tools

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 NMIM and convert them to the appropriate age distribution input tables for MOVES. These converters are available at http://www.epa.gov/otaq/models/moves/tools.htm.

An example of age distribution data developed for MOVES is shown in Figure 4.1.2 for Harris County, Texas for Passenger Cars (Source Type 21). These data were developed for the Texas Commission on Air Quality (TCEQ) 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 4.1.4 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 4.1.2 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 4.1.6 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 4.1.3 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 4.1.4 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 4.1.3 Distribution of States Observed on Los Angeles Interstate Highways

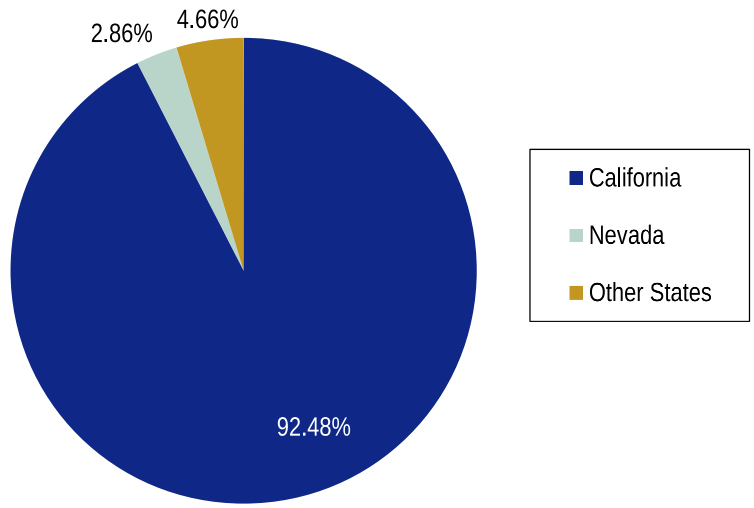
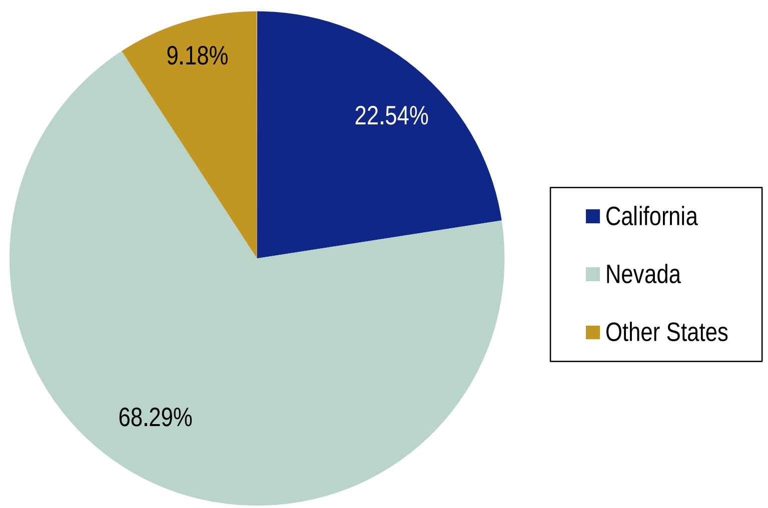


Figure 4.1.4 Distribution of States Observed on Las Vegas Interstate Highways



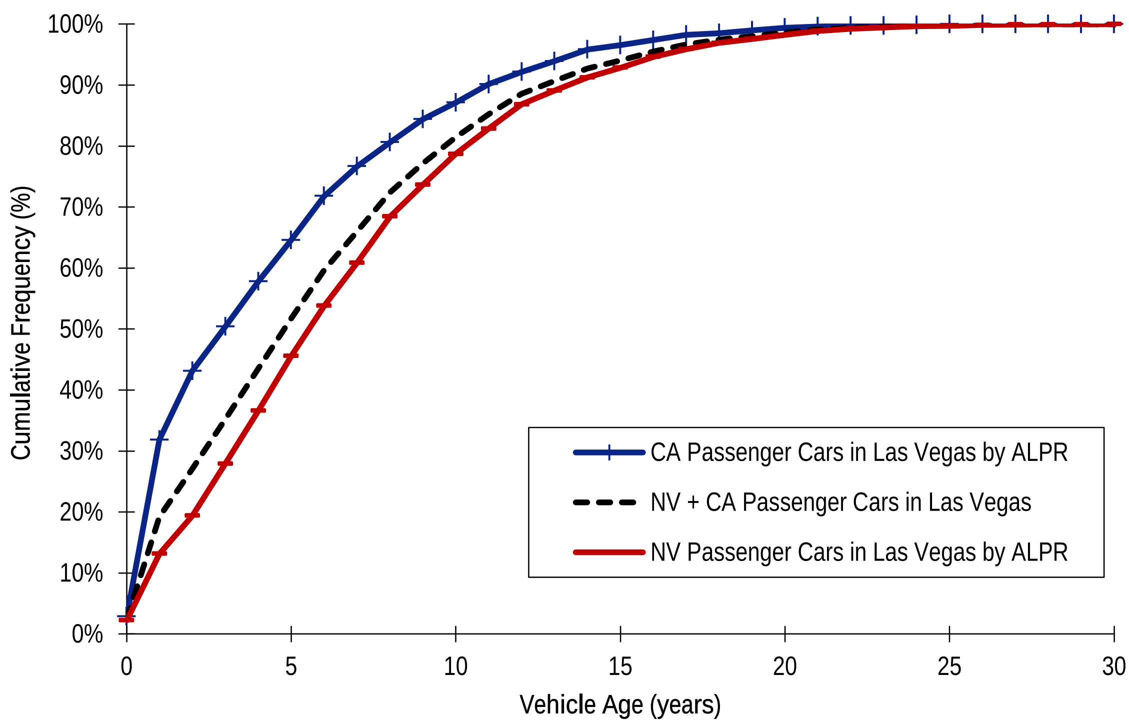
The plate numbers of California and Nevada license plates were submitted to their respective states to provide model years and other information on the individual vehicles that were videoed. Based on that information, the age distributions of the different MOVES vehicle classes were obtained for the California and Nevada vehicles in the Los Angeles and Las Vegas datasets. Figure 4.1.5 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.

These data can be used directly to develop a composite Nevada and California vehicle age distribution for project-scale analysis. The fleet observed through ALPR is a direct representation of the fleet on the road at a particular location and time, which is what project scale is meant to represent. The composite age fractions for each age can be calculated as follows:

$$\text{Age Fraction}_{\text{age } x} = (\text{NV Vehicles}_{\text{age } x} + \text{CA Vehicles}_{\text{age } x})/(\text{Total NV+CA Vehicles})$$

Figure 4.1.5 also shows the resulting age distribution (cumulative) as the black dashed curve. This age distribution can be used directly for project-scale analysis, reflecting the influence of the California vehicles on age distribution for this roadway in Clark County.

Figure 4.1.5 Age Distributions of Passenger Cars Observed on Las Vegas Interstate Highways on Weekdays



4.2 Link Source Type

4.2.1 Description and Format

Link source type (also referred to as project-level fleet mix) is a project-scale input that represents the percentage of vehicle hours traveled by each of the 13 MOVES source types (vehicle types) on a particular link. The SourceTypeHourFraction field refers to the vehicle mix, expressed as fractions of vehicle *hours* traveled, on each link.

A link input table consists of the following elements:

- LinkID: This field must include all LinkIDs defined in the Links input.
- SourceType: Refers to the 13 MOVES source types, which are defined as follows:
  - 11 – Motorcycle
  - 21 – Passenger Car
  - 31 – Passenger Truck
  - 32 – Light Commercial Truck
  - 41 – Intercity Bus
  - 42 – Transit Bus
  - 43 – School Bus
  - 51 – Refuse Truck
  - 52 – Single Unit Short-Haul Truck
  - 53 – Single Unit Long-Haul Truck
  - 54 – Motor Home
  - 61 – Combination Short-Haul Truck
  - 62 – Combination Long-Haul Truck
- SourceTypeHourFraction: Refers to the vehicle mix (fraction of vehicle hours traveled) on each link. SourceTypeHourFraction must sum to one across all source types for each LinkID.

If the user enters data for source types which are not selected in the Runspec, MOVES will ignore that data. The project-level calculator will not renormalize the fractions to omit the contribution of source types which are not selected in the Runspec.

An example link source type table is shown in Table 4.2.1.

Table 4.2.1 Example of Link Source Type Input

linkID	sourceTypeID	sourceTypeHourFraction
1	11	0.0053
1	21	0.5442
1	31	0.2832
1	32	0.0946
1	41	0.0009
1	42	0.0003
1	43	0.0010
1	51	0.0006
1	52	0.0218
1	53	0.0037
1	54	0.0013
1	61	0.0163
1	62	0.0267
2	11	0.0053
2	21	Etc.

4.2.2 Source of Embedded Data and EPA Guidance

No defaults are available for this input. The following EPA guidance documents are relevant to defining user-specified input:

- MOVES2010b User Guide: Section 2.3.3.4.12, Link Source Types Importer;
- PM Hot-Spot Analysis Guidance: Section 4.5.5, Link Source Type; and
- CO Analysis Guidance: Section 2.4.5, Link Source Type.

The PM and CO Analysis Guidance note two sources for link source type hour fractions:

- For projects that will have an entirely different source type distribution than that of the regional fleet, the preferred option is for the user to collect project-specific data.
- If the project traffic data suggests that the source type distribution for the project can be represented by the distribution of the regional fleet for a given road type, the user can provide a source type distribution consistent with the road type used in the latest regional emissions analysis.

4.2.3 Data Sources, Procedures, and Methods

Classified traffic counts at the project location are a preferred basis for estimating link source types, but they will typically need to be broken out further (using state registration data, MOVES embedded data, or another source) to get to the 13 source types required by MOVES. At a minimum, it is important to consider local splits of light versus heavy vehicles. Project-specific data from similar projects may be used as an alternative or supplemental source, if the traffic mix is believed to be similar. Alternatively, distributions from regional emissions modeling performed for SIP/conformity analysis may be used if project-specific data are unavailable, although population fractions should be converted to activity (vehicle-hours of travel) fractions. The various local source type data options are summarized in Table 4.2.2.

Table 4.2.2 Overview of Data Sources for Link Source Type Options

Data Source or Procedure	Current Use	Uses and Advantages	Limitations
State/regional source type mix	Common	Readily available estimate for source types.	Limited accuracy since estimates would not be based on usage (VHT), would not account for out-of-area or unregistered vehicles, and would not be link-specific.
Manual (visual) classification counts collected for project area	Common	Simple method to develop link-level source type classifications.	Requires performing a brief field survey, may not account for temporal variability in source types. Unable to distinguish between short- and long-haul trucks.
Video data collection with license plate information	Limited	Could be used to provide a fairly accurate source type allocation on a specific link.	Possibly costly data collection and processing, would not include unregistered or out-of-state vehicles (unless manually included through visual classification). From a cost and time standpoint, probably only feasible as part of a broader effort.
State-operated automatic vehicle classification sensors	Limited	Would provide direct measure of vehicle population on roadways.	Limited with respect to accurate classification of the 13 vehicle source types. Only available for roadways on which sensors are placed.
Travel demand models	Limited	Output from models may be used to estimate VHT by source type.	Models may be limited with respect to link-specific output, and model will distinguish at best up to three source types (e.g., car, medium truck, heavy truck).

Developing accurate link-level source type allocations is important in project-level analysis as emission estimates could be sensitive to this factor, especially the relative fraction of trucks versus cars. The various options listed in Table 4.2.1 for estimating source type fractions are described below.

Forecast year data. If a travel demand forecasting model is used that has separate car and truck models (rather than simply factoring total VMT by percent truck traffic), or different growth factors are available for car and truck traffic, the source type mix may be different for the future and base years. Otherwise, it is typical to use the same source type mix for future analysis years as for the base year.

4.2.3.1 State/Regional Source Type Mix

Existing regional or local distributions from other modeling efforts may be used as a basis for estimating link source type hour fractions, if project-specific data cannot be obtained. Usually these distributions will be based on vehicle registration data or another population-based source. Sources for regional distributions, such as state vehicle registration databases, I/M programs, and bus fleet data, are discussed in Volume 1, Section 4.2. There are several limitations with this approach, however:

- Data from these programs will not include vehicles such as those commuting from out of area (commercial and tourism) or unregistered vehicles;
- The general regional profiles from registration-based vehicle data will likely differ from a specific link's profile;
- There may not be complete coverage of all MOVES source types; and
- Registration-based vehicle source profiles are not activity based and must be adjusted to accurately represent vehicle-hours of travel (VHT) source profiles.

Population distributions may be scaled by population:VMT ratios as discussed later in this section to obtain a mileage-based profile, which may then be converted to a VHT-based speed distribution using source-based speed profiles or a data converter developed by EPA and available at http://www.epa.gov/otaq/models/moves/tools.htm.

4.2.3.2 Manual (Visual) Classification Counts Collected for Project Area

This may involve visual surveys with immediate characterization or video collection with subsequent review and source type characterization. Performing manual classification counts is a well-established technique which accounts for "out of area" vehicles (such as commuter vehicles) and unregistered vehicles. Hover, use of this method would not distinguish between short- and long-haul trucks. If speed measurements are also taken, vehicle populations can be adjusted by average speed by vehicle type to obtain VHT distributions that may differ from vehicle count distributions.

4.2.3.3 Video Data Collection with License Plate Capture

Video data recording with automatic license plate recognition can also be used to characterize a link's usage-based vehicle source fractions. For this approach, vehicle license plates are captured on video and automatically transcribed with optical character recognition (OCR) software. The digitized license plate is then matched with registration data, yielding some vehicle characteristics (such as make, model, model year, gross vehicle weight rating, fuel type, and vehicle type) which can be mapped to the 13 vehicle source types. Alternatively, registration vehicle identification numbers may be decoded and mapped to the 13 vehicle source types. Vehicles for which OCR fails can be manually reviewed and mapped to the appropriate vehicle source type.

This approach characterizes the VHT profile for a specific link's fleet. However, some effort and cost is required to perform this type of characterization, primarily limiting this to projects for which a number of links must be characterized (or as part of another, larger study). As with most other data collection methods, short- and long-haul trucks cannot be readily distinguished, although the location of the vehicle's registration could be used to make inferences. In addition, out-of-area and unregistered vehicles may need to be manually classified or not included in the sample.

4.2.3.4 State-Operated Automatic Vehicle Classification Systems

Vehicle classification count data are generally available from state departments of transportation 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 collected in the expanded set of 13 FHWA classifications requires mapping to MOVES source types. Also, as discussed in Volume 1, Section 4.3, classification counters are typically poor at distinguishing light-duty automobiles from light-duty trucks, and it may be preferable to use another source to break out light-duty activity.

Vehicle counts can provide an estimate of the number of vehicles on roadways in a modeling domain, including variation by months, days, and hour. However, link-based VHT estimates may not be available for the specific link of interest, so use of data from a nearby but similar link may be necessary, depending on data availability.

4.2.3.5 Travel Demand Models

If the regional or statewide travel demand model includes an explicit truck modeling component, it may be used to estimate the split of VHT between light- and heavy-duty vehicles for individual links within the model domain. This may serve as a supplemental source when real-world counts are not available. However, few models include a truck component; most simply factor total vehicle trips by observed VMT fractions for cars and trucks from the HPMS or other traffic counts.

4.2.4 Sample Data and Tools

To perform link-level analysis, the distribution of vehicles traveling on each link for the given hour being modeled is required by MOVES. Vehicle registration data may be used for developing population-based source type fractions in MOVES, as described in EPA's MOVES User Guide. Ratios available in Table A.1 of the Appendix of the MOVES SIP and Conformity Guidance may be used to convert MOBILE6 vehicle populations to MOVES source types. However, users should understand that the vehicles registered in a county for a given point in time do not necessarily correspond to the VMT driven over that same period in the county (FHWA, no date). Population:VMT ratios may be used to obtain a mileage-based profile, which may then be converted to a VHT-based speed distribution using a data converter developed by EPA and available at http://www.epa.gov/otaq/models/moves/tools.htm.

Due to the differences which arise when comparing county-level activity estimates to link-level estimates, using one of the link-specific sources of VHT information previously described is preferable to use of county-level estimates.

4.2.5 Example: License Plate Survey

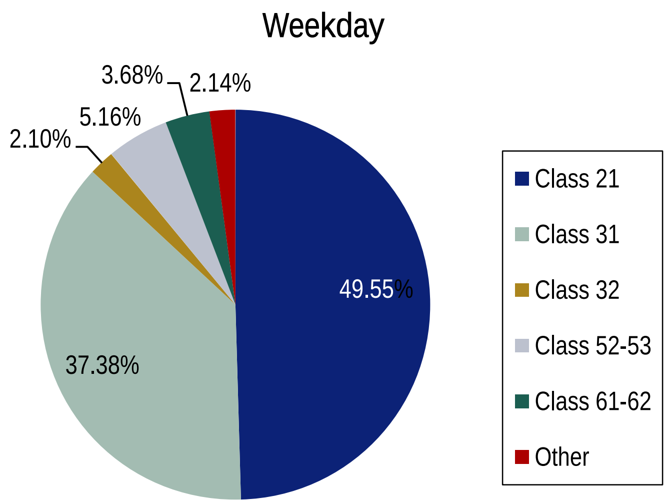
ALPR lends itself well to directly characterizing the link-specific fleet. ALPR conducted on the specific link to be modeled can help quantify the actual fleet on the road, accounting for pass-through traffic, localized commercial activity, and other factors affecting the source type mix. For this example, the ALPR data are taken from the UC Riverside study referenced in Section 4.1, Age Distribution. Researchers at UC Riverside conducted the study in July 2010 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. The videos were examined to determine license plate state and numbers (Figure 4.2.1). From these data, MOVES vehicle classes were identified using vehicle make and model information derived from information in the state registration database.

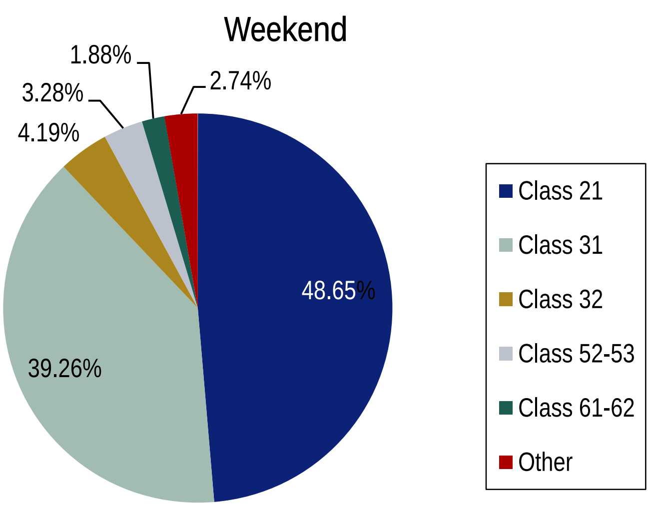
Figure 4.2.1 UC Riverside ALPR Setup

Source: Boriboonsomsin et al., 2011.

Figure 4.2.2 shows the mix of MOVES source types derived from the Las Vegas ALPR data, for weekdays and weekends. The ability to differentiate weekday from weekend allows a more precise estimation of link source type fraction, especially for trucks. In this example, the fraction of heavier trucks (source type 52 and higher) on weekdays is about double that on weekends.

Figure 4.2.2 MOVES Source Type Fractions
Las Vegas ALPR Study





Source: Boriboonsomsin et al., 2011.

4.3 Link Characteristics – Volume

4.3.1 Description and Format

Traffic volume is one of the required fields in the link inputs table. Link volume is defined as the total number of vehicles traversing the link in one hour. If links are defined as unidirectional links, volume would be one-way volume. If the link is bidirectional, the volume would be the two-way volume. (Unidirectional links are typically required for intersection analysis, but bidirectional links might be adequate for free-flow segments with zero grade and similar speeds and fleet characteristics in both directions.) An example of the link input table is shown in Table 4.0.2.

4.3.2 Source of Embedded Data and EPA Guidance

There are no embedded values for traffic volumes. This input will require link-specific data to be entered by the user.

EPA recommends using data from project documentation for these inputs. EPA guidance also provides information on how to define links for the purposes of emissions modeling (see Section 4.4 of this document for further information on this topic). The following guidance documents are relevant:

- MOVES2010b User Guide: Section 2.3.3.4.12, Link Source Types Importer;
- PM Hot-Spot Analysis Guidance: Section 4.5, Link Source Type; and
- CO Analysis Guidance: Section 2.4.5, Link Source Type.

4.3.3 Data Sources, Procedures, and Methods

Options for obtaining local traffic volume data are listed in Table 4.3.1.

Forecast year data. The first two methods provide only base/historical year data, while the last two methods provide forecast year data. If forecast year data are to be used that are different from base year data, a traffic forecasting method (model or growth factor) must be used.

The following subsections provide additional details on the methods and sources for developing link volumes.

Table 4.3.1 Overview of Data Sources for Link Input Characteristics

Data Source or Procedure	Current Use	Uses and Advantages	Limitations
Project-specific traffic counts	Common	Relatively easy to obtain. Could be manually conducted or automated such as temporary deployment of pneumatic-tube counting systems.	Data must be collected for time periods to be represented in emissions modeling. Only current, not forecast volumes.
Counts from state traffic monitoring system	Limited	Provide direct measure of vehicle volumes on link.	Information only available for certain links with counters installed. Only current, not forecast volumes.
Travel demand models	Common	Provide estimated volumes for links without counters. Can provide forecast year volumes.	Modeled volume may differ from actual volume on link.
Growth factors	Common	Can be used where model forecasts are not available to inflate current volumes to future-year volumes.	Usually simple trend-based factors, do not explicitly account for underlying growth factors.

4.3.3.1 Project-Specific Traffic Counts

Link volume (traffic volume) may be estimated using traffic count data collected using pneumatic road tubes, radar, video, manual counts, or other methods. Depending on the number of links to characterize, a study could be performed specifically for the project to characterize the project's roadway links, or counts conducted for previous studies may be available. Care must be taken to ensure the traffic volume estimate is appropriate for the time of day, day of week, and time of year for which emissions are to be modeled. Multiple days of counts are preferable to reduce the effects of daily fluctuations in traffic (traffic monitoring protocol typically calls for a minimum of at least three observations). Also, if older counts are used, care should be taken to ensure that traffic conditions have not changed substantially.

4.3.3.2 Counts from State Traffic Monitoring System

State transportation agencies maintain statewide networks of permanent traffic counters to support reporting of traffic volumes and VMT to the Federal Highway Administration. Temporary counters may also be deployed to sample additional links on a rotating basis. If the segment(s) that are part of the project are also part of this monitoring system, vehicle counts may be obtained directly from the agency. Permanent counters should be able to provide data for the specific time period required for air quality analysis; data from temporary counters should be reviewed to ensure that it represents the hour, day of week, and season required.

4.3.3.3 Travel Demand Models

Traffic volume may also be estimated using output from a traffic demand model. Although regional model output may not always closely match traffic counts, it can be a reasonable source if actual counts are not available. Furthermore, it has the advantage that forecasts are generally produced as well as base or historical year estimates. If the model has not been updated or recalibrated recently, growth factors may need to be applied to reflect current conditions. Also, if forecast years do not match the project analysis year, output for different years may need to be interpolated or extrapolated to the analysis year.

4.3.3.4 Growth Factors

When travel demand model data are not available but forecast year volumes are needed, growth factors can be applied to traffic counts from a base or historical year. Sometimes, the state DOT will have growth factors representative of different roadway types. Growth factors may also be developed from local data such as population or employment trends or projections. Growth factors should be applied with caution as they usually are based on historical trends which may or may not hold in the future. In areas where significant development is occurring, it may be desirable to separate growth factors representing regional traffic (based on regional trends or projections) from the specific contribution of local development.

4.3.4 Sample Data and Tools

EPA has not developed tools for producing link characteristic inputs for MOVES. Also, since link characteristics were not used in MOBILE6, there is no need for conversion of data from MOBILE6 inputs.

4.3.5 Examples

No examples are provided for this input. However, Example 3 in Section 5.0 illustrates how links can be defined and associated link-specific data developed for a sample project.

4.4 Link Characteristics – Length and Grade

4.4.1 Description and Format

A link input table includes a variety of elements. The geometry of the link is specified using two parameters: Link Length (distance in miles) and Link Grade. Grade is the average grade expressed in percent (rise over run, where 100 percent is a 45-degree slope).

Both of these inputs have significant effects on emissions. Link length is a direct input to source-hours of operation (SHO is calculated by MOVES as traffic volume * length/ speed). Grade affects the operating mode (vehicle-specific power). In sensitivity analysis, grade was found to have a significant effect on emissions. For example, a 2 percent uphill grade increases emissions by about 20 to 40 percent depending on the pollutant, while a 2 percent downhill grade decreases emissions by about 15 to 30 percent. Impacts are larger for larger grades, with emissions of NO_x and PM increasing over 100 percent on a 6 percent grade. Since the effect is nonlinear, links should be defined so that they do not include sections of road with very different grades.

4.4.2 Source of Embedded Data and EPA Guidance

If the user chooses to enter operating mode distributions rather than average speed or drive cycles, or uses an appropriate MOVES default OpMode distribution, grade is implicit. Otherwise, there are no embedded values for length and grade and the user will need to enter link-specific data.

The following EPA guidance documents are relevant:

- MOVES2010b User Guide: Section 2.3.3.4.11, Links Importer.
- PM Hot-Spot Analysis Guidance: Section 4.2, Characterizing a Project in Terms of Links; and Appendix D, Characterizing Intersection Projects for MOVES.
- CO Analysis Guidance: Section 2.1, Characterizing a Project in Terms of Links; and Appendix A, Characterizing Intersection Projects for CO Refined Analysis Using MOVES.

EPA recommends using data from project documentation for these inputs. While the overall geometry of road segments included in the project modeling domain may be obtained from plan specifications or field measurements, the user may need to apply judgment to further divide the project segments into discrete "links" for which characteristics are input to MOVES, especially in the vicinity of intersections. The CO and PM Hot-Spot Guidance provide information on how to define links for the purposes of emissions modeling. The definition of links affects the volume and speed (drive-cycle or operating mode) inputs as well as length and grade. The guidance differs somewhat for CO screening analysis versus CO refined and PM analysis, and can be summarized as follows:

- CO screening analysis (CO Analysis Guidance Section 2.1): Define free-flow approach, free-flow departure, and queue (idling) links. Free-flow links extend to the centroid of each intersection ("overlapping" the queue links), with a maximum of 300 meters sufficient. The exact length of the queue link is not important since MOVES calculates a gram per vehicle emission factor.

- CO refined analysis (CO Analysis Guidance Appendix A) and PM analysis (PM Hot-Spot Analysis Guidance Appendix D): Define approach links (including deceleration and idling zones) and departure links (acceleration zones) at each intersection.

Free-flow links can be defined for project analysis areas outside the vicinity of intersections, that are not affected by acceleration, deceleration, or queuing. The guidance also notes that different links can be defined to represent different types of vehicles (such as light and heavy vehicle) with different speed/acceleration profiles. Not explicitly discussed in the guidance, separate links also may be defined to represent major turn movements.

4.4.3 Data Sources, Procedures, and Methods

Options for obtaining local data to provide local project-level geometric characteristics are listed in Table 4.4.1.

Table 4.4.1 Overview of Data Sources for Link Input Characteristics

Data Source or Procedure	Current Use	Uses and Advantages	Limitations
Project as-built plans	Common	Could provide link length and grade with suitable accuracy	May be time-consuming to acquire or may not be available
Field surveys	Common	Accurate direct measurement of link of interest	Can be costly and time consuming, especially for larger project-scale modeling
Aerial or satellite imagery	Common	Length can be measured easily	Does not provide grade information
State roadway databases	Limited	Most state roadway inventories contain grade information	Roadway links may not align with definition of project links
USGS national elevation dataset	Limited	Easily obtained and publicly available dataset for grade information	Resolution may not be sufficient (3 meters or lower)
On-line bike mapping tools	Experimental	Easily obtained and publicly available dataset for grade information	Some of these contain grade information, but resolution and coverage may be limited
GPS, 3-D accelerometers, and barometric altimeters	Experimental	Measurements can easily be taken using consumer electronic devices	Data resolution/accuracy limitations for grade
Lidar	Experimental	Extremely accurate	Costly – may not be practical unless required for other purposes

The various options exist for determining link length and grade are described below. One challenge for grade characterization is to accurately represent point-to-point changes in grade with sufficient resolution. Also, preexisting sources may not align well with the links defined for air quality analysis.

Forecast year data. It is not expected that these inputs will change between the forecast and base year, unless the project involves a realignment, in which case forecast year parameters should be taken from project plans.

4.4.3.1 Project As-Built Plans

For projects that are in design or have recently been constructed, as-built plans are likely to be available from which accurate geometric information can be obtained. For roadways that have not undergone recent design or construction, as-built plans may be more difficult or impossible to obtain. The plans would need to be obtained from the agency that owns the road or is sponsoring the design. Also, it may not be possible to determine grade for the exact segment corresponding to the defined link for air quality analysis.

4.4.3.2 Field Surveys

Sending a team of surveyors into the field is a way of obtaining accurate information for the specific links that are defined for modeling purposes. However, this approach is expensive. Usually this will be done if accurate survey information is needed for other purposes such as project design.

4.4.3.3 Aerial or Satellite Imagery

Aerial or satellite imagery is available on-line via tools, including Google Earth and Bing maps, and Google Earth includes a measurement tool. This can be a reasonably accurate way of easily obtaining length measurements. Measurements can also be taken directly from imagery that may be available from project-specific aerial surveys.

4.4.3.4 State Roadway Databases

State transportation agencies, and sometimes local agencies, typically maintain databases characterizing the roads in the state or municipality. The data elements are roadway links (which may be identified by route number and start/end milepost). Attributes include length and (typically) grade. However, the links will likely not correspond to the links defined for emissions modeling. For example, the roadway database link may refer to the road segment between two major intersections, whereas the MOVES user may want to divide that segment into subsegments represent acceleration, deceleration, and free-flow regions. As a result, the grade for the road segment may not represent the grade of the individual links to be modeled in MOVES.

4.4.3.5 USGS National Elevation Dataset

The United States Geological Survey (USGS) National Elevation Dataset contains elevation information which could be used for grade estimations. However, the highest-precision dataset (approximately three meters) may not be adequate to obtain accurate grade information.

4.4.3.6 On-Line Bike Mapping Tools

On-line bike mapping tools such as toporoute.com, mapmyride.com, and ridewithGPS.com can provide average grade information for links selected by the user. These tools typically use publicly available USGS data and are subject to the same resolution limitations.

4.4.3.7 GPS, 3-D Accelerometers and Barometric Altimeters

Relatively cheap and simple tools to make field measurements of length and grade include global positioning systems (GPS) devices, GPS-instrumented smartphones, three-dimensional accelerometers, and barometric altimeters (grade only). Measurements can easily be taken using low-cost consumer devices. However, resolution for determining grades is likely to be insufficient unless the grade is substantial and/or the link is long.

4.4.3.8 Lidar

Lidar refers to the use of laser to measures distances based on the time it takes a reflected laser beam to return to the detection unit. It is extremely accurate but requires expensive equipment and a trained operator. Lidar from airplanes can be used to create digital elevation models, or it can be used to take measurements from ground-based instruments.

4.4.4 Sample Data and Tools

EPA has not developed tools for producing link characteristic inputs for MOVES. Also, since link characteristics were not used in MOBILE6, there is no need for conversion of data from MOBILE6 inputs.

4.4.5 Examples

No examples are provided for this input. However, Example 3 in Section 5.0 illustrates how links can be defined and associated link-specific data developed for a sample project.

4.5 Link Average Speed

4.5.1 Description and Format

This input asks for the average speed (in mph) on each link in the project, where average speed = average travel time/distance (length of link). It may be used as an alternative to providing drive cycles or operating mode fractions for each link, if such data are not available. If no other information is available, MOVES uses default assumptions of vehicle activity patterns (drive cycles) for average speed and type of roadway to estimate emissions.

A single average speed is input for all source (vehicle) types. MOVES2010 and MOVES2010a place limits on the average speed of different source types to ensure they fall within the drive cycles embedded in MOVES (User Guide, p. 79). For example, speed for passenger cars must be between 2.5 and 73.8 mph, for combination trucks between 5.8 and 71.7 mph, and for transit and school buses between 15.0 and 72.8 mph. MOVES2010b will accept any speed and properly calculate emissions for that speed even if it falls outside of the limits associated with the drive cycles.

Travel time should account for the total delay attributable to traffic signal operation, including the portion of travel when the light is green and the portion of travel when the light is red.

4.5.2 Source of Embedded Data and EPA Guidance

MOVES does not include embedded data on link-level speeds. Speeds must be input by the user for each link of each project evaluated.

The following EPA guidance documents are relevant:

- MOVES2010b User Guide: Section 2.3.3.4.11, Links Importer.
- PM Hot-Spot Analysis Guidance: Section 4.2, Characterizing a Project in Terms of Links; and Appendix D, Characterizing Intersection Projects for MOVES.
- CO Analysis Guidance: Section 2.1, Characterizing a Project in Terms of Links; and Appendix A, Characterizing Intersection Projects for CO Refined Analysis Using MOVES.

These guidance documents note that hot-spot analysis fundamentally depends on the availability of accurate data on roadway link speed and traffic volumes for build and no-build scenarios. The project should be divided into separate links to allow sufficient resolution of different vehicle traffic and activity patterns. The definition of the links, therefore, will depend in part upon traffic speed characteristics.

The CO Analysis Guidance indicates that the hot-spot analysis should reflect peak-period emissions and should therefore be based on congested speeds. The PM Hot-Spot Analysis Guidance recommends the use of speeds for four time periods: a.m. peak, p.m. peak, mid-day average hour, and overnight average hour. These time periods are combined with four months, representing different seasons, to make a total of 16 MOVES runs.

Free-flow highway links can be defined where vehicle behavior (and speeds) are relatively uniform. If the project analysis involves intersections, the intersections need to be treated separately from the free-flow links that connect to those intersections. The CO guidance recommends defining three types of links for screening-level analysis: 1) free-flow approach links, 2) free-flow departure links, and 3) queue links, where idling occurs. For refined CO analysis, and for PM analysis, EPA guidance suggests that intersection approach and departure links should be defined. The speeds on these links are not free-flow, but rather should account for time lost to deceleration and idling (approach links) and acceleration (departure links).

EPA's guidance documents on PM and CO hot-spot analysis recommend that project sponsors determine average congested speeds by using appropriate methods based on best practices used for highway analysis. This may include post-processing of link-level speed data from travel demand models. The documents note that resources are available through FHWA's Travel Model Improvement Program program and that methodologies for computing intersection control delay are provided in the Highway Capacity Manual (HCM). See Volume 1, Section 4.7 of this document (Average Speed Distribution) for further information on regional-level speed estimation methods.

4.5.3 Data Sources, Procedures, and Methods

There are two basic methodological 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. For project-level analysis, some type of modeling will be required in order to compare "build" and "no-build" conditions. Measurement of current speeds may be used to validate or refine modeled speed estimates. If existing traffic monitoring systems include the link(s) to be evaluated, additional field data collection to determine current speeds may not be necessary. Local data source options for this input are summarized in Table 4.5.1

Table 4.5.1 Summary of Options for Link Average Speed

Data Source or Procedure	Use	Uses and Advantages	Limitations
Monitoring – Historical Speeds Only			
Posted speed limit	Common	Easily obtained.	May not accurately represent true speed of vehicles on link.
Site-specific speed studies with radar, video, or Bluetooth, or floating car method	Common	Data collection customized to project location.	Additional cost versus relying on existing sources.
Public agency ITS systems (loops, radar, video)	Limited	Makes use of public agencies' ITS traffic monitoring system data which exist in many cities.	Usually only deployed on urban restricted access roads.
Traffic monitoring data from private sources (GPS, cell phone, Bluetooth)	Limited/ Experimental	Potentially broader coverage than public ITS systems; may be available at no incremental cost if purchased for other purposes.	Generally must be purchased. Accuracy of some sources (e.g., cell phone) at a link level not fully demonstrated.
Modeling – Build versus no-Build Scenarios and Forecast Year Speeds			
Travel demand forecasting model	Common	Available for most network links in most urban areas.	Most model speeds are not calibrated to match real-world speeds and may require post-processing. Model resolution is generally not suited for project-specific speed analysis.
Macroscopic traffic models (e.g., Highway Capacity Manual)	Common	Easy to apply using basic roadway information (volume, capacity, intersection green times, etc.).	Do not replicate queues or interactions between adjacent sections very well.
Mesoscopic and microscopic traffic models	Limited	Produce more accurate speed estimates, especially under congested conditions.	More data- and labor-intensive to apply.

Existing systems may include regional intelligent transportation systems (ITS) using loop detectors, video, radar, and/or Bluetooth readers; as well as private-sector sources based on GPS or Bluetooth probe vehicle measurements or cell phone triangulation. Public agencies are increasingly purchasing these data sources for the purposes of performance monitoring and operations planning. However, the spatial resolution of some data sources (segmentation of links) may not be adequate for the purposes of MOVES project-level analysis. Also, some sources (such as cell phone triangulation) have not been fully validated for accuracy at a link level.

Travel demand forecasting models are widely used for identifying link-level vehicle speeds, but usually are not the best tool for project-level speed analysis. Model speeds are not calibrated to match real-world speeds and may require post-processing. Even if reasonably accurate speeds can be identified for the "no-build" condition, the regional-scale models are not suited for evaluating the impact of a specific roadway improvement on speeds. The use of project-specific methods, such as HCM formulas or traffic simulation models, will generally give more accurate results.

4.5.3.1 Posted Speeds

Posted speeds may be obtained from field observation, from a roadway database maintained by the transportation agency, a travel demand model, or project as-built plans. Posted speeds have the distinct advantage that they clearly relate to free-flow speeds on the road segment (as opposed to some combination of free-flow and intersection delay which are inherent in many of the methods described in this section). Posted speeds may be adjusted upwards or downwards (e.g., by 5 mph) to represent actual typical speeds on the link. Posted speeds may not be a good representation even of free-flow speeds under very congested conditions.

4.5.3.2 Site-Specific Speed Studies

If site-specific field measurements are to be conducted, a number of methods may be used. 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. Other technologies that can be deployed for specific studies include:

- Radar, microwave, or lidar units placed at the roadside.
- 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.
- 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.
- Bluetooth or toll transponder readers placed at the roadside to identify vehicles with these technologies active.

Travel time data collection methods have evolved rapidly in recent years due to new advances in technology. FHWA (2013) provides an overview of travel time data collection methods.

Radar, microwave, lidar, and video all measure spot-speed (speed at a single point). This technique may be most appropriate for measuring speeds on “free-flow” links, with approach and departure speeds at intersections estimated based on free-flow speeds. Methods such as ALPR and transponder readers can provide average speeds over the entire length of a project, but do not differentiate free-flow from approach and departure speeds at intersections. Approach and departure speeds are often assumed to be one-half of free-flow speeds (not accounting for stopped delay).

The floating car with GPS method, while labor-intensive and sampling a relatively small number of vehicles, has the advantage of being able to measure speeds for multiple segments of a roadway section. If this method is used, however, the analyst should have enough data to use the drive-cycle input rather than the average speed input.

Radar and video methods can generally detect vehicle length as well as speed. Any measurement 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 can also distinguish vehicle types.

4.5.3.3 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. Data collection methods include in-pavement magnetic and inductive loop detectors; radar, microwave, or lidar; video cameras; Bluetooth readers; and toll tag readers. More information on these methods is given in Section 4.7 of Volume 1.

Data collected in agencies' ITS systems are typically archived at intervals of five minutes or even less. Data processing is generally required to aggregate the data into the hourly time period required for MOVES. 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. 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.

Spot measurement methods (loop detectors, radar, microwave, lidar, or video) are best for measuring free-flow speeds. Segment measurement methods (Bluetooth and toll tag readers) can measure average speeds over a road segment considering acceleration, deceleration, and stopped delay. However, the analyst should compare the measured segment with the links defined for MOVES analysis to ensure that the measured average speed over the segment is a reasonable representation of the speed on the link(s) defined for MOVES analysis.

4.5.3.4 Traffic Monitoring Data from Private Sources

A growing number of primarily private sources are collecting and aggregating travel time data using vehicle-based monitoring methods, including GPS navigation units, Bluetooth detectors, 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. More information on these methods is given in Section 4.7 of Volume 1.

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 geographic information systems (GIS) format so that they can be associated with a road network. However, the sources rarely contain information on the type of vehicle and therefore cannot be used to identify speeds by source type.

The underlying measurement methods need to be evaluated to ensure that they are appropriate for the purposes of MOVES project-level modeling. For example, the distance between Bluetooth readers may be much longer than the length of the project to be evaluated, in which case reported speeds may not be representative of speeds in the project area. Data from cell phones, triangulated from signals at different towers, may be more appropriate estimating zone-to-zone travel times than actual link speeds.

4.5.3.5 Travel Demand Forecasting Models and Post-Processing Methods

Travel demand forecasting models can produce forecast year as well as historical year speed estimates and are widely used for estimating regional vehicle speed distributions (see Volume 1, Section 4.7). 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. 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 project-level speed estimation. First, models are not calibrated to match speeds, but rather to match traffic counts. Second, the quality of speed estimates can be limited. For example, speed is usually a simple function of link-level volume-to-capacity (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. 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. However, the links in the travel model are still likely to be defined as intersection-to-intersection segments, which does not align with EPA guidance to model intersection approach, departure, and free-flow links.

Post-processing techniques can be applied to improve model speed estimates, although they do not eliminate some of the more fundamental limitations. Post-processing typically involves estimation of link v/c ratios and average speeds by hour of the day, then computation of volume-weighted average speeds. Post-processing methods also can more closely match model speeds with observed speeds. More information on post-processing methods is given in Section 4.7 of Volume 1.

4.5.3.6 Highway Capacity Manual and Macroscopic Traffic Models

Macroscopic traffic models are based on deterministic relationships of the flow, speed, and density of the traffic stream. The Highway Capacity Manual methodologies and tool procedures are one of the most common applications of macroscopic methods. HCM is a static approach which estimates the average speed or delay over a one-hour period or the peak 15 minutes of an hour. Other macroscopic models may apply dynamic approaches which predict density, speed, and delay for each time slice within an analytical period. A wide variety of software and other tools implement HCM-based approaches.

FHWA's Traffic Analysis Toolbox provides an overview of various types of traffic models, and compares HCM methods with other methods. The toolbox notes that HCM procedures are good for analyzing the performance of isolated facilities with relatively moderate congestion problems. However, they are of limited value in analyzing queues and the effects of the queues. An example of how HCM methods can be used to estimate speed data is shown in Section 4.5.5.

4.5.3.7 Mesoscopic and Microscopic Traffic Models

According to FHWA's Traffic Analysis Toolbox:

- **Mesoscopic** simulation models combine the properties of both microscopic and macroscopic simulation models. The unit of traffic flow is the individual vehicle, but their movement follows the approach of the macroscopic models and is governed by the average speed on the travel link.

- **Microscopic** models simulate the movement of individual vehicles based on car-following and lane-changing theories. Typically, vehicles enter a transportation network using a statistical distribution of arrivals and are tracked through the network over small time intervals (e.g., one second or less).

The Toolbox notes that mesoscopic and microscopic models are effective in evaluating the dynamic evolution of traffic congestion problems, as well as the interference that occurs when congestion builds up at one location and impacts the capacity of another location. They can also model the variability in driver/vehicle characteristics. However, they require a large amount of input data and considerable effort to validate the data and manipulate calibration parameters.

Simulation models are most often used on larger projects when the time and effort required for model application pays off in terms of enhanced project design. The development of improved speed estimates for emissions modeling will be a by-product of the traffic analysis. The output of these models – which includes second-by-second vehicle trajectories – can generally be used to develop drive-cycle inputs; applying them simply to develop average speed estimates would be overkill. The use of simulation models to develop drive-cycle inputs to MOVES is discussed in Section 4.6.

4.5.4 Sample Data and Tools

There are no tools available to aid in the development of average speed inputs for MOVES. Sample data are contained in the examples in the next section.

4.5.5 Examples

Example 4.5.1 – Defining Speeds from Highway Capacity Manual Methods

In this example, the analyst wants to estimate the average speed on a roadway segment that includes one or more intersections. The analyst has the following information:

- The segment length;
- Free-flow speed; and
- Stopped (control) delay from an intersection analysis.

Equation 15-6 in the Highway Capacity Manual 2000 defines the average travel speed of vehicles through a segment as follows:[8]

$$S_A = \frac{3600L}{T_R + d}$$

Where:

S_A = average travel speed across segment (miles per hour);

L = segment length (miles);

T_R = total running time across the segment; and

d = control delay for through movements at the signalized intersection(s).

Total running time is based on the running time per mile and the free-flow speed (FFS) as shown in Exhibit 15-3. In this example, assume that the link is defined as a quarter-mile Class II urban street segment approaching an intersection (L = 0.25 mi) with FFS = 35 mph. Running time is 119 sec/mi (from Exhibit 15-3), so T_R = 119 sec/mi * 0.25 mi = 29.8 sec. Further assume that the analyst has performed an intersection analysis using HCM methods or other simulation software and determined the control delay on this intersection approach to be 40.2 sec. S_A is then computed as follows:

$$S_A = \frac{3600 * 0.25}{29.8 + 40.2} = 12.9 \text{ mi/hr}$$

[8] The methodology has changed somewhat in HCM 2010 and is now described in Chapter 17. It includes a procedure for predicting the free-flow speed based on a number of roadway variables. The method in HCM 2000 is used here for simplicity.

This speed is appropriate if the link defined for MOVES analysis includes the entire road segment approaching the intersection. If a shorter representation of an approach link is desired, T_R should be recalculated based on the desired length.

Example 4.5.2 – Developing Link Average Speeds from Travel Time Monitoring Data

Nearly all metropolitan areas have freeway management centers that carry out a variety of traffic management strategies. It is common for these centers to collect detailed traffic data for use in implementing these strategies. These data come from closely spaced (one-half-mile is typical) roadway-based detectors. Different technologies are used but the resulting data are all the same: speeds, volumes, and lane occupancies by lane. (Older systems only collect volumes and lane occupancies; speed is derived from these by using macroscopic traffic flow relationships.) Note that these data are measured at a specific point, not over a distance of highway.

The measurements from these systems have been aggregated to some degree. In the field, the detectors measure every vehicle that passes through its detection zone. However, to reduce communication burden, the data are aggregated into 20- or 30-second packets prior to transmission. During the archiving process, the data may be aggregated again. The data are stored at intervals ranging from 20 seconds to 15 minutes; five-minute intervals are very common. Because of the close spacing present on most systems, there will be at least one detector per link for most links defined for emissions analysis.

The data from these systems are simple in structure but voluminous. Typical data items include:

- Date/time of the measurements;
- Station (detector) identification;
- Lane number of the measurements; and
- Volume, speed, and lane occupancy measurements.

Station identification can usually be linked to a configuration file that has details about the location: route, direction, milepoint or other georeference, etc.

To compute average speed by link, a volume-weighted harmonic speed is the most correct method to use:

$$S = 1/[(w_1/s_1) + (w_2/s_2)\ldots + (w_n/s_n)]$$

Where:

S = volume-weighted harmonic speed;

w_i = weight for speed measurement *i*;

= v_1/v_T;

s_i = speed measurement *i*;

v_i = volume associated with speed measurement *i*; and

v_T = $\sum v_i$.

The calculations are done for whatever time slice is of interest. Table 4.5.2 shows an example of raw data obtained from a traffic management center.

Table 4.5.2 Sample Traffic Management Center Data from Jacksonville

timestamp	detector_id	lane_id	speed	volume	occupancy
0:00:00	RTMS 95S035	R95S035-R_04RampN_01	46	0	0
0:00:00	RTMS 95S035	R95S035_03Lane_03	73	1	1
0:00:00	RTMS 95S035	R95S035_02Lane_02	62	1	1
0:00:00	RTMS 95S035	R95S035_01Lane_01	75	3	3
0:00:01	VDS 10W016_btwn I-295/Lane EB	R10W016E_01LaneE_01	54	2	2
0:00:01	VDS 10W016_btwn I-295/Lane EB	R10W016E_02LaneE_02	55	1	1
0:00:01	VDS 10W016_btwn I-295/Lane EB	R10W016E_03LaneE_03	0	0	0
0:00:01	VDS 95N009_Golfair Exit NB	R95N009N-R_Ramp01_N	50	2	2
0:00:01	VDS 95N009_Golfair Exit NB	R95N009N_Lane03_N	0	0	0
0:00:01	VDS 95N009_Golfair Exit NB	R95N009N_Lane02_N	0	0	0
0:00:01	VDS 95N009_Golfair Exit NB	R95N009N_Lane01_N	0	0	0

4.6 Drive Schedules and Operating Mode Distributions

4.6.1 Description and Format

Project-level inputs in MOVES must be entered for each roadway link that is used to define a project. Project-level link activity may be described using operating mode distributions, drive schedules, or average speed. If operating mode distributions are chosen, the input is a set of fractions, which represent the percent of time spent in each operating mode bin, where a bin is a combination of vehicle-specific power (VSP) and speed (Tables 4.6.1 and 4.6.2). If drive schedules are chosen, the input is a set of second-by-second speeds, also known as vehicle trajectories (Table 4.6.3). MOVES then converts the vehicle trajectories to operating mode distributions.

Table 4.6.1 Example of Default Operating Mode Distribution Input

sourceTypeID	hourDayID	linkID	polProcessID	opModeID	opModeFraction
11	75	101	101	0	0.01
11	75	101	101	1	0.01
11	75	101	101	111	0.01
11	75	101	101	12	0.02
11	75	101	101	13	0.03
11	75	101	101	21	0.005
11	75	101	101	22	0.005
11	75	101	101	23	0.005
11	75	101	101	33	0.005

For link speed and grade, MOVES includes default OpMode distributions based on typical driving cycles, an example of which is shown in Table 4.6.2.

Table 4.6.2 Example OpMode Distribution for Link Input

sourceTypeID	hourDayID	linkID	polProcessID	opModeID	opModeFraction
61	0	5	11101	11	0.33
61	0	5	11101	1	0.33
61	0	5	11101	0	0.33
54	0	5	11101	39	0.25
54	0	5	11101	38	0.25
54	0	5	11101	37	0.25
54	0	5	11101	35	0.25

Table 4.6.3 Example of Drive Schedule Distribution Input

linkID	secondID	speed	grade
1	1	44.0	0
1	2	43.7	0
1	3	42.6	0
1	4	41.3	0
1	5	40.0	0
1	6	39.0	0
1	7	38.0	0
1	8	38.7	0
1	9	39.5	0
1	10	39.9	0
1	11	40.6	0
1	12	41.0	0
1	13	39.0	0
1	14	38.0	0
1	15	37.5	0
1	16	38.7	0
1	17	40.0	0
1	18	39.6	0
1	19	39.0	0
1	20	38.6	0

For operating mode distribution input, the user must also specify the source type (vehicle type), the hour of the day and the link to which the operating mode pertain, and the pollutant and process of interest (polProcessID). The operating mode bin is identified by a number code (opModeID). Table 4.6.4 describes the number codes for the MOVES operating mode bins. The group description is not found in MOVES, but is shown in this table to describe the emissions process generally associated with each group of operating mode bins and to denote which groups of bins must have opModeFractions that sum to one. When exporting an operating mode distribution template from the MOVES Project Data Manager, it will typically only ask for one group of operating mode bins for each pollutantprocessID. The operating mode template may include more operating mode bins than are included in Table 4.6.4, but a number of operating mode bins are inactive, including 100, 300, 301-316, and 400-416.

Table 4.6.4 MOVES Operating Mode Bins

Group Description	opModeID	opModeName
Running	0	Braking
Running	1	Idling
Running	11	Low-Speed Coasting; VSP< 0; 1<=Speed<25
Running	12	Cruise/Acceleration; 0<=VSP< 3; 1<= Speed<25
Running	13	Cruise/Acceleration; 3<=VSP< 6; 1<=Speed<25
Running	14	Cruise/Acceleration; 6<=VSP< 9; 1<=Speed<25
Running	15	Cruise/Acceleration; 9<=VSP<12; 1<=Speed<25
Running	16	Cruise/Acceleration; 12<=VSP; 1<=Speed<25
Running	21	Moderate Speed Coasting; VSP< 0; 25<=Speed<50
Running	22	Cruise/Acceleration; 0<=VSP< 3; 25<=Speed<50
Running	23	Cruise/Acceleration; 3<=VSP< 6; 25<=Speed<50
Running	24	Cruise/Acceleration; 6<=VSP< 9; 25<=Speed<50
Running	25	Cruise/Acceleration; 9<=VSP<12; 25<=Speed<50
Running	27	Cruise/Acceleration; 12<=VSP<18; 25<=Speed<50
Running	28	Cruise/Acceleration; 18<=VSP<24; 25<=Speed<50
Running	29	Cruise/Acceleration; 24<=VSP<30; 25<=Speed<50
Running	30	Cruise/Acceleration; 30<=VSP; 25<=Speed<50
Running	33	Cruise/Acceleration; VSP< 6; 50<=Speed
Running	35	Cruise/Acceleration; 6<=VSP<12; 50<=Speed
Running	37	Cruise/Acceleration; 12<=VSP<18; 50<=Speed
Running	38	Cruise/Acceleration; 18<=VSP<24; 50<=Speed
Running	39	Cruise/Acceleration; 24<=VSP<30; 50<=Speed
Running	40	Cruise/Acceleration; 30<=VSP; 50<=Speed
Running	501	brakewear;stopped
Starts	101	Soak Time < 6 minutes
Starts	102	6 minutes <= Soak Time < 30 minutes
Starts	103	30 minutes <= Soak Time < 60 minutes
Starts	104	60 minutes <= Soak Time < 90 minutes
Starts	105	90 minutes <= Soak Time < 120 minutes
Starts	106	120 minutes <= Soak Time < 360 minutes
Starts	107	360 minutes <= Soak Time < 720 minutes
Starts	108	720 minutes <= Soak Time
Extended Idle	200	Extended Idling

The drive-cycle input bears further attention. The data are input for a single vehicle traversing a link. This vehicle can represent a single vehicle or multiple vehicles – the number of vehicles it represents is coded in the Links input file. For example, if the trajectory vehicle represents a single vehicle, then linkVolume for this link is coded as "1." If multiple vehicles traverse a link for the hour being studied, the input process becomes more complicated. The linkID field is used to keep track of link-vehicle combinations. For example, if two vehicles traverse a link during the analysis hour, linkID must be unique to each vehicle. Tables 4.6.5 and 4.6.6 show how the input files are structured to handle multiple vehicle trajectories for the same link.

Table 4.6.5 Example of Drive Schedule Distribution Input for Multiple Vehicles on a Link

linkID	secondID	speed	grade
100	1	49.4	0
100	2	49.7	0
100	3	50.1	0
100	4	50.5	0
100	5	51.3	0
100	6	52.3	0
100	7	52.4	0
100	8	52.0	0
100	9	51.9	0
100	10	51.7	0
101	3	41.0	0
101	4	39.6	0
101	5	39.0	0
101	6	38.0	0
101	7	38.7	0
101	8	39.5	0
101	9	40.0	0
101	10	39.6	0
101	11	39.0	0
101	12	38.1	0
101	13	37.2	0
101	14	36.5	0

Table 4.6.6 Example of Link Input for Multiple Vehicle Trajectories on a Link

linkID	countyID	zoneID	roadTypeID	linkLength	linkVolume	linkAvgSpeed	linkDescription	linkAvgGrade
100	26161	261610	3	0.56	1	51.1	Mainline	0
101	26161	261610	3	0.56	1	38.9	Mainline	0

Note that in this example, each of the vehicles represents only itself (linkVolume = 1). If these were just two chase cars among many in the traffic stream, then the total link volume would have to be apportioned to each vehicle. Note also that the link input file requires that average speed be entered; this can be easily computed from the trajectory data.

Clearly, this process can get very cumbersome and will have serious run time implications if a large number of individual vehicles are entered. As an alternative, operating mode distributions can be created from the individual drive cycles. A procedure for doing so appears in Section 4.6.5, and a tool was developed for this project to assist in converting drive cycles to operating mode distributions (see Section 4.6.4). The same rules apply for coding the Link input file as for the drive-cycle input.

4.6.2 Source of Embedded Data and EPA Guidance

For project-level analysis, drive cycles or operating mode distributions specific to each link must be entered, unless average speeds are used. If average speeds are input without operating mode distributions or drive cycles, MOVES assumes a default drive cycle based on the speed and roadway type.

The following EPA guidance documents are relevant:

- MOVES2010b User Guide: Section 2.3.3.4.11, Links Importer.
- PM Hot-Spot Analysis Guidance: Section 4.2, Characterizing a Project in Terms of Links; and Appendix D, Characterizing Intersection Projects for MOVES.
- CO Analysis Guidance: Section 2.1, Characterizing a Project in Terms of Links; and Appendix, Characterizing Intersection Projects for CO Refined Analysis Using MOVES.

These guidance documents note that hot-spot analysis fundamentally depends on the availability of accurate data on roadway link speed and traffic volumes for build and no-build scenarios. The project should be divided into separate links to allow sufficient resolution at different vehicle traffic and activity patterns. The definition of the links, therefore, will depend in part upon traffic flow characteristics. The hot-spot analysis should reflect peak-period operating conditions (for CO) or operating conditions during four different time periods (for PM), as described in Section 4.5.2. For emissions modeling purposes, link definition is more important when using the average speed input (to provide a finer resolution in average speeds) than when using the drive-cycle or operating mode inputs. For the purpose of estimating total emissions, with the latter inputs there is no need to split road segments with the same traffic volume into distinct model links, as the drive cycle across all links will be the same as the aggregation of drive cycles for each link. However, it may still be desirable to split links for greater spatial accuracy in assigning pollutants for dispersion modeling. For example, the concentration of pollutants may be much heavier on intersection approach segments than on free-flow segments.

EPA encourages the use of validated methods for collecting verifiable vehicle operating mode distribution or drive-cycle data. EPA's guidance notes that operating mode distributions may be obtained from other locations with similar geometric and operational (traffic) characteristics, or output from traffic microsimulation models with validated speed and acceleration patterns. For both free-flow highway and intersection links, users may directly enter output from traffic simulation models in the form of second-by-second individual vehicle trajectories using the drive-cycle input feature in MOVES. (Alternately, the vehicle trajectories can be processed into operating mode distributions for input to MOVES; when the number of vehicles becomes large, this is a more practical way to provide the MOVES input.) EPA also mentions that chase (or floating) cars, traffic cameras, and radar guns that are used to collect traffic data for other applications could be a source of these input data for MOVES, but this is true only if the data collection has been set up to capture second-by-second vehicle trajectories. For example, surveillance cameras routinely used for highway surveillance would have to be specially configured to capture vehicle trajectories, something for which they are not well suited.

4.6.3 Data Sources, Procedures, and Methods

Local data source options for this input are summarized in Table 4.6.7. Field data collection can be used to collect drive cycles under existing conditions, but traffic simulation models (mesoscopic or microscopic) are needed to predict drive cycles after implementation of a project. Therefore, it is somewhat resource-intensive to develop this information. As an alternative to doing project-specific data collection and/or modeling, it may be possible to develop drive cycles that are representative of different conditions.

Table 4.6.7 Summary of Options for Drive Cycles and/or Operating Mode Distributions

Data Source or Procedure	Use	Uses and Advantages	Limitations
Monitoring – Historical Data Only			
Vehicle trajectories from probe vehicles (field data using GPS or logger-equipped vehicles)	Experimental		Typically a limited sample, sometimes collected from a single vehicle.
Modeling – Build versus No-Build Scenarios and Forecast Year Activity			
Mesoscopic and microscopic traffic models	Limited	Both can produce vehicle trajectories for drive-cycle input, but mesoscopic trajectories are less precise. Also, it is more practical to first convert these to operating mode distributions external to MOVES.	More data- and labor-intensive to apply.
"Typical" drive schedules for different project types	Experimental	Can provide input reflective of typical conditions without the need for field data collection.	Limited examples exist. Examples must be carefully matched to ensure they represent local conditions in the project analysis area.

4.6.3.1 Vehicle Data Collection

Field measurements from vehicles equipped with vehicle data logger or GPS equipment can be used to develop vehicle trajectory or operating mode inputs to MOVES. With the prevalence of on-board diagnostic (OBD) ports on vehicles, gathering vehicle trajectory data is becoming increasingly cost-effective and unobtrusive. Low-cost data loggers slightly larger than a thumb drive can be plugged into OBD ports to record real-time vehicle speed and numerous other parameters reported by the vehicle computer. These data can be used either to develop drive schedules entered directly into the driveScheduleSecondLink table, or VSP distributions entered directly into the opModeDistribution table. Since the primary objective is to represent traffic flow, a single vehicle could be instrumented and run over the relevant link(s) at different points during the day. Such instrumented data may already exist, as insurance companies gather and store vehicle trajectory data from voluntary customer participation in safe driver discount programs.

GPS data can also be used for this purpose. While GPS data are not part of the OBD data stream, commercial data loggers are available that include GPS as well as OBD-streamed data. Makers of commercial GPS devices also gather and store data from customer-deployed devices, and may also be a source of data for specific links.

4.6.3.2 *Mesoscopic and Microscopic Traffic Models*

According to FHWA's Traffic Analysis Toolbox:

- **Mesoscopic** simulation models combine the properties of both microscopic and macroscopic simulation models. The unit of traffic flow is the individual vehicle, but their movement follows the approach of the macroscopic models and is governed by the average speed on the travel link.

- **Microscopic** models simulate the movement of individual vehicles based on car-following and lane-changing theories. Typically, vehicles enter a transportation network using a statistical distribution of arrivals and are tracked through the network over small time intervals (e.g., one second or less).

Simulation models require a large amount of input data and considerable effort to validate the data and manipulate calibration parameters. However, they are the only way of directly forecasting drive cycles under project.

Simulation models are most often used on larger projects when the time and effort required for model application pays off in terms of enhanced project design. The development of improved speed estimates for emissions modeling will be a by-product of the traffic analysis. The output of these models – which includes second-by-second vehicle trajectories for every vehicle in the simulation – can generally be used to develop drive-cycle inputs. Average speed estimates can be developed from this output. However, if such models are already being used for other reasons, it makes sense to use the more detailed drive-cycle output to improve the emissions estimates.

4.6.3.3 *"Typical" Drive Schedules for Different Project Types*

This approach is a simplification so that simulation models are not needed for every project. The concept is to use simulation models, preferably microscopic, to develop prototypical drive cycles that are representative of certain conditions. However, while it is possible to design tests to capture the influence of certain factors, such as congestion level and link location relative to a bottleneck, actual drive cycles will be influenced by site-specific design factors such as interchange and intersection geometry. As this method is currently untested, care should be taken if agencies decide to develop their own representative drive cycles.

As an example of how this might be applied, first consider that a set of representative drive cycles for freeways have been developed using microsimulation experiments, and the drive cycles vary by volume-to-capacity level and link type (e.g., upstream from bottleneck, downstream from bottleneck, ramp). If a lane is added to the freeway, then the v/c level will decrease, indicating a new set of drive cycles. Clearly this approach is not as accurate as performing unique simulations, but it could be applied in the planning stages of a project to develop emission information quickly and cheaply.

4.6.4 Sample Data and Tools

As part of this research project, a tool was produced for generating operating mode distributions from the output of traffic simulation models. The tool takes output from traffic simulation models, in the form of second-by-second speeds for modeled vehicles, and converts these to operating mode distributions in the MOVES input format. The tool is a stand-alone executable file that is made available in conjunction with this report.

4.6.5 Examples

Example 4.6.1 – Defining Operating Mode Distribution Inputs Using Microscopic Traffic Simulation Models

Most commercially available microscopic traffic simulation packages have the option of producing individual vehicle trajectories as an output. These files vary in structure, but they include the instantaneous speed and acceleration for every vehicle in the simulation period for every second of the simulation. This can lead to files with enormous numbers of records; a multiple hour simulation in a high-volume corridor can easily exceed 100 million records.

The basis for converting the vehicle trajectories to an operating mode distribution is the same as used by MOVES: vehicle-specific power is computed for each vehicle for each second, the speed is noted, and it is assigned an operating mode bin. To accomplish this task, the following vehicle and link characteristic data are needed from simulation output:

- Link number.
- Vehicle number.
- Time stamp (second).
- Vehicle type – this is the MOVES sourceTypeID. Simulation models use a different definition for vehicle class than MOVES, so a cross-walk needs to be established between the two types. The soureTypeID determines the parameters of the VSP equation.
- Vehicle speed.
- Vehicle acceleration – if not present, this can be determined from the change in speed from the previous second for each vehicle.
- Vertical grade of the link (percent).

A VSP equation is then applied to the data and parameters:

$$VSP = (A/M) \bullet v + (B/M) \bullet v^2 + (C/M) \bullet v^3 + (a + g \bullet \sin\theta) \bullet v$$

Where:

A, B, and C = road load coefficients specific to a source type;

M = fixed mass factor for the sourceTypeID in metric tons;

g = acceleration due to gravity (9.8 meters per second^2);

v = vehicle speed in meters per second;

a = vehicle acceleration in meters per second^2; and

θ = (fractional) road grade.

Finally, VSP for each individual vehicle and time stamp is aggregated into an overall VSP distribution (percent time in each opMode category) for all vehicles.

Example 4.6.2 – Developing Link Drive Schedules from Vehicle Probe Data

In this example, the MOVES user has acquired instrumented vehicle data from either a regional study of local drive cycles or from runs on a specific project corridor by a small number of instrumented vehicles. This example is based on a regional study of local drive cycles in Kansas City (U.S. EPA, 2008). Similar data with second-by-second speed information are known to exist for multiple regions of Texas (Farzaneh et al., 2013) and are likely to exist from GPS-based household travel surveys conducted in many metropolitan areas, such as Atlanta, Cincinnati, Chicago, Portland, and Los Angeles.[9] Some research projects have used instrumented vehicle data to develop MOVES drive schedule inputs for specific corridors. If this type of corridor-specific data is available for a project-level hot-spot analysis, procedures would be followed that are similar to those when using a subset of regional data. This example explains how vehicle trajectories from probe vehicles (field data using GPS or logger-equipped vehicles) traveling throughout the region or on the project-specific corridor can be used to create the link drive schedule input for a MOVES project-level run.

Step 1: Gather in-use driving data for the fleet of interest. This typically includes outfitting selected vehicles from the fleet with GPS or OBD data loggers that collect data similar to that collected for the Kansas City study. In the Kansas City study, a large number of light-duty vehicles were equipped with data loggers which operated while the vehicles were driven on various routes. If collecting data only on the project-specific corridor, a smaller number of vehicles could be used. The data loggers collected and stored second-by-second vehicle operating information, including vehicle speed, engine speed, mass air

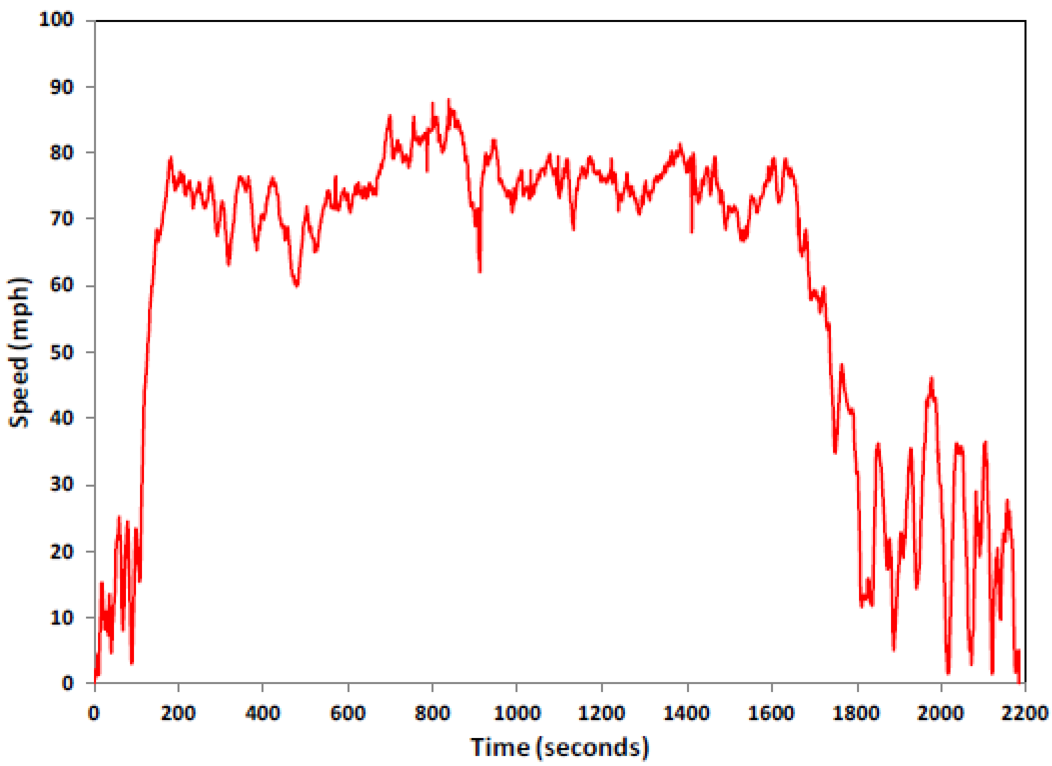
[9] GPS travel survey data are archived at the National Renewable Energy Laboratory Transportation Secure Data Center.

flow, and other data, as well as the time, and the latitude and longitude of the location of each second of driving.

Step 2: Interpret and QA/QC the driving data. Once the second-by-second data are collected, they need to be checked for accuracy and consistency. This typically involves the manual examination of plots of second-by-second driving data, in addition to analysis of statistics for each trip (e.g., mean speed, number of seconds at idle, maximum and minimum acceleration).

Step 3: Convert the driving data into a pool of micro-trips. The Kansas City data were divided into "micro-trips," where each micro-trip was defined as the driving that began either at vehicle-on or after an idle period, and ended either at vehicle-off or when the vehicle returned to idle. Figure 4.6.1 shows an example plot of the second-by-second speeds for a single micro-trip that is about 37 minutes long and consists mainly of freeway driving. Care should be taken in deciding whether or not to include idling in the micro-trip since it would be an important consideration for certain transportation projects, such as transit terminals, but not as much for other projects such as freeway widening.

Figure 4.6.1 Example Plot of Second by Second Speeds for a Micro-Trip



Source: Xu, Guensler and Rodgers (2013).

Step 4: Select the micro-trips that occur on the project corridor. The micro-trips that occurred at least partially on a project corridor could be selected from the regional data set using the latitude and longitude information. This step can be skipped if the instrumented vehicle data were collected only on the project corridor.

Step 5: Select micro-trips that represent typical conditions on the project corridor. This involves comparing each individual micro-trip with the pool of all micro-trips on the corridor and choosing the micro-trips that best represent the overall pool. If a large number of micro-trips are available, this step allows for outlier cases to be discarded. If only a few micro-trips are available, this step will allow for the selection of the ones that best represent the average conditions. In the Kansas City study a vector comparison process was used to select a small number of micro-trips that best represented the overall pool of micro-trips.

Step 6: Post-process the selected drive schedules. This includes checking statistics for the final drive schedule, looking at plots of second-by-second speed and acceleration to check for anomalous data, and, depending on the data logger used, possibly smoothing out noise from the stored driving data.

The steps in this example may entail a significant level of effort. For smaller link-level projects, users may opt for simply inputting the link average speed and percent grade using the links input table as described in Section 4.5 and from this, MOVES would calculate operating mode distributions the link. However, the approach in this example may be worthwhile for larger-scale efforts in which accurate site-specific link-level emissions estimates are required.

4.7 Off-Network Data

4.7.1 Description and Format

Off-network emissions constitute a broad array of situations in MOVES. The inclusion of off-network features in MOVES was intended to better characterize the spatial and temporal distribution of emissions that are not produced on the roadway network. Examples of off-network locations include parking lots, with vehicle start-up and evaporative emissions; truck stops, with long-duration idle emissions; and bus terminals or ports, with low speed and short-duration idle emissions. These data sources are expected to become a larger part of overall emission inventories as emission standards continue to drive down over-the-road emissions. Off-network application is also intended to decouple the spatial and temporal allocation of these emissions from traditional VMT-based approaches, which assign start and evaporative emissions to roadways with the highest VMT. Off-network application is designed to better account for real-world factors such as daily commuter flow, truck stops with long-duration idle, the concentration of starting and parking in neighborhoods or workplaces, and operation that that occurs outside of the VMT-sampled network.

Characterization of off-network activity depends on the analysis scale chosen by the user. For project-scale analysis, specific off-network locations are defined and populated based on site-specific data. This is done primarily through the "offNetwork" data table, which allows users to define specific locations (e.g., parking lots, bus terminals) within the project domain, and provide inputs for vehicle population, start fraction, idling fraction and parking fraction (inactive in MOVES2010a and 2010b) for each specific location and time period. However, **off-network locations which are dominated by running emissions, such as port terminals, are more appropriately set up in the project scale by defining these locations as links and populating the model accordingly, as described in Sections 4.2-4.6.**

Because of the highly specialized nature of off-network analyses, this feature of MOVES has not been widely used. Roughly 80 percent of respondents in a 2012 survey of MOVES users said they had not conducted off-network project-level analysis, or did not know if data were available from their agency to conduct such an analysis.

MOVES2014 provides two additional options for user inputs, which are not discussed further in this handbook:

- **Hotelling Importer** – In the county and project data manager, users will now have the option of providing local hotelling activity by long-haul combination trucks (source type 62. Users can specify the fraction of long-haul combination trucks (by model year) that are in extended idle mode, Auxiliary Power Unit (APU) mode, or engine-off mode during the modeling period, as well as total hotelling hours.

- **Starts Importer** – Users may input starts per day, the distribution of starts throughout the day, starts by source type, monthly adjustments, and/or vehicle soak times.

4.7.2 Source of Embedded Data and EPA Guidance

The following EPA guidance documents are relevant:

- MOVES2010b User Guide: Section 2.2.2.1, Domain/Scale; 2.3.3.4.11, Links Importer; and 2.3.3.4.15 Off-Network Importer; and Appendix G – MOVES Project-Level Example.
- PM Hot-Spot Analysis Guidance: Section 4.2.2, Transit and Other Terminal Projects (p. 31), and Section 4.5.9, Off-Network (p. 47).
- CO Analysis Guidance: Section 2.4.8 and Section 4.0 (example of computing start and idle emissions for a transit facility).

Off-network inputs are not discussed separately in Volume 1 because they are typically dealt with by the model through embedded assumptions and indirectly through other inputs (source type population), rather than as direct user inputs. However, these embedded assumptions are discussed here for context.

4.7.2.1 National and County-Scale Inputs and Data

For national and county-scale analysis, total off-network activity is estimated across the modeling domain, with allocation factors used to apportion off-network activity to user-defined zones within the domain (counties, by default). This allocation does not impact total emissions in the model domain, but can be used to improve the spatial resolution of emissions estimates.

National and county-scale off-network inputs are captured by defining trip characteristics of vehicles. The sampleVehicleTrip table includes trip-level data from instrumented vehicle activity studies, and is used as the basis of the number of starts (based on source type population) and source hours parked (SHP), two fundamental activity elements of off-network start and evaporative emissions. The fundamental activity basis for extended idle is Source Hours Idling (SHI), calculated from another user input, IdleSHOFactor, which defines the amount of extended idle operation per hour of on-the-road operation (SHO).

In additional to inputs that are used to estimate total off-network activity, the second component of off-network emissions at the national/county scale is the allocation factors: startAllocFactor, SHPAllocFactor, and idleAllocFactor. These tables store allocation factors that distribute activity from the modeling domain to individual zones. For the national embedded case, these factors allocate national activity to the county level based on VMT, so the decoupling of these emission processes from running emissions is not realized in the default treatment of off-network emissions.

For county-scale analyses, zones can be defined to more strategically place off-network emissions based on residential versus commercial areas, truck stops, etc. This feature in MOVES is generally not used, however; with the integration of MOVES with programs that produce gridded emissions for air quality modeling (e.g., SMOKE-MOVES), there is less demand for spatial allocation to the subcounty level within MOVES.

4.7.2.2 Project-Scale Inputs and Data

At the project scale, estimating off-network emissions requires data characterizing the specific off-network location being modeled. For some inputs, embedded defaults can be used, but a complete off-network analysis cannot be performed without some site-specific data. In the MOVES User Guide, off-network data is discussed in Section 2.2.2 (Scale), 2.3.3.4.11 (Links Importer), and 2.3.3.4.15 (Off-Network Importer), as well as the project-level example in Appendix G.

The offNetwork table allows entry of the number of vehicles and the fraction of vehicle starting, parking or extended idling, to calculate emissions from these processes. This framework allows modeling of specific off-network locations dominated by start or extended idle activity (and parking, which is not active in MOVES2010 versions), including:

- Parking lots/garages;
- Truck stops; and
- Residential neighborhoods (e.g., gated communities).

Emission can also occur when vehicles are operating, but not accumulating significant VMT; or operating in areas not captured by VMT measurement estimates, including commercial locations. Examples of this would include:

- School drop-off zones;
- Bus terminals; and
- Port terminals.

Such locations where the majority of activity is running operation, rather than starts or parking, are more appropriately modeled in MOVES by defining these locations as links, rather than using the offNetwork table,. A list of the data tables requiring population for off-network analysis is shown in Table 4.7.1. These inputs are suitable for an off-network location where the primary activities are starting, idling, and parking.

Table 4.7.1 Overview of Data Sources for Off-Network Population

Project-Scale Input	Description	Embedded data available?
Off-Network	Parking Lot: population, fraction of vehicles starting/parking/idling	No
Age Distribution	Similar to county-scale – defines fraction of vehicles age 0-30	Yes – national level
Meteorology	Needed for all analyses[a]	Yes
Fuel Supply		
Fuel Formulation		
Fuel Type and Technology		
I/M		
Operating Mode Distribution	Parking Lot: soak distribution Extended Idle (opmode 200)	No

[a] Discussed in Sections 4.8-4.10 of this document.

4.7.3 Data Sources, Procedures, and Methods

Characterizing an off-network project to a high degree of detail can require significant site-specific data on vehicle counts, mix, age distribution, and activity from the off-network location. This level of detail generally is not available unless a specific study has been undertaken to collect these data; for this reason, most MOVES users to date have not undertaken off-network analyses. It is possible to set up simplified off-network scenarios, however, using estimates of how many vehicles are in the off-network modeling domain, and a simplified representation of their activity. Data sources to quantify these two components are emerging, so conducting a basic off-network analysis is becoming more feasible. Table 4.7.2 provides potential data sources focused on quantifying population and activity.

Table 4.7.2 Overview of Data Sources for Off-Network Population and Activity

Data Source or Procedure	Uses and Advantages	Limitations
Entrance/exit data	Available for certain off-network locations, including parking garages, port terminals. Excellent source of data for estimating population. Starts can be inferred as well.	Certain locations, e.g., parking garages, will not provide vehicle-specific data.
Parking studies	Common to evaluate parking usage and future planning. Can be used to estimate start and parking fraction, and in some cases operating mode (soak) distribution.	Tend to focus on utilization of existing spaces, not direct measure of vehicles entering/ exiting during the hour.
Field observation – with or without license plate information, vehicle identification number decoders and registration database	Can be as simple as counting vehicles entering/exiting for a period of time, observing extended idle, or counting vehicles in parking lot. License plate info can be useful for determining age distribution.	Time-intensive.
Fleet records	If locations are fleet-centered, such as bus terminals or distribution centers, fleet tracking data can be used to develop population estimates.	Would apply to a narrow range of off-network locations with vehicles from small number of fleets.
Satellite imagery	Can easily capture "snapshot in time" for any outdoor location (parking lot, truck stop, port terminal, etc.). Can be useful for quantifying extended idle.	Only a snapshot in time, not able to control when data is taken; not applicable to indoor/covered locations such as parking garages.
Portable data loggers	Inexpensive, small, and easy to install on vehicles equipped with On-Board Diagnostics/Electronic Control Modules. Can be useful for quantifying extended idle.	Requires vehicle recruitment and sampling.
Third-party data logging/reporting (e.g., insurance company safe driver programs)	Becoming more prevalent; does not require vehicle recruitment or instrumentation. Summary data can be purchased from insurance companies.	Limited sample.
Heavy-duty vehicle telematics	Becoming more prevalent; does not require vehicle recruitment or instrumentation. Summary data can be purchased from trucking companies. Can be useful for quantifying extended idle.	Limited sample.

Population and activity, and the data sources used to estimate them, vary greatly depending on whether the location is a parking lot dominated by light-duty start/ parking, or terminal dominated by heavy-duty bus or truck operation. The data sources below tend to be tailored to certain types of projects, depending on the analysis need.

Forecast year data. Total population may be projected for a forecast year if growth factors for the site or facility can be estimated. For other activity parameters (such as operating mode distributions), unless a detailed simulation model has been developed, forecast year inputs will typically be assumed the same as base year inputs.

4.7.3.1 Entrance/Exit Data

Some off-network locations, by their nature, track vehicles entering and exiting the premises. Parking lots/garages with ticket systems, or port terminals with gate entry/exit data, are prime examples of this. From this estimate of vehicle population, the fraction of vehicles starting (departing) or parking (remaining) can be estimated to populate the "off-network" table. Tracking of individual vehicle entry/exit to a parking lot can also provide estimates of operating mode (soak) distribution. The second example in Section 4.7.5 uses port gate entry/exit data as the basis for vehicle population within the port.

4.7.3.2 Parking Studies

It is common for municipalities to conduct parking studies to understand how capacity is being used throughout the day and week, and to plan for future demand. While levels of detail differ across studies, these studies often provide, for individual parking lots, the number of spaces occupied in any given hour, and in some cases, the change hour to hour. From this estimates of vehicle population, the number of vehicles starting (departing) parking fraction can be estimated to populate the off-network table. The first example in Section 4.7.5 uses data from an existing parking study to estimate vehicle population, start fraction, parked fraction, and operating mode (soak) distribution, and calculate the resulting emissions.

4.7.3.3 Field Observation

Field observation studies are akin to parking studies, though tailored more specifically to quantifying vehicle population and activity needed for emissions estimation. Field observation can be as simple as recording the number, type, and time of vehicles entering and exiting over a day, to enable estimation of population, start fraction and parking fraction. A more sophisticated approach is to use license plate recognition software (see Section 4.1) to allow quantification of vehicle source type and age distribution. Tracking individual vehicles entering, parking, and exiting will provide data for operating mode (soak) distribution as well.

4.7.3.4 Fleet Records

Fleets track the location of fleet vehicles, particularly as GPS becomes more standard. Off-network locations dominated by one or a small number of fleets can use these records to estimate populations and perhaps activity in fleet locations. This is a specialized data source, but could be very valuable for specific locations. Bus terminals, port terminals dedicated to one company, or taxi fleets would be some examples where fleet data could be used in this way.

4.7.3.5 *Satellite Imagery*

Satellite imagery is now easily available on the Internet and can be used to capture a "snapshot in time" for any outdoor location (parking lot, truck stop, port terminal, etc.). Satellite imagery has been used to estimate total parking capacity in an urban area [cite], which in combination with estimates of parking utilization can be used to estimate the population of vehicles parked. Drawbacks of satellite imagery are that it is only a snapshot in time, with no control when data are cleaned; and it is not applicable to indoor/ covered locations such as parking garages.

4.7.3.6 *Portable Data Loggers*

The availability of small, portable data loggers that are unobtrusive and can be installed easily by a technician (or by vehicle owners themselves) is increasing. These devices are designed to interface with on-board diagnostics or electronic control module data streams, and can stay on the vehicles for weeks at a time. Some devices include GPS data, allowing activity at specific locations to be isolated an analyzed. This allows characterization of activity in specific off-network locations, including startups, parking duration, soak distribution, and distribution. While the data loggers are easy to put on the vehicles, an effort to instrument vehicles for this purpose does require an up-front effort to recruit participants and oversee the instrumentation, data collection, and analysis needs.

4.7.3.7 *Third-Party Data Logging/Telematics*

Another option for logged activity data mentioned above is data collected by third-party entities for other purposes. Some insurance companies are putting in place "safe driver" programs that reward safe driving habits, through use of data logging devices similar to those discussed above. Summaries of these data may be purchased from insurance companies and their data providers, and could provide activity data for certain off-network locations. Heavy-duty fleets track truck movement using telematic systems [cite], which may be purchased from trucking companies. An advantage of this data source is that it does not require vehicle recruitment or instrumentation. However, the data are for a limited sample, not controlled by the user, and may only be applicable to a subset of off-network conditions.

4.7.4 Sample Data and Tools

There are no tools available to aid in the development of off-network inputs for MOVES. Sample data are contained in the examples in the next section.

4.7.5 Examples

Because off-network analysis encompasses a wide variety of situations, three examples are provided. These include:

1. A parking lot, dominated by start and park activity from light-duty vehicles;
2. A port terminal, dominated by low speed and short-duration idle from heavy-duty diesel “drayage” trucks; and
3. A rest area with extended idling from long-haul diesel trucks.

Two of these examples – the parking lot and the rest area – are off-network according to the MOVES definition. The port is a location that would not be classified as a road (i.e., it is off the highway network), but is modeled as a link rather than using the off-network MOVES input table. It is included here to show how a unique off-highway location such as a port terminal can be modeled as a link using the project scale in MOVES. The parking lot example shows how this situation can be modeled as a link as well as an off-network location, in order to capture running emissions associated with vehicles in the parking lot.

4.7.5.1 Parking Lot

Background

In 2002, the BSC Group performed a parking lot study in Belmont, Massachusetts (BSC Group, 2002), also known as an accumulation study since it tracks the accumulation of vehicles in specific parking areas. The study characterized on- and off-street parking capacity for multiple areas across town. For this example, one municipal parking lot was used to demonstrate how parking study data can be applied to a simple project level example in MOVES. The Claflin Street Municipal Parking Lot was one of the off-street sites included in the study. This lot, shown in Figure 4.7.1, had 140 parking spaces at the time of the study. The lot can be modeled as an off-network link for engine start emissions and an urban unrestricted link for driving emissions.

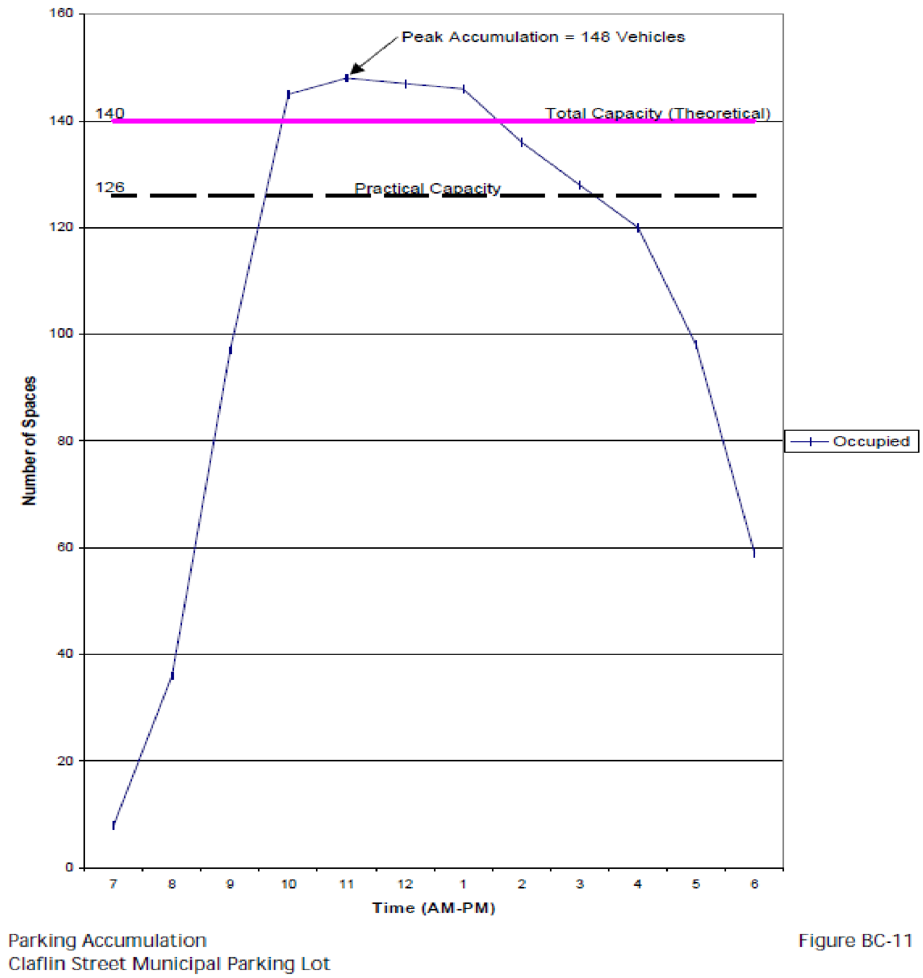
Figure 4.7.1 Claflin Street Lot, Belmont, Massachusetts

Source: Google Earth.

Defining MOVES Project and Data Sources

The parking accumulation study tracked the number of spaces filled in the Claflin Street lot hour-by-hour over the course of a day, with results shown in Figure 4.7.2. The study also tracked the duration of parking events in the lot (average of 5.9 hours), the average turnover (1.3 vehicles per space) and total vehicles parked in the lot over the course of the day (193). These data can be used to estimate population, start fraction, and operating mode distribution.

Figure 4.7.2 Parking Accumulation Data in Claflin Street Lot



Source: BSC Group (2002).

The definition of the project and data sources for each field are outlined in Table 4.7.3. Bold entries denote fields for which local data are developed from the Claflin Street study. This example takes advantage of the data collected in the study to populate vehicle population, start fraction, and parked fraction. The remainder of the necessary fields can be populated with MOVES defaults. For this example, the emissions from running operation within the parking lot are also included, based on an assumed average speed of 5 mph. This is not a required element of off-network analysis, but is included to show the relative emission contributions estimated between start and running emissions.

Table 4.7.3 Project Definition and Data Sources

Project-Scale Input	Definition for This Project	Data Sources
Period	Weekday 4:00-5:00 p.m., June 2002	–
Links	2	–
Off-Network	Claflin Street Municipal Lot	
Population	Vehicles in lot	Accumulation study
Start Fraction	Vehicle exiting lot	Accumulation study
Parked Fraction	Vehicle remaining in lot	Accumulation study
Link Source Types	Passenger cars	–
Age Distribution	–	MOVES National Database
Meteorology	–	MOVES Default
Fuel Supply	–	MOVES Default
Fuel Formulation	–	MOVES Default
Fuel Type and Technology	Gasoline	–
I/M	Not used	–
Operating Mode Distribution	Duration of parks	Accumulation study
Link Drive Schedules (Link 2)	Default (Urban Unrestricted)	–

Populating MOVES Inputs

Off-Network Data Table

Populating the off-network table in MOVES requires an estimate of vehicle population by source type, start fraction, extended idle fraction, and parked fraction. Because this study did not track the ingress and egress of specific vehicles, assumptions are required to develop these estimates based on the study data. For this simple example, all vehicles are assumed to be passenger cars. For the specific study hour (4:00-5:00 p.m.), the parking accumulation data presented in Figure 4.7.2 can be used to estimate population, start fraction, and parking fraction. Population is defined as the number of vehicles in the lot at the start of the hour (120). According to Figure 4.7.2, at 5:00 p.m., the data showed 100 vehicles in the lot. A simplifying assumption is that at this stage of the day, vehicles are only exiting. The change in vehicles is therefore assumed to be the result of 20 vehicles starting and exiting; this yields a start fraction of 20/120 = 0.167. There are 100 vehicles remaining parked, yielding a parked fraction of 100/120 = 0.833.

Entries for the off-network table are shown in Table 4.7.4.

Table 4.7.4 "Off-Network" Table Entries for Parking Lot Example

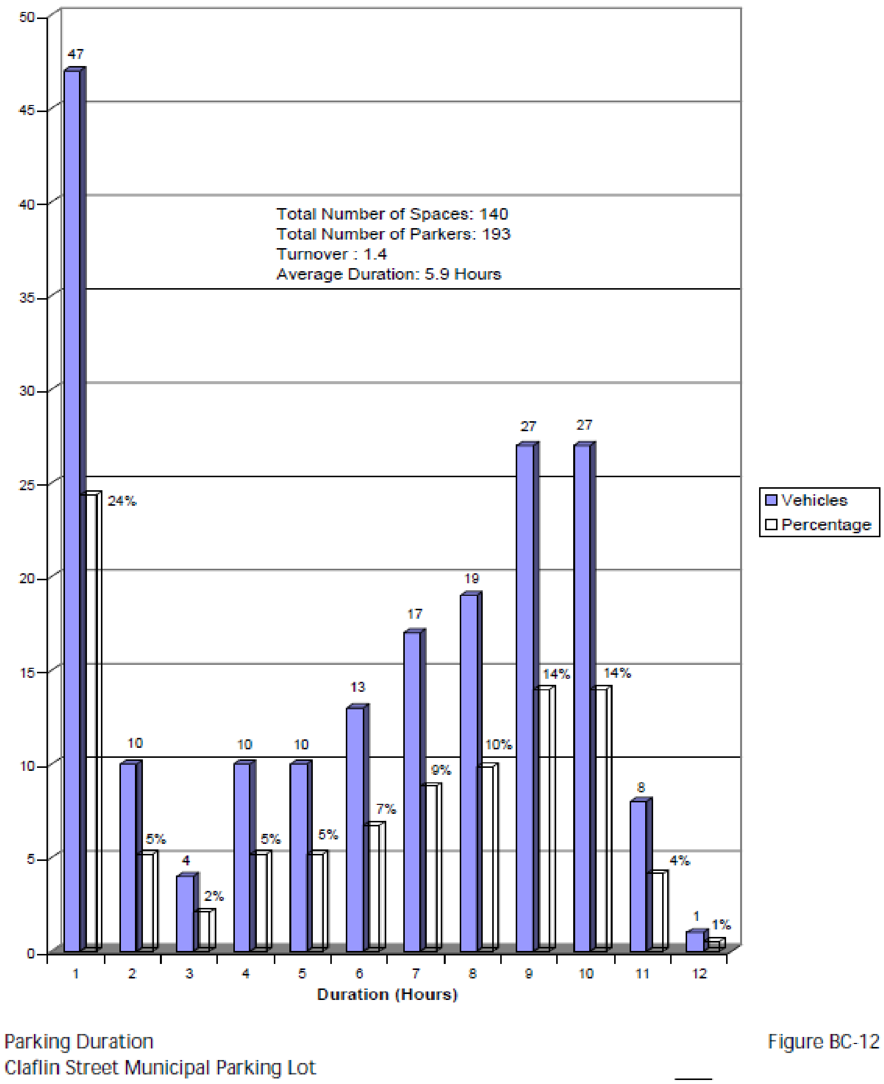
Field	Entry
sourceTypeID	21
vehiclePopulation	120
startFraction	0.167
extendedIdleFraction	0
parkingFraction	0.833

Operating Mode Distribution Data Table

For this example, the relevant operating mode distribution is how long the vehicles in the lot from 4:00-5:00 p.m. have been parked prior to starting. This characterizes the soak distribution that influences emissions upon start-up. This is also important for characterizing the evaporative emissions of parked vehicles, though project level in MOVES does not currently estimate evaporative emissions.

Ingress/egress tracked through a ticket system or observation is a direct source of soak distribution data; the Belmont study did not track soak durations of individual vehicles, but reported summary data in terms of the overall daily distribution. Realistically, the soak duration will change significantly over the course of the day; vehicles exiting the lot in the morning would have shorter soak durations than those existing in the afternoon. For this example, the daily soak duration is used as it is readily available in the study report. The daily soak duration for the Claflin Street lot is shown in Figure 4.7.3.

Figure 4.7.3 Distribution of Park (Soak) Times in Claflin Street Lot



Source: BSC Group (2002).

The percentages in each hour bin of parking duration in Figure 4.7.3 can be mapped directly to the operating mode bins in MOVES for soak duration. For this example, a parking duration of 1 hour is assumed to be split equally between < 30 minutes (MOVES bin 102) and 30 to 60 minutes (MOVES bin 103). Parking duration of 2 hours is assumed to be split equally between 60-90 minutes (MOVES bin 104) and 90-120 minutes (MOVES bin 105). Parking duration of 3-6 hours can be combined into MOVES bin 106, parking duration of 6-12 hours can be combined into MOVES bin 107, and parking duration of 12 or more hours can be used for MOVES bin 108. These mappings can then be used to populate the opModeDistribution table, as shown in Table 4.7.5.

Table 4.7.5 "opModeDistribution" Table Entries

Field	Entry
sourceTypeID	21
hourDayID	165
linked	1
polProcessID	102, 202, 302, 9102, 10102, 10202
opModeID	102,103,104,105,106,107,108
opModeFraction	$Fraction_{opMode\ 102}$…$Fraction_{opMode\ 108}$

The operating mode bins 102 through 108 were populated using the parking duration distribution as follows. The fractions given for each operating mode were identical among all of the pollutant process IDs (Table 4.7.6).

Table 4.7.6 Operating Mode Distribution

Operating Mode ID	Fraction
102	0.12
103	0.12
104	0.025
105	0.025
106	0.19
107	0.52
108	0

Source Type Age Distribution Data Table

The vehicle age distribution was taken from the MOVES national database. In project mode, MOVES does not have a default age distribution by county. In order to generate the age distribution, a separate MOVES runspec was created for a national project, and the default distribution (available on EPA's MOVES web site) was taken from this example. The passenger car age distribution was then read into the Belmont input database.

Link Data Table (On-Network Driving)

For this example the parking lot is also modeled as a link to include emissions from vehicles driving in the parking lot while entering and exiting (start emissions in MOVES only characterize incremental emissions added due to a vehicle start). This is included here to show the relative contribution of running versus start emissions. In order to add the running emissions to the start emissions for the parking lot, a separate link was needed to simulate these emissions. This was modeled as an urban unrestricted link in order to most closely simulate the slow and transient operation within the parking lot. Based on the size of the Claflin Street lot, the length of a typical drive out of the lot was estimated to be about 350 feet, or 0.0663 miles, and the average speed was assumed to be 5 mph. The link length and average speed were input into MOVES, and no specific VSP bins or drive cycles were given. MOVES automatically estimates the driving cycle based on the given average speed and the selected road type. The link volume was set at 20 vehicles, to be equal to the previously described number of starts (i.e., vehicles exiting). Again, the assumption for this example is that all cars operating during the modeled hour are departing the lot. The entries to the Link table are shown in Table 4.7.7.

Table 4.7.7 On-Network Link Entries

Field	Entry
LinkID	2
RoadtypeID	5
LinkLength	0.0663
LinkVolume	20
LinkavgSpeed	5
LinkAvgGrade	0

Results

The results are presented in Table 4.7.8, broken down by start and running exhaust emissions. The values given represent the total emissions by all vehicles that started and ran in the lot during the modeled hour. They are relatively low, which reflects that emissions from each vehicle are only produced for a small fraction of the hour, as it starts and exits the lot – and it is only 20 vehicles. The results represent average emission levels taking the emission rates of all modeled vehicle model years into consideration. As shown, in this example start emissions dominate for all pollutants. The amount of "warmed up" driving in the parking lot is almost inconsequential for the criteria pollutants, though it does contribute about 38 percent of total CO_2. This suggests that for parking lot studies, running emissions are only important to include if GHGs are being analyzed.

Table 4.7.8 Parking Lot Example Results

Emission Process	HC (g)	CO (g)	NO_x (g)	CO_2 (g)	$PM_{2.5}$ (g)
Running	1.7	26.9	3.4	1,536	0.001
Start	44.2	383.5	42.2	2,531	0.033
Total	45.9	410.4	45.6	4,067	0.034

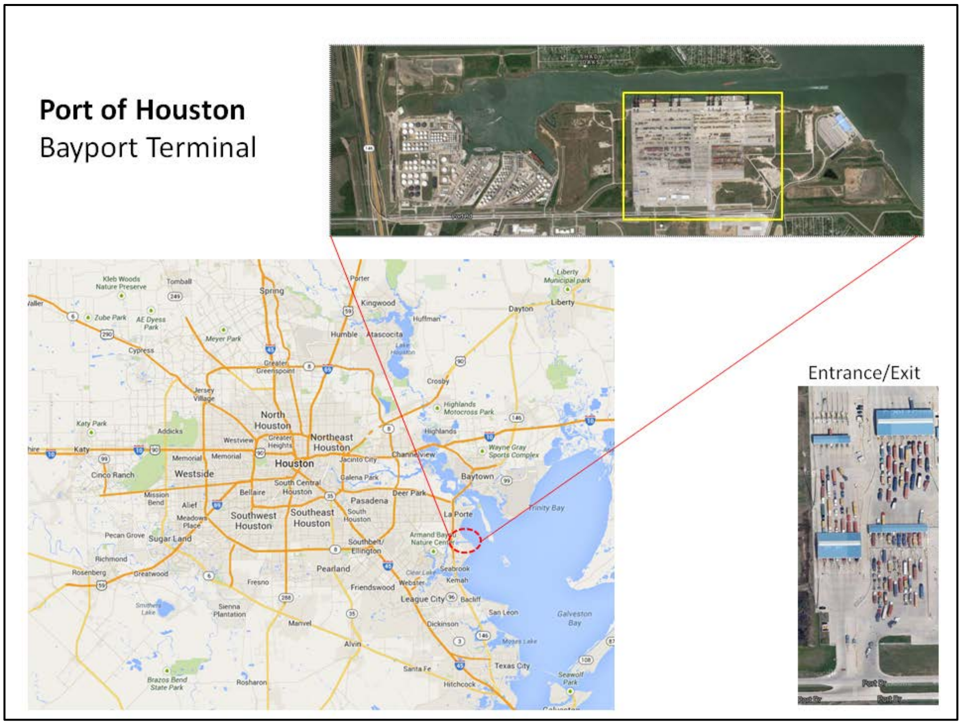
4.7.5.2 Port Terminal

This example does not fit the technical definition of off-network in MOVES, but it included to show how a specific location not classified as a road on the transportation network can be modeled using project-scale inputs.

Background

Bayport Terminal is one of two major container terminals in the Port of Houston. Combining Bayport with the Barbour's Cut terminal, The Port of Houston is the largest Gulf Coast container port (seventh in the U.S.), handling about 70 percent of containerized cargo in the U.S. Gulf of Mexico (Figure 4.7.4). In 2009-2010, a study sponsored by EPA, TCEQ and the Houston-Galveston Area Council characterized the activity and emissions of heavy-duty port "drayage" trucks in both the Bayport and Barbour's Cut terminals (EPA, 2010). Data collected from this study can be used to populate an off-network project in MOVES to estimate emissions from heavy-duty trucks in the port terminal.

Figure 4.7.4 Bayport Terminal, Port of Houston



Source: Google Maps and Google Earth.

The dray fleet is made up of combination heavy-duty diesel vehicles entering the terminal, operating within, and exiting the terminal for the purpose of dropping off and/or picking up containers for commercial ship traffic. Data collected from the drayage truck study over several months included gate entry/exit counts, fleet age distribution, vehicle activity inside the port and over the road, and emissions using portable monitors. During the study period, the Bayport terminal saw 30,000-40,000 entries per month, a significant amount of diesel truck activity not captured from "on-network" sources. Data collected during the study can be used to set up Bayport terminal as an "off-network" project in MOVES, to evaluate emissions produced in the terminal. For this example, the project is considered off-network because the activity (and hence emissions) within the port terminal would not typically be captured through standard vehicle count, HPMS, or travel model activity estimation approaches.

Defining MOVES Project and Data Sources

There are multiple approaches to defining Bayport terminal as an off-network project-level analysis within MOVES. These include using only the off-network input for MOVES project scale, using link-based and off-network inputs for MOVES, or using only link-based inputs for MOVES. The choice of these approaches depends on the aim of the analysis, and sources being modeled. The focus of this analysis is heavy-duty diesel trucks, which have no evaporative and very little start emissions, and will not be undergoing long-duration idle. Emissions from these trucks within the port will be generated due to "running" engine operation; what makes the port unique is the prevalence of low-speed, low-load operation. Finally, the goal of the analysis is to quantify emissions not already on a roadway link. Therefore, using only link-based inputs for MOVES to characterize activity only within the terminal is the best option to account for the majority of emissions, while maintaining a simple project setup.

Table 4.7.9 shows how each project-scale input needed for MOVES would be defined for the project using this approach. Bold entries denote fields for which local data are developed from the Houston port study. Although the study included on-board emissions data collection using portable emissions monitoring systems, the most resource-intensive and costly part of the study, emissions data are not needed to populate the MOVES inputs for project-scale analysis. The data collected in the study that are relevant to this example are gate entry/exit data, license plate video capture (a process similar to ALPR), and activity monitoring within the port.

Table 4.7.9 Project Definition and Data Sources

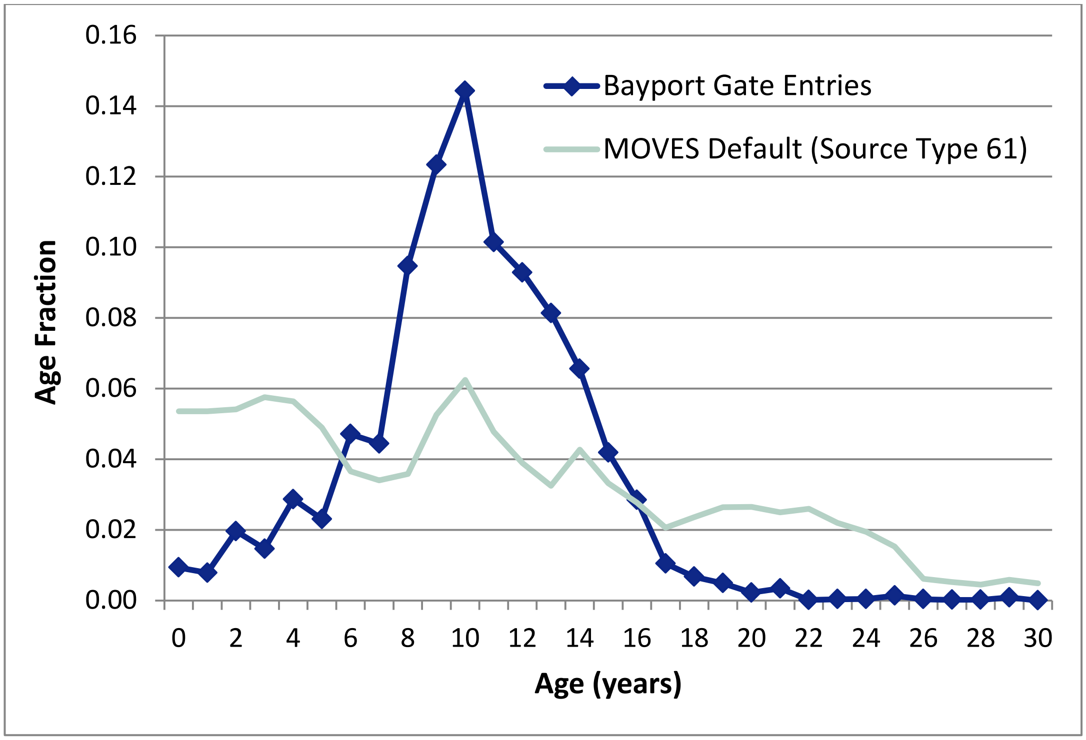
Project-Scale input	Definition for This Project	Data Sources
Period	Weekday 10:00-11:00 a.m. June 2009	–
Links	Single "within port" link	Portable activity monitoring with GPS
Off-Network	Not used, because majority of time in port is spent in operation, and start/evap emissions for diesel trucks is minimal	–
Link Source Types	100% combination short-haul trucks (Source Type 61)	–
Age Distribution	–	Captured plate data matched with TxDOT registration records
Meteorology	–	MOVES Default
Fuel Supply	–	MOVES Default
Fuel Formulation	–	MOVES Default
Fuel Type and Technology	Diesel	–
I/M	Not used	–
OperatingMode Distribution	Within port VSP distributions	Portable activity monitoring
Link Drive Schedules	Not used (not needed if VSP distributions supplied directly)	–

Populating MOVES Inputs

Age Distribution Data Table

Age distributions for port trucks are important to characterize, as these trucks may be older than their over-the-road counterparts. Age distribution data are available from capture of truck license plates entering the gate at the Bayport terminal gate, and matched against truck registration data. In this study, license plate data were captured as part of remote sensing emission measurements; however, for the purpose of populating MOVES, automatic license plate reader technology could be used to solely gather the needed information. Age distribution data gathered in the study (in 2009) are shown in Figure 4.7.5. The embedded data for MOVES for single unit combination trucks (source type 61), where drayage trucks would be classified, are also shown. Note that there is a much higher fraction of middle-age trucks and much lower fractions of new and old trucks than in the MOVES embedded data.

Figure 4.7.5 Age Distribution Data from Bayport Gate Entry Data



The Bayport gate entries shown in Figure 4.7.5 were entered into MOVES via the sourcetypeAgeDistribution table. This table was populated as shown in Table 4.7.10.

Table 4.7.10 SourceTypeAgeDistribution Table Entries

Field	Entry
sourceTypeID	61
yearID	2009
ageID	0…30
ageFraction	Fraction $_{age\ 0}$…Fraction $_{age\ 30}$ (See Figure 4.7.5)

Link Data Table

MOVES provides versatility for setting up this type of project depending on the mix of vehicles and nature of activity at the project location. Because the majority of emissions in the port are from running exhaust emissions over a unique set of low-speed, low-load operation, this project can be set up to capture within-port operation as a single link, with a unique operating mode distribution. This is done through population of the Link and OpModeDistribution tables.

Data in the Link table for this example associate within-port operation with a specific link, and provide the population of trucks operating within the port. The primary inputs for Link are linkLength, linkVolume, and linkAvgSpeed. In this example, linkLength, linkVolume, and linkAvgSpeed only have meaning with respect to the calculation of total activity within the port, defined as Source Hours Operating. Within MOVES, SHO is calculated as follows:

$$SHO = (linkVolume * linkLength)/linkAvgSpeed$$

SHO can be calculated directly from gate data, because the entry and exit time of all trucks in the port during the hour being modeled are available. SHO is the total amount of vehicle-hours calculated for a June day from 10:00-11:00 a.m. in Bayport: 149 vehicle-hours. This accounts for trucks already in the port as of 10:00 a.m., trucks entering between 10:00-11:00, and the amount of time they spent in the port during that hour, as tracked by the exit data.

For this example, linkVolume is set to 149, and linkLength and linkAvgSpeed are set to one to calculate SHO equal to the observed vehicle hours. The Link table can then be populated as shown in Table 4.7.11.

Table 4.7.11 "Link" Table Entries

Field	Entry	Notes[a]
linkID	1	
countyID	48201	Harris
zoneID	482010	
roadTypeID	5	Arbitrary; not a road in transportation system, drive cycle will be provided
linkLength	1	
linkVolume	149	
linkAvgSpeed	1	
linkDescription	"Within port"	Optional field
linkAvgGrade	0	

[a] This column is not part of the input table.

Operating Mode Distribution Data Table

The operation of trucks within the port is also important to characterize for this example. Trucks in the port operate at very low speeds, with considerable short-duration idle while waiting in queues and during loading/unloading. For the Houston port study, the needed data were obtained directly from portable activity monitors placed on trucks, which measured vehicle speed, acceleration, and location along with other parameters. Since the monitors were monitoring truck activity outside the port as well, GPS data were required to isolate the activity of the truck in the port. Inexpensive portable data monitors can provide GPS in addition to standard vehicle parameters; many trucks fleets are now equipped with telematics systems, which can also provide these data.

In the absence of such activity data, the operating mode distribution in the port can be approximated by assigning a very low average speed in the link (e.g., 2.5 mph). This will invoke embedded drive cycles with most operation in the idle and low-speed regime, meant to represent "creep" operation.

Based on the Houston data, the opModeDistribution table was populated as shown in Table 4.7.12. As shown the majority of operation (two-thirds) is idle, with the remainder of time spent in very low power bins. Nearly all operation is below 25 mph.

Table 4.7.12 "opModeDistribution" Table Entries

Field	Entry
sourceTypeID	61
hourDayID	115
linkID	1
polProcessID	301
opModeID	opModeFraction
0 (braking)	0.02145
1 (short-duration idle)	0.67567
11 (speed < 25, vsp <0)	0.18305
12 (speed < 25, vsp 0-3)	0.09501
13 (speed < 25, vsp 3-6)	0.01707
14 (speed < 25, vsp 6-9)	0.00444
15 (speed < 25, vsp 9-12)	0.00093
16 (speed <25, vsp >12)	0.00033
21 (speed 25-50, vsp <0)	0.00094
22 (speed 25-50, vsp 0-3)	0.00074
23 (speed 25-50, vsp 3-6)	0.00020
24 (speed 25-50, vsp 6-9)	0.00006
25 (speed 25-50, vsp 9-12)	0.00004
27 (speed 25-50, vsp 12-18)	0.00005
28 (speed 25-50, vsp 18-24)	0.00000

Results

MOVES results for this example are shown in Table 4.7.13. Only running emissions are included in this example, as start emissions are assumed negligible. To put the results in context, the percent of Bayport emissions relative to NO_x, CO_2, and $PM_{2.5}$ estimates from all single-unit combination trucks (61) and all vehicles in Harris County for that hour are shown. These estimates were developed from a MOVES2010b inventory run in Harris County, TX using all embedded data for 10:00-11:00 a.m. on a June 2009 weekday.

Table 4.7.13 Port Terminal Example Results

Emission Process	HC (kg)	CO (kg)	NO_x (kg)	CO_2 (Metric Tons)	$PM_{2.5}$ (kg)
Running	2.6	9.0	19.6	2.1	1.1
Start	–	–	–	–	–
Total	2.6	9.0	19.6	2.1	1.1
Percent of Total Harris County 61s	–	–	2.2%	1.3%	2.0%
Percent of Total Harris County	–	–	0.2%	0.1%	0.4%

4.7.5.3 Truck Stop/Rest Area (Extended Idle)

Background

A report for the Pennsylvania Department of Transportation (Michael Baker, 2007) reviewed the many places and reasons for extended idling of diesel vehicles in the State. One of the prominent sources of idling was the overnight idling of long-haul trucks at truck and rest stops. The report made overall state-level estimates of idling and emissions, with specific numbers of truck stops and idling down to the county level. For this example, the published estimates were used to model a single "average" truck stop in Cumberland County, Pennsylvania. Cumberland County has the largest number of overnight truck parking spaces in the State. Values such as number of parking spaces, number of truck stops, and estimates of county-level idling were averaged to model a single truck stop in the County.

Defining MOVES Project and Data Sources

The project can be defined similarly to the parking lot example above; namely, the lot itself could be defined as an off-network link, and the running operation of trucks entering and departing the rest stop as a separate link. For this example only off-network extended idling is quantified. Data from the report were initially used to estimate the number of parking spaces in the modeled truck stop. For this example, the public rest areas and private truck stops were taken together. With 14 locations containing 1,515 spaces, the modeled truck stop would have 108 spaces. The period was taken to be summer, from 1:00-2:00 p.m. on a weekday in July 2007. Based on this information, the project setup is shown in Table 4.7.14.

Table 4.7.14 Project Definition and Data Sources

Project-Scale Input	Definition For This Project	Data Sources
Period	Weekday 1:00-2:00 p.m. July 2007	–
Link	1	–
Off-Network	Typical Cumberland County truck stop	Baker Report
Population	Vehicles in lot	Baker Report
Start Fraction		–
Idling Fraction	Vehicle idling in lot	Baker Report
Link Source Types	Long-haul combination	–
Age Distribution	–	MOVES National Database
Meteorology	–	MOVES Default
Fuel Supply	–	MOVES Default
Fuel Formulation	–	MOVES Default
Fuel Type and Technology	Diesel	–
I/M	Not used	–
Operating Mode Distribution	Not used	–
Link Drive Schedules	N/A	–

Populating MOVES Inputs

Off-Network Data Table

Populating the off-network table in MOVES requires an estimate of vehicle population by source type, start fraction, extended idle fraction and parked fraction. As with the modeling of the truck stop, these estimates were taken from the report for an average truck stop in the county. Only the extended idling from parked trucks was modeled at the project level. The report estimates that trucks idle for about 2,300,000 hours per year in the rest and truck stops in Cumberland County. From the report's estimate of seasonal breakdown of idling, we can estimate that about 230,000 hours of idling take place in the county in each of the summer months. According to the report, there are 1,515 truck parking spots across 14 truck stops in the county. Based on these estimates, there are 152 hours per month spent idling in each of the county's truck parking spaces, or 20 percent of the total available time available per space. We assume these hours are spread out equally over time (as daytime idling occurs during periods of driver rest) and over the spaces in the example truck stop.

For this example, we used 108 total spots in the rest area, the county average per truck stop. The total truck population for the project period is estimated as 66 trucks, based on the parking space utilization rate of 0.65 listed in the report. The number of trucks idling is estimated as 22, based on 20 percent of 108. This means that one-third of the truck population is idling (22/66) for this example, with the rest parked. These estimates become the entries for the off-network table are shown in Table 4.7.15. Only those trucks operating with extended idling were modeled in this example.

Table 4.7.15 "Off-Network" Table Entries

Field	Entry
sourceTypeID	62
vehiclePopulation	66
startFraction	0
extendedIdleFraction	0.333
parkingFraction	0.667

Operating Mode Distribution Data Table

The operating mode distribution is straightforward. All emissions are due to extended idling, which is operating mode 200. The pollutant process IDs correspond to extended idling for various HC, CO, NO_x, PM, and CO_2/energy calculations. The entries to the OpModeDistribution table are shown in Table 4.7.16.

Table 4.7.16 "OpModeDistribution" Table Entries

Field	Entry
sourceTypeID	62
hourDayID	145
linkID	1
polProcessID	102, 190, 202, 290, 302, 390, 9090, 9102, 9190, 10102, 10202, 10590
opModeID	200
opModeFraction	1

Results

The results of the example are shown in Table 4.7.17. To place these in context, the percent of truck stop emissions relative to NO_x, CO_2, and $PM_{2.5}$ estimates from all combination long-haul trucks (62) and all vehicles in Cumberland County for that hour are shown. These estimates were developed from a MOVES2010b inventory run in Cumberland County using all embedded data for 1:00-2:00 p.m. on a July 2007 weekday.

Table 4.7.17 Truck Stop Example Results

Emission Process	HC (kg)	CO (kg)	NO_x (kg)	CO_2 (Metric Tons)	$PM_{2.5}$ (kg)
Extended Idle	1.2	1.9	4.3	0.2	0.08
Percent of Total Cumberland County 62s	–	–	1.5%	0.5%	0.6%
Percent of Total Cumberland County	–	–	0.3%	0.06%	0.2%

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 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

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

monthID	zoneID	hourID	temperature	relHumidity
1	481410	8	38	46
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).
- PM Hot-Spot Analysis Guidance: Section 4.5.1, Meteorology (p. 42).
- CO Analysis Guidance: Section 2.4.1, Meteorology (p. 21).
- 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).

The EPA PM and CO Analysis Guidance state that temperatures must be consistent with those used for the project's county in the regional emissions analysis, as well as the air quality modeling inputs used in the hot-spot analysis. Meteorological data may be obtained from the National Weather Service as part of a site-specific measurement program, or from other local sources. Data should correspond to the specific time periods (months and hours) being analyzed.

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 data are collected via land-based stations, ships, buoys, weather balloons, radars, satellites, 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 (NMIM) 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 (1981-2000) 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 1999-2008 (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 Project 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 http://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.

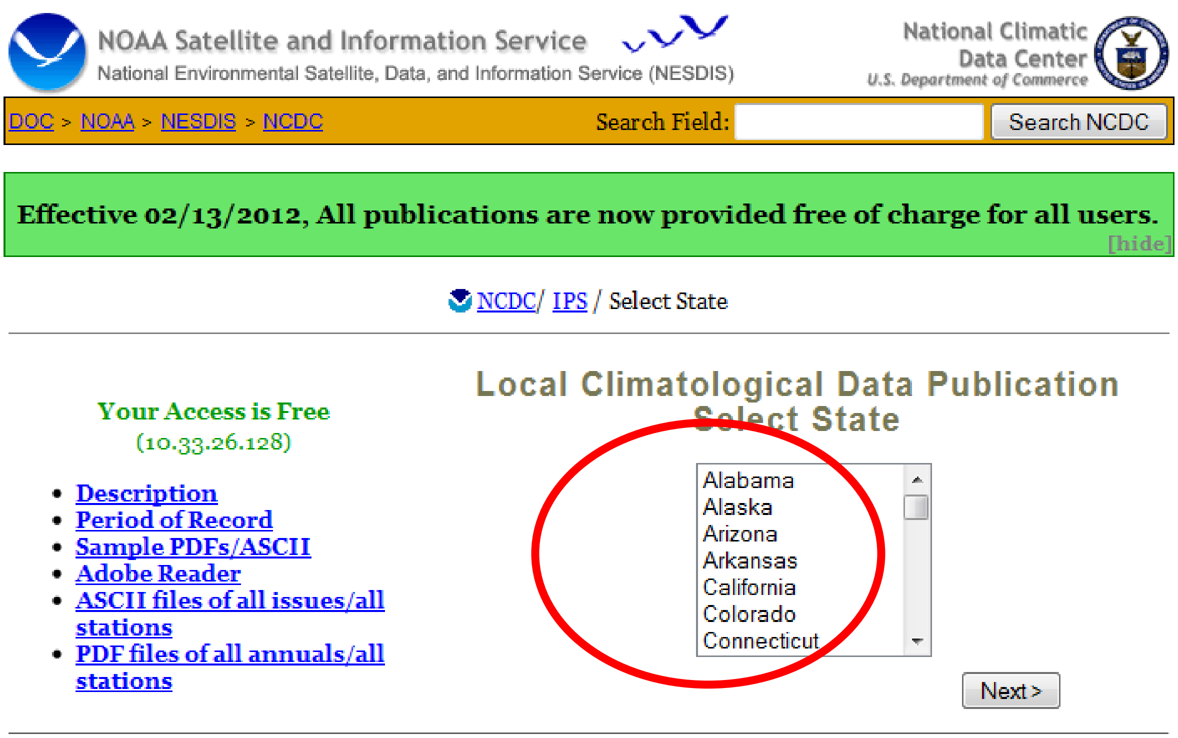
4.8.5 Examples

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 National Climatic Data Center web site at http://www.ncdc.noaa.gov/IPS/lcd/lcd.html.

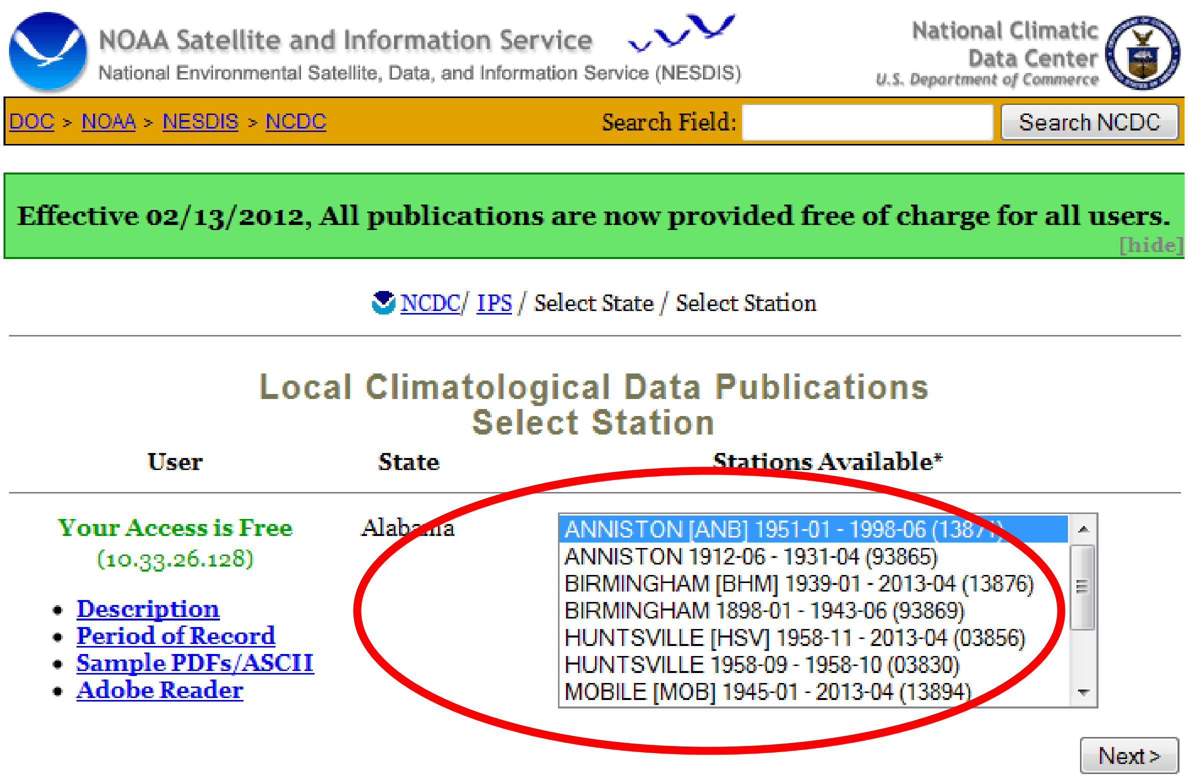
Step 1: Select the state you are interested in modeling and click Next >.

Figure 4.8.1 State Selection Screen
NCDC Local Climatological Data Report



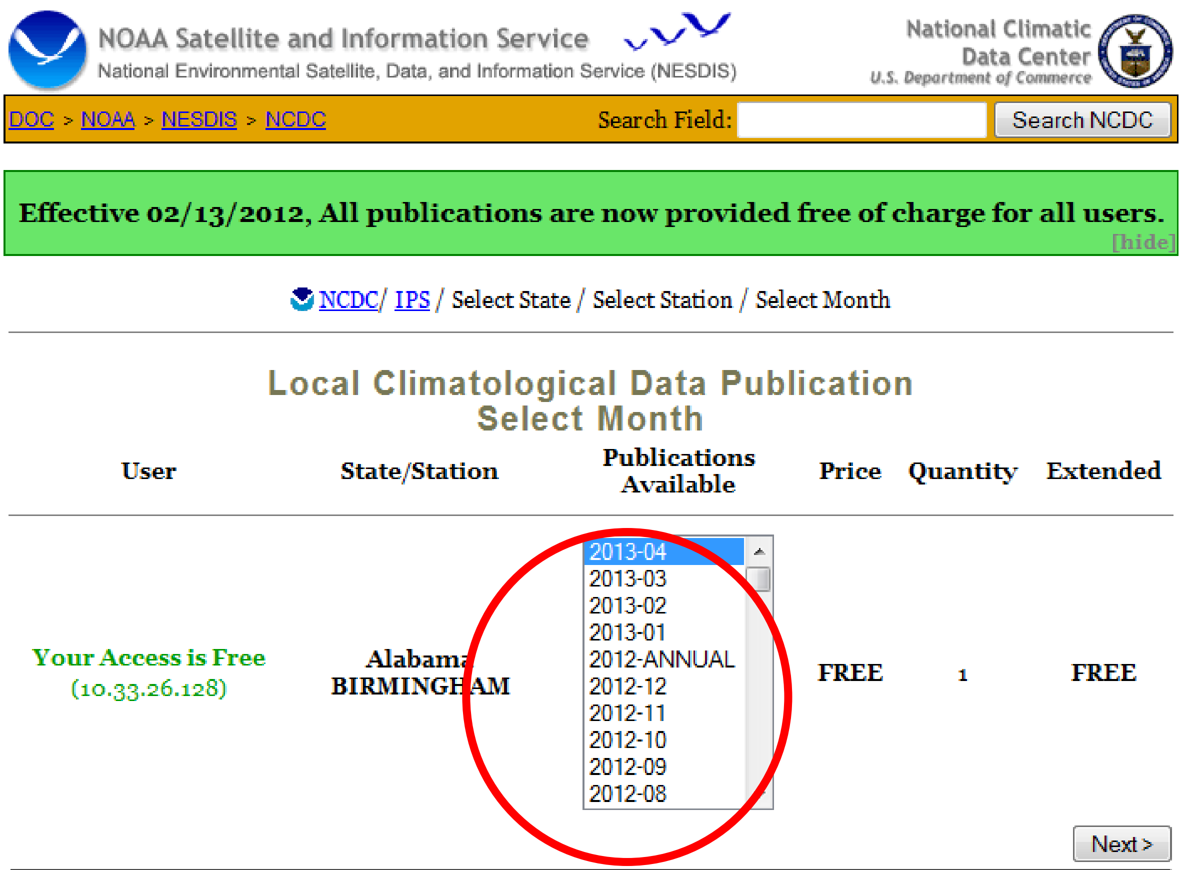
Step 2: Select the appropriate weather station and date range applicable to a modeling scenario and click Next >. Pick a station representative of each county you are modeling. For most users an airport Automated Surface Observing System (ASOS) station will be the best choice. Note that users modeling 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)	
	CEILOMETER	EFT CLD AMT	DRY BULB	DEW POINT	WET BULB	RELATIVE HUMIDITY	PRESSURE (Inches, HG) STATION	PRESSURE (Inches, HG) 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.)

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

SUMMARY BY HOUR

HOUR (LST)	AVERAGES										RESULTANT WIND (MPH)	
							PRESSURE (Inches, HG)					
	CEILOMETER	EFF CLD AMT	DRY BULB	DEW POINT	WET BULB	RELATIVE HUMIDITY	STATION	SEA LEVEL	VISIBILITY (Miles)	WIND SPEED (MPH)	SPEED	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 Project Data Manager.[10]

- **Step 7a –** Export the Meteorology Data Template from MOVES by selecting the Meteorology Data tab in the MOVES Project 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.
- **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 PDM.

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.

[10] 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.

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 Project 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, 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	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.

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 MOVES will use default fuel data if the fuel year is 2013 or later.

While the discussion in this section focuses on the current official version of MOVES, MOVES2010, it is important to note that significant changes are planned for MOVES2014 related to fuels. Per information shared publicly by EPA (U.S. EPA, 2013), major updates are being made to underlying fuel effects in the model, default fuel formulation and fuel supply entries, and in the ability of the user to update local fuels information. These changes may include retroactive changes to the current default fuel supply, as far back as 2004, but are dependent upon data availability. Analysis of the 2011 compliance data may be integrated into MOVES2014 default fuel supply data. MOVES2014 may also include 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.

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).
- PM Hot-Spot Analysis Guidance: Section 4.10, Fuel Supply and Fuel Formulation (p. 44).
- CO Analysis Guidance: Section 4.5.3, Fuel Supply and Formulation (p. 23).
- 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.[11]

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

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 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 profile, 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 formulation. 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 geographic 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 variations 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 recommended 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 should also 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-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 can be seen 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 should also 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 may also 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 also 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 (TxDOT) Districts (Figure 4.9.1).

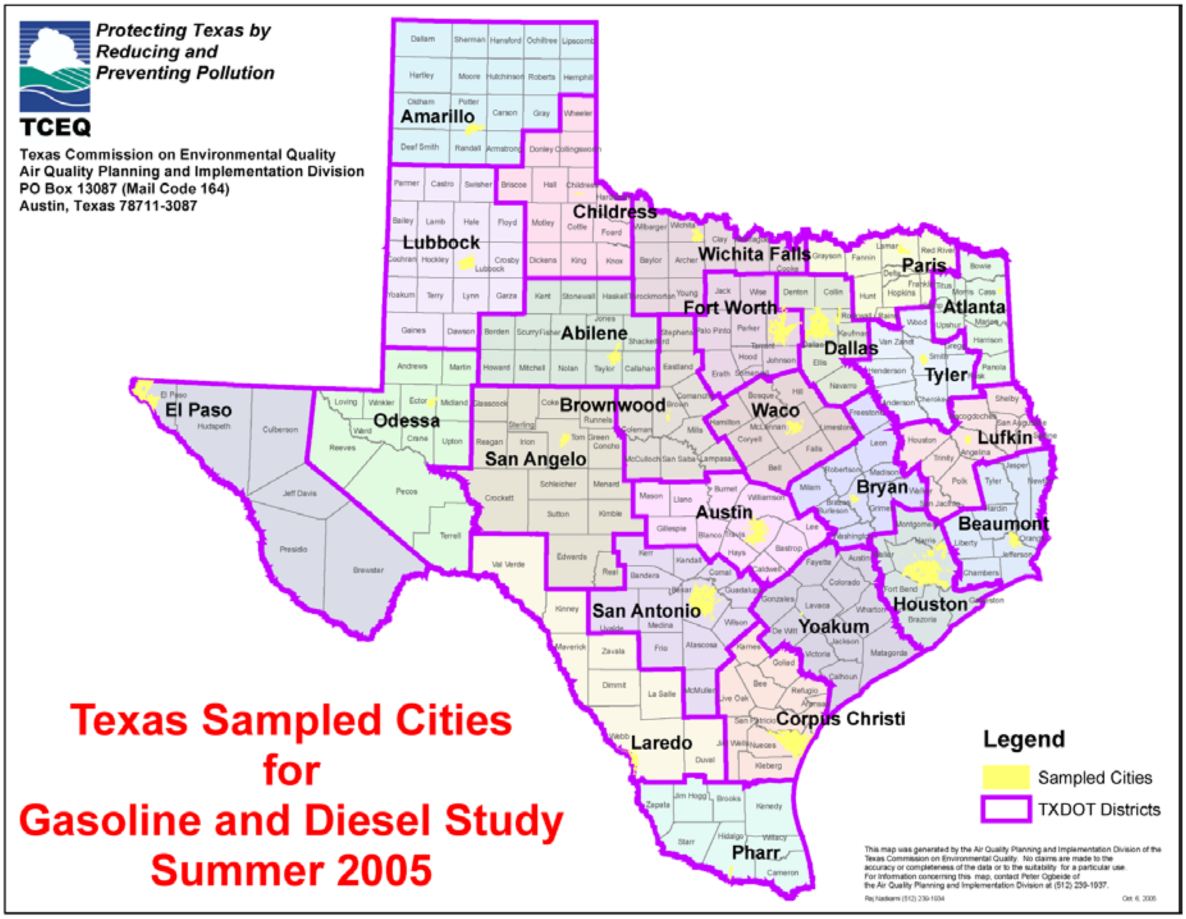
The first step in the process was site selection. Background information to help assess the geographic and temporal boundaries for sampling at retail stations was obtained and included:

- 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 2011. Specific contaminants, as they related to MOVES, were extracted from the data. Since three grades of gasoline were sampled, regular, mid-grade, 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 premium 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 (percent weight);
- Aromatics (percent weight);
- Benzene (percent weight); and
- Oxygenates (percent volume).

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 Project 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 Project 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 percent weight 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.

Table 4.10.1 I/M Coverage Data Table (continued)

Parameter	Description
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:

1. **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.

2. **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.

3. **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 I/M 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, 2,500 RPM/ Idle Test	Test performed while vehicle idles and at 2,500 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.

Table 4.10.2 I/M Emission Test Types (continued)

Test Standards ID	Test Standards Description	Description
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: 420b10023 SIP Tech Guidance 2010.

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 PM Analysis Guidance: Section 4.5.4, Inspection and Maintenance Programs (p. 44);
- MOVES CO Analysis Guidance: Section 2.4.4, Inspection and Maintenance (I/M) (p. 24); 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 may take advantage of state data submitted as part of the NEI.

The CO Analysis Guidance states that users should first examine the default 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 Project Data Manager. Users should review the details of the default I/M program and make any necessary changes to match the actual local program that is planned to be in place in the year being analyzed. The PM Hot-Spot Analysis Guidance notes that MOVES does not provide a PM emission benefit from an I/M program. If the user includes an I/M program in the run specification, the selection will have no impact on PM emissions.

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, can also be difficult for new users.

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 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 I/M 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 two 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 1 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 can also 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 overestimate 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	useIMyn	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

Table 4.10.4 Sample IMCoverage Data (continued)

polProcessID	stateID	countyID	yearID	sourceTypeID	fuelTypeID	IMProgramID	inspectFreq	testStandardsID	begModelYearID	endModelYearID	useIMyn	complianceFactor
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

This section provides a comprehensive example of how inputs might be prepared for a project-level analysis. Both on and off-network effects are illustrated. Examples 1 and 2 in Volume 1 illustrate the preparation of inputs for regional-level analysis.

A discussion of the general context of the example is first provided, followed by a step-by-step illustration for each input. The example is fictional but is 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 hot-spot 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 No. 3 – Project-Level Analysis

5.1.1 Overview

This example illustrates the development of MOVES inputs at the project scale of analysis using the Project Data Manager. The example includes the intersection of two major arterials, a park-and-ride lot, and a bus terminal. The example is a subset of that used in EPA's PM hot-spot analysis training course and many of the MOVES inputs are based on that example, but with modifications in places to meet the needs of this research. For example, this example provides grade inputs instead of assuming zero grade; therefore, some links from the EPA's training course are split if there is a grade change in the middle of the link. Also, more detailed approaches are used to calculate traffic volumes and speeds in this example compared to the EPA example. Figure 5.1 is a diagram of the general analysis area. In this example, inputs are shown for the intersection circled at lower left, as well as the adjoining park-and-ride lot and bus terminal (labeled "proposed" in the figure).

Figure 5.1 Project Analysis Area

5.1.2 Uses

The primary use of MOVES in this context is likely to be for PM and/or CO hot-spot analysis for conformity (to develop inputs to a dispersion model) and the example is written with this in mind. However, the model might also be used for analysis of criteria pollutants, air toxics, and/or greenhouse gas emissions to support alternatives evaluation or support a funding application for a Congestion Mitigation and Air Quality (CMAQ) program project. Box 5.1 shows an example of simple project-level MOVES runs to produce idle emission rates to use for emissions calculations associated with a CMAQ funding application.

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.

Box 5.1 Producing Idle Emission Rates from MOVES Project-Level Runs

Simple project-level MOVES runs with a single link can be used to estimate idle emission rates for any pollutant required in CMAQ funding applications or other uses. The following steps would be used:

1. Set up a project level MOVES run with the appropriate year, geographic bounds, pollutants, and other run specifications. Use inventory mode to produce grams per hour idle emission rates.
2. Since project level mode can only run one hour at a time, 24 runs should be completed for each of the 24 hours of the day, or a single temperature and humidity value that represents the whole day could be used in a single run.
3. For the link data input file include a single link with average speed of 0 and volume of 1. Use the appropriate road type for the location where the idle emission rates will be used, such as road type 5 (urban unrestricted access) for an urban intersection.
4. If idle emission rates are desired for one source type, use the link source type hour fraction input to set the fraction for that source type to 1 and all others to 0. If a single idle emission rate is desired for a mix of vehicle traffic, set the appropriate fractions for all source types that sum to 1 and be sure that source use type is not selected in the output emissions detail screen of the MOVES GUI. If individual idle emission rates are desired for each of the 13 source types set the link volume to 13, set the link source type hour fractions to 1/13 (0.0769), and be sure that source type is selected in the output emissions detail screen of the MOVES GUI.
5. Use the full project level example in this section for help to produce the rest of the project level inputs. Off-network inputs are not needed.
6. Run MOVES and retrieve the gram/hour idle emission rates. If running 24 hours use the hour VMT fraction input from a regional run or other VMT distributions over the 24 hours of the day to provide a proper weighted average.

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 run specs for the applications listed above would include:

Scale: Project-level.

Calculation type: All inputs in this example are prepared to allow the use of either inventory mode or emission rate mode. The calculation type choice will likely depend on the dispersion model that will be used in the subsequent step of the hot-spot analysis. EPA guidance recommends using inventory mode to produce gram per hour emission rates for AERMOD and emission rate mode to produce gram per vehicle-mile emission rates for CAL3QHCR.

Time span: Inputs are prepared for both a build and no-build scenario in the year 2040. Traffic inputs, including volumes and speeds, are prepared for a peak and off-peak hour. Since each project-level run can only include one hour, the MOVES user should utilize EPA guidance to determine the number of runs necessary to represent the time period they are trying to model for a particular pollutant. For example, for a PM hotpot analysis, EPA recommends a series of 16 runs to represent an entire year using four seasons (January to represent winter, April to represent spring, July to represent summer, and October to represent fall) and four daily time periods (a.m. peak hour, p.m. peak hour, mid-day average hour, and overnight average hour). EPA recommends a single hour that represents the peak traffic scenario during worst case conditions for a CO screening analysis. A CO refined analysis may include multiple hours. The inputs in this example could be used for any month and hour chosen for a particular analysis. In the case of 16 runs to represent annual conditions for particulate matter, the peak traffic inputs could be used for a.m. and p.m. peak hour and the off-peak traffic inputs could be used for mid-day and overnight average hours.

Geographic Bounds: The countyID for Washtenaw County, Michigan (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: This example uses road types 1 and 5.

Pollutants and processes: All inputs in this example are prepared for MOVES runs of any of the pollutants/processes available; however, the most common pollutants used in project-level applications are CO, $PM_{2.5}$, and PM_{10}.

5.1.4 Overview of Input Data Sources

Table 5.1 provides an overview of the data source for each required input.

Table 5.1 Data Sources for Project-Level Example

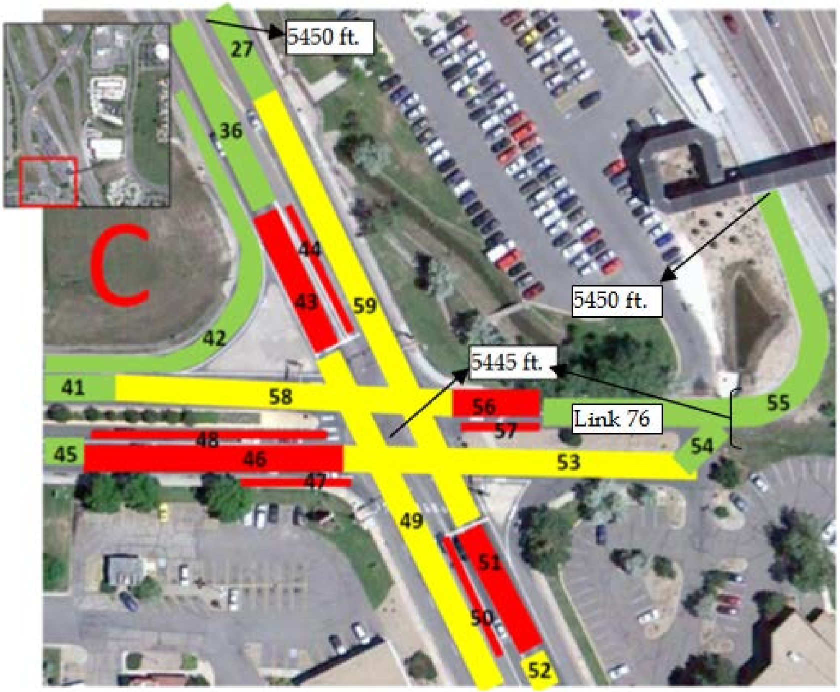
Input	Data Sources
Age distribution	Regional age distribution from registration data
Link data:	
Source type hour fractions	Classified traffic counts
Traffic volumes	For no-build, traffic counts (current year) projected with population-based growth factors (future year), for peak and off-peak periods; project-generated volumes from survey of similar facility added to no-build volumes
Length and grade	Field measurements (length); USGS topo maps (grade)
Average speed	Travel demand model for peak and off-peak periods, adjusted for intersection approach, departure, and queue links
Operating mode distributions and drive schedules	Not used
Off-network data:	
Population	Field survey of similar existing park-and-ride lot
Start, park, and idle fractions	Field survey of similar existing park-and-ride lot
Operating mode distribution	Field survey of similar existing park-and-ride lot
Meteorology	Regional meteorology
Fuel formulation and supply	Regional fuel data
Inspection and maintenance programs	Regional I/M program data

5.1.5 Defining Links

An important part of preparing MOVES project-scale inputs is to divide the project area into links based on the project-level inputs that can vary by link, including average speed, volume, grade, and source type mix. This example uses the average speed approach to define vehicle activity. The links may be defined differently if drive schedules or operating mode distributions are used in place of average speeds. The geometry and characteristics of a roadway should also be considered when defining links since they often impact the vehicle activity. For example, decelerating and queuing vehicles approaching and waiting at an intersection should be treated as one link, accelerating vehicles departing an intersection should be treated as a separate link, and vehicles cruising between intersections should be treated as another separate link. Section 4.2 and Appendix D of EPA's PM hot-spot guidance provide detailed guidance on defining links.

For this example, the link definitions from intersection C of the class project for EPA's PM hot-spot training course are used as shown in Figure 5.2. Also, three bus-only links (60, 61, and 62) will be used from Figure 5.3. Most link IDs and link lengths are used from the class project. The build scenario includes all intersection links plus the three bus-only links (60, 61, and 62). The no-build scenario does not include the links on the east leg of the intersection (53, 54, 55, 56, 57) and does not include the bus-only links (60, 61, and 62) since these eight links are considered part of the park-and-ride/bus terminal project that is being built.

Figure 5.2 Intersection Links



Key: Green = Cruise links; Yellow = Acceleration Links; Red = Queue Links.

Figure 5.3 Bus-Only Links (60, 61, 62)

Key: Green = Cruise links; Yellow = Acceleration Links; Red = Queue Links.

5.1.6 Age Distribution

Source:

- Since site-specific age distribution is difficult to obtain without extensive data collection, the regional age distribution is used for this input. Examples 5.1 and 5.2 in Volume 1 of this Resource Document illustrate how to obtain a regional age distribution.

Alternative sources and methods:

- A license plate survey could be conducted to identify a sample of vehicles using each link or off-network link, and match these vehicles with registration data to determine their ages. This method would require a much larger level of effort, but would likely provide a more accurate estimate of the actual age distribution of vehicles using the facility. Age distributions can vary locally depending upon the demographic and socioeconomic characteristics of an area, as well as the amount of local versus pass-through traffic.

5.1.7 Link Traffic Volumes

Source:

- The link traffic volumes for the north, south, and west legs of the intersection are derived from hypothetical traffic counts conducted at the intersection before the park-and-ride lot/bus terminal was built. These counts were conducted for both a peak and off-peak period. The no-build volumes for year 2040 are the traffic counts inflated by a growth factor to account for general traffic increases in the area between the year of the counts (2010) and the no-build scenario year (2040) due to population growth. The build volumes are the no-build volumes plus the additional vehicles expected on the links due to the project being built. These are estimated using the gate survey of a similar facility as described in the off-network start section of this example.

- The link traffic volumes for the east leg of the intersection are zero for the no-build condition since these links do not exist before the project is built. The build volumes for these links are based solely on the gate survey of a similar facility since these links are only serving the park-and-ride lot/bus terminal and do not provide any connection to the rest of the roadway network that would lead to any general traffic.

- The link traffic volumes for the three bus-only links are zero for the no-build condition since these links do not exist before the project is built. The build volumes for these links are based solely on the survey of a similar facility since these links only serve buses travel to and from the bus terminal and do not allow any car traffic.

Source data format:

- The hypothetical traffic counts at the intersection provided a table of link volumes with the format shown in Table 5.2.

Table 5.2 Sample Traffic Count Data

linkID	Link Description	Link Type	2010 Link Volume (Off-Peak Hour)	2010 Link Volume (Peak Hour)
27	intersection NB connect	cruise	302	656
36	intersection SB approach	cruise	277	602
41	intersection WB connect	cruise	297	644
42	intersection SB exit-WB connect	cruise	98	213
43	intersection SB queue	queue	157	341
44	intersection SB LT queue	queue	22	48
45	intersection EB approach	cruise	253	549
46	intersection EB TH queue	queue	29	62
47	intersection EB RT queue	queue	83	180

Processing steps required:

North, south, and west leg of intersection

1. Inflate the traffic counts by a growth factor to calculate the no-build volumes. For this example, 31.43 percent is used, which was calculated based on population growth in the VMT by vehicle class section of Volume 1, Example 5.1. Multiply each of the off-peak and peak volumes by 1.3143 to calculate the no-build volumes for 2040. The result is shown in Columns D and E of Table 5.3.

2. To estimate the additional light-duty traffic due to the project in the peak hour the gate survey information from the similar facility is used. It showed 100 vehicles entering and exiting during peak hours. Half of this volume is assumed for off-peak hours. The additional volume is split among the three directions from which vehicles could enter or leave the facility. Based on existing patterns a distribution is assumed of 50 percent from/to the west, 25 percent from/to the south, and 25 from/to the north. For example, out of the 100 peak-period vehicles, 50 vehicles travel west on links 58 and 41, 25 travel south on link 49, and 25 travel north on links 59 and 27. The resulting values are shown in Columns F and G.

3. To estimate the additional bus traffic due to the project the planned bus schedule is used, which shows two routes each with four buses per hour during the peak (total of eight buses per hour in the peak) and two routes with two buses per hour during the off-peak (total of four buses per hour in the off-peak). One route travels westbound

from the intersection and one route travels southbound from the intersection. No routes travel northbound and no routes enter the facility through this intersection (they enter via link 62 from another intersection and travel in one direction on the bus-only links). Therefore, the westbound links (58 and 41) and the southbound link (49) have four buses per hour in the peak and two buses per hour in the off-peak. The resulting values are shown in Columns H and I.

4. Add light-duty vehicle and bus project traffic to no-build volumes to calculate build volumes. In Table 5.3 the proper operations would be Column D + F + H = J and Column E + G + I = K.

East leg of intersection and bus-only links

1. The no-build volumes are zero (these links do not exist in the no-build).

2. To estimate the additional light-duty traffic due to the project in the peak hour the gate survey information from the similar facility is used. It showed 100 vehicles entering and exiting during peak hours. Half of this volume is assumed for off-peak hours. Links 53, 54, and 76 receive all of this additional traffic. Link 56 and 57 split it based on the existing patterns of receiving links (resulting in 75 percent going to link 56 and 25 percent to link 57). Links 55, 60, 61, and 62 are bus-only links and do not have light-duty traffic. The resulting values are shown in Columns F and G.

3. To estimate the additional bus traffic due to the project the planned bus schedule is used, which shows two routes each with four buses per hour during the peak (total of eight buses per hour in peak) and two routes with two buses per hour during the off-peak (total of four buses per hour in off-peak). All of these buses travel on links 60, 61, 62, 55, and 76. Half of them go straight via link 56 and half of them turn left via link 57. The resulting values are shown in Columns H and I.

4. Add light and bus project traffic to no-build volumes to calculate build volumes. In Table 5.3 the proper operations would be Column D + F + H = J and Column E + G + I = K.

Input data example:

The information in Table 5.3 has to be placed into one of four link input files. Volumes from Column D are used for the no-build off-peak file, Column E for the no-build peak file, Column J for the build off-peak file, and Column K for the build peak file. Table 5.7, at the end of the Average Speed section, includes an example of volume inputs. The full files can be found in the Examples workbook.

Alternative sources and methods:

- More detailed traffic counts could be conducted for each of the four hours included in the MOVES run instead of just peak and off-peak.

- In the absence of traffic counts, travel demand model volumes could be used.

Table 5.3 Traffic Volume Calculations

A	B	C	D	E	F	G	H	I	J	K
linkid	2010 Traffic Counts (Off-Peak)	2010 Traffic Counts (Peak)	2040 No-Build Volume (Off-Peak)	2040 No-Build Volume (Peak)	2040 Light-Duty Project Traffic (Off-Peak)	2040 Light-Duty Project Traffic (Peak)	2040 Bus Project Traffic (Off-Peak)	2040 Bus Project Traffic (Peak)	2040 Build Volume (Off-Peak)	2040 Build Volume (Peak)
27	302	656	397	862	13	25	0	0	410	887
36	277	602	364	791	13	25	0	0	377	816
41	297	644	390	846	25	50	2	4	417	900
42	98	213	129	280	0	0	0	0	129	280
43	157	341	206	448	0	0	0	0	206	448
44	0	0	0	0	13	25	0	0	13	25
45	253	549	333	722	25	50	0	0	358	772
46	0	0	0	0	25	50	0	0	25	50
47	83	180	109	237	0	0	0	0	109	237
48	141	307	185	403	0	0	0	0	185	403
49	279	606	367	796	12	25	2	4	381	825
50	129	280	170	368	0	0	0	0	170	368
51	166	360	218	473	12	25	0	0	230	498
52	166	360	218	473	12	25	0	0	230	498
53	0	0	0	0	50	100	0	0	50	100
54	0	0	0	0	50	100	0	0	50	100
55	0	0	0	0	0	0	4	8	4	8
56	0	0	0	0	38	75	2	4	40	79
57	0	0	0	0	12	25	2	4	14	29
58	199	431	262	566	25	50	2	4	289	620
59	302	656	397	862	13	25	0	0	410	887
60	0	0	0	0	0	0	4	8	4	8
61	0	0	0	0	0	0	4	8	4	8
62	0	0	0	0	0	0	4	8	4	8
76	0	0	0	0	50	100	4	8	54	108

5.1.8 Link Length and Grade

Source:

- The link length comes from hypothetical field measurements that were conducted as part of the park-and-ride/bus terminal project.
- The link grade is derived from calculations that use the link length and roadway elevation at certain points. Elevation data is used from topographic maps to calculate grade for some of the links. The USGS national map store[12] and ArcGIS "World Topographic Map"[13] were both found to be useful in figuring out the elevation of certain points along a roadway. Note that the roadways in this example follow the ground elevation and do not have any bridges or overpasses that would be higher than the ground below it. Field surveys would likely be more accurate than topographic maps, especially if the project involves bridges and overpasses. On-line bike mapping tools were explored as a data source, but were found to lack the resolution necessary to calculate grade for short links. More possible data sources for grade information are discussed in Section 4.4 of this document.

Source data format:

The hypothetical field measurements provided a table of links with their length in meters as shown in Table 5.4.

Table 5.4 Example of Link Length Measurements

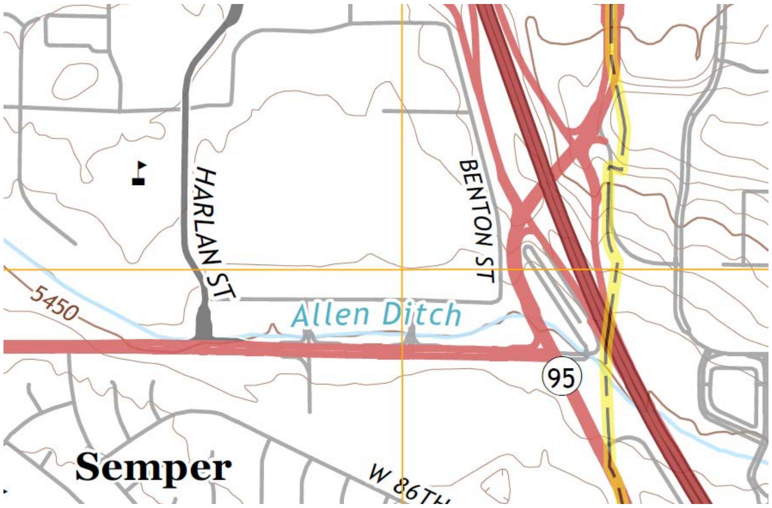
linkID	Link Description	Link Length (Meters)
27	intersection NB connect	30.0
36	intersection SB approach	60.0
41	intersection WB connect	294.0
42	intersection SB exit-WB connect	73.4
43	intersection SB queue	38.9
…	…	…

[12] http://nationalmap.gov/ustopo/index.html. Click Download Maps (Map Store) from the second item on the left hand side menu. Zoom in to a specific location, mark a point of interest, click on the marker and download a map with "U.S. Topo" in its name.

[13] http://goto.ArcGISonline.com/maps/World_Topo_Map. In ArcMap 10.0 or higher click "Add Basemap" and select "Topographic."

Figure 5.4 shows the USGS topographic map used to assign elevation to points along roadways in the project area.

Figure 5.4 USGS Topographic Map



Source: United States Geological Service.

Processing steps required:

Link Length

1. Using the table of hypothetical field measurements, convert the units of the link length from meters to miles by dividing by 1,609 meters/mile.

2. Record the miles of each link in the “linkLength” field of the links input table.

Link Grade

1. In this example, only links to the north of the intersection (27, 36, 42, 43, 44, 59, 60, 61, 62, and a portion of link 55) are found to have an elevation difference after examination of topographic maps. As discussed above link 55 is split since the part of it that lines up with the east-west intersection street is flat and the rest of it is on a downhill grade. The contour lines on the topographic map indicate that the east-west street of the intersection is basically at a level elevation and that while the roadway to the south of the intersection eventually increases in elevation it is flat for the links that are being modeled.

2. Record on a map the elevation at certain points along the links with an elevation difference using as much detail as is known from the topographic map or other data source. For example, the topographic maps used for this example had contour lines every 5 or 10 feet so elevations are recorded on the map every 5 or 10 feet along the roadways (the 5-foot contour map was not as clear near the bus links so less detail is shown there). Figures 5.2 and 5.3 above show the elevation points on a map.

3. Calculate the elevation difference from one known elevation point to the next and divide by the length to calculate the grade. For the case of the links on the northern leg of the intersection (27, 36, 42, 43, 44, and 59) the elevation difference is 5 feet (5,450 feet minus 5,445 feet) and the length is 98.9 meters (60 meters plus 38.9 meters for links 36 and 43), which converts to 324.5 feet. Therefore the grade is calculated as:

$$Grade = \frac{rise}{run} = \frac{5\ feet}{324.5\ feet} = 0.0154 = 1.54\%$$

   This grade is applied to links 59 and 27 since they are the uphill links that should have a positive grade. Negative 1.54 percent is applied to the downhill links (36, 43, 44, 42).

4. For the case of the bus-only links (55, 60, 61, and 62) the elevation is known at the beginning and end point of each link; therefore, grade is calculated for each of those links individually using the same formula above.

5. All remaining links (41, 45-54, 56-58, and 76) have been determined to be flat and are assigned a grade of zero.

6. Record the grade of each link in the "linkAvgGrade" field of the links input table. The units should be percent (from 0-100), so the grade recorded for links 59 and 27 was "1.54" and the grade recorded for links 36, 42, 43, and 44 was "-1.54."

Input data example:

Table 5.7, at the end of the Average Speed section, includes sample grade inputs. The full file can also be found in the Examples workbook.

Alternative sources and methods:

- Link length and elevation information can be derived from a variety of sources as described in Section 4.4 of this handbook.

5.1.9 Link Average Speed

Source:

- Average speed for cruise links that exist in the no-build condition (on the north, west, and south leg of the intersection) are obtained from hypothetical travel demand model congested speed outputs by peak and off-peak period. The model uses a BPR equation to calculate congested speed based on the free-flow speed and volume-to-capacity ratio of each link. Therefore, the congested speed outputs can be considered to be the average speed on a cruise link, but adjustments must be made for other links types. Acceleration links are assumed to have half the cruise speed and queue links are assumed to have a 5.9 mph speed that corresponds to a calculation done to incorporate signal delay into the average speed.

- The additional project traffic is expected to have little to no impact on the average speeds for the build condition since the area has plenty of roadway capacity. Therefore, the estimated speeds for the build condition are assumed to be the same as the no-build condition. For major development projects or major roadway capacity projects where additional traffic and/or capacity is expected to significantly change average speeds, an additional travel demand model run could be conducted with altered socioeconomic data and roadway capacity data to reflect the project. This additional travel demand model run could provide a second set of congested speeds for the build condition.

- Average speed for cruise links associated with the project (on the east leg of the intersection and the bus-only links) are not available from the travel demand model since they are not regionally significant roadways. The expected posted speed of 25 mph is used instead since there is expected to be little to no congestion on these links. Acceleration links are assumed to have half the cruise speed and queue links are assumed to have a 5.9 mph speed that corresponds to a calculation done to incorporate signal delay into the average speed.

Source data format:

- The hypothetical travel demand model provided congested speed outputs for three links: the north leg, west leg, and south leg of the intersection. The model has two times of day, peak and off-peak, so congested speeds are available for these two periods. The travel demand model output only provides a single congested speed per link that considers volume and capacity of both directions. Table 5.5 shows the congested speeds provided by the travel demand model.

Table 5.5 Travel Demand Model 2040 Congested Speeds

Link	TDM Off-Peak Speed (mph)	TDM Peak Speed (mph)
Northern leg of intersection	37.2	31.5
Southern leg of intersection	38.4	32.6
Western leg of intersection	34.1	27.8

Processing steps required:

1. Assign cruise speeds to all links based on travel demand model congested speed outputs or speed limit. As shown in Columns D and E of Table 5.8 all links on each leg of the intersection receive the same cruise speed. The eastern leg of the intersection and the bus-only links are assigned a speed of 25 mph based on the expected posted speed once the project is built. The remaining legs are assigned congested speeds from the travel demand model output.

2. Assign link types to all links in Column C based on the expected vehicle activity patterns on each link. Link type options include cruise for links where vehicle speed are not influenced by the traffic signal or turning movements; queue for links where vehicles may be stopped and decelerating if the signal is red; and acceleration for links where vehicles may be accelerating to return to cruise speed after being stopped at the signal. Link 61 where buses pick up and drop off passengers at the transit terminal is considered an idle link that will receive an average speed of zero since buses will spend as long as 15 minutes idling there while waiting for their scheduled departure time.

3. Estimate the average speed for each link using the model or posted speeds and the link type information. Use an IF statement to assign the model or posted speed for cruise links, half cruise speed for acceleration links, 5.9 mph for queue links, and 0 mph for idle links. The resulting values are shown in Columns F and G of Table 5.8.

   a. Half the cruise speed is deemed to be an appropriate assumption based on the calculation for acceleration link 49 as shown in Table 5.6. The calculation makes use of equations suggested in EPA training for PM hot-spot analysis. The average speed uses the equation for space mean speed, which uses the average *travel time* for all vehicles passing over a link (see Volume 1, Section 4.7 for further explanation). The calculated ratio is actually higher than 0.5, but acceleration events could be argued to have higher emissions than typical driving at the same average speed; therefore, a lower ratio associated with lower speed and higher emissions is justified.

Table 5.6 Sample Speed and Acceleration Calculations for Acceleration Link

Item	Value	Units	Source
Cruise Speed	38.4	mph	travel demand model
Cruise Speed	56.32	ft/s	unit conversion
Acceleration	7	ft/s2	assumed based on common light-duty vehicle
Travel Time during Acceleration	8.045714	seconds	calculated using $t=(v_f-v_0)/a$
Distance of Link	226.5673	feet	calculated using $d=v_0*t+0.5*a*t^2$
Travel Time during Cruise	4.022857	seconds	calculated using v=d/t
Average Travel Time	6.034286	seconds	average of travel time during acceleration and cruise assuming half the vehicles pass through the link at cruise speed and half accelerate from 0 mph at the stop bar
Average Travel Time	0.001676	hours	unit conversion
Distance of Link	0.04291	miles	unit conversion
Average Speed (space mean speed)	25.6	mph	calculated using average speed = distance/average travel time of all vehicles
Ratio of Average Speed/Cruise Speed	0.666667		calculated

b. The 5.9 mph average speed for queue links is deemed to be an appropriate assumption based on the calculation for queue link 43 as shown in Table 5.7. The calculation uses the same space mean speed equation for average speed as the calculation above for the acceleration link. The travel time across the link for queuing vehicles is assumed to be equal to the intersection delay obtained from a hypothetical intersection timing model, such as Synchro.

Table 5.7 Sample Speed and Acceleration Calculations for Queue Link

Item	Value	Units	Source
Cruise Speed	37.2	mph	travel demand model
Distance of Link	38.9	meters	hypothetical field measurements
Distance of Link	0.024177	miles	unit conversion
Travel Time during Cruise	2.339662	seconds	calculated using v=d/t
Travel Time during Queuing	27.1	seconds	intersection delay from hypothetical intersection timing model (e.g., Synchro)
Average Travel Time	14.71983	seconds	average of travel time during cruise and queuing assuming half the vehicles pass through the link at cruise speed (get green light) and half stop to queue for the intersection delay time (get red light)
Average Travel Time	0.004089	hours	unit conversion
Average Speed (space mean speed)	5.912801	mph	calculated using average speed = distance/average travel time of all vehicles

Table 5.8 Average Speed Calculations for 2040

A	B	C	D	E	F	G
linkID	Link Description	Link Type	Model Off-Peak Speed (mph)	Model Peak Speed (mph)	Avg. Speed Off-Peak (mph)	Avg. Speed Peak (mph)
27	intersection NB connect	cruise	37.2	31.5	37.2	31.5
36	intersection SB approach	cruise	37.2	31.5	18.6	15.8
41	intersection WB connect	cruise	34.1	27.8	34.1	27.8
42	intersection SB exit-WB connect	cruise	37.2	31.5	18.6	15.8
43	intersection SB queue	queue	37.2	31.5	5.9	5.9
44	intersection SB LT queue	queue	37.2	31.5	5.9	5.9
45	intersection EB approach	cruise	34.1	27.8	17.1	13.9
46	intersection EB TH queue	queue	34.1	27.8	5.9	5.9
47	intersection EB RT queue	queue	34.1	27.8	5.9	5.9
48	intersection EB LT queue	queue	34.1	27.8	5.9	5.9
49	intersection SB departure	accel	38.4	32.6	19.2	16.3
50	intersection NB LT queue	queue	38.4	32.6	5.9	5.9
51	intersection NB TH/RT queue	queue	38.4	32.6	5.9	5.9
52	intersection NB approach	cruise	38.4	32.6	19.2	16.3
53	intersection EB departure	accel	25.0	25.0	12.5	12.5
54	intersection EB Transit entrance	cruise	25.0	25.0	12.5	12.5
55	Bus terminal SB bus connect	cruise	25.0	25.0	25.0	25.0
56	intersection WB TH/RT queue	queue	25.0	25.0	5.9	5.9
57	intersection WB LT queue	queue	25.0	25.0	5.9	5.9
58	intersection WB departure	accel	34.1	27.8	17.1	13.9
59	intersection NB departure	accel	37.2	31.5	18.6	15.8
60	Bus terminal SB bus departure	accel	25.0	25.0	12.5	12.5
61	Bus terminal passenger pick up	idle	0.0	0.0	0.0	0.0
62	Bus terminal SB approach	cruise	25.0	25.0	12.5	12.5
76	intersection WB approach	cruise	25.0	25.0	12.5	12.5

Input data example:

The information shown in Table 5.8 has to be placed into one of four link input files. Average speeds for off-peak periods from Column F are used for both the no-build and build off-peak files. Average speeds for peak periods from Column G are used for both the no-build and build peak files. An example including link volume, length, grade, and speed inputs is shown in Table 5.9 for the no-build, off-peak condition. The files can also be found in the Examples workbook.

Alternative sources and methods:

- Real world speed data could be collected for the no-build condition with a variety of sources, including a spot speed study (using radar guns), ITS/in-pavement counting equipment, or from observed travel time data available from vendors such as INRIX, HERE, TomTom, etc.

- More detailed equations could be used to calculate the average speed for acceleration and queue links as demonstrated in processing Steps 3a and 3b. Using these equations for all acceleration and queue links could make use of signal timing and intersection delay information by link from more detailed traffic analysis techniques. These include a Highway Capacity Manual intersection analysis and intersection timing models such as Synchro, SimTraffic, and CORSIM. These models could help estimate how delay changes between the no-build and build condition.

- The average speed of queue links could be divided into left turn, straight, and right turn links to account for different signal delays and different free-flow speeds for these different movements. For example, right turn links will likely have shorter signal delay and thus higher average speeds since vehicles can usually turn right on red after stopping.

- Instead of using the average speed approach, the drive schedule or operating mode distribution approach could be used to describe vehicle activity. Drive schedules that show second-by-second speed information could be obtained from traffic simulation models. Operating mode distributions could also be created from this traffic simulation model data using the MOVES Operating Mode Data Import Tool produced for this research project. A simpler way to use operating mode distributions would be to start with a MOVES default operating mode distribution for a certain average speed and alter the idling operating mode using intersection delay information.

Table 5.9 Sample Input File – Link Data for 2040 No-Build Off-Peak

linkID	countyID	zoneID	roadTypeID	linkLength	linkVolume	linkAvgSpeed	linkDescription	linkAvgGrade
27	26161	261610	5	0.018645	397	37.20	intersection NB connect	1.54095
36	26161	261610	5	0.03729	364	18.60	intersection SB approach	-1.54095
41	26161	261610	5	0.182722	390	34.10	intersection WB connect	0
42	26161	261610	5	0.045618	129	18.60	intersection SB exit-WB connect	-1.54095
43	26161	261610	5	0.024177	206	5.90	intersection SB queue	-1.54095
44	26161	261610	5	0.006153	0	5.90	intersection SB LT queue	-1.54095
45	26161	261610	5	0.175264	333	17.05	intersection EB approach	0
46	26161	261610	5	0.04972	0	5.90	intersection EB TH queue	0
47	26161	261610	5	0.019888	109	5.90	intersection EB RT queue	0
48	26161	261610	5	0.044997	185	5.90	intersection EB LT queue	0
49	26161	261610	5	0.08614	367	19.20	intersection SB departure	0
50	26161	261610	5	0.023679	170	5.90	intersection NB LT queue	0
51	26161	261610	5	0.026538	218	5.90	intersection NB TH/RT queue	0
52	26161	261610	5	0.030702	218	19.20	intersection NB approach	0
53	26161	261610	5	0.057365	0	12.50	intersection EB departure	0
54	26161	261610	5	0.019888	0	12.50	intersection EB Transit entrance	0
55	26161	261610	5	0.02542	0	25.00	Bus terminal SB bus connect	-3.72616
56	26161	261610	5	0.019888	0	5.90	intersection WB TH/RT queue	0
57	26161	261610	5	0.009447	0	5.90	intersection WB LT queue	0
58	26161	261610	5	0.055935	262	17.05	intersection WB departure	0
59	26161	261610	5	0.061467	397	18.60	intersection NB departure	1.54095
60	26161	261610	5	0.024052	0	12.50	Bus terminal SB bus departure	-3.93798
61	26161	261610	5	0.035053	0	0.00	Bus terminal passenger pick up	0
62	26161	261610	5	0.017775	0	12.50	Bus terminal SB approach	-5.32867
76	26161	261610	5	0.02486	0	12.50	intersection WB approach	0

5.1.10 Link Source Type Hour Fraction

Source:

- The hypothetical traffic counts conducted at the site for the volume calculations were classified counts that provided volumes by five vehicle types for the intersection. MOVES defaults are used to further divide these into 13 source types. The vehicle type mix is assumed to stay the same between 2010, which is the year of the classified traffic counts, and 2040, which is the analysis year used in this example. The vehicle type mix is also assumed to be the same for the no-build and build condition due to the small amount of additional volume added by the project.

- The bus-only links will have 100 percent source type 42 (transit buses).

Source data format:

- The traffic counting firm that provided the traffic counts by link for the volume calculations provided the following table to show how the total of their counts for all links breaks down by vehicle type for the off-peak and peak hour that they counted. Their field personnel conducted the classified counts by link, but they lost the spread-sheet file that contained the details on vehicle type by link. Luckily they found this summary file of all links (Table 5.10).

Table 5.10 Example 2010 Traffic Count Summary File

Vehicle Type	Off-Peak	Peak
Motorcycles	23	42
Cars and Light Trucks	2,719	6,004
Buses	10	32
Single Unit Trucks	69	75
Combination Trucks	28	32

Processing steps required:

Intersection links

1. Use MOVES defaults to further allocate the classified volumes into 13 MOVES source types. Obtain MOVES defaults by conducting a 2040 national-scale run that includes activity type ID=1 (distance traveled) by road type and source type. Pull the 13 VMT numbers by source type for road type 5 (urban unrestricted access). Assign motorcycles to source type 11. Allocate cars and light trucks by using the MOVES default VMT proportions for source types 21, 31, and 32. Allocate buses by using the MOVES default VMT proportions for source types 41, 42, and 43. Allocate single unit trucks by using the MOVES default VMT proportions for source types 51, 52, 53, and 54.

Allocate combination trucks by using the MOVES default VMT proportions for source types 61 and 62. These calculations are shown in Table 5.11.

2. Calculate a percent for each source type by dividing the source type volume by the total volume. Repeat to get a percent for each source type. The 13 source type percent numbers should sum to 100 percent. The link source type input asks for the fraction of vehicle **hours** traveled by source type. If the vehicle were traveling at different speeds this would require calculating VMT from the volumes and link lengths and converting VMT to VHT using link average speeds by vehicle type. For this example, all vehicles travel at the same speed. Therefore, conducting this conversion to VHT would result in the same distribution as using the volumes by source type. These calculations are shown in Table 5.11 as "off-peak distribution" and "peak distribution."

Table 5.11 Link Source Type Hour Fraction Calculations

Source Type	MOVES Defaults within Vehicle Type Group	Off-Peak Volume	Peak Volume	Off-Peak Distribution	Peak Distribution
11	100.00%	23.00	42.00	0.008073	0.006791
21	71.81%	1,952.63	4,311.72	0.685373	0.697126
31	21.13%	574.46	1,268.50	0.201635	0.205092
32	7.06%	191.92	423.78	0.067363	0.068518
41	42.08%	4.21	13.47	0.001477	0.002177
42	11.75%	1.18	3.76	0.000413	0.000608
43	46.16%	4.62	14.77	0.00162	0.002388
51	0.68%	0.47	0.51	0.000165	8.25E-05
52	82.51%	56.93	61.88	0.019983	0.010005
53	12.10%	8.35	9.07	0.00293	0.001467
54	4.71%	3.25	3.53	0.001141	0.000571
61	40.60%	11.37	12.99	0.00399	0.0021
62	59.40%	16.63	19.01	0.005838	0.003073

Bus-only links

1. For links 55, 60, 61, and 62 assign 100 percent (1.0) to source type 42 and 0 to all other source types.

Input data example:

The link source type hour fraction file requires the calculated distributions to be repeated for all links to which they apply. Two files are created, one for peak and one for off-peak. A sample for the off-peak is shown in Table 5.12 and the full files can be found in the Examples workbook.

Table 5.12 Sample Input File – Link Source Type Hour Fractions

linkID	sourceTypeID	sourceTypeHourFraction
27	11	0.0081
27	21	0.6854
27	31	0.2016
27	32	0.0674
27	41	0.0015
27	42	0.0004
27	43	0.0016
27	51	0.0002
27	52	0.0200
27	53	0.0029
27	54	0.0011
27	61	0.0040
27	62	0.0058
36	11	0.0081
36	21	0.6854
…	…	…

Alternative sources and methods:

- If classification counts are not feasible to conduct at the site, regional distributions could be obtained from the agency responsible for conducting regional MOVES runs. Also, statewide classification count data for the appropriate road type could be used. Finally, Highway Statistics Table VM-4, which comes from statewide classification counts, could also be used.

5.1.11 Off-Network Population, Start, Park, and Idle Fractions

Source data format:

- In this example, the source data for off-network information come from a supposed survey of the operations of a similar park-and-ride facility. This survey, for the purpose of this example, was conducted once each day over the course of a week, and the results of each day averaged. At one point during each day, the survey team counted the number of each type of vehicle parked in the lot, and also counted the number of idling buses at the moment the vehicle count was complete. Between these two sources of data, the population data can be estimated. For this example, the survey team provided the average number of motorcycles, cars, and light trucks parked in the lot at any given time, and the average number of idling buses that are parked in the lot loading and unloading passengers at any given time.

- The same survey data along with data from the entry and exit gates are also used for start, park, and idle fraction inputs. The number of gate exits per hour can be used to estimate the vehicle start frequency of the cars and light trucks in the parking lot. The surveyor's report that no cars or light trucks were running under extended idle, but, on average, four buses were on site and idling at any given time.

- If the proposed park-and-ride lot is a different size than the surveyed lot, the vehicle counts may be scaled by the relative capacities of the two lots, or another basis for estimating a difference in demand, to estimate population for the proposed facility. Other characteristics (start, park, and idle fractions) are assumed to be similar for the existing and proposed facility.

Processing steps required:

Vehicle population

1. Using the survey results for each vehicle type, enter the average population of each in the vehiclePopulation column of the table. Adjust for differences in lot capacity if needed.

Idle fractions

1. If the buses that are operating on-site are idling, enter the fraction of the buses present that are idling in extendedidlefraction. In this case, all buses that are present are idling, so this value is entered as 1.

Start fractions

For motorcycles, cars, and light trucks:

1. At the time of each survey, use the gate exit data to establish the number of vehicles that left the lot within the previous hour.

2. Divide the number of exiting vehicles by the total population counted in the survey.

3. This ratio is the start fraction, calculated for each vehicle type.

The buses are observed not to shut down their engines and therefore do not make any starts.

Input data example:

In this example, the survey team reports counting an average of 12 motorcycles, 421 cars, and 216 light trucks during the surveys. They also report that there are, on average, four buses idling in the passenger loading and unloading area at any given time. This is entered in the excerpt of the off-network table shown in Table 5.13. It is also observed that on average, two motorcycles, 80 cars, and 31 light trucks left the parking lot during the hour of the surveys. Each of these vehicles is assumed to have been started immediately prior to departing.

Table 5.13 Example Input File – Off-Network Data

sourceType	sourceTypeID	vehiclePopulation	startfraction	extendedidlefraction
Motorcycle	11	12	0.167	0
Passenger Car	21	421	0.19	0
Passenger Truck	31	216	0.145	0
Transit Bus	42	4	0	1

Alternative sources and methods:

- Instead of counting the vehicles manually, the log of vehicles entering and leaving could be used to maintain the number of vehicles present at any given time. The running log of the number of vehicles present could be examined for randomly chosen times, and these counts averaged to find the desired population to be modeled. This method may not record the vehicle types, however. In this case, a regional source type distribution based on registration data, or a default source type distribution, could provide an estimate of the breakdown among the various source types. For a park-and-ride lot it would be appropriate to use only the light-duty vehicle fractions, in addition to estimates of the number of transit buses.

5.1.12 Off-Network Operating Mode Distribution

Source data format:

- For the operating modes in this example, engine-off soak times are the key value to be determined from information regarding each vehicle's entry and exit time from the lot. The entry and exit time of each vehicle, taken over the course of the day, allow for the creation of a distribution of soak times. This can be cataloged in spreadsheet form.

Processing steps required:

1. Obtain the entry and exit time of each vehicle and calculate the duration of each visit to the parking lot.

2. Sort the visit durations in ascending order of duration, and count the percentage of vehicles within each opmode distribution cutoff time. The percentage in each is the opmodefraction, and the soak time cutoffs are 6, 30, 60, 90, 120, 360, and 720 minutes.

3. Populate each opmodefraction with each opmodeID. Replicate the distribution into every polprocessID, and then replicate all cells into each hourdayID, and then replicate all into each sourcetypeID.

4. For buses, the survey team determined that the only opmodeID is extended idling, which is opmodeID 200.

Input data example:

This example presents the inputs required to complete an excerpt of an opmodedistribution input table. This example focuses on passenger cars and buses, and is limited only to hydrocarbon emissions. The passenger cars will use polprocessID 102, for engine starts, and the buses will use polprocessID 200, for extended idling. For the passenger cars in this example, the lot entries and exits of 100 cars are reviewed. Table 5.14 shows the number of vehicles that stayed a length of time within each soak time cutoff.

Table 5.14 Number of Vehicles by Soak Time

Soak Time Range	Number of Vehicles
0-6 minutes	0
6-30 minutes	12
30-60 minutes	12
60-90 minutes	3
90-120 minutes	2
120-360 minutes	45
360-720 minutes	7

The operating mode distribution table is not required for all project-level MOVES runs; it is only required if nonrunning emissions are to be modeled. In this example, the start emissions are not considered running emissions, so the operating mode distribution table must be included. If only running emissions were to be modeled, MOVES would be able to use defaults as necessary in order to calculate emissions results.

The passenger cars (with pollutant process ID 102) should be entered in the opmodedistribution table as shown in the top eight rows in Table 5.15. The buses are represented by the final row of the table. Note that the linkID can be any unique number that describes only the off-network link in the scenario.

Table 5.15 Sample Input File – Off-Network Operating Mode Distribution

sourceTypeID	hourdayID	linkID	polProcessID	opModeID	opModeFraction
21	15	99	102	101	0.00
21	15	99	102	102	0.12
21	15	99	102	103	0.12
21	15	99	102	104	0.03
21	15	99	102	105	0.02
21	15	99	102	106	0.19
21	15	99	102	107	0.45
21	15	99	102	108	0.07
42	15	99	101	200	1.00

To complete the opmodedistribution table, the data for sourcetype 21 must be replicated for all of the other polprocessIDs that need to be modeled. In this example, these include 202, 302, 9002, and 9102 for light-duty vehicles, and 290, 390, 9090, and 9190 for the buses. These correspond to CO, NO_x, CO_2, and energy consumption, respectively, in addition to HC. All of the resulting data must then be replicated again for all of the hourdayIDs that are to be modeled. The process must be performed again for each of the other customer vehicle types. For buses, the extended idle row must be replicated for all other desired polprocessIDs, and all of the resulting bus data must again be replicated for each hourdayID that is to be modeled.

Alternative sources and methods:

- Any alternative source of data would need to accomplish what the entry and exit gate data were used for in the example. If entry and exit data were not available that allow "ins" and "outs" to be matched for specific vehicles, a survey team could be used to establish, for a selected subset of vehicles in the lot, the distribution of how long each vehicle was parked in the lot.

5.1.13 Meteorology Data

For this example, the Meteorology input will use the same data as was generated for the "limited data" regional case (Volume 1, Section 5.1). This was taken from the NCDC data for Detroit/Wayne County airport in Michigan.

5.1.14 I/M Programs

For this example, the I/M inputs will use the same data as was generated for the "limited data" regional case (Volume 1, Section 5.1). This was based on data for Hartford County, Connecticut.

5.1.15 Fuel Formulation and Supply

For this example, the fuel formulation and supply inputs will use the same data as was generated for the "more extensive data" regional case (Volume 1, Section 5.2). This was based on data for Harris County, Texas.

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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
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
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
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
PDM	Project Data Manager
PM	Particulate matter
RFG	Reformulated gasoline
RFID	Radio frequency identification
RSD	Remote sensing device
RVP	Reid vapor pressure
SHI	Source hours idling
SHO	Source-hours of operation
SHP	Source hours parked
SIP	State Implementation Plan
TDFM	Travel demand forecasting model
TRB	Transportation Research Board
USGS	United States Geological Survey
v/c	Volume-to-capacity
VHT	Vehicle-hours traveled
VIN	Vehicle Identification Number
VIUS	Vehicle Inventory and Use Survey
VMT	Vehicle miles of travel
VSP	Vehicle-specific power
WIM	Weigh-in-motion