Population and Activity of On-road Vehicles in MOVES2014

United States Environmental Protection Agency

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Assessment and Standards Division
Office of Transportation and Air Quality
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1 Introduction

The United States Environmental Protection Agency's Motor Vehicle Emission Simulator—commonly referred to as MOVES—is a set of modeling tools for estimating emissions produced by onroad and nonroad mobile sources. MOVES estimates the emissions of greenhouse gases (GHGs), criteria pollutants, and selected air toxics. The MOVES model is currently the official model for use for state implementation plan (SIP) submissions to EPA and for transportation conformity analyses outside of California. The model is also the primary modeling tool to estimate the impact of mobile source regulations on emission inventories.

MOVES calculates emission inventories by multiplying emission rates by the appropriate emission-related activity, applying correction and adjustment factors as needed to simulate specific situations, and then adding up the emissions from all sources and regions. An inventory can be pictured as a stool; the three legs of the stool are the emission rates, activity, and populations, while the seat is the inventory. The emission rates are inputs to the model specified for various "processes" including running exhaust, start exhaust, and a number of evaporative processes, among others. These processes also define the activity, populations, and technology inputs required.

Vehicle population and activity data are critical inputs for calculating emission inventories from emissions processes such as running exhaust, start exhaust, and evaporative emissions. In MOVES, most running emissions are distinguished by operating modes, depending on road type and vehicle speed. Start emissions are determined based on the time a vehicle has been parked prior to the engine starting, known as a "soak". Evaporative emissions modes are affected by vehicle operation and the time that vehicles are parked. Emission rates are further categorized by source bins with similar fuel type, regulatory classification, and other vehicle characteristics.

This report describes the sources and derivation for onroad vehicle population and activity information and associated adjustments as stored in the MOVES2014 and MOVES2014a[a] default databases. This data has been extensively updated from MOVES2010b and previous versions of MOVES. Emission measurement and rates, correction factor values, and information for nonroad equipment in the default database are described in other MOVES technical reports.[1]

There have not been any major updates between this final report and the earlier released public draft in July 2015.[2] However, this final report does have some notable revisions from the draft, namely some added or improved explanatory tables and figures, a new introductory subsection on vehicle model year groups, movement of content to different sections and appendices for better readability, clarifications to ambiguous descriptions, and a new appendix documenting peer review comments along with EPA's responses to those comments.

The MOVES2014 default database has a domain that encompasses all onroad (highway) vehicle and nonroad equipment activity and emissions for the entire United States, Puerto Rico, and the

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[a] In this report, "MOVES2014" refers to both MOVES2014 and MOVES2014a unless specified otherwise.

Virgin Islands. Properly characterizing emissions from the onroad vehicle subset requires a detailed understanding of the cars and trucks that make up the vehicle fleet and their patterns of operation. The national default activity information in MOVES2014 provides a reasonable basis for estimating national emissions. The most important of these inputs, such as VMT and population estimates, come from long-term systematic national measurements.

Given the availability of these national measurements when MOVES2014 was being developed, 2011 was chosen as the base year for future year projections. Like in previous versions of MOVES, users may analyze emission inventories in 1990 to correspond with the last Clean Air Act amendments as well as every year from 1999 to 2050.

In addition to uncertainties associated with projections, the uncertainties and variability in the default data contribute to the uncertainty in the resulting emission estimates. In particular, when modellers estimate emissions for specific geographic locations, EPA guidance recommends replacing many of the MOVES fleet and activity defaults with local data. This is especially true for inputs where local data is more detailed or up-to-date than that provided in the MOVES defaults. MOVES has been specifically designed to accommodate the input of alternate, user-supplied activity data for the most important parameters. EPA's Technical Guidance[3] provides more information on customizing MOVES2014 with local inputs.

This report documents the sources and calculations used to produce the default population and activity data in the MOVES2014 database for computing national-level emissions. In particular, this report will describe the data used to fill the tables listed below in Table 1-1.

Population and activity data are ever changing. As part of the MOVES development process, the model undergoes major updates and review every few years. As MOVES progresses, the development of fleet and activity inputs including projections will continue to be an important area of focus and improvement.

Table 1-1 MOVES database elements covered in this report

Database Table Name	Content Summary	Report Sections
AvgSpeedDistribution	Distribution of time among average speed bins	Section 9
DayVMTFraction	Distribution of VMT between weekdays and weekend days	Section 12
DriveSchedule	Average speed of each drive schedule	Section 10
DriveScheduleAssoc	Mapping of which drive schedules are used for each combination of source type and road type	Section 10
DriveScheduleSecond	Speed for each second of each drive schedule	Section 10
FuelType	Broad fuel categories that indicate the fuel vehicles are capable of using	Section 2
HotellingActivityDistribution	Distribution of hotelling activity to the various operating modes	Section 11
HotellingCalendarYear	Rate of hotelling hours per rural restricted access VMT	Section 11
HourVMTFraction	Distribution of VMT among hours of the day	Section 12
HPMSVtypeYear	Annual VMT by HPMS vehicle types	Section 4
ModelYearGroup	A list of years and groups of years corresponding to vehicles with similar emissions performance	Section 2
MonthGroupHour	Coefficients to calculate air conditioning demand as a function of heat index	Section 15
MonthVMTFraction	Distribution of annual VMT among months	Section 12
PollutantProcessModelYear	Assigns model years to appropriate groupings, which vary by pollutant and process	Section 4
RegulatoryClass	Sorts vehicles into weight-rating based groups in which emission regulations are applied	Section 2
RoadOpModeDistribution	Operating mode distributions by source type, road type, and speed bin	Section 10
RoadType	Distinguishes roadways by population density of geographic area and by type of access, particularly the use of ramps for entrance and exit	Section 2
RoadTypeDistribution	Distribution of VMT among road types	Section 8
SampleVehicleDay	Identifies vehicles in the SampleVehicleTrip table	Section 12
SampleVehiclePopulation	Fuel type and regulatory class distributions by source type and model year.	Section 4
SampleVehicleTrip	Trip start and end times used to determine vehicle start and soak times	Section 12
SCC	Source Classification Codes that identify the vehicle type, fuel type, road type and emission process in MOVES output	Section 2
SourceBinDistribution	Distribution of population among different vehicle sub-types (source bins)	Section 4

Table 1-1 MOVES database elements covered in this report

Database Table Name	Content Summary	Report Sections
SourceTypeAge	Rate of survival to subsequent age, relative mileage accumulation rates, and fraction of functional air conditioning equipment	Section 7 Section 15
SourceTypeAgeDistribution	Distribution of vehicle population among ages	Section 7
SourceTypeHour	The distribution of total daily hotelling among hours of the day	Section 12
SourceTypeModelYear	Prevalence of air conditioning equipment	Section 15
SourceTypePolProcess	Indicates which source bin discriminators are relevant for each source type and pollutant/process	Section 4
SourceTypeYear	Source type vehicle counts by year	Section 5
SourceUseType	Mapping from HPMS class to source type, including source type names	Section 2
SourceUseTypePhysics	Road load coefficients and vehicle masses for each source type used to calculate vehicle specific power (VSP) and scaled tractive power (STP)	Section 14
Zone	Allocation of activity to zone (county)	Section 12
ZoneRoadType	Allocation of driving time to zone (county) and road type	Section 13

2 MOVES Vehicle and Activity Classifications

In developing MOVES, we needed to pull together information on vehicle activity and emissions. We wanted to enter vehicle population and activity data in a form as close as possible to how this data is collected by highway departments and vehicle registrars, but we had to map this to existing information on emission standards and in-use emission rates. Thus, EPA developed MOVES-specific terminology classifying vehicles according to how they are operated, such as “source types,” and to emission-related characteristics, such as “regulatory classes” and “fuel types.” At the most detailed level, vehicles are classified into “source bins” which have a direct mapping to the rates in the MOVES emission rate tables.

This section provides definitions of the various vehicle classifications used in MOVES. The MOVES terms introduced in this section will be used throughout the report. Later sections explain how default vehicle populations and activity are assigned and allocated to these classifications.

2.1 HPMS Class

In this report, MOVES HPMS class refers to one of five categories derived from the US Department of Transportation (DOT) Highway Performance Monitoring System (HPMS) based vehicle classes used by the Federal Highway Administration (FHWA) in the Table VM-1 of their annual Highway Statistics report. The five HPMS classes used in MOVES are as follows: motorcycles (HPMSVTypeID 10), light-duty vehicles (25), buses (40), single unit trucks (50), and combination trucks (60).

Note that in MOVES2014, what we call the HPMS class for light-duty vehicles (25) denotes the sum of the VM-1 values for long wheelbase and short wheelbase light-duty vehicles. HPMSVTypeID 25 is new for MOVES2014 and replaces HPMSVTypeID 20 (passenger cars) and 30 (other two-axle four-tire vehicles) in MOVES2010. As such, in MOVES2014 any VMT input by HPMS class for passenger cars and light-duty trucks must be entered as a combined value in the new HPMSVTypeID 25. This change in HPMS classes has come about as passenger vehicles have evolved over time with the physical characteristics of “cars” and “trucks” becoming less distinct. In response, US DOT changed the organization of HPMS classifications and MOVES has evolved to reflect this change.

2.2 Source Use Types

The primary vehicle classification in MOVES is source use type, or, more simply, source type. Source types are intended to be groups of vehicles with similar activity and usage patterns. HPMS vehicle classes were differentiated into MOVES onroad source types.

Source types cannot be fully determined using field observations and must be paired with additional information about the vehicle’s activity to determine whether it typically travels short- or long-haul routes (greater than 200 miles per day), whether it has specific travel routines such as a refuse truck, and whether it is a commercial or personal vehicle. Estimates for short-haul/long-haul and commercial/personal distributions relied on information from the federal

Vehicle Inventory and Use Survey (VIUS). The MOVES2014 source types are listed in Table 2-1 along with the associated HPMS classes. More detailed source type definitions are provided in Section 6.1.

Table 2-1 MOVES2014 onroad source types

sourceTypeID	Source Type Name	HPMSVTypeID	Description
11	Motorcycles	10	Motorcycles
21	Passenger Cars	25	Light-Duty Vehicles
31	Passenger Trucks (primarily personal use)	25	Light-Duty Vehicles
32	Light Commercial Trucks (primarily non-personal use)	25	Light-Duty Vehicles
41	Intercity Buses (non-school, non-transit)	40	Buses
42	Transit Buses	40	Buses
43	School Buses	40	Buses
51	Refuse Trucks	50	Single Unit Trucks
52	Single Unit Short-Haul Trucks	50	Single Unit Trucks
53	Single Unit Long-Haul Trucks	50	Single Unit Trucks
54	Motor Homes	50	Single Unit Trucks
61	Combination Short-Haul Trucks	60	Combination Trucks
62	Combination Long-Haul Trucks	60	Combination Trucks

In MOVES, the distinction between light-duty (LD) and heavy-duty (HD) source types is essential because light- and heavy-duty operating modes are assigned by source type and their calculation differs for light- and heavy-duty vehicles. Light-duty vehicles (sourceTypeID 11, 21, 31, and 32) use vehicle specific power (VSP) operating modes, which are dependent on the measured mass of the test vehicle. Heavy-duty vehicles (sourceTypeID 41, 42, 43, 51, 52, 53, 54, 61, and 62) use scaled tractive power (STP) operating modes which are scaled by a fixed mass factor since their emission rates correlates better with absolute vehicle power than vehicle specific power. For more discussion on VSP and STP definitions, please refer to Section 14 of this report and the MOVES2014 reports on light-duty and heavy-duty vehicle emission rate development, respectively.[4,5]

2.3 Regulatory Classes

In contrast to source types, regulatory classes are used to group vehicles subject to similar emission standards. The EPA regulates vehicle emissions based on groupings of technologies and classifications that do not necessarily correspond to DOT activity and usage patterns. To properly estimate emissions, it is critical for MOVES to account for these emission standards. Thus, we must map the two schemas.

The regulatory classes used in MOVES are summarized in Table 2-2 below. The “doesn’t matter” regulatory class is used internally in the model if the emission rates for a given pollutant and process are independent of regulatory class. The motorcycle (MC) and light-duty vehicle (LDV) regulatory classes have a one-to-one correspondence with source type. Other source types are allocated between regulatory classes based primarily on gross vehicle weight rating (GVWR) classification, which is a set of eight classes defined by FHWA based on the manufacturer-defined maximum combined weight of the vehicle and its load. Urban buses have their own regulatory definition, and therefore have an independent regulatory class.

Table 2-2 Regulatory classes in MOVES2014

regClassID	Regulatory Class Name	Description
0	Doesn't Matter	Doesn't Matter
10	MC	Motorcycles
20	LDV	Light-Duty Vehicles
30	LDT	Light-Duty Trucks
40	LHD<=10k	Class 2b Trucks with 2 Axles and 4 Tires (8,500 lbs < GVWR <= 10,000 lbs)
41	LHD<=14k	Class 2b Trucks with 2 Axles and at least 6 Tires or Class 3 Trucks (8,500 lbs < GVWR <= 14,000 lbs)
42	LHD45	Class 4 and 5 Trucks (14,00 lbs < GVWR <= 19,500 lbs)
46	MHD	Class 6 and 7 Trucks (19,500 lbs < GVWR < =33,000 lbs)
47	HHD	Class 8a and 8b Trucks (GVWR > 33,000 lbs)
48	Urban Bus	Urban Bus (see CFR Sec. 86.091_2)

The EPA regulatory distinction between light-duty (LD) and heavy-duty (HD) trucks falls in the midst of FHWA GVWR Class 2. Trucks of 6,001-8,500 lbs. GVWR are Class 2a; in MOVES they are considered light-duty trucks in regulatory class 30. Vehicles of 8,500-10,000 lbs. GVWR are Class 2b, and considered light heavy-duty vehicles (LHD) in regulatory classes 40 or 41.

In MOVES2014, we introduced a new regulatory class 40 for vehicles that are classified as light-duty by FHWA (because they have only two axles and four tires), and are thus mapped to source type 30 (passenger trucks) or 31 (light-commercial trucks) in MOVES, but have a GVWR that puts them in Class 2b, so are subject to heavy-duty emission standards. As described above, these regulatory class 40 vehicles use light-duty (VSP-based) operating modes because they are light-duty source types, but the new regulatory class maps them to emission rates that are more consistent in how these vehicles are regulated. Meanwhile, Class 2b trucks with two axles and at least six tires (colloquially known as "dualies") and Class 3 trucks are considered single unit trucks by DOT, and therefore fall into regulatory class 41 and are modeled as the heavy-duty source types using STP-based operating modes. In summary, the light-duty truck source types (31 and 32) map only to regulatory classes 30 and 40 in MOVES2014, while the heavy-duty vehicle source types (41 and above) map to regulatory classes 41 and above. Section 6.2 provides more information on the distribution of vehicles among regulatory classes.

2.4 Fuel Types

MOVES also classifies vehicles by the fuel they are designed to use. MOVES2014 models vehicles and equipment powered by following fuel types: gasoline, diesel, E-85 (a nominal blend of 85 percent ethanol and 15 percent gasoline), compressed natural gas (CNG), electricity, and liquefied petroleum gas (LPG, only available for nonroad equipment). Note that in some cases, a single vehicle can use more than one fuel; for example, flexible fuel vehicles are capable of running on either gasoline or E-85. In MOVES, fuel type refers to the capability of the vehicle rather than the fuel in the tank. The fuel use actually modeled depends on a number of factors including the location, year, and month in which the fuel was purchased, as explained in the MOVES2014 technical report on the fuel supply.[6] Table 2-3 below summarizes the fuel types available in MOVES.

Table 2-3 A list of allowable fuel types to power vehicles/equipment in MOVES2014

fuelTypeID	defaultFormulationID	Description
1	10	Gasoline
2	20	Diesel Fuel
3	30	Compressed Natural Gas (CNG)
4	40	Liquefied Petroleum Gas (LPG)*
5	50	Ethanol (E-85) Capable
9	90	Electricity

* MOVES2014 models LPG use only in nonroad equipment.

It is important to note that not all fuel type/source type combinations can be modeled in MOVES. That is, MOVES2014 will not model gasoline fueled long-haul combination trucks, gasoline intercity buses, or diesel motorcycles. Though other natural gas vehicles such as CNG refuse trucks can found in the US today, CNG transit buses are the most prevalent and well-tested, and thus are currently the only onroad source type that may be modeled using CNG. Similarly, flexible fuel (E85-compatible) and electric vehicles are only modeled for passenger cars, passenger trucks, and light commercial trucks. None of the onroad (highway) source types can be modeled as fueled by LPG. For more information on how MOVES models the impact of fuels on emissions, please see the MOVES documentation on fuel effects.[7]

2.5 Road Types

MOVES calculates emissions separately for each of four road types and for "off-network" activity when the vehicle is not moving. It also allows separate output for ramp and non-ramp, as described in Section 10.2 below. The road type codes used in MOVES are listed in Table 2-4. The four MOVES road types (2-5) are aggregations of FHWA functional facility types.

Table 2-4 Road type codes in MOVES2014

roadTypeID	Description	FHWA Functional Types
1	Off Network	Off Network
2	Rural Restricted Access	Rural Interstate
3	Rural Unrestricted Access	Rural Principal Arterial, Minor Arterial, Major Collector, Minor Collector & Local
4	Urban Restricted Access	Urban Interstate & Urban Freeway/Expressway
5	Urban Unrestricted Access	Urban Principal Arterial, Minor Arterial, Collector & Local
6	Rural Restricted without Ramps	
7	Urban Restricted without Ramps	
8	Rural Restricted only Ramps	
9	Urban Restricted only Ramps	
100	Nonroad	

The MOVES road types are based on two important distinctions in how FWHA classifies roads: 1) urban versus rural roadways are distinguished based on land use and human population density, and 2) unrestricted versus restricted are distinguished based on roadway access—restricted roads require the use of ramps. The urban/rural distinction is used primarily for national level calculations. It allows different default speed distributions in urban and rural settings. Of course, finer distinctions are possible. Users with more detailed information on speeds and acceleration patterns may choose to create their own additional road types, or may run MOVES at project level where emissions can be calculated for individual links.

2.6 Source Classification Codes (SCC)

Source Classification Codes (SCC) are used to group and identify emission sources in large-scale emission inventories. They are often used when post-processing MOVES output to further allocate emissions temporally and spatially when preparing inputs for air quality modeling. In MOVES, SCCs are single numerical codes that identify the vehicle type, fuel type, road type, and emission process. The SCCs were redesigned for MOVES2014 to directly relate to the source use types and road types used by MOVES.

The new SCCs retain the previous 10-digit design, but use different numerical combinations to avoid conflicts with existing codes. The new codes for onroad vehicles use MOVES numerical identification (ID) codes in the following form:

AAAFVVRRPP, where

- AAA indicates mobile source (this has a value of 220 for both onroad and nonroad),
- F indicates the MOVES fuelTypeID value,
- VV indicates the MOVES sourceTypeID value,
- RR indicates the MOVES roadTypeID value, and
- PP indicates the MOVES emission processID value.

Building the SCC values in this way will allow additional source types, fuel types, road types, and emission processes to be easily added to the list of SCCs as changes are made to future versions of MOVES. The explicit coding of fuel type, source type, road type, and emission process also allows the new SCCs to indicate aggregations. For example, a zero code (00) for any of the sourceTypeID, fuelTypeID, roadTypeID, and processID strings that make up the SCC indicates that the reported emissions are an aggregation of all categories of that type. Using the mapping described above, modelers can also easily identify the sourceTypeID, fuelTypeID, roadTypeID, and processID of emissions reported by SCC. Refer to tables in the MOVES User Guide[3] or appropriate sections in this document for the descriptions of the sourceTypeID, fuelTypeID and roadTypeID values currently used by MOVES. A description of mapping between older SCCs in MOVES2010b and newer SCCs in MOVES2014 can be found in Section 21(Appendix E: SCC Mappings). Emission processes are discussed in other MOVES reports on emission rate development[4,5] and are not described here. All feasible SCC values are listed in the SCC table within the default database.

2.7 Model Year Groups

MOVES uses model year groups to avoid unnecessary duplication of emission rates for vehicles with similar technology and similar expected emission performance. For example, there is a model year group for, "1980 and earlier." In MOVES2014a, model year refers to the year in which the vehicle was produced, built, and certified as compliant with emission standards.

The default ModelYearGroup table provides information on the model year group names, beginning and ending years, and a two-digit shorthand identifier (shortModelYrGroupID). However, the model year groups that are relevant for a given calculation can vary depending on pollutant and emission process as defined in the PollutantProcessModelYear table. For example, a 2011 vehicle belongs to the "2011" model year group for estimating hydrocarbon running exhaust emissions, but belongs to the "2011-2020" group for estimating nitrous oxide running emissions. Because these groupings are determined based on analysis of the actual or expected emissions performance, the rationale for each model year grouping is provided in the MOVES2014 emission rate reports.[4,5]

2.8 Source Bins

The MOVES default database identifies emission rates by emission-related characteristics such as the type of fuel that a vehicle uses and the emission standards it is subject to. These classifications are called "source bins." They are named with a sourceBinID that is a unique 19-digit identifier in the following form:

$1FFEERRMM0000000000$, where

- 1 is a placeholder,
- FF is a MOVES fuelTypeID,

- EE is a MOVES engTechID,[b]
- RR is a MOVES regClassID,
- MM is a MOVES shortModYrGroupID, and
- 10 trailing zeros for future characteristics.

The model allocates vehicle activity and population to these source bins as described below. A mapping of model year to model year groups is stored in the PollutantProcessModelYear table. Distributions of fuel and engine technologies and regulatory class are stored by model year in the SampleVehiclePopulation table. The MOVES Source Bin Distribution Generator combines information from these two tables (see Table 2-5) to create a detailed SourceBinDistribution. These bins may vary by pollutant and process as indicated in the SourceTypePolProcess table. In general, fuel type and model year group are relevant for all emission calculations, but the relevance of regulatory class and model year group depend on the pollutant and process being modeled. If desired, MOVES2014 can produce results by various vehicle classifications—source type, SCC, or regulatory class—and by fuel type and model year.

Table 2-5 Data tables used to allocate source type to source bin

Generator Table Name	**Key Fields***	**Additional Fields**	**Notes**
SourceTypePolProcess	sourceTypeID polProcessID	isRegClassReqd isMYGroupReqd	Indicates which pollutant-processes the source bin distributions may be applied to and indicates which discriminators are relevant for each sourceTypeID and polProcessID (pollutant/process combination)
PollutantProcessModelYear	polProcessID modelYearID	modelYearGroupID	Assigns model years to appropriate model year groups for each polProcessID.
SampleVehiclePopulation	sourceTypeID modelYearID fuelTypeID engTechID regClassID	stmyFuelEngFraction stmyFraction	Includes fuel type and regulatory class fractions for each source type and model year, even for some source type/fuel type combinations that do not currently have any appreciable market share (i.e. electric cars). This table provides default fractions for the Alternative Vehicle Fuel & Technology (AFVT) importer.

* In these tables, the sourceTypeID and modelYearID are combined into a single sourceTypeModelYearID.

While details of the SourceTypePolProcess and PollutantProcessModelYear tables are discussed in the reports on the development of the light- and heavy-duty emission rates[4, 5], the SampleVehiclePopulation (SVP) table is a topic for this report and is discussed in Section 6.2.

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[b] In MOVES2014, engTechID 1 is used for all fuel types except electric vehicles, where engTechID 30 is used instead. Thus, in this version, engTechID is somewhat redundant with fuel type and adds no new information when determining source bin distributions or calculating emissions.

2.9 Allowable Vehicle Modeling Combinations

In theory, the MOVES source bins would allow users to model any combination of source type, model year, regulatory class, and fuel type. However, each combination must have accompanying emission rates; combinations that lack emissions testing or have negligible market share cannot be directly modeled in MOVES2014.

Table 2-6 summarizes the allowable source type-fuel type combinations. Most of the gasoline and diesel combinations exist with a few notable exceptions, but options for alternative fuels are limited, as discussed earlier in Section 2.4. MOVES also stores regulatory class distributions by source type in the SampleVehiclePopulation table. Table 2-7 summarizes the allowable source type-regulatory class combinations in MOVES2014. Table 2-8 combines the information in the two preceding tables. Each source type-fuel type combination contains all regulatory classes listed, except for gasoline transit buses, which have been called out separately. Additional discussion about decisions to include and exclude certain types of vehicles can be found in Section 6.

Table 2-6 Matrix of the allowable source type-fuel type combinations in MOVES2014 (Allowable combinations are marked with an X)

		Source Use Types												
		Motorcycles	Passenger Cars	Passenger Trucks	Light Commercial Trucks	Intercity Buses	Transit Buses	School Buses	Refuse Trucks	Short-Haul Single Unit Trucks	Long-Haul Single Unit Trucks	Motor Homes	Short-Haul Combination Trucks	Long-Haul Combination Trucks
Fuel Types		11	21	31	32	41	42	43	51	52	53	54	61	62
Gasoline	1	X	X	X	X		X	X	X	X	X	X	X	
Diesel	2		X	X	X	X	X	X	X	X	X	X	X	X
CNG	3						X							
E85-Capable	5		X	X	X									
Electricity	9		X	X	X									

Table 2-7 Matrix of the allowable source type-regulatory class combinations in MOVES2014 (Allowable combinations are marked with an X)

		Source Use Types												
		Motorcycles	Passenger Cars	Passenger Trucks	Light Commercial Trucks	Intercity Buses	Transit Buses	School Buses	Refuse Trucks	Short-Haul Single Unit Trucks	Long-Haul Single Unit Trucks	Motor Homes	Short-Haul Combination Trucks	Long-Haul Combination Trucks
Regulatory Classes		11	21	31	32	41	42	43	51	52	53	54	61	62
MC	10	X												
LDV	20		X											
LDT	30			X	X									
LHD<=10k	40			X	X									
LHD<=14k	41					X		X	X	X	X	X		
LHD45	42					X	X	X	X	X	X	X		
MHD67	46					X	X	X	X	X	X	X	X	X
HHD8	47					X	X	X	X	X	X	X	X	X
Urban Bus	48						X							

Table 2-8 A summary of source type, fuel type, and regulatory class combinations in MOVES2014

sourceTypeID	fuelTypeID	regClassID
11	1	10
21	1, 2, 5, 9	20
31	1, 2, 5, 9	30, 40
32	1, 2, 5, 9	30, 40
41	2	41, 42, 46, 47
42	1	42, 46, 47
	2, 3	48
43	1, 2	41, 42, 46, 47
51	1, 2	41, 42, 46, 47
52	1, 2	41, 42, 46, 47
53	1, 2	41, 42, 46, 47
54	1, 2	41, 42, 46, 47
61	1, 2	46, 47
62	2	46, 47

2.10 Default Inputs and Fleet and Activity Generators

As explained in the introduction, vehicle population and activity data are critical inputs for calculating emission inventories and MOVES calculators require information on vehicle population and activity at a very fine scale. In project-level modeling, this detailed information may be available and manageable. However, in other cases the fleet and activity data used in the MOVES calculators must be generated from inputs in a condensed or more readily available format. MOVES uses “generators” to create fine-scale information from user inputs and MOVES defaults.

The MOVES Total Activity Generator (TAG) estimates hours of vehicle activity using vehicle miles traveled (VMT) and speed information to transform VMT into source hours operating (SHO). Other types of vehicle activity are generated by applying appropriate factors to vehicle populations. Vehicle starts, extended idle hours, and source hours (including hours operating and not-operating) are also generated. The default database for MOVES2014 contains national estimates for VMT, vehicle population, and vehicle age distributions for every possible analysis year (1990 and 1999-2050). For national inventory runs, annual national activity is distributed temporally and spatially using allocation factors.

The Source Bin Distribution Generator (SBDG) uses information on fuel type fractions, regulatory class distributions, and similar information to estimate the number of vehicles belonging to each source bin as a function of source type and model year. The SBDG maps the activity data (by source types) to source bins which map directly to the MOVES emission rates.

There are a number of MOVES modules that generate operating mode distributions based on vehicle activity inputs. The Rates Operating Mode Distribution Generator and the Link Operating Mode Distribution Generator use information on speed distributions and driving patterns (driving schedules) to develop operating mode fractions for each source type, road type, and time of day. Similarly, the Evaporative Emissions Operating Mode Generator and the Start Operating Mode Distribution Generator use MOVES inputs to develop operating mode distributions for starts and vapor venting. The details of each these generators and other MOVES2014 algorithms are described in the MOVES2014 Module Reference.[8]

3 Data Sources

A number of organizations collect data relevant to this report. The most important sources used to populate the national default vehicle population and activity portions of the MOVES database are described here. These sources are referred to throughout this document by the abbreviated name given in this description, but the reference citation is only given here.

The MOVES Technical Guidance[3] provides detailed information on recommended data sources for users developing their own inputs.

3.1 VIUS

Until 2002 the US Census Bureau conducted the Vehicle Inventory and Use Survey (VIUS)[9] to collect data on the physical characteristics and activity of US trucks every five years. The survey is a sample of private and commercial trucks that were registered in the United States as of July of the survey year. The survey excludes automobiles, motorcycles, government-owned vehicles, ambulances, buses, motor homes, and nonroad equipment.

For MOVES, VIUS provides information to characterize trucks by source type and to estimate age, fuel type, and regulatory class distributions as well as relative mileage accumulation rates. MOVES2014 uses data from both the 1997 and 2002[10] surveys. While the survey includes a large number of vehicles and was designed to be representative of the US fleet, information on model year is not available for many of the older trucks. Thus, the distribution data for many older model years is sparse and sometimes erratic. Note that the Census Bureau discontinued VIUS in 2002, although there has been discussion recently about reinitiating the survey.

3.2 Polk NVPP® and TIP®

Acquired by IHS in July 2013, R.L. Polk & Co. was a private company providing automotive information services. The company maintained two databases relevant for MOVES: the National Vehicle Population Profile (NVPP®)[11] and the Trucking Industry Profile (TIP®Net) Vehicles in Operation[12] database. The first focused on light-duty cars and trucks, the second focused on medium and heavy-duty trucks. Both compiled data from state vehicle registration lists. For MOVES2014, EPA used NVPP® and TIP® datasets purchased for 1999 and 2011. Polk/IHS data was used in determining vehicles populations by age, fuel type, and regulatory class. At the time of these EPA data purchases Polk was independently operated, so we will continue to refer to these datasets under the Polk name in this report.

3.3 EPA Sample Vehicle Counts

Neither VIUS nor the Polk dataset contained enough information separately to develop distributions by regulatory class, fuel type, and age for each vehicle source type in MOVES, so EPA combined these datasets, and incorporated additional data sources to cover vehicles types, such as motorcycles, buses, and motor homes that were excluded from either the VIUS or Polk datasets. The resulting sample vehicle counts dataset is the basis for the MOVES2014 SampleVehiclePopulation table and the 2011 age distributions. More details on how we constructed the Sample Vehicle Counts dataset can be found in Section 6.2.

3.4 FHWA *Highway Statistics*

Each year the US DOT Federal Highway Administration's (FHWA) Office of Highway Policy Information publishes *Highway Statistics*. This volume summarizes a vast amount of roadway and vehicle data from the Highway Performance Monitoring System, a national information system that collects data from states and other sources on many facets of the US roadway system.

In MOVES2014, vehicle miles traveled (VMT) and vehicle population data for the historic years 1990 and 1999-2011 come from four tables in *Highway Statistics*: MV-1[13], MV-10[14], VM-1[15], and VM-2[16], which we will reference by table name. For some years, the VMT values were revised by FHWA in subsequent publications. Table 3-1 summarizes the data source and revision date we used for each historical year.

Table 3-1 Corresponding *Highway Statistics* data source for historical years

Year	FHWA Publication Source (Publication/Revision Date)
1990	*Highway Statistics 1991* (October 1992)
1999	*Highway Statistics 1999* (October 2000)
2000	*Highway Statistics 2000* (April 2011)
2001	*Highway Statistics 2001* (April 2011)
2002	*Highway Statistics 2002* (April 2011)
2003	*Highway Statistics 2003* (April 2011)
2004	*Highway Statistics 2004* (April 2011)
2005	*Highway Statistics 2005* (April 2011)
2006	*Highway Statistics 2006* (April 2011)
2007	*Highway Statistics 2007* (April 2011)
2008	*Highway Statistics 2008* (April 2011)
2009	*Highway Statistics 2010* (December 2012)
2010	*Highway Statistics 2010* (December 2012)
2011	*Highway Statistics 2011* (March 2013)

3.5 FTA National Transit Database

The US DOT, Federal Transit Administration (FTA) summarizes financial and operating data from mass transit agencies across the country in the National Transit Database (NTD).[17] For MOVES2014, we used 1999-2011 vehicle counts from the NTD Revenue Vehicle Inventory for motor buses (MB) to determine fuel type distributions and populations.

3.6 School Bus Fleet Fact Book

The *School Bus Fleet Fact Book* includes estimates, by state, of the number of school buses and total miles traveled.[18] The Fact Book is published by Bobit Publications. School bus mileage accumulation rates came from the 1997 Fact Book, originally used in MOBILE6. We have used 1999-2011 sales data from the 2009 and 2012 Fact Book to calculate age distributions.

3.7 MOBILE6

MOBILE6 was a precursor to MOVES used to estimate highway vehicle emissions. In some cases, we have used estimates from MOBILE6 model with only minor adaptation. In particular, we used MOBILE6 data for some relative mileage accumulation rates, air conditioning usage rates, and driving schedules. The MOBILE6 data is documented in technical reports, particularly M6.FLT.002, *Update of Fleet Characterization Data for Use in MOBILE6 - Final Report*.[19] Additional MOBILE6 documentation is available online.[20]

3.8 *Annual Energy Outlook* & National Energy Modeling System

The *Annual Energy Outlook* (AEO)[21] describes Department of Energy forecasts for future energy consumption. The National Energy Modeling System (NEMS) is used to generate these projections based on economic and demographic forecasts. Vehicle sales and miles traveled are included in the projections because they strongly influence fuel consumption. Therefore, the AEO is an important source of future projections in MOVES. For MOVES2014, we used AEO2014 to forecast VMT and vehicle populations in years 2012-2050.

3.9 Transportation Energy Data Book

Each year Oak Ridge National Laboratory produces the annual Transportation Energy Data Book (TEDB) for the Department of Energy. This book summarizes transportation and energy data from a variety of sources, including EPA, FHWA, Polk, and Ward's Automotive, Inc. For MOVES2014 we used information for estimating vehicle sales and survival fractions for historic years 1990 and 1999-2011 from TEDB Edition 32, published in 2013.[22]

3.10 FHWA Weigh-in-Motion

FHWA compiles truck weight data by axle configuration and roadway type from individual states' Weigh-in-Motion (WIM) programs.[23] The average weight for single unit trucks and combination trucks was determined from FHWA's Vehicle Travel Information System (VTRIS) W-3 Tables using data collected in 2011.

3.11 Motorcycle Industry Council *Statistical Annual*

The Motorcycle Industry Council (MIC) collects data on sales, ownership, and activity trends each year. MIC's *Statistical Annual* summarizes this data,[24] which we used in MOVES2014, particularly the 1999-2011 sales of highway motorcycles.

4 VMT by Calendar Year and Vehicle Type

For national level calculations, MOVES calculates source operating hours from national VMT by vehicle type. The default database contains national VMT estimatesfor all analysis years, which include 1990 and 1999-2050. Years 1991-1998 are excluded because there is no regulatory requirement to analyze them and including them would increase model complexity. Calendar year 1990 continues to be a base year because of the Clean Air Act Amendments of 1990.

The national VMT estimates are stored in the HPMSVTypeYear table[c], which includes three data fields: HPMSBaseYearVMT (discussed below), baseYearOffNetVMT, and VMTGrowthFactor. Off network VMT refers to the portion of activity that is not included in travel demand model networks or any VMT that is not otherwise reflected in the other four road types. The field baseYearOffNetVMT is provided in case it is useful for modeling local areas. However, the reported HPMS VMT values, used to calculate the national averages discussed here, are intended to include all VMT. Thus, for MOVES2014 national defaults, the baseYearOffNetVMT is zero for all vehicle types. Additionally, the VMTGrowthFactor field is not used in MOVES2014 and is set to zero for all vehicle types.

4.1 Historic Vehicle Miles Traveled (1990 and 1999-2011)

The HPMSBaseYearVMT field stores the total national VMT for each HPMS vehicle type for all analysis years. For historical years 1990 and 1999-2011, the VMT is derived from the FHWA VM-1 tables. In reporting years 2007 and later, the VM-1 data use an updated methodology[25], which implements state-reported data directly rather than a modeled approach and which has different vehicle categories. The current HPMS-based VM-1 categories are 1) light-duty short wheelbase, 2) light-duty long wheelbase, 3) motorcycles, 4) buses, 5) single unit trucks, and 6) combination trucks. Because MOVES categorizes light-duty source types based on vehicle type and not wheelbase length, the short and long wheelbase categories are combined into a single category of light-duty vehicles (HPMSVTypeID 25). Internally, the MOVES Total Activity Generator[8] allocates this VMT to MOVES source types and ages using vehicle populations, age distributions, and relative mileage accumulation rates.

For years prior to 2007, the VM-1 data with historical vehicle type groupings are inconsistent with the current VM-1 vehicle categories used in MOVES and cannot be used as they are currently reported. However, in early 2011, FHWA released revised VMT data for years 2000-2006 to match the new category definitions. Shortly afterward, the agency replaced these revised numbers with the previously published VMT data stating, “[FHWA] determined that it is more

[c] In MOVES2014a, users can enter VMT estimates using four different input methods: annual miles by HPMS class, annual miles by source type, annual average daily miles by HPMS class, and annual average daily miles by source type. As in MOVES2014, the default table, HPMSVTypeYear, continues to use annual miles by HPMS class in MOVES2014a. Considering the default table has not changed in MOVES2014a, any discussion in this report on annual VMT estimates will be in the context of annual miles traveled by HPMS class.

reliable to retain the original 2000-2006 estimates because the information available for those years does not fully meet the requirements of the new methodology."[d] However, needing continuity of the VM-1 vehicle categories, we used these FHWA-revised values by the new categories as the VMT for 2000-2006.

This left two years, 1990 and 1999, that needed to be adjusted to be consistent with the new HPMS vehicle categories. Since the methodology that FHWA used to revise the 2000-2006 data is unknown, we adjusted 1990 and 1999 using the average ratio of the change for each vehicle category. This was found by dividing the FHWA-adjusted VMT for each vehicle category by the original VMT for each year 2000-2006 and then calculating the average ratio for each category. This ratio was then applied to the corresponding VMT values reported in VM-1 for 1990 and 1999. Since FHWA's adjustments conserved the original total VMT estimates, we normalized our adjusted values such that the original total VMT for the years were unchanged.

The resulting values for historic years by HPMS vehicle class are listed in Table 4-1. The VMT for 1990 and 1999 were EPA-adjusted from VM-1, 2000-2006 were FHWA-adjusted, and 2007-2011 were unadjusted, other than the simple combination of the short and long wheelbase classes into light-duty vehicles.

Table 4-1 Historic year VMT by HPMS vehicle class (millions of miles)

Year	Motorcycles	Light-Duty Vehicles	Buses	Single Unit Trucks	Combination Trucks
1990	11,404	1,943,197	10,279	70,848	108,624
…					
1999	13,619	2,401,408	14,853	100,534	160,921
2000	12,175	2,458,221	14,805	100,486	161,238
2001	11,120	2,499,069	12,982	103,470	168,969
2002	11,171	2,555,467	13,336	107,317	168,217
2003	11,384	2,579,194	13,381	112,723	173,539
2004	14,975	2,652,092	13,523	111,238	172,960
2005	13,773	2,677,641	13,153	109,735	175,128
2006	19,157	2,680,535	14,038	123,318	177,321
2007	21,396	2,691,034	14,516	119,979	184,199
2008	20,811	2,630,213	14,823	126,855	183,826
2009	20,822	2,633,248	14,387	120,207	168,100
2010	18,513	2,648,457	13,770	110,738	175,789
2011	18,500	2,646,641	13,783	103,515	163,692

4.2 Projected Vehicle Miles Traveled (2012-2050)

The previous section describes historic fleet VMT. This section explains how EPA projected those values into the future. The VMT growth in years beyond 2011 is based on the VMT projections as described in AEO2014. Due to differences in methodology, the absolute VMT values presented in AEO differ slightly from the HPMS values in VM-1 where the analysis years overlap. Therefore, the projections in AEO were not used directly. Instead, percent changes from

[d] This text appears in a footnote to FHWA's *Highway Statistics* Table VM-1 for publication years 2000-2009.

year to year in the projected values were calculated and applied to the HPMS data. Since AEO2014 only projects out to 2040, VMT for years 2041-2050 were assumed to continue to grow at the average growth rate over 2031-2040.

A mapping between the two data sources was necessary because the vehicle categories differed between AEO and HPMS. AEO's light-duty percent growth was mapped to both the combined HPMS light-duty and the motorcycle categories. Motorcycles were included here because they were not explicitly accounted for elsewhere in AEO. Since buses span a large range of heavy-duty vehicles and activity, the combination of AEO's light medium, medium, and heavy heavy-duty growth rates was mapped to the HPMS bus category. AEO's light medium and medium heavy-duty growth rates were combined for mapping to the HPMS single unit truck category, and AEO's heavy heavy-duty growth was mapped to the HPMS combination truck category. We acknowledge that using VMT growth estimates from different vehicle types as surrogates for motorcycles and buses in particular will introduce additional uncertainty into these projections.

The percent growth over time was calculated for each of the groups described above and applied by HPMS category to the 2011 base year VMT from the Table VM-1. The resulting values are presented in Table 4-2 below.

Table 4-2 VMT projections for 2012-2050 by HPMS class (millions of miles)

Year	Motorcycles	Light-Duty Vehicles	Buses	Single Unit Trucks	Combination Trucks
2012	18,776	2,686,152	13,384	103,284	157,396
2013	19,030	2,722,469	13,954	108,811	163,467
2014	19,073	2,728,546	14,374	113,054	167,837
2015	19,162	2,741,392	14,991	118,343	174,804
2016	19,375	2,771,828	15,612	123,348	181,988
2017	19,590	2,802,578	16,036	126,693	186,928
2018	19,756	2,826,337	16,325	128,737	190,433
2019	19,931	2,851,349	16,609	130,692	193,905
2020	20,107	2,876,481	16,906	132,833	197,484
2021	20,284	2,901,914	17,222	135,237	201,214
2022	20,454	2,926,116	17,550	137,759	205,076
2023	20,627	2,950,908	17,877	140,171	208,983
2024	20,807	2,976,667	18,173	142,243	212,579
2025	20,997	3,003,914	18,495	144,418	216,551
2026	21,205	3,033,572	18,799	146,389	220,329
2027	21,426	3,065,195	19,052	147,999	223,510
2028	21,662	3,099,033	19,277	149,382	226,348
2029	21,897	3,132,690	19,509	150,824	229,268
2030	22,133	3,166,361	19,765	152,391	232,509
2031	22,378	3,201,376	20,005	153,916	235,518
2032	22,625	3,236,805	20,198	155,034	237,990
2033	22,867	3,271,436	20,429	156,435	240,929
2034	23,086	3,302,691	20,725	158,246	244,678
2035	23,293	3,332,329	21,017	159,910	248,437
2036	23,493	3,360,885	21,308	161,452	252,265
2037	23,687	3,388,760	21,600	162,945	256,123
2038	23,880	3,416,287	21,887	164,353	259,948
2039	24,060	3,442,035	22,146	165,603	263,426
2040	24,217	3,464,551	22,417	166,905	267,050
2041	24,436	3,495,877	22,701	168,431	270,775
2042	24,657	3,527,485	22,989	169,970	274,552
2043	24,880	3,559,380	23,280	171,524	278,381
2044	25,105	3,591,563	23,575	173,091	282,264
2045	25,332	3,624,036	23,874	174,673	286,201
2046	25,561	3,656,804	24,176	176,270	290,193
2047	25,792	3,689,868	24,483	177,881	294,241
2048	26,025	3,723,230	24,793	179,507	298,345
2049	26,261	3,756,894	25,107	181,147	302,507
2050	26,498	3,790,863	25,425	182,803	306,726

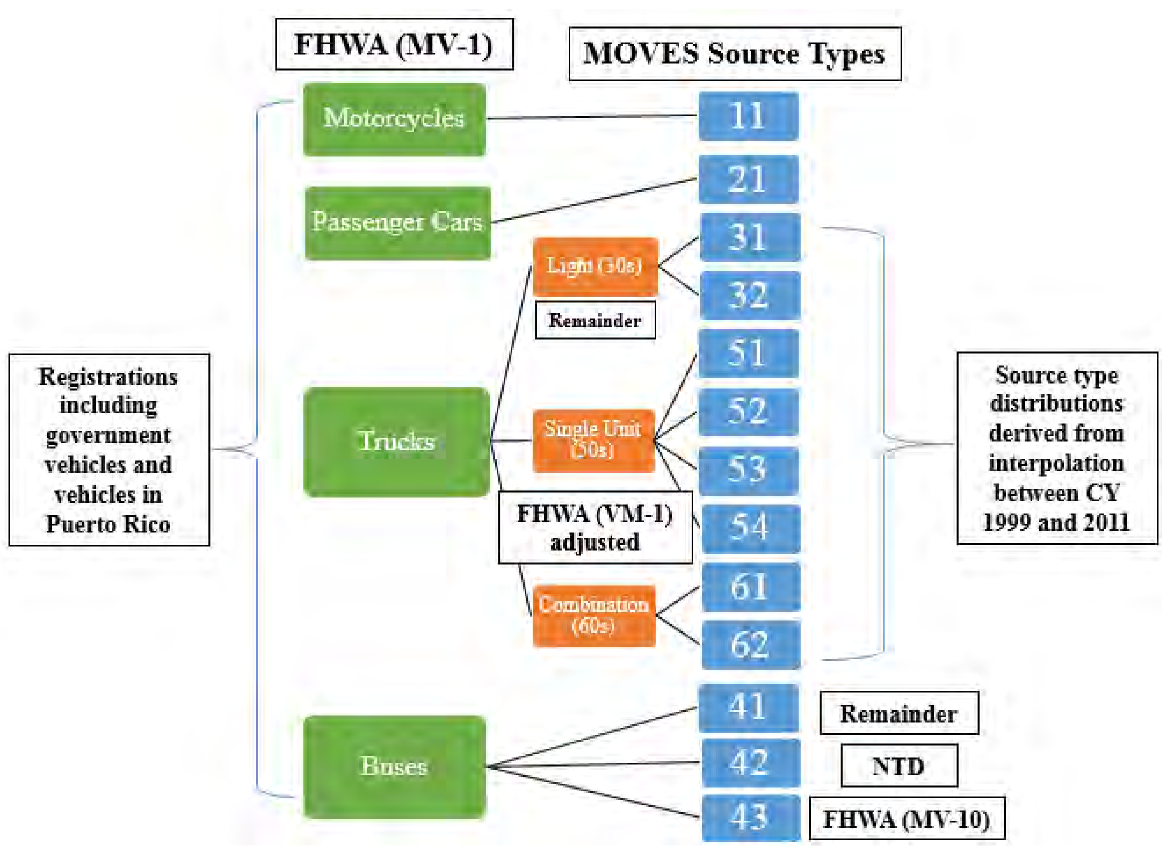
5 Vehicle Populations by Calendar Year

MOVES uses vehicle populations to characterize emissions activity that is not directly dependent on VMT. These data are also used to allocate VMT from HPMS class to source type and age. (For more details, see Section 7) The default database stores historic estimates and future projections of total US vehicle populations in 1990 and 1999-2050 by source type. All of these values have been updated in MOVES2014 with improved data sources. The MOVES database stores this information in the SourceTypeYear table, which has three data fields: sourceTypePopulation, salesGrowthFactor, and migrationRate. However, the salesGrowthFactor and migrationRate fields are not used in MOVES2014.

5.1 Historic Source Type Populations (1990 and 1999-2011)

MOVES populations for calendar years 1990 and 1999-2011 are derived top-down from registration data in Table MV-1 of the Federal Highway Administration's annual *Highway Statistics* report. In this table, vehicles are separated into four general vehicle categories: motorcycles, passenger cars, trucks, and buses. These categories include government vehicles and vehicles in Puerto Rico but do not account for vehicles in the Virgin Islands due to their relatively small effects on national population estimates. Motorcycle and car data were used without adjustment, but since MOVES populations are input by source type, allocations within the general categories of trucks and buses were necessary, as shown in Figure 5-1.

Figure 5-1 Conceptual map of allocating FHWA MV-1 vehicle registration estimates to MOVES source types



Trucks were separated into single unit and combination trucks using registration data in the *Highway Statistics* Table VM-1. The remaining MV-1 truck registrations were allocated to the light-duty trucks. Single unit and combination trucks were further allocated among their respective source types using the EPA sample vehicle counts data (see Section 6.2.2). Since we only had sample vehicle counts for calendar years 1999 and 2011, the 2000-2010 source type allocations within the general truck categories were linearly interpolated between 1999 and 2011 rather than using the predictions for these years as in MOVES2010b. For example, we fit a linear regression of the fraction of long-haul combination trucks out of total combination trucks between 1999 and 2011 and then fit another regression for the short-haul combination truck fraction. Regressions were fit in a similar fashion to allocate source type populations among light-duty and single unit trucks. For reference, the interpolated fractions for MOVES2014 that distribute the populations of light-duty, single unit, and combination trucks to the MOVES source types by calendar year are shown below in Table 5-1.

Table 5-1 MOVES2014 linearly interpolated fractions to allocate truck populations to source types, such as refuse trucks (sourceTypeID 51) among all single unit trucks (50s), by calendar year*

Year	***31/30s***	***32/30s***	***51/50s***	***52/50s***	***53/50s***	***54/50s***	***61/60s***	***62/60s***
1999	0.7496	0.2504	0.0155	0.7807	0.0462	0.1577	0.5744	0.4256
2000	0.7541	0.2459	0.0161	0.7786	0.0450	0.1604	0.5673	0.4327
2001	0.7586	0.2414	0.0166	0.7765	0.0438	0.1631	0.5601	0.4399
2002	0.7631	0.2369	0.0172	0.7745	0.0426	0.1657	0.5529	0.4471
2003	0.7676	0.2324	0.0178	0.7724	0.0414	0.1684	0.5457	0.4543
2004	0.7721	0.2279	0.0184	0.7703	0.0402	0.1711	0.5386	0.4614
2005	0.7767	0.2233	0.0190	0.7682	0.0390	0.1738	0.5314	0.4686
2006	0.7812	0.2188	0.0196	0.7662	0.0378	0.1765	0.5242	0.4758
2007	0.7857	0.2143	0.0201	0.7641	0.0366	0.1792	0.5171	0.4829
2008	0.7902	0.2098	0.0207	0.7620	0.0354	0.1819	0.5099	0.4901
2009	0.7947	0.2053	0.0213	0.7600	0.0341	0.1846	0.5027	0.4973
2010	0.7992	0.2008	0.0219	0.7579	0.0329	0.1873	0.4955	0.5045
2011	0.8037	0.1963	0.0225	0.7558	0.0317	0.1900	0.4884	0.5116

*Some fractions shown in this table may not sum exactly to one due to rounding. Fractions used to calculate source type populations had more significant digits than shown and sum precisely to one.

These interpolated fractions were then multiplied by the FHWA populations of light-duty, single unit, and combination trucks, respectively. This ensured that every source type population would more or less track its Highway Statistics population, as shown for combination trucks in Figure 5-2, for single unit trucks in Figure 5-3, and light-duty trucks in Figure 5-4. Car and motorcycle populations are reported directly in the Table MV-1 and thus were not subject to linear interpolation adjustments. Note that 1990 source type fractions were not interpolated and were instead retained from MOVES2010b.

Figure 5-2 Combination truck source type populations interpolated for 1999-2011

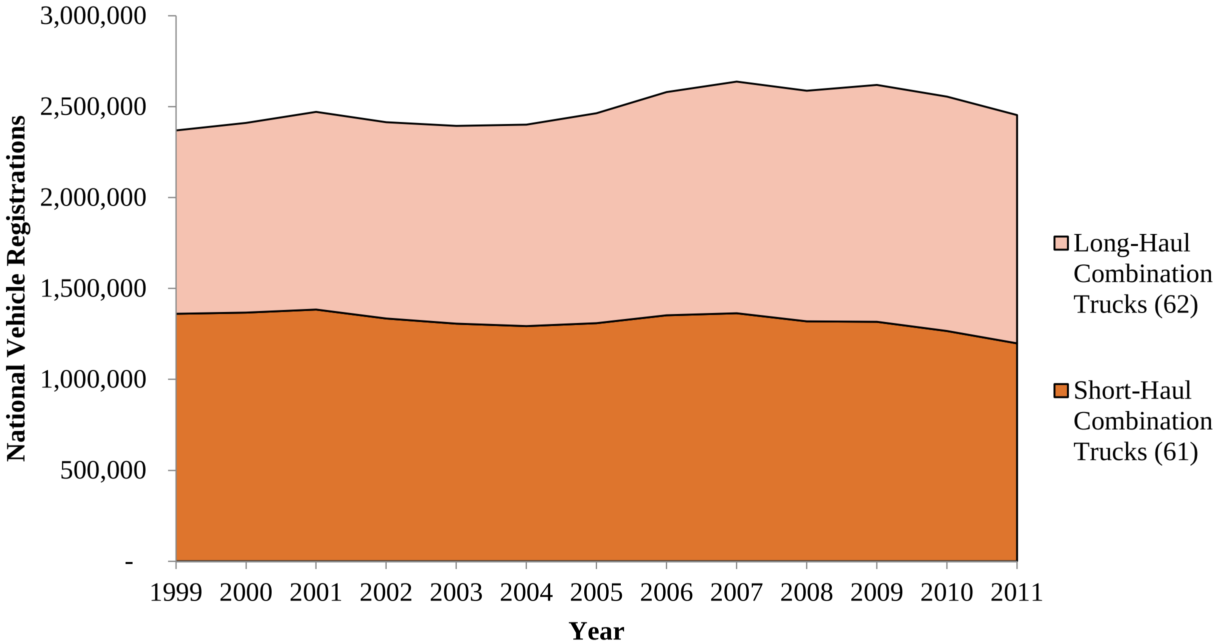


Figure 5-3 Single unit truck source type populations interpolated for 1999-2011

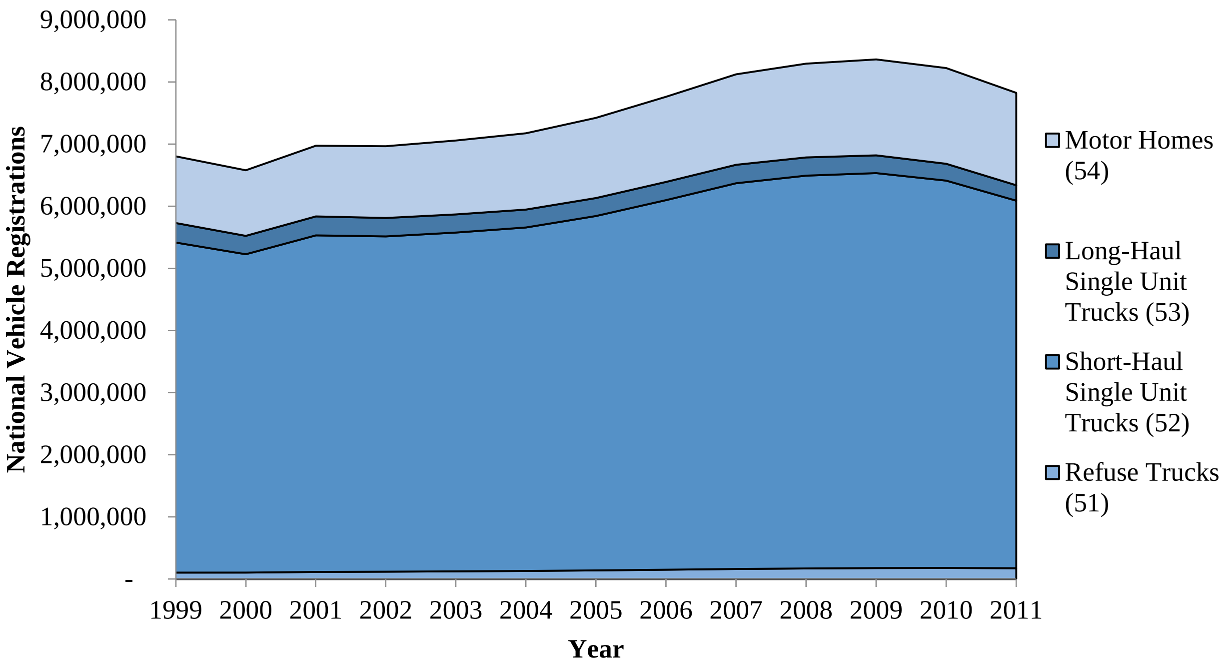


Figure 5-4 Light-duty vehicle source type populations; light trucks interpolated for 1999--2011

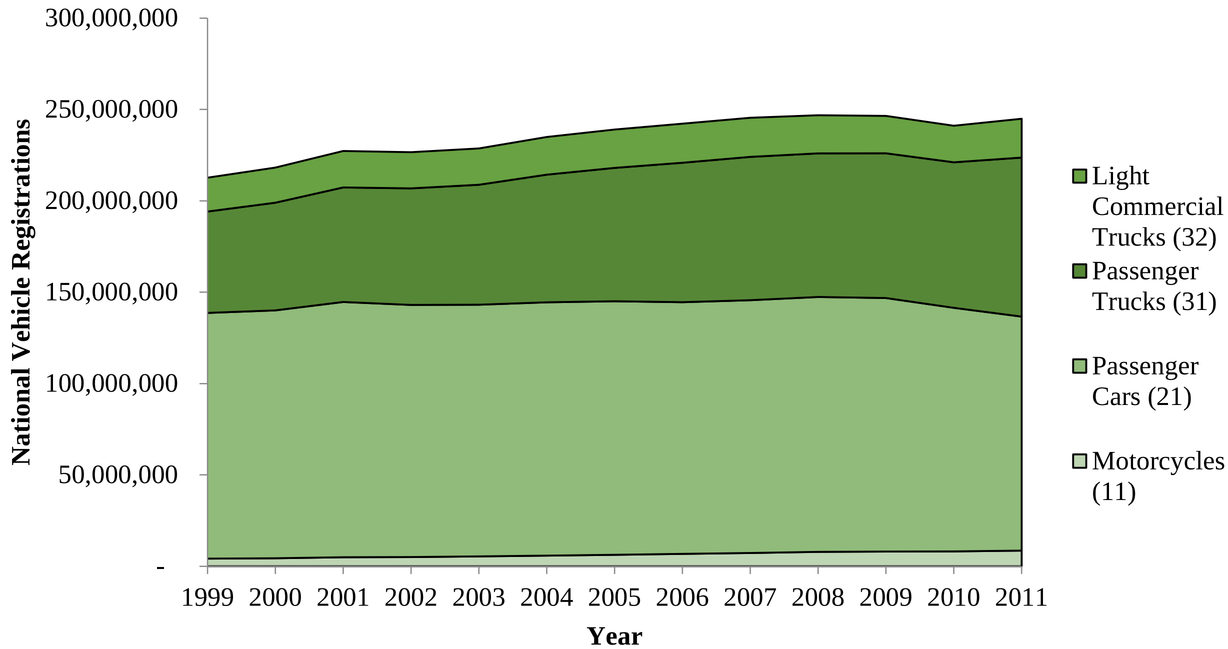
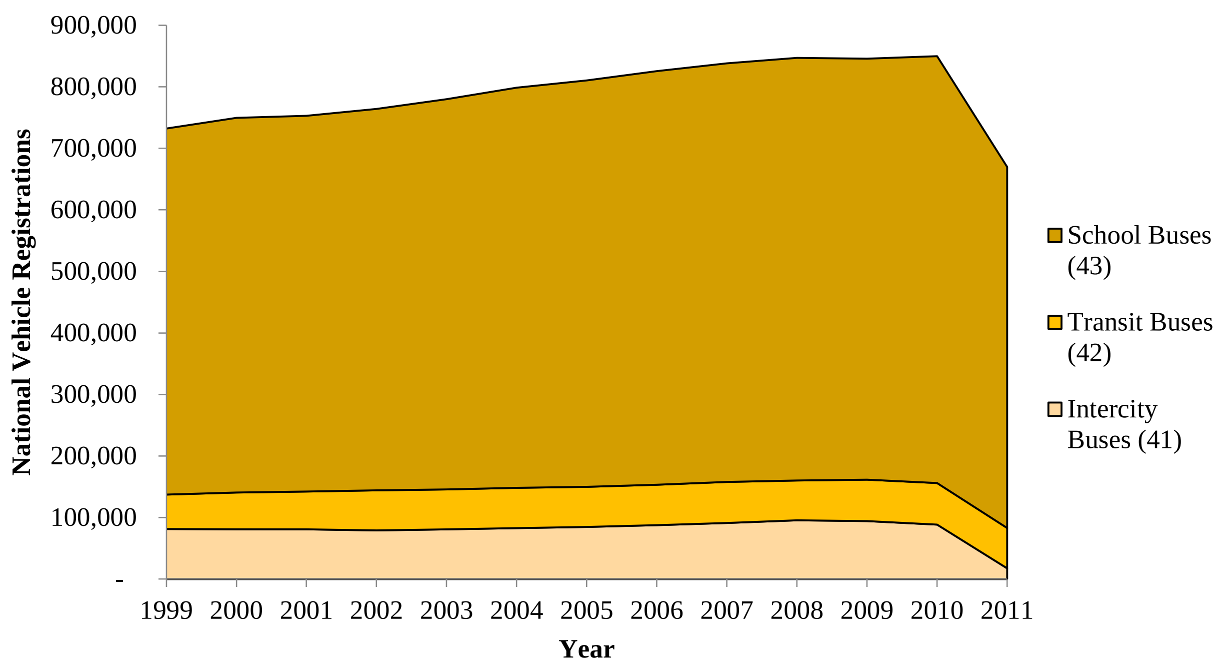


Figure 5-5 Bus source type populations in MOVES2014



Buses were allocated in a similar fashion as trucks, but using different data sources (see Figure 5-5). School bus estimates for all years 1999-2011 were taken from the *Highway Statistics* Table MV-10 and transit bus estimates for these years were taken from the National Transit Database (NTD) compiled by the Federal Transit Administration. The remainder of MV-1 bus registrations were allocated to the intercity bus source type. Since school and transit bus registrations in Puerto Rico were not readily available, we estimated them by multiplying the US transit or school bus registrations by the ratio of bus registrations in Puerto Rico to the total MV-1 bus registrations. Note that the precipitous drop in bus populations from 2010 to 2011 is reflected in the MV-1 bus registration data published by FHWA, which has been used in MOVES2014 without adjustment.

Table 5-2 Historic source type populations for calendar years 1990 and 1999-2011 (in thousands)

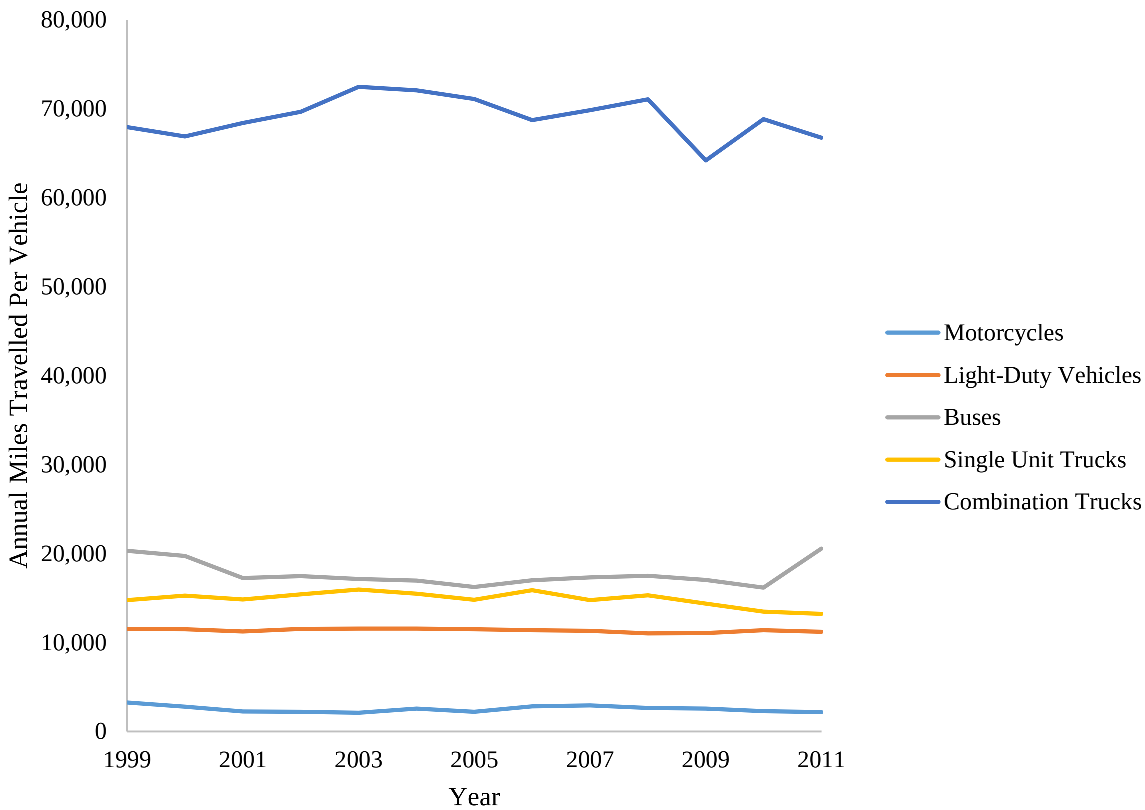
Year	Motorcycle	Passenger Car	Passenger Truck	Light Commercial Truck	Intercity Bus	Transit Bus	School Bus	Refuse Truck	Single Unit Short-Haul Truck	Single Unit Long-Haul Truck	Motor Home	Combination Short-Haul Truck	Combination Long-Haul Truck
1990	4,281	145,112	27,700	9,903	60	59	511	67	3,870	145	927	1,177	705
…													
1999	4,174	134,480	55,472	18,532	81	56	595	105	5,312	314	1,073	1,361	1,008
2000	4,368	135,670	58,930	19,217	81	60	609	106	5,123	296	1,055	1,368	1,043
2001	4,925	139,709	62,685	19,947	81	61	611	116	5,416	305	1,137	1,384	1,087
2002	5,026	137,996	63,789	19,801	79	65	620	120	5,396	297	1,155	1,335	1,080
2003	5,392	137,745	65,651	19,873	81	65	634	126	5,452	292	1,189	1,307	1,088
2004	5,813	138,642	69,860	20,616	83	65	650	132	5,528	288	1,228	1,293	1,108
2005	6,259	138,779	72,980	20,987	85	65	660	141	5,703	289	1,290	1,309	1,155
2006	6,770	137,742	76,321	21,380	88	66	672	152	5,948	293	1,370	1,353	1,228
2007	7,254	138,354	78,443	21,398	91	67	680	164	6,208	297	1,456	1,364	1,274
2008	7,869	139,501	78,596	20,868	96	65	687	172	6,322	293	1,509	1,319	1,268
2009	8,046	138,743	79,219	20,464	94	67	684	178	6,356	286	1,544	1,317	1,303
2010	8,125	133,313	79,641	20,007	89	68	694	180	6,234	271	1,540	1,266	1,289
2011	8,553	128,078	87,030	21,252	18	66	587	176	5,915	248	1,487	1,198	1,255

Note that the decline in sales seen in the 2008 recession results in a flattening of total population growth rates, and eventually a decline in total population for passenger cars and long-haul combination trucks as shown in Table 5-2. This suggests that the decline in sales was accompanied by a delay in the scrappage of older vehicles. The dynamic vehicle survival rates in MOVES and their impact on age distributions are discussed in Section 7.1.2.

5.2 Projected Vehicle Populations (2012-2050)

The previous section described the historic fleet as it appeared in the data. This section presents how EPA projected those vehicle populations into the future. This work is inherently dependent on projections of both vehicle sales and scrappage. While future vehicle sales are commonly included in economic forecasts, there are no reliable sources for projected national vehicle scrappage. Therefore, we decided to use projected VMT growth as a surrogate for vehicle population growth. In examining VMT per vehicle by HPMS class in historic years, this surrogate appears reasonable. Figure 5-6 shows the VMT values of Table 4-1 divided by the vehicle populations of Table 5-2 grouped by HPMS classification. At this level of aggregation, VMT per vehicle is relatively constant with no clear trends over time.

Figure 5-6 MOVES2014 annual miles traveled per vehicle by HPMS class, 1999-2011



Therefore, the AEO growth factors used to project future VMT as described in Section 4.2 were used to project populations. Motorcycle growth was calculated using factors from light-duty vehicles. Since these growth factors are by HPMS class, the 2011 source type populations were aggregated by HPMS class before the growth factors were applied to the base populations. The resulting HPMS class population projections are presented in Table 5-3. However, MOVES cannot use populations in this format as it requires them to be disaggregated by source type. The distribution projected HPMS class populations to source type was calculated with the same algorithm used to produce age distributions. Please see Section 7.1.2.2 for a detailed discussion on this topic. The resulting projected source type populations are tabulated in Section 17 (Appendix A).

Table 5-3 Projected HPMS class populations for 2012-2050 (in thousands)

Year	Motorcycles	Light-Duty Vehicles	Buses	Single Unit Trucks	Combination Trucks
2012	8,571	236,285	704	8,198	2,471
2013	8,687	239,479	734	8,637	2,566
2014	8,706	240,028	757	8,973	2,635
2015	8,747	241,178	789	9,393	2,745
2016	8,844	243,868	822	9,790	2,857
2017	8,943	246,584	844	10,056	2,935
2018	9,018	248,692	860	10,218	2,990
2019	9,098	250,904	875	10,373	3,045
2020	9,178	253,126	890	10,543	3,100
2021	9,260	255,371	906	10,733	3,159
2022	9,337	257,508	923	10,934	3,220
2023	9,416	259,695	941	11,126	3,281
2024	9,498	261,966	956	11,290	3,338
2025	9,585	264,368	974	11,463	3,400
2026	9,680	266,983	990	11,620	3,459
2027	9,781	269,767	1,004	11,747	3,510
2028	9,888	272,745	1,015	11,858	3,554
2029	9,996	275,707	1,027	11,978	3,600
2030	10,103	278,670	1,041	12,107	3,650
2031	10,215	281,752	1,053	12,234	3,698
2032	10,328	284,871	1,063	12,335	3,737
2033	10,439	287,918	1,075	12,454	3,783
2034	10,538	290,669	1,091	12,606	3,842
2035	10,633	293,277	1,106	12,745	3,901
2036	10,724	295,790	1,122	12,877	3,961
2037	10,813	298,244	1,137	13,007	4,021
2038	10,901	300,667	1,152	13,129	4,081
2039	10,983	302,932	1,166	13,238	4,136
2040	11,055	304,914	1,180	13,346	4,193
2041	11,155	307,671	1,196	13,472	4,251
2042	11,256	310,453	1,210	13,599	4,311
2043	11,357	313,260	1,226	13,731	4,371
2044	11,460	316,092	1,241	13,864	4,432
2045	11,564	318,951	1,257	13,998	4,494
2046	11,668	321,835	1,273	14,135	4,556
2047	11,774	324,745	1,289	14,273	4,620
2048	11,880	327,681	1,304	14,411	4,684
2049	11,988	330,642	1,322	14,550	4,750
2050	12,096	333,632	1,338	14,691	4,816

6 Fleet Characteristics

Despite the availability of vehicle registration databases, comprehensive surveys for characterizing travel pattern, and sophisticated sensors and cameras for measuring vehicle activity, it is still difficult to estimate vehicle populations in the categories needed for emissions inventory modeling. Differentiating, for example, between passenger car and trucks, or between light-duty and heavy-duty trucks presents substantial modeling challenges since the characteristics that are important for emissions are not always readily observable.[26, 27] To develop MOVES defaults, we have merged registration and survey data with activity measurements in an effort identify key vehicle parameters such as weight, axle and tire configuration, and typical trip range.

MOVES categorizes vehicles into thirteen source use types as described in Section 2.1, which are defined using physical characteristics, such as number of axles and tires, and travel behavior characteristics, such as typical trip lengths. This section describes the defining characteristics of the source types in greater detail, explains how source type is related to fuel type and regulatory class, primarily through the SampleVehiclePopulation table, and how MOVES2014 estimates and projects the number of vehicles in each category.

6.1 Source Type Definitions

MOVES source types are intended to further divide HPMS vehicle classifications into groups of vehicles with similar activity patterns For example, passenger trucks and light commercial trucks are expected to have different daily trip patterns. VIUS was our main source of information for distinguishing these vehicles. Table 6-1 summarizes how the VIUS2002 parameters were used to delineate the light-duty, single unit, and combination truck source types for MOVES2014.

Axle arrangement (AXLE_CONFIG) was used to define four categories: straight trucks with two axles and four tires (codes 1, 6, 7, 8), straight trucks with two axles and six tires (codes 2, 9, 10, 11), all straight trucks (codes 1-21), and all tractor-trailer combinations (codes 21+). Primary distance of operation (PRIMARY_TRIP) was used to define short-haul (codes 1-4) for vehicles with primary operation distances less than 200 miles and long-haul (codes 5-6) for 200 miles and greater. The VIN-decoded gross vehicle weight (ADM_GVW) and survey weight (VIUS_GVW) were used to distinguish vehicles less than 10,000 lbs. as light-duty and vehicles greater than or equal to 10,000 lbs. as heavy-duty. Any vehicle with two axles and at least six tires was considered a single unit truck regardless of weight. We also note that refuse trucks have their own VIUS vocational category (BODYTYPE 21) and that MOVES distinguishes between personal (OPCLASS 5) and non-personal use.

Table 6-1 VIUS2002 parameters used to distinguish truck source types in MOVES2014

Source Type	Axle Arrangement	Primary Distance of Operation	Weight	Body Type	Operator Classification
Passenger Trucks	AXLE_CONFIG in (1,6,7,8)[†]	Any	ADM_GVW in (1,2) & VIUS_GVW in (1,2,3)	Any	OPCLASS =5
Light Commercial Trucks	AXLE_CONFIG in (1,6,7,8)[†]	Any	ADM_GVW in (1,2) & VIUS_GVW in (1,2,3)	Any	OPCLASS ≠5
Refuse Trucks*	AXLE_CONFIG in (2,9,10,11)	TRIP_PRIMARY in (1,2,3,4)	Any	BODYTYPE =21	Any
	AXLE_CONFIG <=21	TRIP_PRIMARY in (1,2,3,4)	ADM_GVW > 2 & VIUS_GVW > 3	BODYTYPE =21	Any
Single Unit Short-Haul Trucks*	AXLE_CONFIG in (2,9,10,11)	TRIP_PRIMARY in (1,2,3,4)	Any	BODYTYPE ≠21	Any
	AXLE_CONFIG <=21	TRIP_PRIMARY in (1,2,3,4)	ADM_GVW > 2 & VIUS_GVW > 3	BODYTYPE ≠21	Any
Single Unit Long-Haul Trucks*	AXLE_CONFIG in (2,9,10,11)	TRIP_PRIMARY in (5,6)	Any	Any	Any
	AXLE_CONFIG <=21	TRIP_PRIMARY in (5,6)	ADM_GVW > 2 & VIUS_GVW > 3	Any	Any
Combination Short-Haul Trucks	AXLE_CONFIG >=21	TRIP_PRIMARY in (1,2,3,4)	Any	Any	Any
Combination Long-Haul Trucks	AXLE_CONFIG >=21	TRIP_PRIMARY in (5,6)	Any	Any	Any

[†] In the MOVES2014 analysis, we did not constrain axle configuration of light-duty trucks, so there are some, albeit very few, light-duty trucks that have three axles or more and/or six tires or more. These vehicles are classified as light-duty trucks based primarily on their weight. Only 0.27 percent of light-duty trucks have such tire and/or axle parameters and they have a negligible impact on vehicle populations and emissions.
* For a source type with multiple rows, the source type is applied to any vehicle with either set of parameters.

Motorcycles and passenger cars in MOVES borrow vehicle definitions from the FHWA Highway Performance Monitoring System (HPMS) classifications from the *Highway Statistics* Table MV-1. Source type definitions for intercity, transit, and school buses are taken from various US Department of Transportation sources. While refuse trucks were identified and separated from other single unit trucks in VIUS, motor homes were not.

6.1.1 Motorcycles

According to the HPMS vehicle description, motorcycles (sourceTypeID 11) are, “all two- or three-wheeled motorized vehicles, typically with saddle seats and steered by handlebars rather than a wheel.”[28] This category usually includes any registered motorcycles, motor scooters, mopeds, and motor-powered bicycles. Neither the 2011 Polk dataset nor VIUS contain any information on motorcycles. As noted in Section 5.1 information on motorcycle populations comes from HPMS MV-1 registrations.

6.1.2 Passenger Cars

Passenger cars are defined as any coupes, compacts, sedans, or station wagons with the primary purpose of carrying passengers.[28] All passenger cars (sourceTypeID 21) are categorized in the light-duty vehicle regulatory class (regClassID 20). Cars were not surveyed in VIUS, but Polk has a robust yet proprietary dataset of car registrations from all fifty states.

6.1.3 Light-Duty Trucks

Light-duty trucks include pickups, sport utility vehicles (SUVs), and vans.[28] Depending on use and GVWR, we categorize them into two different MOVES source types: 1) passenger trucks (sourceTypeID 31), and 2) light commercial trucks (sourceTypeID 32). According to 2011 VM-1 vehicle classifications from FHWA, light-duty vehicles are those weighing less than 10,000 pounds, specifically vehicles with a GVWR in Class 1 and 2, except Class 2b trucks with two axles or more and at least six tires are assigned to the single unit truck category.

VIUS contains many survey questions on weight; we chose to use both a VIN-decoded gross vehicle weight rating (ADM_GVW) and a respondent self-reported GVWR (VIUS_GVW) to differentiate between light-duty and single unit trucks. For the passenger trucks, there is a final VIUS constraint that the most frequent operator classification (OPCLASS) must be personal transportation. Inversely, light commercial trucks (sourceTypeID 32) have a VIUS constraint that their most frequent operator classification must not be personal transportation.

6.1.4 Buses

MOVES has three bus source types: intercity (sourceTypeID 41), transit (sourceTypeID 42), and school buses (sourceTypeID 43). Buses were not included in either VIUS or the Polk dataset, so supplementary data sources were necessary. MOVES uses various US Department of Transportation definitions for buses.

Transit buses are defined in the Federal Transit Administration's National Transit Database (NTD), which states that they are buses owned by a public transit organization for the primary purpose of transporting passengers on fixed routes and schedules.[29] According to FHWA, school buses are defined as vehicles designed to carry more than ten passengers, used to transport K-12 students between their home and school.[30] Intercity buses are, as defined by the Bureau of Transportation Statistics, "interstate motor carrier of passengers with an average annual gross revenue of at least one million dollars,"[31] but MOVES also considers any bus that cannot be categorized as either a transit or school bus to be an intercity bus, such as motor coaches and airport shuttles.

6.1.5 Single Unit Trucks

The single unit HPMS class in MOVES consists of refuse trucks (sourceTypeID 51), short-haul single unit trucks (sourceTypeID 52), long-haul single unit trucks (sourceTypeID 53), and motor homes (sourceTypeID 54). With 2013 VM-1 updates to vehicle classifications, FHWA now defines a single unit truck as a single-frame truck with a gross vehicle weight rating of greater than 10,000 pounds or with two axles and at least six tires—colloquially known as a "dualie." As with light-duty truck source types, single unit trucks are sorted using VIUS parameters, in this case that includes axle configuration (AXLE_CONFIG) for straight trucks (codes 1-21), vehicle weight (both ADM_GVW and VIUS_GVW), most common trip distance (TRIP_PRIMARY), and body type (BODYTYPE). All short-haul single unit trucks must have a primary trip distance of 200 miles or less and must not be refuse trucks and all long-haul trucks must have a primary trip distance of greater than 200 miles. Refuse trucks are short-haul single unit trucks with a body type (code 21) for trash, garbage, or recyclable material hauling. Motor homes are not included in VIUS.

6.1.6 Combination Trucks

A combination truck is any truck-tractor towing at least one trailer according to VIUS. MOVES divides these tractor-trailers into two MOVES source types: short-haul (sourceTypeID 61) and long-haul combination trucks (sourceTypeID 62). Like single unit trucks, short-haul and long-haul combination trucks are distinguished by their primary trip length (TRIP_PRIMARY) in VIUS. If the tractor-trailer's primary trip length is equal to or less than 200 miles, then it is considered short-haul. If the tractor-trailer's primary trip length is greater than 200 miles, then it is considered long-haul. Short-haul combination trucks are older than long-haul combination trucks and these short-haul trucks often purchased in secondary markets, such as for drayage applications, after being used primarily for long-haul trips.[32]

6.2 Sample Vehicle Population

To match source types to emission rates, MOVES must associate each source type with specific fuel types and regulatory classes. As vehicle markets shift, this mapping changes with model year.

Much of default the information on fleet characteristics is stored in the SampleVehiclePopulation table, which contains two fractions: 1) stmyFraction, and 2) stmyFuelEngFraction. The former fraction defines the default fuel type distribution, which can be modified by the user through the Alternative Fuel Vehicle and Technology (AVFT) table. The latter fraction forms the default regulatory class distribution. Both fractions are computed using the EPA sample vehicle counts dataset that joins 2011 national R.L. Polk vehicle registration data with 2002 Vehicle Inventory and Use Survey (VIUS) classifications.

6.2.1 Fuel Type and Regulatory Class Distributions

The stmyFraction is the default national fuel type and regulatory class allocation for each source type and model year. Written out mathematically in Equation 1, we define the stmyFraction as,

$$f(stmy)_{i,j,k,l} = \frac{N_{i,j,k,l}}{\sum_{j \epsilon J, k \epsilon K} N_{i,j,k,l}}, \qquad \text{Equation 1}$$

where the number of vehicles N in a given model year i, regulatory class j, fuel type k, and source type l is divided by the sum of vehicles across the set of all regulatory classes J and all fuel types K. That is, the denominator is the total for a given source type and model year. For example, model year 2010 passenger trucks have stmyFractions that indicate the distribution of these vehicles between gasoline, diesel, E85, and electricity and regulatory classes 30 and 40. These values must sums to one for each source type and model year. A value of zero indicates that the MOVES default population of vehicles of that source type, model year, fuel type, and regulatory class is negligible or does not exist.

While stmyFraction indicates MOVES default values, the stmyFuelEngFraction allows the modeling of non-default fuel type distributions. For each allowable combination of source type, model year and fuel type, the stmyFuelEngFraction indicates the expected regulatory class distribution, whether or not these vehicles exist in the default. Similar to the stmyFraction above, we define stmyFuelEngFraction in Equation 2 as,

$$f(stmyfueleng)_{i,j,k,l} = \frac{N_{i,j,k,l}}{\sum_{j \in J} N_{i,j,k,l}}, \qquad \text{Equation 2}$$

for number of vehicles N, model year i, regulatory class j, fuel type k, source type l, and the set of all regulatory classes J. In this case, the denominator is the total for a given source type, model year, and fuel type.. For example, for model year 2010 gasoline passenger trucks, the table will list a stmyFuelEngFraction for regulatory class 30 and another for regulatory class 40. These fractions sum to one for each combination of source type, model year and fuel type.

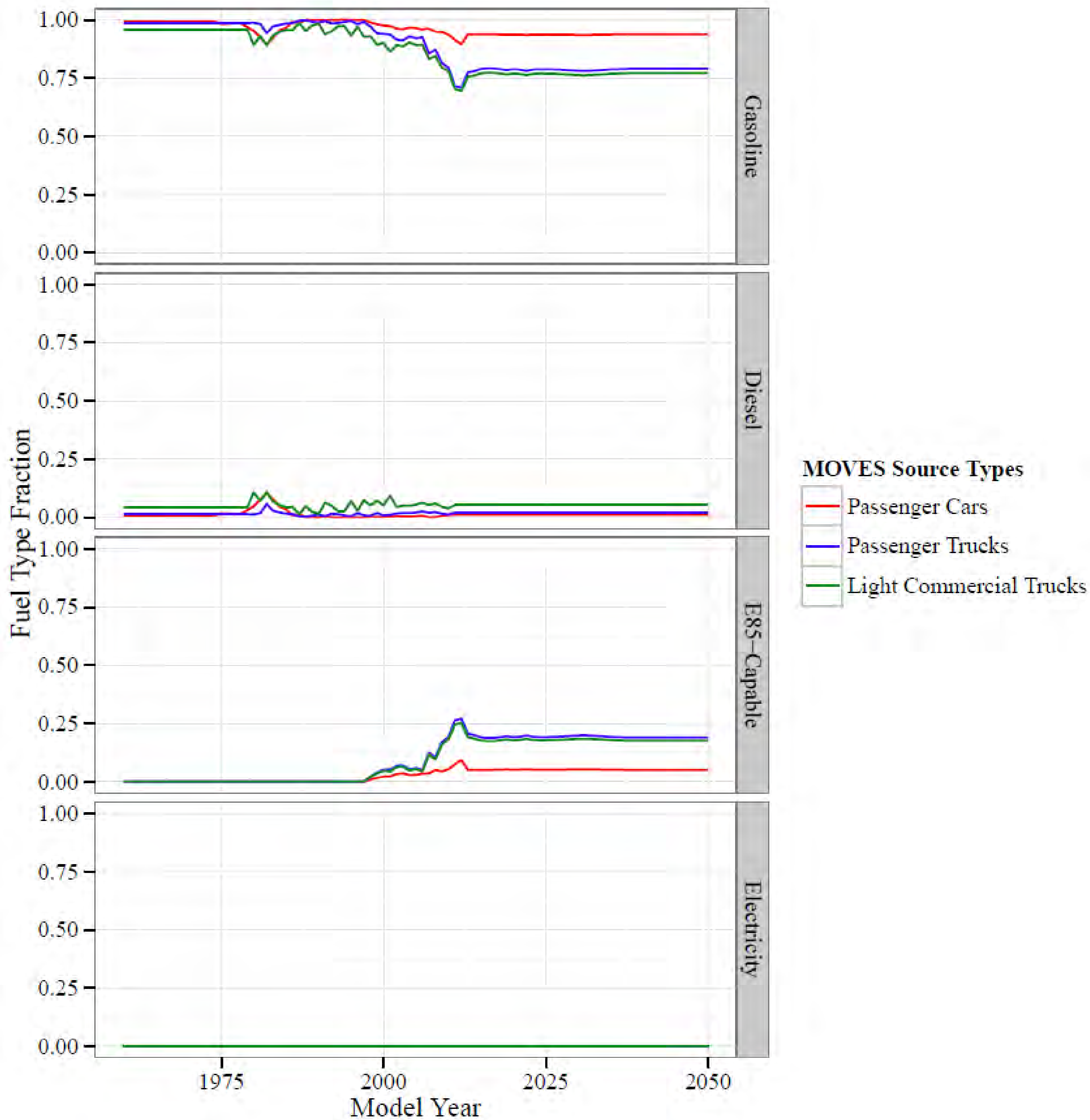
For example, while the stmyFraction indicates that the MOVES defaults assign zero fraction of model year 2010 passenger trucks to the electricity fuel type, the stmyFuelEngFraction indicates a default (hypothetical) regulatory class distribution if these vehicles existed. In this case, MOVES would model any electric passenger trucks as belonging to regulatory class 30. The stmyFraction is particularly important because users can edit fuel type distributions using the Alternative Vehicle Fuel and Technology (AVFT) importer. For instance, a user can create a future scenario in which there is a high penetration of electric passenger trucks. The stmyFuelEngFraction allows MOVES to assign vehicles to regulatory class without requiring this input from the user. This means an allowed stmyFuelEngFraction must never be zero.

As noted in Section 2.4, these fuel type fractions indicate the fuel capability of the vehicle and not the fuel being used by the vehicle.[e] In this report's nomenclature, E85-capable and flexible fuel vehicles are synomous—meaning they can accept either gasoline or E85 fuel. The amount of E85 versus the amount of gasoline used out of all the fuel consumed by the vehicle is stored in

[e] MOVES allocates fuel to specific vehicles in a two-step process: 1) vehicles are classified by the type of fuel they can use in the fuel type fraction, and then 2) fuels are distributed according to how much of each fuel is used relative to the vehicles' total fuel consumption in the fuel usage fraction. For example, Figure 6-1 below shows the national default fuel type fractions for all light-duty vehicles among the different MOVES fuel types.

the fuel usage fraction. Discussion on fuel usage can be found in the MOVES2014 Fuel Supply Report.[6]

Figure 6-1 Default fuel type fractions for light-duty source types in MOVES2014, where being E85-capable indicates flexible fuel vehicle populations and all default electric vehicle populations are zero



MOVES2014 does not explicitly model hybrid electric cars but accounts for these vehicles in calculating fleet-average energy consumption and CO_2 rates.[f]

6.2.2 Sample Vehicle Counts

The SampleVehiclePopulation table fractions were developed by EPA using the sample vehicle counts dataset referenced in Section 3, which primarily joins calendar year 2011 registration data from R.L. Polk and the 2002 Vehicle Inventory and Use Survey (VIUS) results. The sample vehicle counts dataset was generated by multiplying the 2011 Polk vehicle populations by the source type allocations from VIUS.

While VIUS provide source type classifications, we relied primarily on the 2011 Polk vehicle registration dataset to form the basis of the fuel type and regulatory class distributions in the SampleVehiclePopulation table. We purchased the Polk dataset in April 2012, so it did not have complete registration records for model year 2012 vehicles, and, therefore, model year 2012 vehicles were omitted from the SVP analysis. The Polk data was provided with the following fields: vehicle type (cars or trucks), fuel type, gross vehicle weight rating (GVWR) for trucks, household vehicle counts, and work vehicle counts. We combined the household and work vehicle counts. The MOVES distinction between personal and commercial travel for light-duty trucks comes from VIUS.

The Polk records by FHWA truck weight class were grouped into MOVES GVWR-based regulatory classes, as shown in Table 6-2 below. As stated above, all passenger cars were assigned to regClassID 20. The mapping of weight class to regulatory class is straightforward with one notable exception: delineating trucks weighing more or less than 8,500 lbs.

Table 6-2 Initial mapping from FHWA truck classes to MOVES regulatory classes

Vehicle Category	FHWA Truck Weight Class	Weight Range (lbs)	regClassID
Trucks	1	< 6,000	30
Trucks	2a	6,001 – 8,500	30*
Trucks	2b	8,501 – 10,000	41*
Trucks	3	10,001 – 14,000	41
Trucks	4	14,001 – 16,000	42
Trucks	5	16,001 – 19,500	42*
Trucks	6	19,501 – 26,000	46
Trucks	7	26,001 – 33,000	46
Trucks	8a	33,001 – 60,000	47
Trucks	8b	> 60,001	47
Cars			20

[f] While we have considered creating a separate category for hybrid vehicles, modeling their emissions separately is not required for regulatory purposes and presents a number of challenges, including obtaining representative detailed data on hybrid vehicle emissions and usage, and accounting for offsetting emissions allowed under the fleet-averaging provisions of the relevant emissions standards.

*After the Polk data had been sorted into source types (described later in this section), some regulatory classes were merged or divided. Any regulatory class 41 vehicles in light-duty truck source types were reclassified into the new regulatory class 40 (see explanation in Section 2.3), any regulatory class 30 vehicles in single unit truck source types were reclassified into regulatory class 41, and any regulatory class 42 vehicles in combination truck source types were reclassified into regulatory class 46.

Since the Polk dataset did not distinguish between Class 2a (6,001-8,500 lbs) and Class 2b (8,501-10,000 lbs) trucks, but MOVES regulatory classes 30, 40, and 41 all fall within Class 2, we needed a secondary data source to allocate the Polk gasoline and diesel trucks between Class 2a and 2b. We derived information from an Oak Ridge National Laboratory (ORNL) paper[33] summarized in Table 6-3 to allocate the Polk Class 2 gasoline and diesel trucks into the regulatory classes. Class 2a trucks fall in regulatory class 30 and Class 2b trucks fall in either regulatory class 40 or 41.

Table 6-3 Fractions used to distribute Class 2a and 2b trucks

Fuel Type	Truck Class	
	2a	**2b**
Gasoline	0.975	0.760
Diesel	0.025	0.240

Additionally, the Polk dataset includes a variety of fuels, some that are included in MOVES and others that are not. Only the Polk gasoline and diesel vehicles were included in our analysis; all other alternative fuel vehicles were omitted. While MOVES2014 does model light-duty E-85 and electric vehicles, and compressed natural gas (CNG) transit buses, these relative penetrations of alternative fuel vehicles have been developed from secondary data sources rather than Polk because Polk excludes some government fleets and retrofit vehicles that could potentially be large contributors to these alternative fuel vehicle populations. Instead we used flexible fuel vehicle sales data reported for EPA certification, and dedicated CNG bus populations from the National Transit Database. The Table 6-4 illustrates how Polk fuels were mapped to MOVES fuel types, and which Polk fuels were not used in MOVES.

The “N/A” mapping shown in Table 6-4 led us to discard 0.22 percent, roughly 530,000 vehicles (mostly dedicated or aftermarket alternative fuel vehicles), of Polk’s 2011 national fleet in developing the default fuel type fractions. However, because the MOVES national population is derived top-down from FHWA registration data, as outlined in Section 5.1, the total population is not affected. We considered the Polk vehicle estimates to be a sufficient sample for the fuel type and regulatory class distributions in the SampleVehiclePopulation table.

Table 6-4 A list of fuels from the Polk dataset used to develop MOVES fuel type distributions

Polk Fuel Type	MOVES fuelTypeID	MOVES Fuel Type
Unknown	N/A	
Undefined	N/A	
Both Gas and Electric	1	Gasoline
Gas	1	Gasoline
Gas/Elec	1	Gasoline
Gasoline	1	Gasoline
Diesel	2	Diesel
Natural Gas	N/A	
Compressed Natural Gas	N/A	
Natr.Gas	N/A	
Propane	N/A	
Flexible (Gasoline/Ethanol)	N/A	
Flexible	N/A	
Electric	N/A	
Cnvrtble	N/A	
Conversion	N/A	
Methanol	N/A	
Ethanol	N/A	
Convertible	N/A	

Next we transformed the VIUS dataset into MOVES format. The VIUS vehicle data was first assigned to MOVES source types using the constraints in Table 6-1 and then to MOVES regulatory classes using the mapping described in Table 6-2, including the allocation between Class 2a and 2b trucks from the ORNL study in Table 6-3. Similar to our fuel type mapping of the Polk dataset, we chose to omit alternative fuel

vehicles, as summarized below in Table 6-5.Table 6-1 VIUS2002 parameters used to distinguish truck source types in MOVES2014

Source Type	Axle Arrangement	Primary Distance of Operation	Weight	Body Type	Operator Classification
Passenger Trucks	AXLE_CONFIG in (1,6,7,8)[†]	Any	ADM_GVW in (1,2) & VIUS_GVW in (1,2,3)	Any	OPCLASS =5
Light Commercial Trucks	AXLE_CONFIG in (1,6,7,8)[†]	Any	ADM_GVW in (1,2) & VIUS_GVW in (1,2,3)	Any	OPCLASS ≠5
Refuse Trucks*	AXLE_CONFIG in (2,9,10,11)	TRIP_PRIMARY in (1,2,3,4)	Any	BODYTYPE =21	Any
	AXLE_CONFIG <=21	TRIP_PRIMARY in (1,2,3,4)	ADM_GVW > 2 & VIUS_GVW > 3	BODYTYPE =21	Any
Single Unit Short-Haul Trucks*	AXLE_CONFIG in (2,9,10,11)	TRIP_PRIMARY in (1,2,3,4)	Any	BODYTYPE ≠21	Any
	AXLE_CONFIG <=21	TRIP_PRIMARY in (1,2,3,4)	ADM_GVW > 2 & VIUS_GVW > 3	BODYTYPE ≠21	Any
Single Unit Long-Haul Trucks*	AXLE_CONFIG in (2,9,10,11)	TRIP_PRIMARY in (5,6)	Any	Any	Any
	AXLE_CONFIG <=21	TRIP_PRIMARY in (5,6)	ADM_GVW > 2 & VIUS_GVW > 3	Any	Any
Combination Short-Haul Trucks	AXLE_CONFIG >=21	TRIP_PRIMARY in (1,2,3,4)	Any	Any	Any
Combination Long-Haul Trucks	AXLE_CONFIG >=21	TRIP_PRIMARY in (5,6)	Any	Any	Any

[†] In the MOVES2014 analysis, we did not constrain axle configuration of light-duty trucks, so there are some, albeit very few, light-duty trucks that have three axles or more and/or six tires or more. These vehicles are classified as light-duty trucks based primarily on their weight. Only 0.27 percent of light-duty trucks have such tire and/or axle parameters and they have a negligible impact on vehicle populations and emissions.
* For a source type with multiple rows, the source type is applied to any vehicle with either set of parameters.

Table 6-5 Mapping of VIUS2002 fuel types to MOVES2014 fuel types

VIUS Fuel Type	VIUS Fuel Code	MOVES fuelTypeID	MOVES Fuel Type
Gasoline	1	1	Gasoline
Diesel	2	2	Diesel
Natural gas	3	N/A	
Propane	4	N/A	
Alcohol fuels	5	N/A	
Electricity	6	N/A	
Gasoline and natural gas	7	1	Gasoline
Gasoline and propane	8	1	Gasoline
Gasoline and alcohol fuels	9	1	Gasoline
Gasoline and electricity	10	1	Gasoline
Diesel and natural gas	11	2	Diesel
Diesel and propane	12	2	Diesel
Diesel and alchol fuels	13	2	Diesel
Diesel and electricity	14	2	Diesel
Not reported	15	N/A	
Not applicable	16	N/A	

This process yielded VIUS data by MOVES source type, model year, regulatory class, and fuel type. The VIUS source type distributions were calculated in a similar fashion to the SampleVehiclePopulation fractions discussed above for each regulatory class-fuel type-model year combination. Stated formally, for any given model year i, regulatory class j, and fuel type k, the source type population fraction f for a specified source type l will be the number of VIUS trucks N in that source type divided by the sum of VIUS trucks across the set of all source types L. The source type population fraction is summarized in Equation 3:

$$f(VIUS)_{i,j,k,l} = \frac{N_{i,j,k,l}}{\sum_{l \epsilon L} N_{i,j,k,l}} \qquad \text{Equation 3}$$

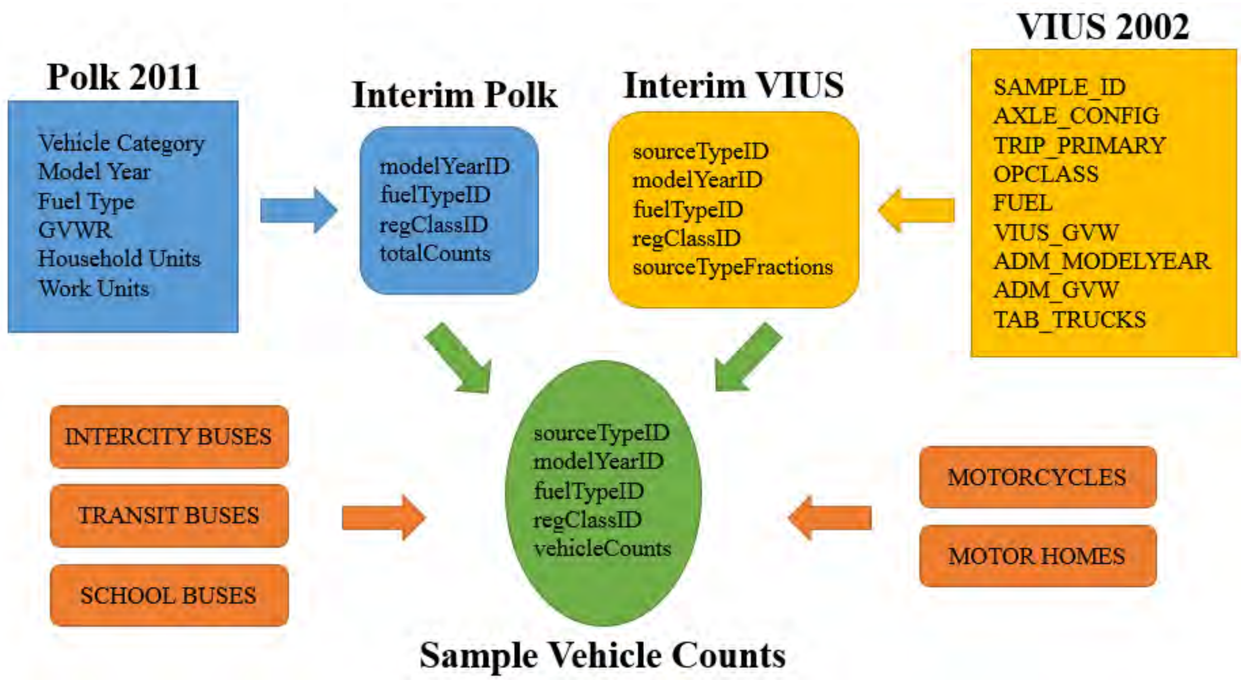
The VIUS data in our analysis spanned model year 1986 to 2002. The 2002 source type distribution has been used for all distributions after MY 2002 and the 1986 distribution for all prior to MY 1986.

From there the source type distributions from VIUS were multiplied by the Polk vehicle populations to generate the sample vehicle counts by source type, as shown schematically in Figure 6-2. Expressed in Equation 4, the sample vehicle counts are,

$$N(SVP)_{i,j,k,l} = P(Polk)_{i,j,k,l} \cdot f(VIUS)_{i,j,k,l}, \qquad \text{Equation 4}$$

where N is the number of vehicles used to generated the SampleVehiclePopulation table, P is the 2011 Polk vehicle populations, and f is the source type distributions from VIUS.

Figure 6-2 A schematic overview of how the 2011 Polk dataset and VIUS 2002 were joined to create EPA's sample vehicle counts for MOVES2014. Note that data on buses, motorcycles, and motor homes was pulled from other sources.



These sample vehicle counts by source type were then utilized to calculate the SVP fractions, stmyFraction and stmyFuelEngFraction, as defined above. Due to a small sample size of vehicles 30 years old and older in both the Polk and VIUS datasets, MOVES2010b SVP fractions were used for MY 1981 and earlier, which were generated following roughly the same procedure outlined above but using a 1999 Polk vehicle registration dataset joined with VIUS. These MOVES2010b SVP fractions for MY 1960-1981 are described in Section 18 (Appendix B). MOVES2014 assumes no changes to fuel type distributions after model year 2011 except for flexible-fuel (E85-capable) vehicles, which are assumed to displace gasoline vehicles based on sales estimates as described below. MOVES2014 estimates any other population growth by source type, as described earlier in Section 5.2 rather than growth for specific fuel types within a source type.

All Class 2b and 3 trucks were initially assigned to regulatory class 41 until vehicles were sorted into source types. Once the sample vehicle counts were available by source type, any light-duty trucks (sourceTypeID 31 or 32) in the original LHD regulatory class less than 14,000 lbs (regClassID 41) were reclassified in the new LHD regulatory class less than 10,000 lbs (regClassID 40), whereas any heavy-duty vehicles (sourceTypeID 41 and above) remained in regClassID 41. Similarly, any single unit trucks (sourceTypeID 52 and 53) in the LDT regulatory class (regClassID 30) were reclassified in regClassID 41 as heavy-duty vehicles. We also moved any regClassID 42 vehicles in combination truck source types to regClassID 46 because tractor-trailers must be either Class 7 or 8 trucks. This ensures a clean break between light- and heavy-duty emission results and that the emission calculations use the appropriate fixedMassFactor when calculating vehicle-specific power (VSP) for light-duty vehicles and scaled tractive power (STP) for heavy-duty vehicles.

As noted above, the initial sample vehicle counts dataset did not contain motorcycles, buses, or motor homes, so information on these source types was appended. Motor homes—even though they are considered single unit vocational vehicles—cannot be identified in VIUS. In the subsections below, we have provided more detailed descriptions by source type.

6.2.2.1 Motorcycles

The representation of motorcycles in the SampleVehiclePopulation table is straightforward. All motorcycles fall into the motorcycle regulatory class (regClassID 10) and must be fueled by gasoline. We acknowledge that some alternative fuel motorcycles have been prototyped and may even be in small production, but they account for a negligible fraction of total US motorcycle sales and cannot be modeled in MOVES2014.

6.2.2.2 Passenger Cars

Any passenger car is considered to be in the light-duty vehicle regulatory class (regClassID 20). Cars were included in the Polk dataset purchased in 2012, and EPA's subsequent sample vehicle counts dataset, which provided the split between gasoline and diesel cars in the SampleVehiclePopulation table. Flexible fuel (E85-capable) cars were also included in the SVP fuel type distributions but added after the sample vehicle counts analysis. We assume that a flexible fuel vehicle would directly displace its gasoline counterpart. For model years 2011 and earlier, we used manufacturer reported sales to EPA in order to calculate the fraction of sales of flexible fuel cars among sales of all gasoline and flexible fuel cars and added those penetrations as the fraction of E85 (fuelTypeID 5) vehicles and deducted them from the gasoline cars in the Polk dataset.

Similarly, for model years 2012 and later, we used Department of Energy car sales projections from AEO2014's table labeled "Light-Duty Vehicle Sales by Technology Type" to derive flexible fuel vehicle penetrations and applied them to the SVP fractions for regulatory class 20.[34] All other alternative fueled cars were determined to have insignificant market shares now and into the future.

While MOVES can model electric vehicles (fuelTypeID 9), the current market share of electric cars is sufficiently small that we have set the default electric car population to zero. Users can model an electric vehicle population by using the AVFT tool to redistribute market share. Electric vehicles do not have any tailpipe emissions, but MOVES2014 has electric vehicle rates for energy consumption, brakewear, and tirewear (electric vehicle brake and tirewear rates are copied from gasoline vehicles). Please consult the MOVES2014 documentation on greenhouse gases[35] and brake and tirewear[36], respectively, for more information on the development of the energy and emission rates themselves.

6.2.2.3 Light-Duty Trucks

Since passenger and light commercial trucks are defined as light-duty vehicles, they are constrained to regulatory class 30 and 40. Within the sample vehicle counts, GVWR Class 1 and

2a trucks were classified as regulatory class 30 and Class 2b trucks with two axles and four tires were classified as regulatory class 40. Both light-duty truck source types are divided between gasoline and diesel using the underlying splits in the sample vehicle counts data. Passenger trucks and light commercial trucks have similar but distinct distributions. Similar to cars, a penetration of flexible fuel (E-85-capable) light-duty trucks was calculated using EPA certification sales for historic years (MY 2011 and earlier) and AEO light truck projections for future years (MY 2012 and later) from the AEO2014 table on light-duty vehicle sales.[34] The flexible fuel vehicle penetration was applied to regClassID 30 for both E-85 (fuelTypeID 5) passenger and light commercial trucks and then deducted from their gasoline counterparts in the same regulatory class.

6.2.2.4 Buses

In line with the US Energy Information Administration (EIA) assumptions, all intercity buses in MOVES are powered by diesel fuel.[37] The following non-school bus regulatory class distribution for intercity buses was applied to all model years based on 2011 FHWA data, as shown in Table 6-6.[38]

Table 6-6 Regulatory class fractions of school and non-school buses using 2011 FHWA data

Vehicle Type	MOVES regClassID				
	41	42	46	47	Total
Non-School Buses	0.1856	0.0200	0.1214	0.6730	1
School Buses	0.0106	0.0070	0.9371	0.0453	1

The National Transit Database (NTD) Revenue Vehicle Inventory (Form 408) closely tracks the number of motor buses (MB) by fuel type each year and those statistics are used to develop the MOVES fuel type distributions for transit buses. The mapping from NTD fuel types to MOVES fuel types is summarized in Table 6-7.

Table 6-7 Mapping National Transit Database fuel types to MOVES fuel types

NTD code	NTD description	fuelTypeID	MOVES Fuel Description
BD	Bio-diesel	2	diesel
BF	Bunker fuel	N/A	
CN	Compressed natural gas	3	CNG
DF	Diesel fuel	2	diesel
DU	Dual fuel	2	diesel
EB	Electric battery	N/A	
EP	Electric propulsion	N/A	
ET	Ethanol	N/A	
GA	Gasoline	1	gasoline
GR	Grain additive	N/A	
HD	Hybrid diesel	2	diesel
HG	Hybrid gasoline	1	gasoline
KE	Kerosene	N/A	
LN	Liquefied natural gas	3	CNG
LP	Liquefied petroleum gas	N/A	
MT	Methanol	N/A	
OR	Other	N/A	

While some other MOVES fuel types are included in the NTD, the transit bus fuel type distributions were allocated between diesel, CNG, and gasoline only. Together these three fuel types account for more than 99 percent of all transit buses in 2011, so no other alternative fuels are allowed within the transit bus source type due to negligible market shares.

Biodiesel does not appear in the SampleVehiclePopulation table—in MOVES it is considered a fuel subtype rather than a fuel type—so biodiesel buses were added to the diesel buses from the NTD. Liquefied natural gas (LNG) comprises less than ten percent of all natural gas transit buses and only about 1.5 percent of the whole transit bus fleet in 2011. Without any readily available emission rate data on LNG buses, we grouped all natural gas fueled transit buses together. This means we effectively model LNG buses as if they were powered by CNG. Due to limited data, we assume that gasoline has a one-percent market share prior to model year 2000 and that diesel has a 99 percent market share prior to MY 1990. All other market shares of transit bus fuel types are derived using the NTD, as shown in Table 6-8. MOVES modelers can adjust these distributions between the fuel types using the AVFT tool.

Table 6-8 Fuel type market shares by model year for transit buses in MOVES2014

Model Year	MOVES Fuel Type		
	Gasoline	Diesel	CNG
1982-1989	1.00%	99.00%	0.00%
1990	1.00%	98.30%	0.70%
1991	1.00%	97.20%	1.80%
1992	1.00%	94.40%	4.60%
1993	1.00%	91.40%	7.60%
1994	1.00%	90.50%	8.50%
1995	1.00%	83.70%	15.30%
1996	1.00%	89.20%	9.80%
1997	1.00%	81.60%	17.40%
1998	1.00%	84.10%	14.90%
1999	1.00%	87.70%	11.30%
2000	0.85%	91.57%	7.58%
2001	0.88%	90.51%	8.60%
2002	0.91%	89.09%	10.00%
2003	0.94%	88.06%	10.99%
2004	0.89%	86.85%	12.27%
2005	1.05%	85.61%	13.34%
2006	1.18%	84.73%	14.09%
2007	1.29%	83.99%	14.72%
2008	1.61%	82.91%	15.49%
2009	1.89%	82.55%	15.56%
2010	2.14%	81.96%	15.90%
2011+	2.46%	81.75%	15.79%

Urban transit buses are regulated separately from other heavy-duty vehicles, under 40 CFR 86.091-2.[39] For this reason, CNG and diesel transit buses are each categorized in regulatory class 48. Lacking better data, we used a single regulatory class distribution from a study of diesel and CNG transit buses, highlighted in the MOVES2014 heavy-duty emission rates report[5], for gasoline transit buses as shown in Table 6-9 below.

Table 6-9 Regulatory class fractions of gasoline transit buses in MOVES2014

MOVES Source Type & Fuel Type	MOVES regClassID			
	42	46	47	Total
Gasoline Transit Buses	0.2683	0.0976	0.6341	1

The MOVES2014 school bus fuel type distribution is based on MOBILE6 estimates, originally calculated from 1996 and 1997 Polk bus registration data, for model years 1982-1996 are summarized in Table 6-10. The Union of Concerned Scientists estimates that roughly one percent of school buses run on non-diesel fuels, so we have assumed that one percent of school buses are gasoline fueled in MY 1997 and later.[40] The school bus regulatory class distribution was also derived from the 2011 FHWA data in Table 6-6.

Table 6-10 Fuel type market shares by model year for school buses in MOVES2014

Model Year	MOVES Fuel Type	
	Gasoline	Diesel
1982	67.40%	32.60%
1983	67.62%	32.38%
1984	61.55%	38.45%
1985	48.45%	51.55%
1986	32.67%	67.33%
1987	26.55%	73.45%
1988	24.98%	75.02%
1989	22.90%	77.10%
1990	12.40%	87.60%
1991	8.95%	91.05%
1992	1.00%	99.00%
1993	12.05%	87.95%
1994	14.75%	85.25%
1995	11.43%	88.57%
1996	4.15%	95.85%
1997+	1.00%	99.00%

6.2.2.5 Single Unit Trucks

The fuel type and regulatory class distributions for the single unit trucks are calculated directly from the EPA's sample vehicle counts datasets, except motor homes. The single unit source types are split between gasoline and diesel only. Single unit vehicle are distributed among the heavy-duty regulatory classes (regClassIDs 41, 42, 46, and 47) based on the underlying sample vehicle data. Motor home was not included as a VIUS body type response, so their fuel type and regulatory class distributions have been developed through supplementary data sources. The fuel type distribution for motor homes is unchanged from MOVES2010b (see Table 6-11), originally based on interpolating information from the Recreation Vehicle Industry Association (RVIA) on fuel type market shares.[41]

Table 6-11 Fuel type market shares for motor homes in MOVES2014

Model Year	Percent of Diesel	Percent of Gasoline
1982-1993	15%	85%
1994	18%	82%
1995	21%	79%
1996	23%	77%
1997	26%	74%
1998	29%	71%
1999	32%	68%
2000	34%	66%
2001	37%	63%
2002	40%	60%
2003	41%	59%
2004	43%	57%
2005	44%	56%
2006	46%	54%
2007	47%	53%
2008	49%	51%
2009	50%	50%
2010+	50%	50%

The motor home regulatory class distribution, shown below in Table 6-12, is used across all model years based on the same 2011 FHWA dataset[38] referenced above for school and non-school buses.

Table 6-12 Regulatory class fractions of motor homes using 2011 FHWA data

MOVES Source Type	MOVES regClassID				
	41	42	46	47	Total
Motor Homes	0.2697	0.3940	0.2976	0.0387	1

6.2.2.6 Combination Trucks

Combination trucks consist mostly of Class 8 trucks in the MOVES HHD regulatory class (regClassID 47) but also contain some Class 7 trucks in the MHD regulatory class (regClassID 46), predominantly in short-haul. Similarly, almost all combination trucks are diesel fueled. MOVES does not model gasoline long-haul combination trucks. Even for the short-haul source type, gasoline combination trucks are being phased out rapidly. After model year 2005, MOVES2014 assumes no gasoline combination trucks sales. These fuel type and regulatory class trends come out of the sample vehicle counts dataset. There has been growing interest in natural gas for freight transportation but currently this remains largely in the planning stages. There has not been sufficient testing of these trucks to develop MOVES emission rates yet. We will consider adding natural gas combination trucks as they become more prevalent and their emissions are more thoroughly tested.

7 Vehicle Characteristics that Vary by Age

Age is an important factor in calculating vehicle emission inventories, identifying high emitters, and characterizing travel behavior. MOVES employs a number of different age dependent factors, including deterioration of engine and emission after-treatment technology due to tampering and malmaintenance, vehicle scrappage and fleet turnover, and mileage accumulation over the lifetime of the vehicle. Deterioration effects are detailed in the MOVES2014 reports on the development of light-duty and heavy-duty emission rates.[4,5] In this section, there is discussion of vehicle age distributions, survival rates, and relative mileage accumulation rates by source type.

7.1 Age Distributions

A vehicle's age is simply the difference between its model year and the year of analysis. Age distributions in MOVES vary by source type and range from zero to 30+ years, so that all vehicles 30 years and older are modeled together. As such, an age distribution is comprised of 31 fractions, where each fraction represents the number of vehicles present at a certain age divided by the vehicle population for all ages, as summarized later in this section in Equation 9. Since sales and scrappage rates are not constant, these distributions vary by calendar year. The age distribution for each source type is stored in the SourceTypeAgeDistribution table, and fractions from each source type's age distribution sum to one across a calendar year. MOVES age distributions were compiled from a variety of data sources, which are discussed below. Age distributions for the 2011 base year are summarized in Table 7-1; all other years are available in the MOVES2014 default database SourceTypeAgeDistribution table.

7.1.1 Age Distributions from Registration Data

Ideally all historic age distributions could be derived from registration data sources for each analysis year available in MOVES. However, acquiring such data is prohibitively costly, so MOVES2014 only contains registration-based age distributions for two analysis years: 1990 and 2011. The following sections detail how these data were analyzed and used in MOVES2014.

7.1.1.1 1990 Age Distributions

MOVES2014 age distributions for calendar year 1990 have not been updated since the last model release. Please refer to Section 19 (Appendix C) for more information on the 1990 age distributions.

7.1.1.2 2011 Age Distributions

The 2011 age distributions for cars and trucks were derived from the sample vehicle counts dataset, as discussed earlier in Section 3.3. This sample vehicle data includes eight of the thirteen source types: passenger cars (21), passenger trucks (31), light commercial trucks (32), refuse trucks (51), short-haul single unit trucks (52), long-haul single unit trucks (53), short-haul combination trucks (61), and long-haul combination trucks (62). We were able to develop zero to 30+ year age distributions in 2011 for the eight source types mentioned.

For the source types that were not included in the sample vehicle data—specifically motorcycles, motor homes, and buses—we calculated the 2011 age distributions from the MOVES2010b default 1999 distributions with the latest sales data available. This approach kept the MOVES2010b base populations and scrappage rates but substituted in MY 1999-2011 sales. We pulled sales for motorcycles (11) from the Motorcycle Industry Council's *Statistical Annual* report[24], for transit buses (42) from internal EPA estimates based on manufacturer reporting, and for school buses (43) from the *School Bus Fleet Fact Book*[18]. Since 2011 age distributions were calculated independently, intercity bus (41) and motor home (54) sales data were based on slightly different assumptions. Both of these source types used an average of Ward's Class 3-8 truck sales in Oak Ridge's *Transportation Energy Data Book*[22], transformed into MOVES source types using the allocation of sample vehicle counts described in Section 6. For more information on these data sources, please revisit Section 3.

Figure 7-1 and Table 7-1 show the fraction of vehicles by age (0-30+ years) and source type for calendar year 2011. These 2011 age distributions became the basis for all the forecast age distributions in Section 7.1.2.2 and all backcast age distributions in Section 7.1.2.3.

Figure 7-1 2011 age distributions by source type in MOVES2014

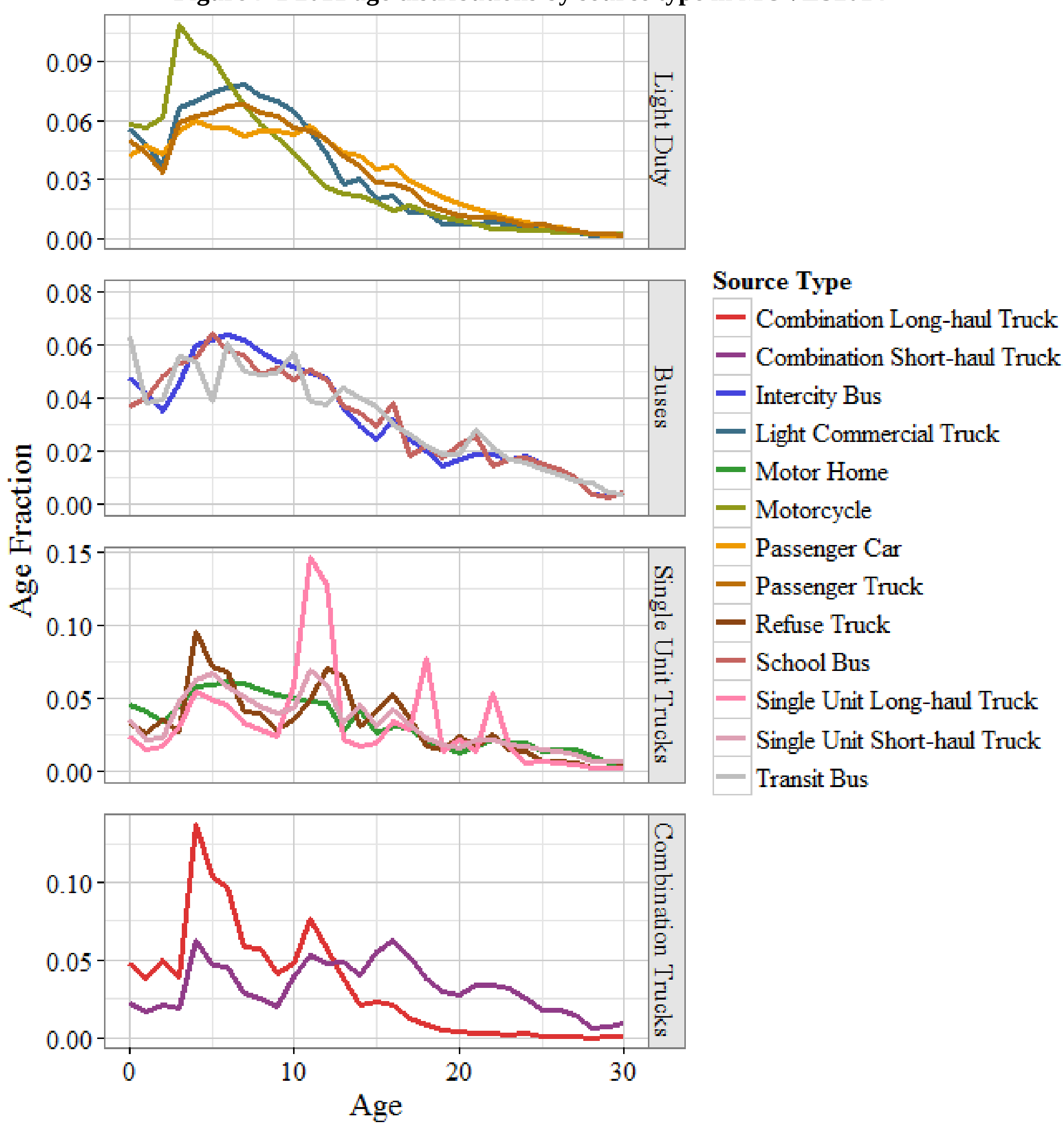


Table 7-1 2011 age fractions by MOVES source type

Age	11	21	31	32	41	42	43	51	52	53	54	61	62
0	0.0585	0.042	0.0496	0.0557	0.0477	0.0628	0.0368	0.0334	0.035	0.0237	0.046	0.0219	0.0478
1	0.0565	0.0472	0.044	0.0482	0.0421	0.0385	0.0403	0.0265	0.0216	0.015	0.0406	0.0164	0.0378
2	0.0614	0.043	0.0335	0.0372	0.0353	0.0393	0.048	0.0351	0.0231	0.0176	0.034	0.0213	0.0501
3	0.1088	0.0545	0.0587	0.0668	0.0458	0.0555	0.0529	0.0273	0.0479	0.031	0.0442	0.0192	0.0392
4	0.0968	0.0597	0.0626	0.0703	0.0601	0.0539	0.0548	0.0956	0.0629	0.0544	0.0579	0.0629	0.1371
5	0.0917	0.0562	0.0644	0.0743	0.0617	0.0389	0.0644	0.0718	0.0666	0.0486	0.0594	0.0468	0.1028
6	0.0803	0.0562	0.0677	0.077	0.0638	0.0607	0.0574	0.0677	0.0577	0.045	0.0615	0.0455	0.0971
7	0.0682	0.0526	0.0686	0.0781	0.062	0.0498	0.0565	0.0407	0.0506	0.0333	0.0597	0.0288	0.0584
8	0.0583	0.0551	0.0638	0.0724	0.0574	0.0488	0.0487	0.04	0.0438	0.0284	0.0553	0.0256	0.057
9	0.0514	0.055	0.0624	0.0702	0.0538	0.0495	0.0511	0.029	0.0393	0.0238	0.0518	0.0199	0.0415
10	0.0436	0.0534	0.0562	0.0647	0.0517	0.057	0.0467	0.0357	0.0427	0.059	0.0498	0.0391	0.0482
11	0.0348	0.0575	0.0545	0.055	0.0492	0.0385	0.0508	0.0488	0.0697	0.1457	0.0474	0.0535	0.0766
12	0.0263	0.05	0.0504	0.0433	0.0478	0.0374	0.047	0.0702	0.0591	0.1267	0.0461	0.0482	0.0572
13	0.0224	0.0441	0.0424	0.0273	0.0362	0.0439	0.0371	0.0645	0.0334	0.0213	0.0271	0.049	0.0381
14	0.0215	0.042	0.0372	0.0305	0.0295	0.0401	0.0345	0.0312	0.0459	0.0175	0.0417	0.0398	0.0215
15	0.0188	0.0354	0.0284	0.0203	0.0244	0.0369	0.0298	0.0406	0.0308	0.0198	0.0258	0.0556	0.0234
16	0.0142	0.0367	0.0274	0.0219	0.0317	0.0303	0.038	0.0521	0.0423	0.0338	0.0305	0.0628	0.0209
17	0.0163	0.029	0.025	0.0137	0.0244	0.0264	0.0184	0.0367	0.0323	0.0279	0.0291	0.0524	0.0127
18	0.0133	0.0249	0.0175	0.0136	0.0201	0.0219	0.0219	0.0167	0.0225	0.0777	0.02	0.038	0.0086
19	0.0111	0.0209	0.0142	0.0073	0.0148	0.019	0.0177	0.0149	0.0179	0.0137	0.0175	0.0292	0.0052
20	0.0088	0.0178	0.012	0.007	0.0168	0.0192	0.0226	0.0233	0.0162	0.0213	0.013	0.0272	0.004
21	0.0071	0.015	0.0106	0.0075	0.0188	0.0281	0.0255	0.0166	0.022	0.0132	0.0171	0.0337	0.0031
22	0.0053	0.0124	0.0108	0.008	0.0187	0.0214	0.0145	0.0256	0.0211	0.0535	0.0221	0.0343	0.0031
23	0.0045	0.0097	0.0092	0.0073	0.0174	0.0168	0.0173	0.0147	0.0188	0.017	0.0196	0.0317	0.0019
24	0.0044	0.008	0.007	0.0057	0.018	0.0156	0.0175	0.0132	0.0171	0.0061	0.0191	0.025	0.0032
25	0.0037	0.0065	0.0071	0.0053	0.0151	0.0131	0.0153	0.0068	0.0154	0.0064	0.0141	0.0174	0.0009
26	0.0031	0.0053	0.0049	0.0037	0.0132	0.0113	0.0131	0.0068	0.0132	0.0055	0.015	0.0177	0.0009
27	0.0028	0.0042	0.004	0.0031	0.0104	0.0088	0.0101	0.0056	0.0113	0.0048	0.0152	0.0145	0.0007
28	0.002	0.0025	0.0024	0.0019	0.0041	0.0083	0.0037	0.0025	0.0067	0.0028	0.0098	0.0062	0.0003
29	0.0016	0.0017	0.0019	0.0015	0.0035	0.0045	0.0027	0.0029	0.0067	0.0028	0.0057	0.0073	0.0004
30+	0.0025	0.0016	0.0016	0.0012	0.0047	0.0039	0.0047	0.0035	0.0066	0.0027	0.0039	0.0089	0.0004

7.1.2 Forecasting and Backcasting Age Distributions

Since purchasing registration data for all calendar years is prohibitively costly for historic years, an algorithm was developed to forecast and backcast age distributions from the 2011 age distribution described above for all other calendar years in the model. In prior versions of MOVES, these age distributions were calculated during the model run using sales estimates and assuming a constant survival rate. In MOVES2014, age distributions for national level runs were pre-calculated using updated sales estimates and assuming a dynamic survival rate. However, while sales data for historic years are well known and projections for future years are common in economic modeling, national trends in projected vehicle survival for every MOVES source type at all ages are not well studied. For MOVES2014, a generic survival rate was scaled up or down for each calendar year based on our assumptions of sales and changes in total populations. The following three sections detail the derivation of the generic survival rate and the algorithms used to forecast and backcast age distributions using an adjusted survival rate in each year.

7.1.2.1 Generic Survival Rates

The survival rate describes the fraction of vehicles of a given source type and age that remain on the road from one year to the next. Although this rate changes from year to year, a single generic rate was calculated from available data. While the use of this generic rate is described in the next couple of sections, its derivation is specified here.

Survival rates for motorcycles were calculated based on a smoothed curve of retail sales and 2008 national registration data as described in a study conducted for the EPA.[42] Survival rates for passenger cars, passenger trucks and light commercial trucks came from NHTSA's survivability Table 3 and Table 4.[43] These survival rates are based on a detailed analysis of Polk vehicle registration data from 1977 to 2002. We modified these rates to consistent with the MOVES format using the following guidelines:

- NHTSA rates for light trucks were used for both the MOVES passenger truck and light commercial truck source types.
- MOVES calculates emissions for vehicles up to age 30 (with all older vehicles lumped into the age 30 category), but NHSTA car survival rates were available only to age 25. Therefore, we extrapolated car rates to age 30 using the estimated survival rate equation in Section 3.1 of the NHTSA report. When converted to MOVES format, this caused a striking discontinuity at age 26 which we removed by interpolating between ages 25 and 27.
- According to the NHTSA methodology, NHTSA age 1 corresponds to MOVES ageID 2, so the survival fractions were shifted accordingly.
- Because MOVES requires survival rates for ageIDs < 2, these values were linearly interpolated with the assumption that the survival rate prior to ageID 0 is 1. Effectively, this results in a near constant survival rate until ageID 3 for light-duty vehicles and until ageID 4 for heavy-duty vehicles.
- NHTSA defines survival rate as the ratio of the number of vehicles remaining in the fleet at a given year as compared to a base year. However, MOVES defines the survival rate as the ratio of vehicles remaining from one year to the next, so we transformed the NHTSA rates accordingly.

Because MOVES ageID 30 is intended to represent all vehicles 30 years old and greater, this age category can grow quite large as our age distribution algorithm eventually transfers all vehicles to this age group. To assure that the population of very old vehicles does not grow excessively, the generic survival rate for ageID 30 was set to 0.3. The actual survival rate of these age 30+ vehicles is unknown.

Quantitatively, the following piecewise formulas were used to derive the MOVES survival rates. In them, s_a represents the MOVES survival rate at age a, and σ_a represents the NHTSA survival rate at age a. When this generic survival rate is discussed below, the shorthand notation $\overrightarrow{S_0}$ will represent a one-dimensional array of s_a values at each permissible age a as described in Equation 5 throughEquation 8 below:

Age 0: $$s_0 = 1 - \frac{1 - \sigma_2}{3}$$ Equation 5

Age 1: $$s_1 = 1 - \frac{2(1 - \sigma_2)}{3}$$ Equation 6

Age 2-29: $$s_a = s_{2\ldots29} = \frac{\sigma_{a-1}}{\sigma_{a-2}}$$ Equation 7

Age 30: $$s_{30} = 0.3$$ Equation 8

With limited data available on heavy-duty vehicle scrappage, survivability for all other source types came from the *Transportation Energy Data Book*. We used the heavy-duty vehicle survival rates for model year 1980 (TEDB32, Table 3.14). The 1990 model year rates were not used because they were significantly higher than rates for the other model years in the analysis (i.e. 45 percent survival rate for 30 year-old trucks), and seemed unrealistically high. While limited data exists to confirm this judgment, a snapshot of 5-year survival rates can be derived from VIUS 1992 and 1997 results for comparison. According to VIUS, the average survival rate for model years 1988-1991 between the 1992 and 1997 surveys was 88 percent. The comparable survival rate for 1990 model year heavy-duty vehicles from TEDB was 96 percent, while the rate for 1980 model year trucks was 91 percent. This comparison lends credence to the decision that the 1980 model year survival rates are more in line with available data. TEDB does not have separate survival rates for medium-duty vehicles; the heavy-duty rates were applied uniformly across the bus, single unit truck, and combination truck categories. The TEDB survival rates were transformed into MOVES format in the same way as the NHTSA rates, including setting age 30+ survival rates to 0.3 for all source types.

The resulting survival rates are listed in the default database's SourceTypeAge table, shown below in Table 7-2. Please note that since MOVES2014 does not calculate age distributions during a run, these survival rates are not actively used by MOVES. However, they were used in the development of the national age distributions stored in the SourceTypeAgeDistribution table, and remain in the default database for reference.

Table 7-2 MOVES survival rate by age and HPMS class

Age	Motorcycles	Light-Duty Vehicles		Buses	Single Unit Trucks	Combination Trucks
		Passenger Cars	Passenger Trucks Light Comm. Trucks			
0	1.000	0.997	0.991	1.000	1.000	1.000
1	0.979	0.997	0.991	1.000	1.000	1.000
2	0.940	0.997	0.991	1.000	1.000	1.000
3	0.940	0.993	0.986	1.000	1.000	1.000
4	0.940	0.990	0.981	0.990	0.990	0.990
5	0.940	0.986	0.976	0.980	0.980	0.980
6	0.940	0.981	0.970	0.980	0.980	0.980
7	0.940	0.976	0.964	0.970	0.970	0.970
8	0.940	0.971	0.958	0.970	0.970	0.970
9	0.940	0.965	0.952	0.970	0.970	0.970
10	0.940	0.959	0.946	0.960	0.960	0.960
11	0.940	0.953	0.940	0.960	0.960	0.960
12	0.940	0.912	0.935	0.950	0.950	0.950
13	0.940	0.854	0.929	0.950	0.950	0.950
14	0.940	0.832	0.913	0.950	0.950	0.950
15	0.940	0.813	0.908	0.940	0.940	0.940
16	0.940	0.799	0.903	0.940	0.940	0.940
17	0.940	0.787	0.898	0.930	0.930	0.930
18	0.940	0.779	0.894	0.930	0.930	0.930
19	0.940	0.772	0.891	0.920	0.920	0.920
20	0.940	0.767	0.888	0.920	0.920	0.920
21	0.940	0.763	0.885	0.920	0.920	0.920
22	0.940	0.760	0.883	0.910	0.910	0.910
23	0.940	0.757	0.880	0.910	0.910	0.910
24	0.940	0.757	0.879	0.910	0.910	0.910
25	0.940	0.754	0.877	0.900	0.900	0.900
26	0.940	0.754	0.875	0.900	0.900	0.900
27	0.940	0.567	0.875	0.900	0.900	0.900
28	0.940	0.752	0.873	0.890	0.890	0.890
29	0.940	0.752	0.872	0.890	0.890	0.890
30	0.300	0.300	0.300	0.300	0.300	0.300

7.1.2.2 2012-2050 Age Distributions

The 2012-2050 age distributions were derived from the 2011 age distribution described above using population, survival, and sales projections. Age distributions are calculated from population counts, if the populations are known by age:

$$f_{a,y} = \frac{p_a}{P_y} \quad \text{Equation 9}$$

Here in Equation 9, $f_{a,y}$ is the age fraction to be calculated, p_a is the population of vehicles at age a, and P_y is the total population in calendar year y. In this section, arrow notation will be used if the operations are to be performed at the individual age level. For example, $\overrightarrow{f_y}$ would be used to represent all age fractions in calendar year y. Another example is $\overrightarrow{P_y}$; it represents an array of p_a values at each permissible age in calendar year y. In contrast, P_y represents the total population in year y.

Intuitively, projecting an age distribution forward one year involves removing the vehicles scrapped in the base year and adding the new vehicles sold in the next year, as shown in Equation 10:

$$\overrightarrow{P_{y+1}} = \overrightarrow{P_y} - \overrightarrow{R_y} + \overrightarrow{N_{y+1}} \quad \text{Equation 10}$$

where $\overrightarrow{P_{y+1}}$ is the population (known at each age) of the next year, $\overrightarrow{P_y}$ is the population in the base year, $\overrightarrow{R_y}$ is the population of vehicles removed in the in the base year, and $\overrightarrow{N_{y+1}}$ is new vehicles sold in the next year. Please note that the final term only includes new vehicles at age 0; if the equation is evaluated for any $a > 0$, the sales term is zero. Equation 10 can be used algorithmically to forecast a known population distribution as follows:

1. Starting with the base population distribution ($\overrightarrow{P_y}$), remove the number of vehicles that did not survive ($\overrightarrow{R_y}$) at each age level.
2. Increase the population age index by one (for example, 3 year old vehicles are reclassified as 4 year old vehicles).
3. Add new vehicle sales ($\overrightarrow{N_{y+1}}$) as the age 0 cohort.
4. Combine the new age 30 and 31 vehicles into a single age 30 group.
5. This results in the next year population distribution ($\overrightarrow{P_{y+1}}$). If this algorithm is to be repeated, $\overrightarrow{P_{y+1}}$ becomes $\overrightarrow{P_y}$ for the next iteration.

Please see Section 20 (Appendix D: Detailed Derivation of Age Distributions) for more information on how this algorithm was applied to derive the projected national default age distributions in MOVES. The resulting age distributions are stored in the SourceTypeAgeDistribution table.

In addition to producing the 2012-2050 default age distributions, a version of this algorithm was implemented in the Age Distribution Projection Tool for MOVES2014.[44] This tool can be used to project future local age distributions from user-supplied baseline distributions, provided that the baseline year is 2011 or later. This requirement ensures that the 2008-2009 recession is fully visible in the baseline. The differences between the default algorithm described above and the algorithm used in the tool are as follows:

- In the tool, the generic survival rate for all vehicle types at age 30 is set to 1.0.
- Step 4 was modified so that in the tool, the new age 30 fraction is set equal to the new age 31 fraction. The new age 31 fraction is then discarded.
- In the tool, the age distribution for ages 1-29 is then normalized such that the full distribution (ages 0-30) sums to 1.0.

The first two bullets were implemented to retain the fraction of 30+ year old vehicles in the user-inputted baseline distribution. This was done because local data frequently indicates a sizeable fraction in this age bin. Since the default scrappage curve was designed to prevent this bin from growing too large, the default algorithm would reduce this fraction in most cases. Therefore, the age 30+ fraction is not modified and the resulting age distribution in each iteration of the algorithm is normalized in the final step so that the full distribution sums to one. The sales rates and scrappage assumptions are the same in the tool as they are in the national case. In general, projections made with the tool tend to converge with the national age distributions the farther out the projection year becomes. This is because local projections of sales and scrappage are generally unavailable, and the national trends are the best available data.

7.1.2.3 1999-2010 Age Distributions

The method used to backcast the 1999-2010 age distributions from the 2011 distribution is very similar to the forecasting method described above. For backcasting an age distribution one year, Equation 10 of the previous section can be rewritten as Equation 11:

$$\overrightarrow{P_{y-1}} = \overrightarrow{P_y} - \overrightarrow{N_y} + \overrightarrow{R_{y-1}} \qquad \text{Equation 11}$$

Essentially, this can be thought of as taking the base year's population distribution, removing the vehicles sold (or added to the population) in that year, and then adding the vehicles that were removed in the year before. This can be represented algorithmically as follows:

1. Starting with the base population distribution ($\overrightarrow{P_y}$), remove the age 0 vehicles ($\overrightarrow{N_y}$).
2. Decrease the population age index by one (for example, 3 year old vehicles are reclassified as 2 year old vehicles).
3. Add the vehicles that were removed in the previous year ($\overrightarrow{R_{y-1}}$).
4. This results in the previous year population distribution ($\overrightarrow{P_{y-1}}$). If this algorithm is to be repeated, $\overrightarrow{P_{y-1}}$ becomes $\overrightarrow{P_y}$ for the next iteration.

Please see Section 20 Appendix D: Detailed Derivation of Age Distributions) for more information on how this algorithm was applied to derive the historic national default age distributions in MOVES. The resulting age distributions are stored in the SourceTypeAgeDistribution table.

7.2 Relative Mileage Accumulation Rate

MOVES uses a relative mileage accumulation rate (RMAR) in combination with source type populations (see Section 5.1) and age distributions described earlier in this section to distribute the total annual miles driven by each HPMS vehicle type (see Section 4) to each source type and age group. Using this approach, the vehicle population and the total annual vehicle miles traveled (VMT) can vary from calendar year to calendar year, but the proportional travel by an individual vehicle of each age will not vary.

VMT is provided, either by default values or by user input, by the five Highway Performance Monitoring System (HPMS) vehicle classifications. These classifications are further broken down into the groupings of the MOVES source use types, as described in Section 2.1.

The RMAR is determined within each HPMS vehicle classification such that the annual mileage accumulation for a single vehicle of each age of a source type is relative to the mileage accumulation of all of the source types and ages within the HPMS vehicle classification. For example, passenger cars, passenger trucks and light commercial trucks are all within the same HPMS vehicle classification. By definition, new (age 0) passenger trucks and light commercial trucks have a RMAR of one (1.0).[g] Based on the data, new passenger cars have a RMAR of 0.885. This means that when the VMT assigned to the HPMS class 25 is allocated to passenger cars, passenger trucks and light commercial trucks, a passenger car of age 0 will be assigned only 88.5 percent of the annual VMT assigned to a passenger truck or light commercial truck of age 0.

The RMAR values for MOVES2014 for the source types 11 (motorcycles), 41 (intercity buses), 42 (transit buses), 43 (school buses) and 54 (motor homes) were not changed from the values used in MOVES2010b. Passenger car and light-duty truck RMAR values were recalculated to reflect the change in the HPMS vehicle classifications used for VMT input and the remaining heavy-duty vehicle classifications were updated with data from the 2002 Vehicle Inventory and Use Survey (VIUS) and recalculated.

7.2.1 Motorcycles

The RMAR values for motorcycles in MOVES2014 were not changed from MOVES2010b estimates. The MOVES2010b RMAR values were calculated from MARs for motorcycles (sourceTypeID 11) based on the model years and odometer readings listed in motorcycle advertisements. A stratified sample of about 1,500 ads were examined. A modified Weibull curve was fit to the data to develop the relative mileage accumulation rates used in MOVES.[42]

[g] Within each HPMS vehicle class, an RMAR value of one is assigned to the source type and age with the highest annual VMT accumulation. Because we use the same mileage accumulation data for passenger trucks and light commercial trucks, they both have a value of one.

7.2.2 Passenger Cars, Passenger Trucks and Light Commercial Trucks

In MOVES2010b, passenger cars had their own HPMS vehicle classification. In MOVES2014, they are grouped with passenger trucks and light commercial trucks. For MOVES2014, the MOVES2010b passenger car RMAR values were adjusted to reflect the relative difference in annual mile accumulation between passenger cars and the light trucks. Analysis of the data determined that new passenger cars (age 0) accumulate only 88.5 percent of the annual miles accumulated by new light trucks. Thus, all of the RMAR values for passenger cars were adjusted to be 88.5 percent of their previous values.

The MOVES2010b RMAR values for passenger cars, passenger trucks and light commercial trucks (sourceTypeID 21, 31 & 32) were taken from the NHTSA report on survivability and mileage schedules.[43] In the NHTSA analysis, annual mileage by age was determined for cars and for trucks using data from the 2001 National Household Travel Survey. In this NHTSA analysis, vehicles that were less than one year old at the time of the survey were classified as "age 1", etc. NHTSA used a simple cubic regression to smooth the VMT by age estimates.

We used NHTSA's regression coefficients to extrapolate mileage to ages 26 through 30 not covered by the report. Since passenger trucks had the highest MAR in what was then the light-duty truck HPMS class, each source type’s mileage by age was divided by passenger truck mileage at age 1 to determine a relative MAR. For consistency with MOVES age categories, we then shifted the relative MARs such that the NHTSA age 1 ratio was used for MOVES age 0, etc. We used NHTSA's light truck VMT to determine relative MARs for both passenger trucks and light commercial trucks.

Since a newer version of the National Household Travel Survey was available, we conducted a preliminary analysis of the impact of updating the MARs based on the 2009 National Household Travel Survey. This resulted in changes to the MOVES allocation of VMT by one percent or less for each of the vehicle categories covered by the survey. As such, we feel that the MARs developed from the 2001 survey are still reasonable for use in MOVES2014. However, the 2009 values may not fully represent current trends in vehicle usage due to the recent economic downturn. A more complete analysis of all available mileage accumulation information in recent years will be necessary to truly update these values.

Table 7-3 NHTSA Vehicle Miles Traveled from 2001

	Annual Vehicle Miles Traveled	
Vehicle Age	**Passenger Cars**	**Light Trucks**
1	14,417	15,806
2	13,803	15,683
3	13,692	15,859
4	13,415	15,302
5	13,183	14,762
6	12,301	13,836
7	12,253	13,542
8	11,709	13,615
9	11,893	12,875
10	11,855	12,203
11	10,620	11,501
12	9,986	10,815
13	10,248	11,391
14	9,515	10,843
15	9,168	10,378
16	8,636	9,259
17	8,941	8,358
18	7,267	9,371
19	8,890	7,352
20	8,759	8,363
21	6,878	6,999
22	7,242	7,327
23	6,350	6,969
24	5,745	6,220
25	4,130	6,312
26		6,745
27		9,515
28		6,635
29		12,108
30		5,067
31		4,577
32		6,923

7.2.3 Buses

The RMAR values for all bus categories in MOVES2014 were not changed from MOVES2010b estimates. The intercity bus (sourceTypeID 41) annual mileage accumulation rate is taken from Motorcoach Census 2000.[45] The data did not distinguish vehicle age, so the same MAR (59,873 miles per year) was used for each age. The school bus (sourceTypeID 43) annual mileage accumulation rate (9,939 miles per year) is taken from the 1997 School Bus Fleet Fact Book. The MOVES model assumes the same annual mileage accumulation rate for each age. The

Transit Bus (category 42) annual mileage accumulation rate are taken from the MOBILE6 values for diesel transit buses (HDDBT). This mileage data was obtained from the 1994 Federal Transportation Administration survey of transit agencies.[46] The MOBILE6 results were extended to calculate values for ages 26 through 30.

Table 7-4 Annual mileage accumulation of transit buses from 1994 Federal Transit Administration data

Age	Miles	Age	Miles	Age	Miles
1	*	11	32,540	21	19,588
2	*	12	32,605	22	22,939
3	46,791	13	27,722	23	26,413
4	41,262	14	28,429	24	23,366
5	42,206	15	32,140	25	11,259
6	39,160	16	28,100	26	23,228
7	38,266	17	24,626	27	21,515
8	36,358	18	23,428	28	25,939
9	34,935	19	22,575	29	20,117
10	33,021	20	23,220	30	17,515
* Insufficient data					

7.2.4 Other Heavy-Duty Vehicles

The RMAR values for source types 51 (refuse trucks), 52 (short-haul single unit trucks), 53 (long-haul single unit trucks), 61 (short-haul combination trucks) and 62 (long-haul combination trucks) were updated from MOVES2010b using the data from the 2002 Vehicle Inventory and Use Survey (VIUS). The total reported annual miles traveled by truck in each source type, as shown in Table 7-5, was divided by the vehicle population to determine the average annual miles traveled per truck by source type.

Table 7-5 VIUS2002 annual mileage by vehicle age

Age	Model Year	Single Unit Trucks			Combination Trucks	
		Refuse (51)	Short-Haul (52)	Long-Haul (53)	Short-Haul (61)	Long-Haul (62)
0	2002	26,703	21,926	40,538	119,867	109,418
1	2001	32,391	22,755	28,168	114,983	128,287
2	2000	31,210	24,446	30,139	110,099	117,945
3	1999	31,444	23,874	49,428	105,215	110,713
4	1998	31,815	21,074	33,266	100,331	99,925
5	1997	28,450	21,444	23,784	95,447	94,326
6	1996	25,462	16,901	21,238	90,563	85,225
7	1995	30,182	15,453	27,562	85,679	85,406
8	1994	20,722	13,930	21,052	80,795	71,834
9	1993	25,199	13,303	11,273	75,911	71,160
10	1992	23,366	11,749	18,599	71,026	67,760
11	1991	18,818	13,675	15,140	66,142	80,207
12	1990	12,533	11,332	13,311	61,258	48,562
13	1989	15,891	9,795	9,796	56,374	64,473
14	1988	19,618	9,309	12,067	51,490	48,242
15	1987	12,480	9,379	16,606	46,606	58,951
16	1986	12,577	4,830	8,941	41,722	35,897
0-3	**1999-2002 Average**	**30,437**	**23,250**	**37,069**	**61,240**	**116,591**

For each source type, in the first few years, the data showed only small differences in the annual miles per vehicle and no trend. After that, the average annual miles per vehicle declined in a fairly linear manner, at least until the vehicles are at age 16 (the limit of the data). MOVES, however, requires mileage accumulation rates for all ages to age 30. For MOVES2014, we assumed that the relative mileage accumulation rate at age 30 would be the same as used for MOVES2010b.

Mileage accumulation rates for these vehicles were determined for each age from 0 to 30 using the following method:

1) Ages 0 through 3 use the same average annual mileage accumulation rate for age 0-3 vehicles of that source type.
2) Ages 4 through 16 use mileage accumulation rates calculated using a linear regression of the VIUS data for the average of ages 0 to 3 as age 3 with ages 4 through 16 from the data summarized in Table 7-6,
3) Ages 17 through 29 use values from interpolation between the values in age 16 and age 30.
4) Age 30 uses the MOVES2010b relative mileage accumulation rate for age 30. These rates were allocated to MOVES source types from MOBILE6 mileage accumulation rates, which were derived from the 1992 TIUS as documented in the ARCADIS report.[46]

Table 7-6 Regression statistics for heavy-duty truck annual mileage accumulation rates (ages 4-16)

Measurement	Refuse Truck (51)	Single Unit Short-Haul (52)	Single Unit Long-Haul (53)	Combination Short-Haul (61)	Combination Long-Haul (62)
Average 0-3*	30,437	23,250	37,069	61,240	116,591
Intercept**	36,315	25,442	36,305	65,773	119,867
Slope**	-1,510	-1,209	-1,794	-3,447	-4,884
Age 30 RMAR	0.0320	0.0518	0.1025	0.0320	0.0571

* Average sample annual miles traveled for ages 0 through 3.
** Intercept and slope from ages 4 through 16.

The resulting relative mileage accumulation rates are shown in Table 7-7 below. Note that the first four values are identical and then decline linearly to age 16 and then linearly to age 30 with a different slope.

7.2.5 Motor Homes

Motor home relative mileage accumulation rates for MOVES2014 are unchanged from MOVES2010b. For motor homes (sourceTypeID 54), the initial MARs were taken from an independent research study[47] conducted in October 2000 among members of the Good Sam Club. The members are active recreation vehicle (RV) enthusiasts who own motor homes, trailers and trucks. The average annual mileage was estimated to be 4,566 miles. The data did not distinguish vehicle age, so the same MAR was used for each age.

Table 7-7 Relative mileage accumulation rates for heavy-duty trucks in MOVES2014

ageID	Refuse (51)	Short-Haul Single Unit (52)	Long-Haul Single Unit (53)	Motor Home (54)	Short-Haul Combination (61)	Long-Haul Combination (62)
0	1.0000	0.6864	0.9729	0.0590	0.5269	1.0000
1	1.0000	0.6864	0.9729	0.0590	0.5269	1.0000
2	1.0000	0.6864	0.9729	0.0590	0.5269	1.0000
3	1.0000	0.6864	0.9729	0.0590	0.5269	1.0000
4	0.9525	0.6484	0.9165	0.0590	0.4941	0.9536
5	0.9050	0.6103	0.8601	0.0590	0.4613	0.9072
6	0.8575	0.5723	0.8036	0.0590	0.4286	0.8607
7	0.8099	0.5343	0.7472	0.0590	0.3958	0.8143
8	0.7624	0.4962	0.6908	0.0590	0.3631	0.7679
9	0.7149	0.4582	0.6343	0.0590	0.3303	0.7215
10	0.6674	0.4202	0.5779	0.0590	0.2975	0.6751
11	0.6199	0.3821	0.5215	0.0590	0.2648	0.6286
12	0.5724	0.3441	0.4650	0.0590	0.2320	0.5822
13	0.5249	0.3061	0.4086	0.0590	0.1993	0.5358
14	0.4773	0.2680	0.3522	0.0590	0.1665	0.4894
15	0.4298	0.2300	0.2957	0.0590	0.1338	0.4430
16	0.3823	0.1920	0.2393	0.0590	0.1010	0.3965
17	0.3573	0.1808	0.2293	0.0590	0.0950	0.3723
18	0.3323	0.1696	0.2194	0.0590	0.0890	0.3481
19	0.3073	0.1585	0.2094	0.0590	0.0830	0.3238
20	0.2822	0.1473	0.1994	0.0590	0.0770	0.2996
21	0.2572	0.1361	0.1894	0.0590	0.0710	0.2753
22	0.2322	0.1249	0.1795	0.0590	0.0649	0.2511
23	0.2072	0.1138	0.1695	0.0590	0.0589	0.2268
24	0.1821	0.1026	0.1595	0.0590	0.0529	0.2026
25	0.1571	0.0914	0.1496	0.0590	0.0469	0.1783
26	0.1321	0.0802	0.1396	0.0590	0.0409	0.1541
27	0.1071	0.0691	0.1296	0.0590	0.0349	0.1298
28	0.0820	0.0579	0.1197	0.0590	0.0289	0.1056
29	0.0570	0.0467	0.1097	0.0590	0.0229	0.0814
30	0.0320	0.0355	0.0997	0.0590	0.0169	0.0571

8 VMT Distribution of Source Type by Road Type

For each source type, the RoadTypeVMTFraction field in the RoadTypeDistribution table stores the fraction of total VMT for each vehicle class that is traveled on each of the MOVES five road types. Users may supply the distribution VMT to vehicle classes for each road type for individual counties when using County Scale, however, for National Scale, the default distribution is applied to all locations.

The national default distribution of VMT to vehicle classes for each road type in MOVES2014 were derived to reflect the VMT data included in the 2011 National Emission Inventory (NEI) Version 1[48] (July 31, 2013). This data is provided by states every three years as part of the NEI project and is supplemented by EPA estimates, based on Federal Highway Administration (FHWA) statistics[49], when state supplied estimates are not available.

The 2011 NEI V1 data[50] is grouped by the source classification code (SCC) used at that time and these older classifications do not cleanly map to the source types used by MOVES. As discussed in Section 2.6, SCCs are now formed as a 10-digit concatenated string, including existing identification codes for MOVES fuel type, source type, road type, and emission process. For reference, we have included a comparison of the MOVES2010b SCCs and MOVES2014 fuel types and regulatory classes in Section 21 (Appendix E: SCC Mappings).

The first seven digits of the 10-digit SCC (SCC7) indicate the vehicle classification. The SCC road types map cleanly to the MOVES road types. The eighth and ninth digits of the 10-digit SCC (SCC89) indicate the road type, as shown below in Table 8-1. The VMT was mapped to the source types used by MOVES by calculating the fraction of VMT for each source type found in each SCC classification result in a national MOVES2010b run for calendar year 2011. The factors calculated from the MOVES2010b run are also shown in Section 21 (Appendix E: SCC Mappings).

Table 8-1 Mapping of SCC road types to MOVES road types

SCC Road Type Code (SCC89)	SCC Road Type	MOVES Road Type ID	MOVES Road Type
11	Rural Interstate	2	Rural Restricted Access
13	Rural Other Principal Arterial	3	Rural Unrestricted Access
15	Rural Minor Arterial	3	Rural Unrestricted Access
17	Rural Major Collector	3	Rural Unrestricted Access
19	Rural Minor Collector	3	Rural Unrestricted Access
21	Rural Local	3	Rural Unrestricted Access
23	Urban Interstate	4	Urban Restricted Access
25	Urban Other Freeways & Expressways	4	Urban Restricted Access
27	Urban Other Principal Arterial	5	Urban Unrestricted Access
29	Urban Minor Arterial	5	Urban Unrestricted Access
31	Urban Collector	5	Urban Unrestricted Access
33	Urban Local	5	Urban Unrestricted Access

Once the SCC VMT values have been mapped to MOVES source types and road types, the national distribution of road type VMT by source type can be calculated from the NEI VMT estimates, summarized in Table 8-2. The off network road type (roadTypeID 1) is not used and is allocated none of the VMT.

Table 8-2 MOVES2014 road type distribution by source type

		Road Type*				
Source Type	**Description**	**Rural Restricted**	**Rural Unrestricted**	**Urban Restricted**	**Urban Unrestricted**	
		2	**3**	**4**	**5**	**All**
11	Motorcycle	0.0805	0.3019	0.1913	0.4263	1.000
21	Passenger Car	0.0847	0.2345	0.2374	0.4434	1.000
31	Passenger Truck	0.0859	0.2754	0.2178	0.4209	1.000
32	Light Commercial Truck	0.0867	0.2756	0.2180	0.4197	1.000
41	Intercity Bus	0.1409	0.2812	0.2196	0.3583	1.000
42	Transit Bus	0.1384	0.2813	0.2196	0.3607	1.000
43	School Bus	0.1384	0.2813	0.2196	0.3607	1.000
51	Refuse Truck	0.2396	0.2718	0.2525	0.2361	1.000
52	Single Unit Short-Haul Truck	0.1635	0.2869	0.2346	0.3150	1.000
53	Single Unit Long-Haul Truck	0.1638	0.2870	0.2346	0.3146	1.000
54	Motor Home	0.1234	0.2876	0.2255	0.3635	1.000
61	Combination Short-Haul Truck	0.2367	0.2744	0.2517	0.2372	1.000
62	Combination Long-Haul Truck	0.2476	0.2705	0.2543	0.2276	1.000
* RoadTypeID = 1 (Off Network) is assigned no VMT.						

9 Average Speed Distributions

Average speed is used in MOVES to convert VMT inputs into the source hours operating (SHO) units that MOVES uses for internal calculations. It is also used to select appropriate driving cycles, which are then used to calculate exhaust running operating mode distributions at the national, county (and sometimes project) level. Instead of using a single average speed in these tasks, MOVES2014 uses a distribution of average speeds by bin. The AvgSpeedDistribution table lists the default fraction of driving time for each source type, road type, day, and hour in each average speed bin. The fractions sum to one for each combination of source type, road type, day, and hour. The MOVES average speed bins are defined in Table 9-1. The default average speed distributions in MOVES2010[51] were based on much more limited data and travel demand model output, and have been substantially updated in MOVES2014.[52]

Table 9-1 MOVES speed bin categories

Bin	Average Speed (mph)	Average Speed Range (mph)
1	2.5	speed < 2.5 mph
2	5	2.5 mph <= speed < 7.5 mph
3	10	7.5 mph <= speed < 12.5 mph
4	15	12.5 mph <= speed < 17.5 mph
5	20	17.5 mph <= speed < 22.5 mph
6	25	22.5 mph <= speed < 27.5 mph
7	30	27.5 mph <= speed < 32.5 mph
8	35	32.5 mph <= speed < 37.5 mph
9	40	37.5 mph <= speed < 42.5 mph
10	45	42.5 mph <= speed < 47.5 mph
11	50	47.5 mph <= speed < 52.5 mph
12	55	52.5 mph <= speed < 57.5 mph
13	60	57.5 mph <= speed < 62.5 mph
14	65	62.5 mph <= speed < 67.5 mph
15	70	67.5 mph <= speed < 72.5 mph
16	75	72.5 mph <= speed

9.1 Light-Duty Average Speed Distributions

For MOVES2014, the light-duty average speed distributions are based on in-vehicle global position system (GPS) data. The data was obtained through a contract with Eastern Research Group (ERG), who subcontracted with TomTom to provide summarized vehicle GPS data.[h] TomTom makes in-vehicle GPS navigation devices and supports cell-phone navigation applications. ERG provided the US EPA with updated values for the AvgSpeedDistribution calculated from the TomTom delivered data based on their consumers, where “virtually all” use them in light-duty cars, trucks, and vans.

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[h] Much of the following text and tables are excerpted from the ERG Work Plan (EPA-121019), submitted to US EPA on January 11, 2012.

Some of the characteristics of the TomTom GPS data are:

- Data is self-selective. Data is only recorded from users of TomTom GPS units and an iPhone application. Additionally, TomTom data is only collected when the units are on. This creates bias not only for users, but also for types of driving. Anecdotally, drivers who own GPS units are less likely to use them when they drive in familiar areas in comparison with unfamiliar areas. Compared to the default VMT by road type information in MOVES, TomTom over-represents behavior on rural restricted access roads, which suggests the higher usage of GPS on vacations and business trips.
- No information on vehicle type is available. TomTom suggests that "virtually all" the vehicles are light-duty cars, trucks, and vans. MOVES allows for separate average speed distributions for each source type. However, due to a lack of information on other source types, the average speed distribution derived from the TomTom light-duty GPS data is applied to all source types—although the combination long-haul trucks distribution was adjusted as described at the end of this section. Other heavy-duty source types such as single unit long-haul trucks were not adjusted. We recognize this as a potential shortcoming, and look to incorporate source type specific average speed information in the future.
- The average speed distributions are based on the average speed in each roadway segment, not the average of all second-by-second speed measurements.
- Only data that is associated with the vehicle network is included in the average speed delivery. As part of the quality control methods, TomTom excludes data that does not "snap to the roadway grid" to remove points caused by loss of satellite signal and errors while the TomTom unit is trying to acquire the satellite signal. TomTom uses data quality control techniques to minimize data arising from non-light-duty-vehicle use, such as from pedestrians, bicycles, and airplanes.

Some of the data characteristics present concerns regarding their representativeness of real-world driving. Despite these concerns, the TomTom data presented a great improvement to the speed distribution information used in previous versions of MOVES.

Under direction of EPA's contractor, ERG, TomTom queried its database of historic traffic probes to produce a table of total distance and total time as a function of road type, weekday/weekend, hour of the day, and average speed bin for the calendar year 2011 for the 50 states and the District of Columbia. TomTom delivered a table identifying the total distance and total time of vehicles travelling at an average speed interval for all combinations of:

1. Identifier for Average Speed Bin (20 levels): average speeds were binned in 5 mph increments, starting at 2.5mph: 0-2.5mph; 2.5mph-7.5mph; 7.5mph-12.5mph; … 92.5mph-97.5mph.

2. Identifier for Month of the Year (12 levels).

3. Identifier for Day of the Week (2 levels): the period for weekday is Monday, 00:00:00 to Friday, 23:59:59, and the period for weekend is Saturday, 00:00:00 to Sunday, 23:59:59.

4. Identifier for Time of Day (24 levels): times are binned in one hour increments, starting at midnight: 00:00:00 to 00:59:59; 01:00:00 to 01:59:59, …, 23:00:00 to 23:59:59.

5. Identifier for Road Type (4 levels): TomTom used the information in Table 9-2 to classify between the TomTom Functional Classes and the MOVES road type description. TomTom also categorized the road types as rural or urban, according to the Census definitions used in MOVES[i].

Table 9-2 Correspondence between TomTom functional class, census information, and MOVES road types

MOVES Road Type Description	Census Information for the TomTom Roadway Segment	TomTom Functional Road Class
Rural Restricted Access	Rural	0 and 1
Rural Unrestricted Access	Rural	2 through 7
Urban Restricted Access	Urban	0 and 1
Urban Unrestricted Access	Urban	2 through 7

TomTom first "snapped" their data points onto road segments. Off-network driving data was not obtained from the TomTom data. Much of the TomTom data that does not "snap to the roadway grid" is caused by loss of satellite signal and errors while the TomTom unit is trying to acquire the satellite signal. Therefore, a difficult analysis would be required to separate real off-network data from GPS error data, and even if the analysis could be done, the reliability of the results would probably be unknown. As such, only data that was associated with the roadway grid was used in the analysis.

Table 9-3 shows the method for using the internal TomTom data (Columns E through I) to produce the desired output, which ERG used to produce the MOVES2014 tables. The example in the table uses 16 observations that might have been recorded on two urban unrestricted roadway segments (Column E) during TomTom personal navigation device use between 14:00:00 and 14:59:59 on a weekday in April 2011. Column F is an internal ID (1-5 occur on Segment A, and 11-21 occur on Segment B). Column G gives the length of the segment. Column H gives the time that the device spent on the segment. Column I gives the average speed of the device on the segment. The 16 observations are sorted by the average speed bin, which is given in Column J. The total distance traveled and the total time spent in each combination of road type, month, weekday/weekend, hour of the day, and average speed bin are given in Columns K and L. TomTom provided Columns A, B, C, D, J, K, and L to ERG. The data in those columns was purchased by ERG from TomTom and is provided under license terms that permit free distribution to EPA and the public. The raw data in Columns E, F, G, H, and I were not provided to ERG and the US EPA.

[i] http://www.census.gov/geo/www/ua/2010urbanruralclass.html

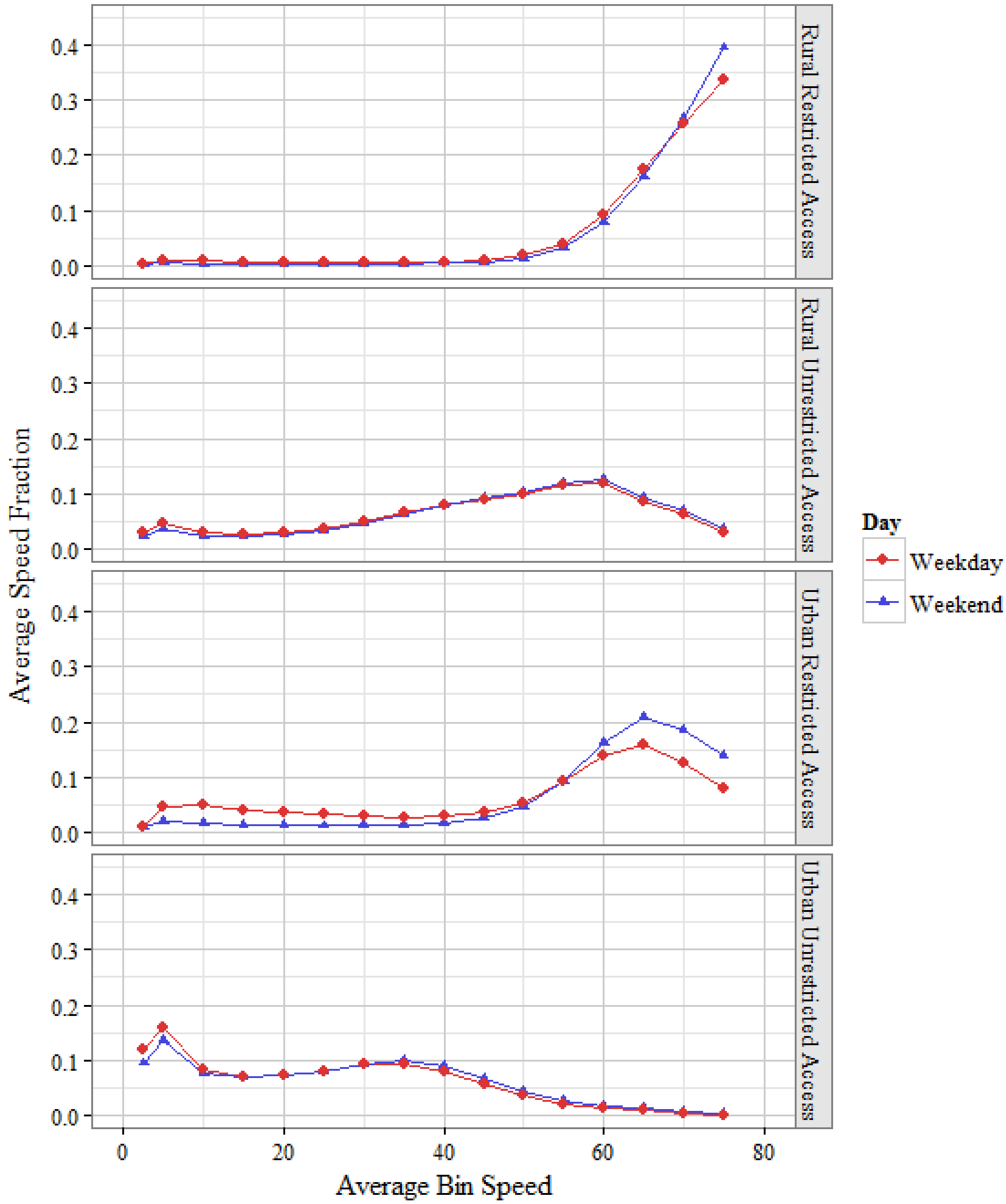
Table 9-3 Example of accumulating total distance and total time for the TomTom deliverable table

A	B	C	D	E	F	G	H	I	J	K	L
Road Type (4 levels)	Month (12 levels)	Weekday/ Weekend (2 levels)	Hour of the Day (24 levels)	Segment	Data Point	Segment Length (feet)	Time in Segment (s)	Average Speed in Segment (mph)	Average Speed Bin (mph) (20 levels)	Total of Segment Lengths for this Speed Bin (feet)	Total of Segment Times for this Speed Bin (s)
Urban Unrestricted	April	Weekday	14:00:00 to 14:59:59	A	5	300	15	13.64	15	550	27
				B	16	250	12	14.20			
				A	1	300	10	20.45	20	1800	60
				B	11	250	8	21.31			
				B	12	250	9	18.94			
				B	15	250	8	21.31			
				B	18	250	8	21.31			
				B	20	250	9	18.94			
				B	21	250	8	21.31			
				A	2	300	9	22.73	25	1650	47
				A	3	300	8	25.57			
				A	4	300	9	22.73			
				B	13	250	7	24.35			
				B	14	250	7	24.35			
				B	19	250	7	24.35			
				B	17	250	6	28.41	30	250	6

Using the table delivered by TomTom, ERG calculated the time-based average speed distribution for each road type, day, and hour of the day using the average speed bin (Column J) and the total of segment times (Column L)[j]. ERG calculated the average speed distribution according to the 16 speed bins used in MOVES. Figure 9-1 plots the average speed distribution for one hour (5pm) stored in the averageSpeedDistribution table in MOVES, which contains average speed distributions for each hour of the day (24 hours). We are using the TomTom data to represent national default average speed distribution in MOVES.

[j] MOVES uses time-based speed because the emission rates are time-based (e.g. gram/hour).

Figure 9-1 Average speed distribution for 5pm (hourID 17) for source types (11 through 54) stored in the AvgSpeedDistribution table in MOVES2014

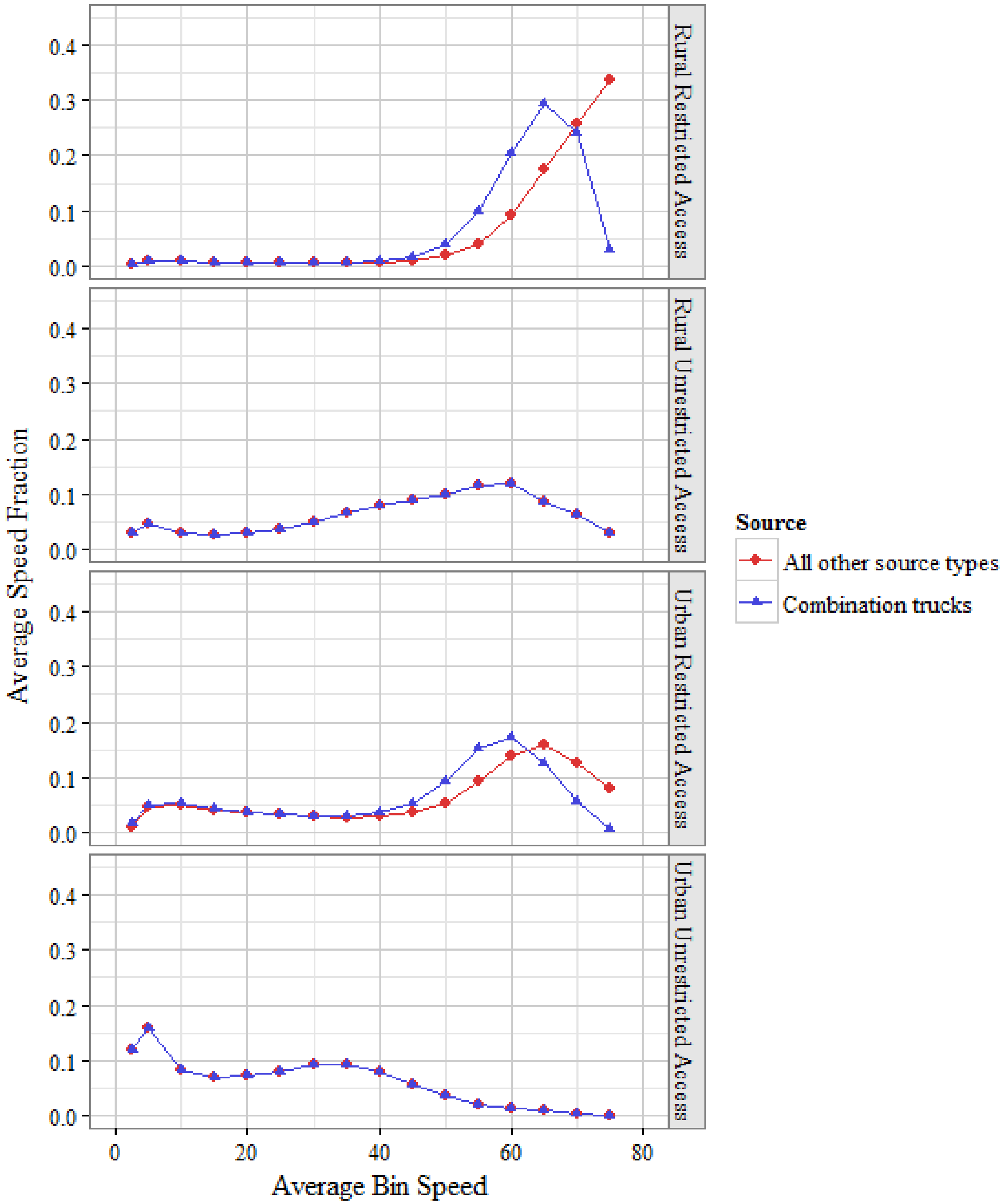


9.2 Heavy-Duty Average Speed Distributions

It has been shown that combination trucks travel at approximately 92 percent of the speed of light-duty vehicles on restricted access roads[53]. Since the TomTom data was developed from light-duty vehicles, the average speed distribution for both short-haul and long-haul combination trucks was adjusted on rural and urban restricted road types to have an 8% lower average speed than the respective TomTom average speed for light-duty vehicles. The equations and assumptions used to adjust the combination truck average speed distributions are located in

Section 22 (Appendix F: Calculation of Combination Truck Average Speed Distributions). Figure 9-2 illustrates the results of this analysis.

Figure 9-2 Average weekday speed distribution for 5pm (hourID 17) by source type stored in the AvgSpeedDistribution table in MOVES



In the absence of additional data, all other heavy-duty vehicles (including single unit heavy-duty vehicles) and all heavy-duty vehicles operating on unrestricted access roads, use the same average speed distributions as light-duty vehicles. We recognize that these assumptions are less than ideal, and we hope to update the heavy-duty average speed distributions using heavy-duty data in the future. Nonetheless, MOVES energy consumption and emission estimates from heavy-duty appear to be only moderately sensitive to changes in the average speed distribution. The 8% speed decrease in average speed distribution on restricted access roadways for combination trucks caused the total onroad predicted NOx emissions to decrease by only ~0.5% and the national onroad diesel fuel consumption to decrease by only ~1.3%. Other researchers[54] have found that other local inputs are significantly more important for emissions inventories than average speed distributions, including population, age distribution, and the combination truck fraction of heavy-duty VMT. Nonetheless, we strongly encourage MOVES users to use local average speed distributions when using MOVES at the regional and county-level.

10 Driving Schedules and Ramps

Drive schedule refers to a second-by-second vehicle speed trajectory. A drive schedule typically includes all vehicle operation from the time the engine starts until the engine is keyed off, both driving (travel) and idling time. Drive schedules are used in MOVES to determine the operating mode distribution for most MOVES running processes for calculation of emissions and energy consumption.

In brief, there is an emission rate (in grams per hour of vehicle operation) for each operating mode of vehicle operation. Each second of vehicle operation is assigned to an operating mode as a function of vehicle velocity in each second and the specific power (VSP), or scaled tractive power (STP) for heavy-duty vehicles, is calculated from the driving schedules. This distinction between VSP and STP is discussed in Section 14. The average speed distribution is used to weight the operating mode distributions determined from driving schedules with different average speeds into a composite operating mode distribution that represents overall travel by vehicles. The distribution of operating modes is used by MOVES to weight the emission rates to account for the vehicle operation.

10.1 Driving Schedules

A key feature of MOVES is the capability to accommodate a number of drive schedules to represent driving patterns across source type, road type, and average speed. For the national default case, MOVES2014 employs 49 drive schedules with various average speeds, mapped to specific source types and road types.

MOVES stores all of the drive schedule information in four database tables. DriveSchedule provides the drive schedule name, identification number, and the average speed of the drive schedule. DriveScheduleSecond contains the second-by-second vehicle trajectories for each schedule. In some cases the vehicle trajectories are not contiguous; as detailed below, they may be formed from several unconnected microtrips that overall represent driving behavior. DriveScheduleAssoc defines the set of schedules which are available for each combination of source use type and road type. Ramps use operating mode distributions directly and do not use drive schedules to calculate operating modes. The RoadOpModeDistribution table lists operating mode distributions used for ramps for each source use type, road type and speed bin, discussed in further detail later in this section.

Table 10-1 through Table 10-6 MOVES driving cycles for combination trucks (61, 62) below list the driving schedules used in MOVES2014. Some driving schedules are used for both restricted access (freeway) and unrestricted access (non-freeway) driving. In most cases, these represent atypical conditions, such as extreme congestion or unimpeded high speeds. In these conditions, we assume that the road type itself has little impact on the expected driving behavior (driving schedule). Normally, these conditions represent only a small portion of overall driving. Similarly, some driving schedules are used for multiple source types where vehicle specific information was not available.

In the past, if there was no appropriate driving schedule to use for modeling an average speed bin, MOVES would use the nearest schedule. MOVES2014 requires driving schedules that can be used as the upper bound and the lower bound for all average speed bins. New default driving schedules have been added to assure that all average speed bins have appropriate driving schedules for all the MOVES average speed bins.

Table 10-1 MOVES driving cycles for motorcycles, passenger cars, passenger trucks, and light commercial trucks (11, 21, 31, 32)

ID	Cycle Name	Average Speed	Unrestricted Access		Restricted access	
			Rural	Urban	Rural	Urban
101	LD Low Speed 1	2.5	X	X	X	X
1033	Final FC14LOSF	8.7			X	X
1043	Final FC19LOSAC	15.7			X	X
1041	Final FC17LOSD	18.6	X	X		
1021	Final FC11LOSF	20.6			X	X
1030	Final FC14LOSC	25.4	X	X		
153	LD LOS E Freeway	30.5			X	X
1029	Final FC14LOSB	31.0	X	X		
1026	Final FC12LOSE	43.3		X		
1020	Final FC11LOSE	46.1			X	X
1011	Final FC02LOSDF	49.1	X			
1025	Final FC12LOSD	52.8		X		
1019	Final FC11LOSD	58.8			X	X
1024	Final FC12LOSC	63.7	X	X		
1018	Final FC11LOSC	64.4			X	X
1017	Final FC11LOSB	66.4			X	X
1009	Final FC01LOSAF	73.8	X	X	X	X
158	LD High Speed Freeway 3	76.0	X	X	X	X

Table 10-2 MOVES driving cycles for intercity buses (41)

ID	Cycle Name	Average Speed	Unrestricted access		Restricted access	
			Rural	Urban	Rural	Urban
398	CRC E55 HHDDT Creep	1.8	X	X	X	X
404	New York City Bus	3.7	X	X		
201	MD 5mph Non-Freeway	4.6	X	X	X	X
405	WMATA Transit Bus	8.3	X	X		
202	MD 10mph Non-Freeway	10.7	X	X	X	X
203	MD 15mph Non-Freeway	15.6	X	X	X	X
204	MD 20mph Non-Freeway	20.8	X	X	X	X
205	MD 25mph Non-Freeway	24.5	X	X	X	X
206	MD 30mph Non-Freeway	31.5	X	X	X	X
251	MD 30mph Freeway	34.4	X	X	X	X
252	MD 40mph Freeway	44.5	X	X	X	X
253	MD 50mph Freeway	55.4	X	X	X	X
254	MD 60mph Freeway	60.4	X	X	X	X
255	MD High Speed Freeway	72.8	X	X	X	X
397	MD High Speed Freeway Plus 5 mph	77.8	X	X	X	X

Table 10-3 MOVES driving cycles for transit and school buses (42, 43)

ID	Cycle Name	Average Speed	Unrestricted access		Restricted access	
			Rural	Urban	Rural	Urban
398	CRC E55 HHDDT Creep	1.8	X	X	X	X
201	MD 5mph Non-Freeway	4.6			X	X
404	New York City Bus	3.7	X	X		
202	MD 10mph Non-Freeway	10.7			X	X
405	WMATA Transit Bus	8.3	X	X		
401	Bus Low Speed Urban*	15	X	X		
203	MD 15mph Non-Freeway	15.6			X	X
204	MD 20mph Non-Freeway	20.8			X	X
205	MD 25mph Non-Freeway	24.5			X	X
402	Bus 30 mph Flow*	30	X	X		
206	MD 30mph Non-Freeway	31.5			X	X
251	MD 30mph Freeway	34.4			X	X
252	MD 40mph Freeway	44.5			X	X
403	Bus 45 mph Flow*	45	X	X		
253	MD 50mph Freeway	55.4	X	X	X	X
254	MD 60mph Freeway	60.4	X	X	X	X
255	MD High Speed Freeway	72.8	X	X	X	X
397	MD High Speed Freeway Plus 5 mph	77.8	X	X	X	X

* To be consistent with the speed distributions described in Section 9, this speed represents the average for the traffic the bus is traveling in, not the average speed of the bus, which is lower due to stops.

Table 10-4 MOVES driving cycles for refuse trucks (51)

ID	Cycle Name	Average Speed	Unrestricted access		Restricted access	
			Rural	Urban	Rural	Urban
398	CRC E55 HHDDT Creep	1.8			X	X
501	Refuse Truck Urban	2.2	X	X		
301	HD 5mph Non-Freeway	5.8			X	X
302	HD 10mph Non-Freeway	11.2	X	X	X	X
303	HD 15mph Non-Freeway	15.6	X	X	X	X
304	HD 20mph Non-Freeway	19.4	X	X	X	X
305	HD 25mph Non-Freeway	25.6	X	X	X	X
306	HD 30mph Non-Freeway	32.5	X	X	X	X
351	HD 30mph Freeway	34.3	X	X	X	X
352	HD 40mph Freeway	47.1	X	X	X	X
353	HD 50mph Freeway	54.2	X	X	X	X
354	HD 60mph Freeway	59.4	X	X	X	X
355	HD High Speed Freeway	71.7	X	X	X	X
396	HD High Speed Freeway Plus 5 mph	77.8	X	X	X	X

Table 10-5 MOVES driving cycles for single unit trucks and motor homes (52, 53, 54)

ID	Cycle Name	Average Speed	Unrestricted access		Restricted access	
			Rural	Urban	Rural	Urban
398	CRC E55 HHDDT Creep	1.8	X	X	X	X
201	MD 5mph Non-Freeway	4.6	X	X	X	X
202	MD 10mph Non-Freeway	10.7	X	X	X	X
203	MD 15mph Non-Freeway	15.6	X	X	X	X
204	MD 20mph Non-Freeway	20.8	X	X	X	X
205	MD 25mph Non-Freeway	24.5	X	X	X	X
206	MD 30mph Non-Freeway	31.5	X	X	X	X
251	MD 30mph Freeway	34.4	X	X	X	X
252	MD 40mph Freeway	44.5	X	X	X	X
253	MD 50mph Freeway	55.4	X	X	X	X
254	MD 60mph Freeway	60.4	X	X	X	X
255	MD High Speed Freeway	72.8	X	X	X	X
397	MD High Speed Freeway Plus 5 mph	77.8	X	X	X	X

Table 10-6 MOVES driving cycles for combination trucks (61, 62)

ID	Cycle Name	Average Speed	Unrestricted access		Restricted access	
			Rural	Urban	Rural	Urban
398	CRC E55 HHDDT Creep	1.8	X	X	X	X
301	HD 5mph Non-Freeway	5.8	X	X	X	X
302	HD 10mph Non-Freeway	11.2	X	X	X	X
303	HD 15mph Non-Freeway	15.6	X	X	X	X
304	HD 20mph Non-Freeway	19.4	X	X	X	X
305	HD 25mph Non-Freeway	25.6	X	X	X	X
306	HD 30mph Non-Freeway	32.5	X	X	X	X
351	HD 30mph Freeway	34.3	X	X	X	X
352	HD 40mph Freeway	47.1	X	X	X	X
353	HD 50mph Freeway	54.2	X	X	X	X
354	HD 60mph Freeway	59.4	X	X	X	X
355	HD High Speed Freeway	71.7	X	X	X	X
396	HD High Speed Freeway Plus 5 mph	77.8	X	X	X	X

The default drive schedules for light-duty vehicles listed in the tables above were developed from several sources. “LD LOS E Freeway” and “HD High Speed Freeway” were retained from MOBILE6 and are documented in report M6.SPD.001.[55] “LD Low Speed 1” is a historic cycle used in the development of speed corrections for MOBILE5 and is meant to represent extreme stop-and-go “creep” driving. “LD High Speed Freeway 3” was developed for MOVES to represent very high speed restricted access driving. It is a 580-second segment of restricted access driving from an in-use vehicle instrumented as part of EPA’s On-Board Emission Measurement Shootout program,[56] with an average speed of 76 mph and a maximum speed of 90 mph. Fifteen new light-duty “final” cycles were developed by a contractor for MOVES based on urban and rural data collected in California in 2000 and 2004.[42] The new cycles were selected to best cover the range of road types and average speeds modeled in MOVES.

Most of the driving schedules used for buses are borrowed directly from driving schedules used for single unit trucks (described below). The “New York City Bus”[57] and “WMATA Transit Bus”[58] drive schedules are included for urban driving that includes transit type bus driving behavior. The “CRC E55 HHDDT Creep” [59] cycle was included to cover extremely low speeds for heavy-duty trucks. The “Bus 30 mph Flow” and “Bus 45 mph Flow” cycles used for transit and school buses were developed by EPA based on Ann Arbor Transit Authority buses instrumented in Ann Arbor, Michigan.[60] The bus “flow” cycles were developed using selected non-contiguous snippets of driving from one stop to the next stop, including idle, to create cycles with the desired average driving speeds. The bus “flow” cycles have a nominal speed used for selecting the driving cycles that does not include the idle time and only considers the free-flow speed between stops. The actual average speed of the cycle (including stops) are shown in Section 23 (Appendix G: Driving Schedules). Note that the “Bus Low Speed Urban” bus cycle is the last 450 seconds of the standard New York City Bus cycle.

The “Refuse Truck Urban” cycle represents refuse truck driving with many stops and a maximum speed of 20 mph but an average speed of 2.2 mph. This cycle was developed by West Virginia University for the State of New York. The CRC E55 HHDDT Creep cycle was used instead for restricted access driving of refuse trucks at extremely low speeds. All of the other driving cycles used for refuse trucks were borrowed from driving cycles developed for heavy-duty combination trucks, described below.

Single unit and combination trucks use driving cycles developed specifically for MOVES, based on work performed for EPA by Eastern Research Group (ERG), Inc. and documented in the report "Roadway-Specific Driving Schedules for Heavy-Duty Vehicles."[61] ERG analyzed data from 150 medium and heavy-duty vehicles instrumented to gather instantaneous speed and GPS measurements. ERG segregated the driving into restricted access and unrestricted access driving for medium and heavy-duty vehicles, and then further stratified vehicles trips according the pre-defined ranges of average speed covering the range of vehicle operation. The medium duty cycles are used with single unit trucks and heavy-duty cycles are used with combination trucks.

The schedules developed by ERG are not contiguous schedules which could be run on a chassis dynamometer, but are made up of non-contiguous "snippets" of driving (microtrips) meant to represent target distributions. For use with MOVES, we modified the schedules' time field in order to signify when one microtrip ended and one began. The time field of the driving schedule table increments two seconds (instead of one) when each new microtrip begins. This two-second increment signifies that MOVES should not regard the microtrips as contiguous operation when calculating accelerations.

Both single unit and combination trucks use the CRC E55 HHDDT Creep cycle for all driving at extremely low speeds. At the other end of the distribution, none of the existing driving cycles for heavy-duty trucks included average speeds sufficiently high to cover the highest speed bin used by MOVES. To construct such cycles, EPA started with the highest speed driving cycle available from the ERG analysis and added 5 mph to each point, effectively increasing the average speed of the driving cycle without increasing the acceleration rate at any point. We have checked the feasibility of these new driving cycles (396 and 397) using simulations with the EPA's Greenhouse Gas Emissions Model (GEM)[62] for medium- and heavy-duty vehicle compliance. GEM is a forward-looking full vehicle simulation tool that calculates fuel economy and GHG emissions from an input drive trace and series of vehicle parameters. One of the aspects of forward-looking models is that the driver model is designed to demand torque until the vehicle drive trace is met. Our results indicate that the simulated vehicles were able to follow the speed demands of the proposed driving cycles without exceeding maximum torque or power.

None of the driving schedules used to represent restricted access (freeway) driving contain vehicle operation on entrance or exit ramps. The effect of ramp operation is added separately in MOVES.

10.2 Ramp Activity

Ramp activity is the driving behavior of vehicles that occurs on entrance and exit ramps as vehicles enter or leave restricted access roads. It includes all of the activity between operation on the unrestricted road and operation on the restricted road.

The driving schedules used to represent restricted access (freeway) driving in MOVES2014 are not intended to represent vehicle operation on entrance or exit ramps. Activity that occurs on the freeway in anticipation of ramps or occurring after entry (including activity on "weaving lanes") is included in the non-ramp freeway driving schedules. The effect of ramp operation is calculated separately. Instead of using driving schedules to generate operating mode distributions for ramps, each average speed bin has an associated operating mode distribution that reflects the power demand expected from ramp operation associated with each nominal average highway speed for each of the source types. The operating mode distributions used for ramps in MOVES2014 were estimated to represent the driving connecting to and from a freeway with the given average speed. These operating mode distributions (i.e. the fractions of time spent in each of the operating modes for each source type on each road type at each average speed) can be found in the in the default MOVES2014 database (RoadOpModeDistribution table).

Each set of ramp operating modes is associated with a corresponding average highway speed that does not include ramp operation. Since operating modes for ramp emissions are affected by the distribution of the average speed bins on the surrounding roads, the determination of average speeds for restricted access roads (both urban and rural) should not include the time or distance of vehicles on ramps. However, the VMT on ramps should be included with restricted access VMT.

The emission impact of ramp activity is combined with the other driving activity found in the restricted access (freeway) driving cycles using a ramp fraction. This fraction defines the fraction of all time spent on a road that occurs on entrance and exit ramps. The fraction used (8 percent) in MOVES2014 is derived from the ramp fraction value developed originally for the MOBILE6 model.[63]

11 Hotelling Activity

MOVES2014 defines "hotelling" as any long period of time that drivers spend in their vehicles during mandated down times during long distance deliveries by tractor/trailer combination heavy-duty trucks. During the mandatory down time, drivers can stay in motels or other accommodations, but most of these trucks have sleeping spaces built into the cab of the truck and drivers stay with their vehicles. Hotelling hours are included in MOVES2014 in order to account for use of the truck engine (referred to as “extended idling”) to power air conditioning, heat, and other accessories and account for the use of auxiliary power units (APU), which are small on-board power generators.

In MOVES2014, only the long-haul combination truck source use type (sourceTypeID 62) is assumed to have any hotelling activity. All of the long-haul combination trucks are diesel fueled. All source use types other than long-haul combination trucks have hotelling activity fractions set to zero.

11.1 National Default Hotelling Rate

Federal law limits long-haul truck drivers to ten hours driving followed by a mandatory eight hour rest period. These regulations are described in the Federal Register.[64] In long-haul operation, drivers will stop periodically along their routes. For MOVES, the total hours of hotelling are estimated by using the national estimate of VMT by long-haul combination trucks divided an estimated average speed to calculate total hours of driving. The total hours of driving divided by ten gives the number of eight-hour rest periods needed and thus the national total hotelling hours.

A method is needed to allocate these total hotelling hours to locations. For MOVES2014, we decided to determine a “hotelling rate” (hours of hotelling per mile of travel) that could be used, in combination with VMT information to allocate the hotelling hours, described in Equation 12 to Equation 15. We calculate a hotelling rate as the national total hours of hotelling divided by the national total miles driven by long-haul trucks on rural restricted access (freeways) roads. Driving time on all roads contributes to the total hotelling hours calculation. However, most locations used for hotelling are located near the roadways (restricted access) most traveled by long-haul trucks. In order to prevent large amounts of hotelling to be allocated to congested urban areas, we decided to only use the VMT on rural restricted roads as the surrogate for allocating the total hotelling hours.

The hotelling rate (hotelling hours per mile of rural restricted access travel by long-haul combination trucks) is applied to the estimate of rural restricted access VMT by long-haul combination trucks to estimate the default hotelling hours for any location, month or day. The allocation of hotelling to specific hours of the day is described below in Section 12.5.

The MOVES2014 default hotelling rate was calculated using default national total VMT estimates for calendar year 2011 shown in Table 11-1.

$$Total\ Hours = \frac{Total\ Vehicle\ Miles\ Traveled}{Average\ Speed} \quad \text{Equation 12}$$

$$Total\ Trips = \frac{Total\ Hours}{10\ hours\ per\ trip} \quad \text{Equation 13}$$

$$Hotelling\ Hours = Total\ Trips * 8\ hours\ per\ trip \quad \text{Equation 14}$$

$$Hotelling\ Rate = \frac{Hotelling\ Hours}{Total\ Rural\ Restricted\ Miles\ Traveled} \quad \text{Equation 15}$$

Where:

- Total Hours is the calculated time long-haul combination trucks spend driving.
- Total Vehicle Miles Traveled is the total miles traveled by diesel long-haul combination trucks in the nation in calendar year 2011 on all road types taken from MOVES defaults.
- Average Speed is an estimate of the average speed (distance divided by time) for diesel long-haul combination trucks on all road types while operating.
- Total Trips is the calculated number of trips by long-haul combination trucks.
- Hotelling Hours is the calculated amount of rest time for long-haul combination trucks.
- Rural Restricted Miles is the total miles traveled by diesel long-haul combination trucks on only rural restricted access roads (freeways) in calendar year 2011 using MOVES defaults.

Table 11-1 Calculation of hotelling hours from long-haul combination truck VMT

Description	Annual Value	units
Rural Restricted	31,392,300,000	miles
Rural Unrestricted	34,301,700,000	miles
Urban Restricted	32,243,100,000	miles
Urban Unrestricted	28,848,900,000	miles
Total annual VMT	126,786,000,000	miles
Hours (58.3 mph)	2,174,716,981	hours
Trips (10 hrs per trip)	217,471,698	trips
Hotelling hours (8 hrs per trip)	1,739,773,585	hours
Hotelling hours per mile on rural restricted roads	0.055414	hours/mile

For the MOVES default, all hotelling activity is assumed to occur in counties with travel on rural restricted access roads, and thus will occur primarily in rural areas of states.

The national rate of hotelling hours per mile of rural restricted access roadway VMT is stored in the HotellingCalendarYear table for each calendar year. The same value calculated for 2011 is used as the default for all calendar years. The County Data Manager includes the HotellingActivityDistribution table which provides the opportunity for states to provide their own estimates of hotelling hours specific to their location and time. Whenever possible states and local areas should obtain and use more accurate local estimates of hotelling hours when modeling local areas.

11.2 Hotelling Activity Distribution

Hotelling differs from simple parking. In MOVES, hotelling hours are divided into operating modes which define the emissions associated with the type of hotelling activity. Long-haul trucks are often equipped with sleeping berths and other amenities to make the drive rest periods more comfortable. These amenities require power for operation. This power can be obtained by running the main truck engine (extended idle) or by use of smaller on-board power generators (auxiliary power units, APU). Some truck stop locations include power hookups (truck stop electrification) to allow use of amenities without running either the truck engines or APUs. Some of rest time may occur without use of amenities at all. Table 11-2 shows the hotelling operating modes used in MOVES.

Table 11-2 Hotelling activity operating modes

OpModeID	Description
200	Extended Idling of Main Engine
201	Hotelling Diesel Auxiliary Power Unit (APU)
203	Hotelling Battery or AC (plug in)
204	Hotelling All Engines and Accessories Off

The HotellingActivityDistribution table (see Table 11-3 below) contains the MOVES default values for the distribution of hotelling activity to the operating modes.

Table 11-3 Default hotelling activity distributions

beginModelYearID	endModelYearID	opModeID	opModeFraction
1960	2009	200	1
1960	2009	201	0
1960	2009	203	0
1960	2009	204	0
2010	2050	200	0.7
2010	2050	201	0.3
2010	2050	203	0
2010	2050	204	0

All of the hotelling hours for long-haul trucks of model years before 2010 are assumed to use extended idle to power accessories. Starting with the 2010 model year, the trucks are assumed to use extended idle 70 percent of the time and use APUs 30 percent of the time based on EPA's assessment of technologies used by tractor manufacturers to comply with the Heavy-Duty Greenhouse Gas standards.

12 Temporal Distributions

MOVES is designed to estimate emissions for every hour of every day type in every month of the year. The vehicle miles traveled (VMT) are provided for MOVES2014 in terms of annual miles. These miles are allocated to months, days and hours using allocation factors, either default values or values provided by users.

Default values for most temporal VMT allocations are derived from a 1996 report from the Office of Highway Information Management (OHIM).[65] The report describes analysis of a sample of 5,000 continuous traffic counters distributed throughout the United States. EPA obtained the data used in the report and used it to generate the VMT temporal distribution inputs in the form needed for MOVES2014.

The OHIM report does not specify VMT by vehicle type, so MOVES uses the same values for all source types, except motorcycles, as described below. In MOVES, daily truck hotelling hours are calculated as proportional to source hours operating (SHO) calculated by MOVES from the VMT and speed distributions for long-haul combination trucks. However, the hours of hotelling activity in each hour of the day are not proportional to VMT, as described in Section 12.5.

The temporal distribution for engine start and corresponding engine soak (parked) distributions are calculated from vehicle activity data stored in the SampleVehicleDay and SampleVehicleTrip tables of the MOVES database, shown below in Table 12-1. These tables contain a set of vehicle trip activity information constructed to represent activity for each source type. Evaporative emissions are also affected by the time of day and the duration of parking. Some of the vehicles in the tables take no trips.

Table 12-1 SampleVehicleDay table

Source Type		Number of Records	
sourceTypeID	**Description**	**Weekday (dayID 5)**	**Weekend (dayID 2)**
11	Motorcycle	2214	983
21	Passenger Car	821	347
31	Passenger Truck	834	371
32	Light Commercial Truck	773	345
41	Intercity Bus	190	73
42	Transit Bus	110	14
43	School Bus	136	59
51	Refuse Truck	205	65
52	Single Unit Short-Haul Truck	112	58
53	Single Unit Long-Haul Truck	123	50
54	Motor Home	5431	2170
61	Combination Short-Haul Truck	130	52
62	Combination Long-Haul Truck	122	49

12.1 VMT Distribution by Month of the Year

In MOVES, VMT is entered as an annual value and allocated to month using the MonthVMTFraction table. For MOVES, we use the data from the OHIM report, Figure 2.2.1 "Travel by Month, 1970-1995," but modified to fit MOVES specifications. The table shows VMT/day taken from the OHIM report, normalized to one for January. For MOVES, we need the fraction of total annual VMT in each month. The report values of VMT per day were used to calculate the VMT in a month using the number of days in each month. The calculations in Table 12-2 assume a non-leap year (365 days).

Table 12-2 MonthVMTFraction

Month	Normalized VMT/day	MOVES Distribution
January	1.0000	0.0731
February	1.0560	0.0697
March	1.1183	0.0817
April	1.1636	0.0823
May	1.1973	0.0875
June	1.2480	0.0883
July	1.2632	0.0923
August	1.2784	0.0934
September	1.1973	0.0847
October	1.1838	0.0865
November	1.1343	0.0802
December	1.0975	0.0802
Sum		**1.0000**

FHWA does not report monthly VMT information by vehicle classification. But it is clear that in many regions of the United States, motorcycles are driven much less frequently in the winter months. For MOVES2014 an allocation for motorcycles was derived using monthly national counts of fatal motorcycle crashes from the National Highway Traffic Safety Administration Fatality Analysis System for 2010.[66] This allocation increases motorcycle activity (and emissions) in the summer months and decreases them in the winter compared to the other source types. These default values in Table 12-3 for motorcycles are only a national average and do not reflect the strong regional differences that would be expected due to climate.

Table 12-3 MonthVMTFraction for motorcycles

Month	Month ID	Distribution
January	1	0.0262
February	2	0.0237
March	3	0.0583
April	4	0.1007
May	5	0.1194
June	6	0.1269
July	7	0.1333
August	8	0.1349
September	9	0.1132
October	10	0.0950
November	11	0.0442
December	12	0.0242
Sum		**1.0000**

12.2 VMT Distribution by Type of Day

The DayVMTFraction distribution divides the weekly VMT into two day types. The OHIM report provides VMT percentage values for each day and hour of a typical week for urban and rural roadway types for various regions of the United States. Since the day-of-the-week data obtained from the OHIM report is not disaggregated by month or source type, the same values were used for every month and source type. MOVES uses the 1995 data displayed in Figure 2.3.2 of the OHIM report.

The DayVMTFraction needed for MOVES has only two categories; week days (Monday, Tuesday, Wednesday, Thursday and Friday) and weekend (Saturday and Sunday) days. The OHIM reported percentages for each day of the week were summed in their respective categories and converted to fractions, as shown in Table 12-4. The OHIM report explains that data for "3am" refers to data collected from 3am to 4am. Thus data labeled "midnight" belongs to and was summed with the upcoming day.

Table 12-4 DayVMTFractions

Fraction	Rural	Urban
Weekday	0.72118	0762365
Weekend	0.27882	0.237635
Sum	**1.00000**	**1.000000**

We assigned the "rural" fractions to the rural road types and the "urban" fractions to the urban road types. The fraction of weekly VMT reported for a single weekday in MOVES will be one-fifth of the weekday fraction and the fraction of weekly VMT for a single weekend day will be one-half the weekend fraction.

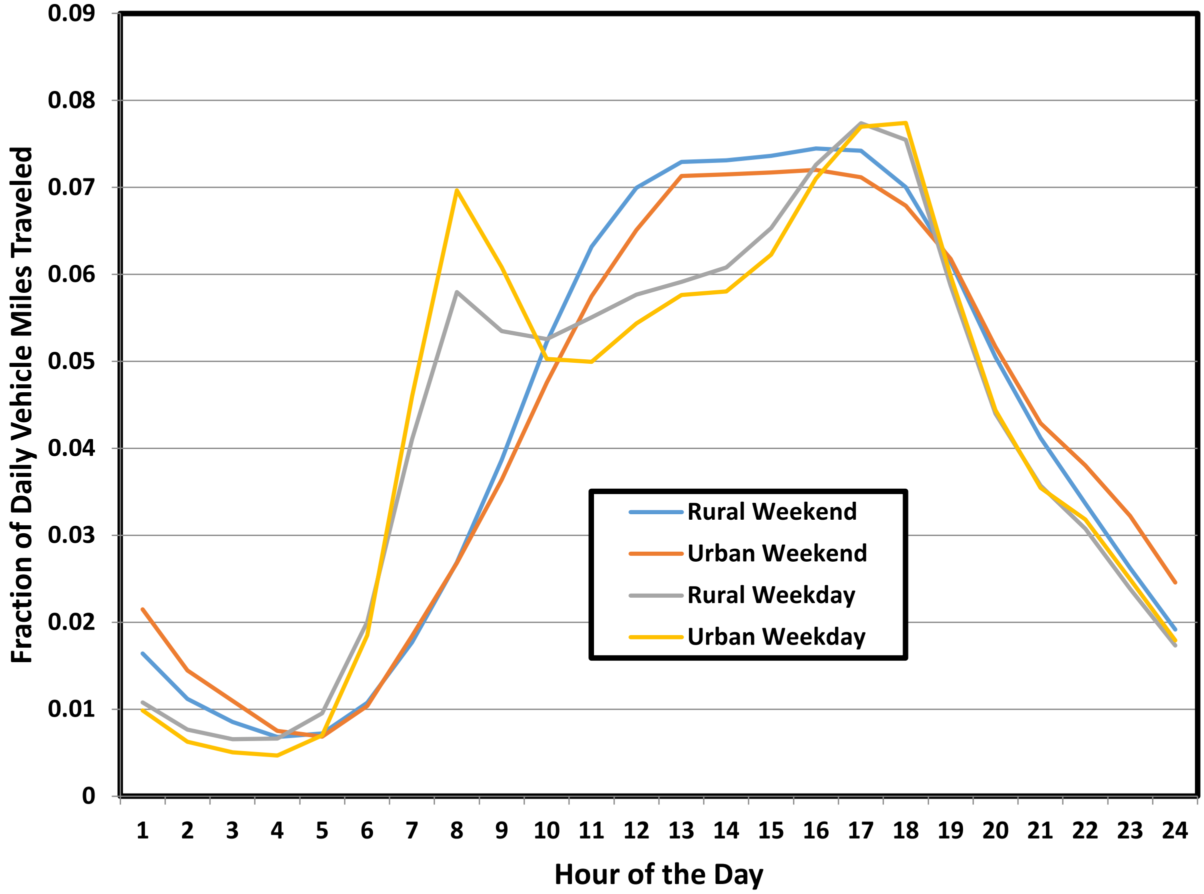
12.3 VMT Distribution by Hour of the Day

HourVMTFraction uses the same data as for DayVMTFraction. We converted the OHIM report's VMT data by hour of the day in each day type to percent of day by dividing by the total VMT for each day type, as described for the DayVMTFraction. There are separate sets of HourVMTFractions for "urban" and "rural" road types, but unrestricted and unrestricted roads use the same HourVMTFraction distributions. All source types use the same HourVMTFraction distributions, and Table 12-5 and Figure 12-1 summarize these default values.

Table 12-5 MOVES distribution of VMT by hour of the day

hourID	Description	Urban		Rural	
		Weekday	Weekend	Weekday	Weekend
1	Hour beginning at 12:00 midnight	0.00986	0.02147	0.01077	0.01642
2	Hour beginning at 1:00 AM	0.00627	0.01444	0.00764	0.01119
3	Hour beginning at 2:00 AM	0.00506	0.01097	0.00655	0.00854
4	Hour beginning at 3:00 AM	0.00467	0.00749	0.00663	0.00679
5	Hour beginning at 4:00 AM	0.00699	0.00684	0.00954	0.00722
6	Hour beginning at 5:00 AM	0.01849	0.01036	0.02006	0.01076
7	Hour beginning at 6:00 AM	0.04596	0.01843	0.04103	0.01768
8	Hour beginning at 7:00 AM	0.06964	0.02681	0.05797	0.02688
9	Hour beginning at 8:00 AM	0.06083	0.03639	0.05347	0.03866
10	Hour beginning at 9:00 AM	0.05029	0.04754	0.05255	0.05224
11	Hour beginning at 10:00 AM	0.04994	0.05747	0.05506	0.06317
12	Hour beginning at 11:00 AM	0.05437	0.06508	0.05767	0.06994
13	Hour beginning at 12:00 Noon	0.05765	0.07132	0.05914	0.07293
14	Hour beginning at 1:00 PM	0.05803	0.07149	0.06080	0.07312
15	Hour beginning at 2:00 PM	0.06226	0.07172	0.06530	0.07362
16	Hour beginning at 3:00 PM	0.07100	0.07201	0.07261	0.07446
17	Hour beginning at 4:00 PM	0.07697	0.07115	0.07738	0.07422
18	Hour beginning at 5:00 PM	0.07743	0.06789	0.07548	0.07001
19	Hour beginning at 6:00 PM	0.05978	0.06177	0.05871	0.06140
20	Hour beginning at 7:00 PM	0.04439	0.05169	0.04399	0.05050
21	Hour beginning at 8:00 PM	0.03545	0.04287	0.03573	0.04121
22	Hour beginning at 9:00 PM	0.03182	0.03803	0.03074	0.03364
23	Hour beginning at 10:00 PM	0.02494	0.03221	0.02385	0.02622
24	Hour beginning at 11:00 PM	0.01791	0.02457	0.01732	0.01917
	Sum of All Fractions	1.00000	1.00000	1.00000	1.00000

Figure 12-1 Hourly VMT fractions by day type and road type



12.4 Engine Starts and Parking

To properly estimate engine start emissions and evaporative fuel vapor losses, it is important to estimate the number of starts by time of day, and the duration of time between vehicle trips. The time between trips with the engine off is referred to as "soak time". To determine typical patterns of trip starts and ends, MOVES uses information from instrumented vehicles. This data is stored in two tables in the MOVES default database, as discussed earlier. We have made only minor changes for MOVE2014.

The first table, SampleVehicleDay, lists a sample population of vehicles, each with an identifier (vehID), an indication of vehicle type (sourceTypeID), and an indication (dayID) of whether the vehicle is part of the weekend or weekday vehicle population. Some vehicles were added to this table to increase the number of vehicles in each day which do not take any trips to better match a recent study of vehicle activity in Georgia.[67] This change is described in greater detail in the report describing evaporative emissions in MOVES2014.[68]

The second table, SampleVehicleTrip, lists the trips in a day made by each of the vehicles in the SampleVehicleDay table. It records the vehID, dayID, a trip number (tripID), the hour of the trip (hourID), the trip number of the prior trip (priorTripID), and the times at which the engine was turned on and off for the trip. The keyOnTime and keyOffTime are recorded in minutes since midnight of the day of the trip. 439 trips (about 1.1 percent) were added to this table to assure that at least on trip is done by a vehicle from each source type in each hour of the day to assure that emission rates will be calculated in each hour. Light-duty vehicle trip and soak data was copied to all the other source types (11, 41, 42, 43, 51, 52, 53, 54, 61, and 62) for both weekdays (dayID 5) and weekends (dayID 2) for hours with no trips.

To account for overnight soaks, many first trips reference a prior trip with a null value for keyOnTime and a negative value for keyOffTime. The SampleVehicleDay table also includes some vehicles that have no trips in the SampleVehicleTrip table to account for vehicles that sit for one or more days without driving at all.

The data and processing algorithms used to populate these tables are detailed in two contractor reports.[69,70] The data comes from a variety of instrumented vehicle studies, summarized in Table 12-6. This data was cleaned, adjusted, sampled and weighted to develop a distribution intended to represent average urban vehicle activity.

Table 12-6 Source data for sample vehicle trip information

Study	Study Area	Study Years	Vehicle Types	Vehicle Count
3-City FTP Study	Atlanta, GA; Baltimore, MD; Spokane, WA	1992	Passenger cars & trucks	321
Minneapolis	Minneapolis/St. Paul, MN	2004-2005	Passenger cars & trucks	133
Knoxville	Knoxville, TN	2000-2001	Passenger cars & trucks	377
Las Vegas	Las Vegas, NV	2004-2005	Passenger cars & trucks	350
Battelle	California, statewide	1997-1998	Heavy-duty trucks	120
TxDOT	Houston, TX	2002	Diesel dump trucks	4

For vehicle classes that were not represented in the available data, the contractor synthesized trips using trip-per-operating hour information from the EPA MOBILE6 model and soak time and time-of-day information from source types that did have data. The application of synthetic trips is summarized in Table 12-7.

Table 12-7 Synthesis of sample vehicles for source types lacking data

Source Type	Based on Direct Data?	Synthesized From
Motorcycles	No	Passenger Cars
Passenger Cars	Yes	n/a
Passenger Trucks	Yes	n/a
Light Commercial Trucks	No	Passenger Trucks
Intercity Buses	No	Combination Long-Haul Trucks
Transit Buses	No	Single Unit Short-Haul Trucks
School Buses	No	Single Unit Short-Haul Trucks
Refuse Trucks	No	Combination Short-Haul Trucks
Single Unit Short-Haul Trucks	Yes	n/a
Single Unit Long-Haul Trucks	No	Combination Long-Haul Trucks
Motor Homes	No	Passenger Cars
Combination Short-Haul trucks	Yes	n/a
Combination Long-Haul trucks	Yes	n/a

The resulting trip-per-day estimates are summarized in Table 12-8. The same estimate for trips per day is used for all ages of vehicles in any calendar year.

Table 12-8 Starts per day by source type

Source Type	MOVES2014 Weekday	MOVES2014 Weekend
Motorcycles	0.78	0.79
Passenger Cars	5.89	5.30
Passenger Trucks	5.80	5.06
Light Commercial Trucks	6.05	5.47
Intercity Buses	2.77	0.88
Transit Buses	4.58	3.46
School Buses	5.75	1.26
Refuse Trucks	3.75	0.92
Single Unit Short-Haul Trucks	6.99	1.28
Single Unit Long-Haul Trucks	4.29	1.29
Motor Homes	0.57	0.57
Combination Short-Haul trucks	5.93	1.16
Combination Long-Haul trucks	4.29	1.29

MOVES2014 now has inputs in the County Data Manager that allows users to specify the number of engine starts in each month, day type and hour of the day, as well as by source type and vehicle age. These user inputs override the default values provided by MOVES.

The same trip information that is used to determine the number of engine starts is also used to determine the vehicle soak time. “Soak time” is the time between trips when the engine is off. The soak times are used to estimate the activity in each of the operating modes for engine start emissions. The base emission rate for engine starts is based on a 12-hour soak period. All engine soaks greater than 12 hours assume the same engine start emission rate as for 12 hours. However, for all engine soaks less than 12 hours, the base engine start emission rate is adjusted based on soak time bins (operating modes).[68] The distribution of operating modes in each hour of the day is part of the calculation used to determine the engine start emissions for that hour of the day.

A more complete discussion of the relationship between engine soak time and emissions will be found in the MOVES report covering engine start emission rates used in MOVES.[4,5]

12.5 Hourly Hotelling Activity

The hotelling hours in each day should not directly correlate with the miles traveled in each hour, since hotelling occurs only when drivers are not driving. Instead, the fraction of hours spent hotelling by time of day can be derived from other sources. In particular, the report, *Roadway-Specific Driving Schedules for Heavy-Duty Vehicles*[61] combines data from several instrumented truck studies and contains detailed information about truck driver behavior. While none of the trucks were involved in long-haul interstate activity, for lack of better data, we have assumed that long-haul truck trips have the same hourly truck trip distribution as the heavy heavy-duty trucks that were studied.

For each hour of the day, we estimated the number of trips that would end in that hour, based on the number of trips that started 10 hours earlier. The hours of hotelling in that hour is the number that begin in that hour, plus the number that began in the previous hour, plus the number that began in the hour before that, and so on, up to the required eight hours of rest time. Table 12-9 shows the number of trip starts and inferred trip ends over the hours of the day in the sample of trucks assuming all trips are 10 hours long. For example, the number of trip ends in hour 1 is the same as the number of trip starts 10 hours earlier in hour 15 of the previous day.

Table 12-9 Hourly distribution of truck trips used to calculate hotelling hours

hourID	Hour of the Day	Trip Starts	Trip Ends
1	Hour beginning at 12:00 midnight	78	171
2	Hour beginning at 1:00 AM	76	167
3	Hour beginning at 2:00 AM	65	144
4	Hour beginning at 3:00 AM	94	98
5	Hour beginning at 4:00 AM	107	71
6	Hour beginning at 5:00 AM	131	73
7	Hour beginning at 6:00 AM	194	71
8	Hour beginning at 7:00 AM	230	52
9	Hour beginning at 8:00 AM	279	85
10	Hour beginning at 9:00 AM	267	48
11	Hour beginning at 10:00 AM	275	78
12	Hour beginning at 11:00 AM	240	76
13	Hour beginning at 12:00 Noon	201	65
14	Hour beginning at 1:00 PM	211	94
15	Hour beginning at 2:00 PM	171	107
16	Hour beginning at 3:00 PM	167	131
17	Hour beginning at 4:00 PM	144	194
18	Hour beginning at 5:00 PM	98	230
19	Hour beginning at 6:00 PM	71	279
20	Hour beginning at 7:00 PM	73	267
21	Hour beginning at 8:00 PM	71	275
22	Hour beginning at 9:00 PM	52	240
23	Hour beginning at 10:00 PM	85	201
24	Hour beginning at 11:00 PM	48	211

An estimate of the distribution of truck hotelling duration times is derived from a 2004 CRC paper[71] based on a survey of 365 truck drivers at six different locations. Table 12-10 lists the fraction of trucks in each duration bin. Some trucks are hotelling for more than the required eight hours, but some are hotelling for less than eight hours.

Table 12-10 Distribution of truck hotelling activity duration

Hotelling Duration (hours)	Fraction of Trucks
2	0.227
4	0.135
6	0.199
8	0.191
10	0.156
12	0.057
14	0.014
16	0.021
Total	**1.000**

We assume that all hotelling activity begins at the trip ends shown in Table 12-9. But not all trip ends have the same number of hotelling hours. The distribution of hotelling durations from Table 12-10 is applied to the hotelling that occurs at each of these trip ends.

Table 12-11 illustrates the hotel activity calculations based on the number of trip starts and trip ends. The hours of hotelling in any hour of the day is the number of trip ends in the current hour plus the trip ends from the previous hours that are still hotelling. However, since not all trips begin and end precisely on the hour, we have discounted the oldest hour included in the calculation by 60 percent to account for those unsynchronized trips.

For example, there are 171 trip ends in hourID 1. If all trip ends idle for two hours, the number of hours is 171 (for hourID 1) and 40 percent of 211 (for hourID 24), and thus 171 + (0.4*211) = 255.4 hours of hotelling. Similarly, the number of hours can be calculated for other hotelling time periods. For four hour hotelling periods, the hotelling hours would be 171 + 211 + 201 + (0.4*240) = 679. Only the oldest hour of the day is discounted.

This calculation accounts for the time in the current hour of the day which is a result of hotelling from trips that ended in the current hour and trips that ended in previous hours. This approach assumes that all hotelling begins at the trip end. For example, in the hour of the day 1 for the four hours hotelling bin, the trip ends in hourID 22 contribute to the hours of hotelling in hourID 1, since these trip ends are still hotelling (four hours) after the trip end. The trip ends in hourID 21 do not contribute to the four hours hotelling bin, since it has been more than four hours since the trip ends occurred.

The initial calculated hours assume that all trucks idle the same amount of time, indicated by the hotelling hours bin. The distribution (weight) from Table 12-10 is applied to the hour estimate in each hotelling hours bin to calculate the weighted total idle hours for each hour of the day.

Table 12-11 Calculation of hourly distributions of hotelling activity

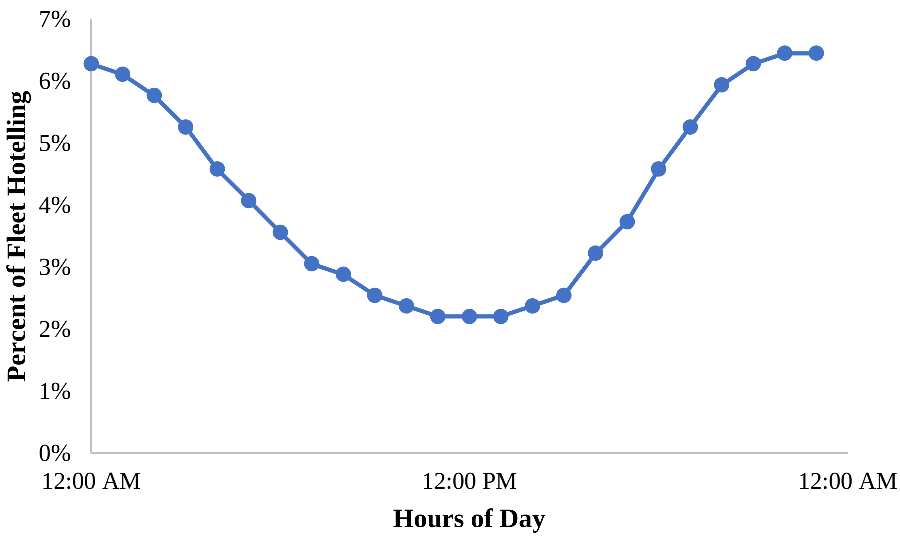
hourID	Trip Starts	Trip Ends*	2 hours	4 hours	6 hours	8 hours	10 hours	12 hours	14 hours	16 hours	Weighted Total Idle Hours	Distribution
1	78	171	255.4	679	1204.8	1736	2120.4	2343.6	2495.4	2638.2	1276	0.0628
2	76	167	235.4	629.4	1100	1643.6	2118.6	2408.8	2593	2739.2	1234	0.0611
3	65	144	210.8	566.4	990	1515.8	2047	2431.4	2654.6	2806.4	1166	0.0577
4	94	98	155.6	477.4	871.4	1342	1885.6	2360.6	2650.8	2835	1056	0.0526
5	107	71	110.2	379.8	735.4	1159	1684.8	2216	2600.4	2823.6	930	0.0458
6	131	73	101.4	299.6	621.4	1015.4	1486	2029.6	2504.6	2794.8	823	0.0407
7	194	71	100.2	254.2	523.8	879.4	1303	1828.8	2360	2744.4	728	0.0357
8	230	52	80.4	224.4	422.6	744.4	1138.4	1609	2152.6	2627.6	630	0.0306
9	279	85	105.8	237.2	391.2	660.8	1016.4	1440	1965.8	2497	581	0.0289
10	267	48	82	213.4	357.4	555.6	877.4	1271.4	1742	2285.6	507	0.0255
11	275	78	97.2	231.8	363.2	517.2	786.8	1142.4	1566	2091.8	479	0.0238
12	240	76	107.2	236	367.4	511.4	709.6	1031.4	1425.4	1896	457	0.0221
13	201	65	95.4	238.2	372.8	504.2	658.2	927.8	1283.4	1707	434	0.0221
14	211	94	120	266.2	395	526.4	670.4	868.6	1190.4	1584.4	447	0.0221
15	171	107	144.6	296.4	439.2	573.8	705.2	859.2	1128.8	1484.4	476	0.0238
16	167	131	173.8	358	504.2	633	764.4	908.4	1106.6	1428.4	526	0.0255
17	144	194	246.4	469.6	621.4	764.2	898.8	1030.2	1184.2	1453.8	635	0.0323
18	98	230	307.6	597.8	782	928.2	1057	1188.4	1332.4	1530.6	767	0.0374
19	71	279	371	755.4	978.6	1130.4	1273.2	1407.8	1539.2	1693.2	933	0.0458
20	73	267	378.6	853.6	1143.8	1328	1474.2	1603	1734.4	1878.4	1068	0.0526
21	71	275	381.8	913	1297.4	1520.6	1672.4	1815.2	1949.8	2081.2	1194	0.0594
22	52	240	350	893.6	1368.6	1658.8	1843	1989.2	2118	2249.4	1268	0.0628
23	85	201	297	822.8	1354	1738.4	1961.6	2113.4	2256.2	2390.8	1289	0.0645
24	48	211	291.4	762	1305.6	1780.6	2070.8	2255	2401.2	2530	1308	0.0645
Totals	**3428**	**3428**	**4799**	**11655**	**18511**	**25367**	**32223**	**39079**	**45935**	**52791**	**20213**	**1.0000**
Weight			0.227	0.135	0.199	0.191	0.156	0.057	0.014	0.021		

*Assumes every trip ends 10 hours after it starts, such that all trips are 10 hours long. The first hour of hotelling in each hour bin column sum is reduced by 60 percent to account for trip ends in a column that are not a full hour.

The distribution calculated using this method is similar to the behavior observed in a dissertation[72] at the University of Tennessee, Knoxville. This study observed the trucks parking at the Petro truck travel center located at the I40/I75 and Watt Road interchange between mid-December 2003 and August 2004. Rather than use results from a single study at a specific location, MOVES2014 uses the more generic simulated values to determine the diurnal distribution of hotelling behavior. The distribution of total hotelling hours to hours of the day is calculated from the total hotelling hours and stored in the SourceTypeHour table of the default MOVES2014 database.

MOVES2014 uses this same default hourly distribution from
Table 12-11 for all days and locations, as shown below in Figure 12-2. Note this distribution of hotelling by hour of the day is similar to the inverse of the VMT distribution used for these trucks by hour of the day.

Figure 12-2 Truck hotelling distribution by hour of the day in MOVES2014



12.6 Single and Multiday Diurnals

The evaporative vapor losses from gasoline vehicle fuel tanks are affected by many factors, including the number of hours a vehicle is parked without an engine start, referred to as engine soak time. Most modern gasoline vehicles are equipped with emission control systems designed to capture most evaporative vapor losses and store them. These stored vapors are then burned in the engine once the vehicle is operated. However, the vehicle storage capacity for evaporative vapors is limited and multiple days of parking (diurnals) will overload the storage capacity of these systems, resulting in larger losses of evaporative vapors in subsequent days.

The soak time calculations are discussed earlier in Section 12.4. The detailed description of the calculation for the number of vehicles that have been soaking for more than a day and the amount of time that the vehicles have been soaking can be found in the MOVES technical report on evaporative emissions.[70]

13 Geographical Allocation of Activity

MOVES is designed to model activity at a “domain” level and then to allocate that activity to “zones.” The MOVES2014 default database is populated for a domain of the entire United States (including Puerto Rico and the Virgin Islands), and the default zones correspond to individual counties. The MOVES design only allows for one set of geographic allocations to be stored in the default database. While geographic allocations clearly change over time, the MOVES2014 defaults were developed using the data from calendar year 2011, and are used for all calendar years. For this reason, the MOVES default allocation of activity is rarely used for any official purpose by either EPA or local areas. National-level emissions can be generated with calendar year specific geographical information by running each year separately, with different user-input allocations for each run. County- and Project-level calculations do not use the default geographical allocation factors at all. Instead, County and Project scales require that the user input local total activity for each individual year being modeled. The MOVES geographic allocation factors are stored in two tables, Zone and ZoneRoadType.

13.1 Source Hours Operating Allocation to Zones

Most of the emission rate calculations in MOVES2014 are based on emission rates by time units (hour). Using time units for emissions is the most flexible approach, since the activity for some processes (like leaks and idling) and some source types (like nonroad generators) are more naturally in units of time. As a result, MOVES converts activity data to hours in many cases in order to produce the hours needed for emissions calculations.

The national total source hours of operation (SHO) are calculated from the estimates of VMT and speed as described in sections above. This total VMT for each road type is allocated to county using the SHOAllocFactor field in the ZoneRoadType table. The allocation factors are derived using 2011 VMT and MOVES default VMT.

In particular, the MOVES2014 default estimates for the VMT by county come from Version 1 of the 2011 National Emission Inventory (NEI) analysis.[48] These estimates are based on the Highway Performance Monitoring System (HPMS) state level data collected by the Federal Highway Administration[73] annually for use in transportation planning. The HPMS state level VMT is distributed to the individual counties in each state as part of the NEI analysis. This data is reviewed and updated by the states as necessary prior to use in the NEI. The default inputs for SHOAllocFactor in MOVES2014 were calculated using the VMT estimates obtained from Version 1 of the 2011 NEI[74] for each county by road type.

Vehicle miles traveled can be converted to hours of travel using average speeds. The average speed estimates were taken directly from the AvgSpeedDistribution table of the MOVES default database. The default average speed distributions do not vary by county or source type, but do vary by road type, day type (weekday and weekend day) and hour of the day. The 2011 NEI VMT was aggregated into the four MOVES road types in each county. The VMT by road type in each county was then allocated to day type and hour of the day using the day type and hour distributions from the MOVES default database tables, DayMVTFraction and HourVMTFraction.

Using the nominal speeds for each average speed bin in the AvgSpeedDistribution table for each hour of each day type and the corresponding VMT, the hours of vehicle operation (SHO) can be calculated for each hour of the day on each road type for each day type in each county. The average speed distribution is in units of time, so the distribution must be converted to units of distance to be applied to the VMT values. For this step, we multiplied each value of each distribution (in terms of time) by the corresponding nominal average speed value for that average speed bin to calculate distance (hours * miles/hour). Then we divided each distance value in the distribution by the sum of all distance values in that distribution to calculate the average speed distribution in terms of distance.

Finally, we multiplied the total VMT corresponding to each average speed distance distribution (by road type, by day type, by hour of the day) by each of the values in the distribution to calculate the VMT corresponding to each average speed bin. We then calculated operating hours by dividing the VMT in each average speed bin by the corresponding nominal average speed value, shown in Equation 16.

$$\text{SHO} = \text{VMT (miles)} / \text{Speed (miles per hour)} \qquad \text{Equation 16}$$

Once the hours of operation have been calculated, the hours in each county were summed by road type. The allocation factor for each county in Equation 17 was calculated by dividing the county hours for each road type by the national total hours of operation for each road type.

$$\text{SHOAllocFactor} = \text{County SHO} / \text{National SHO} \qquad \text{Equation 17}$$

The county allocation values for each roadway type sum to one (1.0) for the nation. The same SHOAllocFactor set is the default for all calendar years at the National scale. County- and Project-level calculations do not use the default SHOAllocFactor allocations at all. Instead, County and Project scales require that the user input all local activity.

13.2 Engine Start Allocations to Zones

The allocation of the domain-wide count of engine starts to zones is stored in the StartAllocFactor in the Zone table. In the default database for MOVES2014, the domain is the nation and the zones are counties. There is no national source for data on the number of trip starts by county, so for MOVES2014, we have used VMT to determine this allocation. VMT for each county was taken from the most recent National Emission Inventory analysis for calendar year 2011.[74]

VMT estimates for each county in each state and the allocation is calculated using Equation 18, where i represents each individual county and I is the set of all US counties.

$$\text{CountyAllocation}_i = \text{CountyVMT}_i \Big/ \sum_{i \in I} \text{CountyVMT}_i \qquad \text{Equation 18}$$

The county allocation values sum to one (1.0) for the nation. The same StartAllocFactor set is the default for all calendar years at the National scale. County- and Project-level calculations do not use the default StartAllocFactor allocations at all. Instead, County and Project scales require that the user input all local activity.

13.3 Parking Hours Allocation to Zones

The allocation of the domain-wide hours of parking (engine off) to zones is stored in the SHPAllocFactor in the Zone table. In the default database for MOVES2014, the domain is the nation and the zones are the counties. There is no national source for hours of parking by county, so for MOVES2014, we have used the same VMT-based allocation as used for the allocation of starts in the StartAllocFactor (see above).

The county allocation values for parking hours sum to one (1.0) for the nation. The same SHPAllocFactor set is the default for all calendar years at the National scale. County- and Project-level calculations do not use the default SHPAllocFactor allocations at all. Instead, County and Project scales require that the user input all local activity.

In MOVES2014, hotelling hours (including extended idling and auxiliary power unit usage) are calculated from long-haul combination truck VMT in each location and does have its own allocation factors.

14 Vehicle Mass and Road Load Coefficients

The MOVES model calculates emissions using a weighted average of emisson rates by operating mode. This level of detail is required for microscale modeling, which in MOVES is called project level analysis. For running exhaust emissions, the operating modes are defined by either vehicle specific power (VSP) or scaled tractive power (STP). Both VSP and STP are calculated based on a vehicle's speed and acceleration but differ in how they are scaled (or normalized). VSP is used for light-duty vehicles (source types 11 through 32) and STP is used for heavy-duty vehicles (source types 41 through 62).

The SourceUseTypePhysics table describes the vehicle characteristics needed for the VSP and STP calculations, including average vehicle mass, a fixed mass factor, and three road load coefficients for each source type averaged over all ages. MOVES uses these to calculate VSP and STP for each source type according to Equation 19 and Equation 20:

$$VSP = \left(\frac{A}{M}\right) \cdot v + \left(\frac{B}{M}\right) \cdot v^2 + \left(\frac{C}{M}\right) \cdot v^3 + (a + g \cdot \sin\theta) \cdot v \qquad \text{Equation 19}$$

$$STP = \frac{Av + Bv^2 + Cv^3 + M \cdot v \cdot (a_t + g \cdot sin\theta)}{f_{scale}} \qquad \text{Equation 20}$$

where A, B, and C are the road load coefficients in units of kW-s/m, kW-s^2/m^2, and kW-s^3/m^3 respectively. A is associated with tire rolling resistence, B with mechanical rotating friction as well as higher order rolling resistance losses, and C with aerodynamic drag. M is the source mass for the source type in metric tons, g is the acceleration due to gravity $(9.8\ \mathrm{m/s^2})$, v is the instantaneous vehicle speed in m/s, a is the instantaneous vehicle acceleration in $\mathrm{m/s^2}$, $\sin\theta$ is the (fractional) road grade, and f_{scale} is a scaling factor.

When mapping actual emissions data to VSP bins with Equation 19, the vehicle's measured weight is used as the source mass factor. In contrast, when calculating average VSP distributions for an entire source type with MOVES, the average source type mass is used instead. STP is calculated with Equation 20, which is very similar to the VSP equation except the denominators are different. In the case of VSP, the power is normalized by the mass of the vehicle ($f_{scale} = M$). For heavy-duty vehicles using STP, f_{scale} depends on their regulatory class and is used to bring the numerical range of tractive power into the same numerical range as the VSP values when assigning operating modes. Class 40 trucks use $f_{scale} = 2.06$, which is equal to the mass of source type 32 in metric tons. This is because operating modes for passenger trucks and light-commercial trucks are assigned operating modes using VSP, and using a fixed mass factor of 2.06 essentially calculates VSP-based emission rates. Running operating modes for all the heavy-duty source types (buses, single unit, and combination trucks) are assigned using STP with f_{scale} =17.1, which is roughly equivalent to the average running weight in metric tons of all heavy-duty vehicles. Additional discussion regarding VSP and STP are provided in the MOVES light-duty[4] and heavy-duty[5] emission rate reports, respectively.

In both cases, operating mode distributions are derived by combining second-by-second speed and acceleration data from a specific drive schedule with the proper coefficients for a specific source type. More information about drive schedules can be found in Section 10.1. The following sections detail the derivation of values used in Equation 19 and Equation 20.

14.1. Source Mass and Fixed Mass Factor

The two mass factors stored in the SourceUseTypePhysics table are the source mass and fixed mass factor. The source mass represents the average weight of a given source type, which includes the weight of the vehicle, occupants, fuel, and payload (M in the equations above), and the fixed mass factor represents the STP scaling factor (f_{scale} in the equations above).

While the source masses for light-duty were unchanged from MOVES2010b, all of the heavy-duty source masses were updated with newer data. Please see Section 24 (Appendix H: MOVES2010b Source Masses) for a discussion of the MOVES2010b source masses. The heavy-duty source masses for 2014+ model year vehicles heavy-duty vehicles were first updated to account for the 2014 Medium and Heavy-Duty Greenhouse Gase Rule as discussed in Section 14.2. Then the heavy-duty source masses were updated with 2011 Weigh-in-Motion (WIM) data made available through FHWA's Vehicle Travel Information System (VTRIS). These data are available from FHWA by state, road type, and HPMS truck type (single unit or combination). The average national mass by truck type was calculated by weighting the masses with VMT by state and road type using FHWA's *Highway Statistics* VM-2 Table. These average values then needed to be allocated from the HPMS truck classification to source types. This allocation was performed using the percent difference between the average WIM HPMS mass and the average MOVES2010b HPMS mass.[k] The MOVES2010b average masses were calculated by weighting the source type masses with the updated 2011 VMT. The percentage difference between the average single unit truck mass in MOVES2010b and the WIM data was then applied to the source masses of short-haul single unit trucks, long-haul single unit trucks, refuse trucks, and motor homes. Likewise, the percentage difference between the average combination truck mass in MOVES2010b and the WIM data was applied to the source masses of short-haul and long-haul combination trucks, including the 2014+ model year groups. These differences are shown in Table 14-1, and the resulting source type masses are presented in Table 14-4.

Table 14-1 Weigh-in-Motion (WIM) masses weighted by VMT

HPMS Category	Average Weight (lbs)	Percent Change from MOVES2010b
Single Unit Trucks	20,107	11.7%
Combination Trucks	52,907	-21.7%

14.2. Road Load Coefficients

The information available on road load coefficients varied by regulatory class. Motorcycle road load coefficients, given in Equation 21 through Equation 23, were empiricially derived in accordance with standard practice[75,76]:

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[k] For the WIM analysis, we only compared to the MOVES2010b masses because the 2014 Medium and Heavy-Duty Rule impact is not assumed to begin phase-in until 2014.

$$A = 0.088 \cdot M \qquad \text{Equation 21}$$

$$B = 0 \qquad \text{Equation 22}$$

$$C = 0.00026 + 0.000194 \cdot M \qquad \text{Equation 23}$$

For light-duty vehicles, the road load coefficients were calculated according to Equation 24 through Equation 26:[77]

$$A = \frac{0.7457}{50 \cdot 0.447} \cdot 0.35 \cdot TRLHP_{@50\text{mph}} \qquad \text{Equation 24}$$

$$B = \frac{0.7457}{(50 \cdot 0.447)^2} \cdot 0.10 \cdot TRLHP_{@50\text{mph}} \qquad \text{Equation 25}$$

$$C = \frac{0.7457}{(50 \cdot 0.447)^3} \cdot 0.55 \cdot TRLHP_{@50\text{mph}} \qquad \text{Equation 26}$$

In each of the above equations, the first factor is the appropriate unit conversion to allow A, B, and C to be used in Equation 19 and Equation 20, the second factor is the power distribution into each of the three load categories, and the third is the tractive road load horsepower rating (TRLHP). Average values for A, B, and C for source types 21, 31, and 32 were derived from applying TRLHP values recorded in the Mobile Source Observation Database (MSOD)[78] to Equation 24 through Equation 26. While we expect light-duty road load coefficients to improve over time due to the Light-Duty Greenhouse Gas Rule, the impact of these changes have been directly incorporated into the emission and energy rates. Therefore, these coefficients remain constant over time in the MOVES (if not in the real-world) to avoid double counting the impacts of actual road load improvements in the fleet.

For the heavier vehicles, no road load parameters were available in the MSOD. For these source types, relationships of road load coefficent to vehicle mass came from a study done by V.A. Petrushov,[79] as shown in Table 14-2. These relationships are grouped by regulatory class; source type values were determined by weighting the combination of MOVES2010b weight categories that comprise the individual source types. The final SourceMass, FixedMassFactor and road load coefficients for all source types are listed in Table 14-4.

Table 14-2 Road load coefficients for heavy-duty trucks, buses, and motor homes for MY 1960-2013 vehicles

Coefficient	8500 to 14000 lbs (3.855 to 6.350 metric ton)	14000 to 33000 lbs (6.350 to 14.968 metric ton)	>33000 lbs (>14.968 metric ton)	Buses and Motor Homes
$A\left(\frac{kW\text{-}s}{m}\right)$	$0.0996 \cdot M$	$0.0875 \cdot M$	$0.0661 \cdot M$	$0.0643 \cdot M$
$B\left(\frac{kW\text{-}s^2}{m^2}\right)$	0	0	0	0
$C\left(\frac{kW\text{-}s^3}{m^3}\right)$	$0.00289 + 5.22 \times 10^{-5} \cdot M$	$0.00193 + 5.90 \times 10^{-5} \cdot M$	$0.00289 + 4.21 \times 10^{-5} \cdot M$	$0.0032 + 5.06 \times 10^{-5} \cdot M$

In MOVES2014, the vehicle mass and road load coefficient were updated for 2014 and later model year heavy-duty vehicles to account for the 2014 Medium and Heavy-Duty Greenhouse Gase Rule.[80] Table 14-3 contains the combination long-haul tractor and vocational vehicle tire rolling resistance, coefficient of drag, and weight reductions expected from the technologies which could be used to meet the standards. The value in the table reflects a 400 pound mass reduction. As discussed in the regulatory impact analysis for the final rulemaking, EPA used a sales mix of 10 percent Class 7 low roof, 10 percent Class 7 high roof, 45 percent Class 8 low roof, and 35 percent Class 8 high roof based on feedback from the manufacturers.

The values in the table reflect a modeling assumption that 8 percent of all tractors (19.7 percent of short-haul tractors) would be considered vocational tractors and therefore will only be required to meet the vocational vehicle standards and not show any aerodynamic or weight improvement. The weight reduction applied to short-haul tractors is 321 pounds, which is calculated from the 400 pound weight reduction assumed for non-vocational tractors, reduced by 19.7 percent. The tire rolling resistance reduction is assumed to be 5 percent based on the data derived in the tire testing program conducted by EPA. Comparatively tire rolling resistance is reduced by 9.6 percent for long-haul tractors and 7 percent for short-haul tractors while aerodynamic drag is reduced 12.1 percent for long-haul tractors and 5.9 percent for short-haul tractors in model year 2014 and later. Further details on the rule's assumptions about reductions to source mass and road load coefficients in the SourceUseTypePhysics table and discussion of incorporating the rule's energy reductions from engine technology improvements into MOVES can be found in the MOVES2014 Heavy-Duty Emission Rate Report.[5]

Table 14-3 Estimated reductions in rolling resistance and aerodynamic drag coefficients from HD GHG Phase 1 Rule for model years 2014 and later

Truck Type	Reduction In Tire Rolling Resistance Coefficient From Baseline	Reduction In Aerodynamic Drag Coefficient From Baseline	Weight Reduction (lbs)
Combination long-haul	9.6%	12.1%	400
Combination short-haul	7.0%	5.9%	321
Vocational vehicles (Single unit trucks, refuse trucks, motor homes, buses, and light commercial trucks)	5.0%	0%	0

These changes are represented in MOVES2014 through new aerodynamic coefficients and weights, and they primarily affect short- and long-haul combination truck source types beginning in MY 2014. The average vehicle mass and road load coefficients are updated by source type through the beginModelYearID and endModelYearID fields in the SourceUseTypePhysics table.

Table 14-4 MOVES2014 SourceUseTypePhysics table

sourceTypeID	Begin Model Year	End Model Year	Rolling Term A (kW-s/m)	Rotating Term B ($kW\text{-}s^2/m^2$)	Drag Term C ($kW\text{-}s^3/m^3$)	Source Mass (metric tons)	Fixed Mass Factor (metric tons)
11	1960	2050	0.0251	0	0.0003	0.2850	0.2850
21	1960	2050	0.1565	0.0020	0.0005	1.4788	1.4788
31	1960	2050	0.2211	0.0028	0.0007	1.8669	1.8669
32	1960	2050	0.2350	0.0030	0.0007	2.0598	2.0598
41	1960	2013	1.2952	0	0.0037	19.5937	17.1
41	2014	2050	1.2304	0	0.0037	19.5937	17.1
42	1960	2013	1.0944	0	0.0036	16.5560	17.1
42	2014	2050	1.0397	0	0.0036	16.5560	17.1
43	1960	2013	0.7467	0	0.0022	9.0699	17.1
43	2014	2050	0.7094	0	0.0022	9.0699	17.1
51	1960	2013	1.5835	0	0.0036	23.1135	17.1
51	2014	2050	1.5043	0	0.0036	23.1135	17.1
52	1960	2013	0.6279	0	0.0016	8.5390	17.1
52	2014	2050	0.5965	0	0.0016	8.5390	17.1
53	1960	2013	0.5573	0	0.0015	6.9845	17.1
53	2014	2050	0.5294	0	0.0015	6.9845	17.1
54	1960	2013	0.6899	0	0.0021	7.5257	17.1
54	2014	2050	0.6554	0	0.0021	7.5257	17.1
61	1960	2013	1.5382	0	0.0040	22.9745	17.1
61	2014	2050	1.4305	0	0.0038	22.8289	17.1
62	1960	2013	1.6304	0	0.0042	24.6010	17.1
62	2014	2050	1.4739	0	0.0037	24.4196	17.1

15 Air Conditioning Activity Inputs

This report describes three inputs used in determining the impact of air conditioning on emissions. The ACPenetrationFraction is the fraction of vehicles equipped with air conditioning. FunctioningACFraction describes the fraction of these vehicles in which the air conditioning system is working correctly. The ACActivityTerms relate air conditioning use to local heat and humidity. More information on air conditioning effects is provided in the MOVES technical report on adjustment factors.[81]

15.1 ACPenetrationFraction

The ACPenetrationFraction is a field in the SourceTypeModelYear table. Default values, by source type and model year were taken from MOBILE6.[82] Market penetration data by model year were gathered from Ward's Automotive Handbook for light-duty vehicles and light-duty trucks for model years 1972 through the 1995 for cars and 1975-1995 for light trucks. Rates in the first few years of available data are quite variable, so values for early model years were estimated by applying the 1972 and 1975 rates for cars and trucks, respectively. Projections beyond 1995 were developed by calculating the average yearly rate of increase in the last five years of data and applying this rate until a predetermined cap was reached. A cap of 98 percent was placed on cars and 95 percent on trucks under the assumption that there will always be vehicles sold without air conditioning, more likely trucks than cars. No data was available on heavy-duty trucks. While VIUS asks if trucks are equipped with A/C, "no response" was coded the same as "no," making the data unusable for this purpose. For MOVES, the light-duty vehicle rates were applied to passenger cars, and the light-duty truck rates were applied to all other source types (except motorcycles, for which A/C penetration is assumed to be zero), summarized in Table 15-1.

Table 15-1 AC penetration fractions in MOVES2014

	Motorcycles	Passenger Cars	All Trucks and Buses
1972-and-earlier	0	0.592	0.287
1973	0	0.726	0.287
1974	0	0.616	0.287
1975	0	0.631	0.287
1976	0	0.671	0.311
1977	0	0.720	0.351
1978	0	0.719	0.385
1979	0	0.694	0.366
1980	0	0.624	0.348
1981	0	0.667	0.390
1982	0	0.699	0.449
1983	0	0.737	0.464
1984	0	0.776	0.521
1985	0	0.796	0.532
1986	0	0.800	0.544
1987	0	0.755	0.588
1988	0	0.793	0.640
1989	0	0.762	0.719
1990	0	0.862	0.764
1991	0	0.869	0.771
1992	0	0.882	0.811
1993	0	0.897	0.837
1994	0	0.922	0.848
1995	0	0.934	0.882
1996	0	0.948	0.906
1997	0	0.963	0.929
1998	0	0.977	0.950
1999+	0	0.980	0.950

15.2 FunctioningACFraction

The FunctioningACFraction field in the SourceTypeAge table (see Table 15-2) indicates the fraction of the air-conditioning equipped fleet with fully functional A/C systems, by source type and vehicle age. A value of 1 means all systems are functional. This is used in the calculation of total energy to account for vehicles without functioning A/C systems. Default estimates were developed for all source types using the “unrepaired malfunction” rates used for 1992-and-later model years in MOBILE6. The MOBILE6 rates were based on the average rate of A/C system failure by age reported in a consumer study and assumptions about repair frequency during and after the warranty period. The MOBILE6 rates were applied to all source types except motorcycles, which were assigned a value of zero for all years.

Table 15-2 FunctioningACFraction by age (all source types except motorcycles)

ageID	functioningACFraction
0	1
1	1
2	1
3	1
4	0.99
5	0.99
6	0.99
7	0.99
8	0.98
9	0.98
10	0.98
11	0.98
12	0.98
13	0.96
14	0.96
15	0.96
16	0.96
17	0.96
18	0.95
19	0.95
20	0.95
21	0.95
22	0.95
23	0.95
24	0.95
25	0.95
26	0.95
27	0.95
28	0.95
29	0.95
30	0.95

15.3 ACActivityTerms

In the MonthGroupHour table, ACActivityTerms A, B, and C are coefficients for a quadratic equation that calculates air conditioning activity demand as a function of the heat index. These terms are applied in the calculation of the A/C adjustment in the energy consumption calculator. The methodology and the terms themselves were originally derived for MOBILE6 and are documented in the report, *Air Conditioning Activity Effects in MOBILE6*.[82] They are based on analysis of air conditioning usage data collected in Phoenix, Arizona, in 1994.

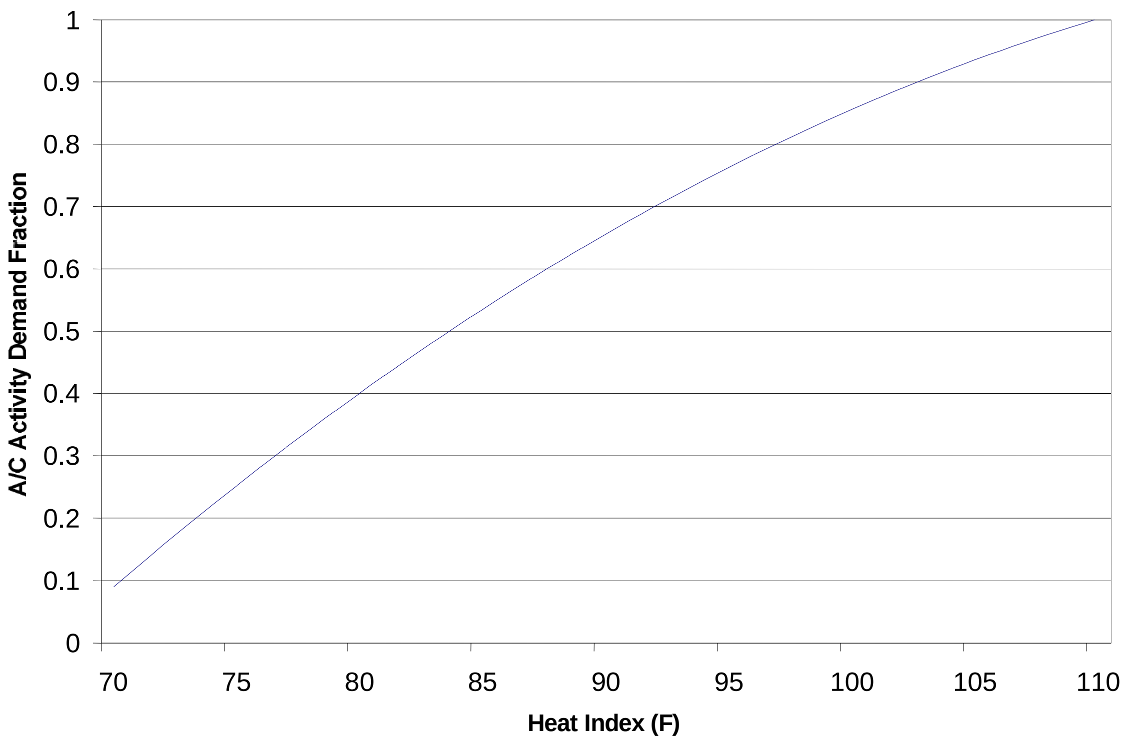
In MOVES, ACActivityTerms are allowed to vary by monthGroup and Hour, in order to provide the possibility of different A/C activity demand functions at a given heat index by season and time of day (this accounts for differences in solar loading observed in the original data). However, for MOVES2014, the default data uses one set of coefficients for all MonthGroups and Hours. These default coefficients represent an average A/C activity demand function over the course of a full day. The coefficients are listed in Table 15-3.

Table 15-3 Air conditioning activity coefficients

A	B	C
-3.63154	0.072465	-0.000276

The A/C activity demand function that results from these coefficients is shown in Figure 15-1. A value of 1 means the A/C compressor is engaged 100 percent of the time; a value of 0 means no A/C compressor engagement.

Figure 15-1 Air conditioning activity demand as a function of heat index



16 Conclusion and Areas for Future Research

Properly characterizing emissions from vehicles requires a detailed understanding of the cars and trucks that make up the vehicle fleet and their patterns of operation. The national default information in MOVES2014 provide a reliable basis for estimating national emissions. The most important of these inputs are well-established: base year VMT and population estimates come from long-term, systematic national measurements by US Department of Transportation. The emission characteristics for prevalent vehicle classes are well-known; base year age distributions are well-measured, and driving activity has been the subject of much study in recent years.

Still, the fleet and activity inputs do have significant limitations, and the uncertainties and variability in this local data can contribute significant uncertainty in resulting emission estimates. Thus it is often appropriate to replace many of the MOVES fleet and activity defaults with local data as explained in EPA's Technical Guidance.[3]

The fleet and activity defaults also are limited by the necessity of forecasting future emissions. EPA utilizes annual US Department of Energy forecasts of vehicle sales and activity. The inputs for MOVES2014 were developed for a 2011 base year and much of the source data is from 2011 and earlier. This information needs to be updated periodically to assure that the model defaults reflect the latest available data and projections on the US fleet.

Updating the vehicle fleet data will be complicated by the fact that one of the primary data sources for this document, the Census Bureau's Vehicle Inventory and Use Survey, has been discontinued. EPA is currently working with DOT and other federal agencies to revive this survey. Doing so becomes more important as the data gathered from the last survey (2002) ages.

A related complication is the cost of data. Collecting data on vehicle fleet and activity is expensive, especially when the data is intended to accurately represent the entire United States. Even when EPA does not generate data directly (for example, compilations of state vehicle registration data), obtaining the information needed for MOVES can be costly and, thus, dependent on budget choices.

In addition to these general limitations, there are also specific MOVES data elements that could be improved with additional research, including:

- real-world highway driving cycles and operating mode distributions;
- off-network behavior including vehicle starts and soaks;
- truck hotelling, particularly extended engine idling, and APU use;
- idling while loading/unloading, in traffic queues (i.e. tolls), or elsewhere;
- VSP/STP adjustments for speed, road grade, and loading;
- activity changes with age, such as mileage accumulation rates, start activity, and soak distributions;
- updated estimates of vehicle scrappage rates used to project vehicle age distributions;
- further incorporation of data from instrumented vehicle studies;
- summaries from large-scale instrumented vehicle studies;

- vehicle identification and sorting by size, sector, and vocation;
- activity weighting of source mass averages;
- air conditioning system usage, penetration, and failure rates;
- vehicle type distinctions in temporal activity;
- heavy truck and bus daily trip activity patterns; and
- ramp activity and operating mode distributions.

We expect many of these MOVES data limitations can be addressed through analysis of data captured on instrumented vehicles. The recent emergence and availability of large streams of activity data from GPS devices, data loggers, and other onboard diagnostic systems will likely lead to a better understanding of travel behavior. These data streams often provide frequent sampling of real-world driving for a large number of vehicles, so, while imperfect, they are useful for improving the nationally representative default inputs in MOVES. EPA is actively acquiring such data for future MOVES updates.

Future updates to vehicle population and activity defaults will need to continue to focus on the most critical elements required for national fleet-wide estimates, namely gasoline light-duty cars and trucks, and diesel heavy-duty trucks. Information collection on motorcycles, refuse trucks, motor homes, diesel light-duty vehicles and gasoline heavy-duty vehicles will be a lower priority. In addition to updating the model defaults, we will need to consider whether the current MOVES design continues to meet our modeling needs. Simplifications to the model to remove categories, such as source types or road types, might make noticeable improvements in run time without affecting the validity of fleet-wide emission estimates. EPA hopes to perform further validation of MOVES activity data using fuel volumes reported from US Department of Transportation in a separate technical report. This type of fuel volume validation and other MOVES2014 validation work was initially presented to the MOVES Federal Advisory Committee Act (FACA) Work Group.[83]

At the same time, the fundamental MOVES assumption that vehicle activity varies by source type and not by fuel type or other source bin characteristic may be challenged by the growing market share of alternative fuel vehicles, such as electric vehicles, which may have distinct activity patterns. As we progress with MOVES, the development of vehicle population and activity inputs will continue to be an essential area of research.

17 Appendix A: Projected Source Type Populations by Year

Table 17-1: Source type populations (in thousands), as derived from HPMS populations in §5.2and the age distribution algorithm in §7.1.2.2

Year	Motorcycle (11)	Passenger Car (21)	Passenger Truck (31)	Light Comm. Truck (32)	Intercity Bus (41)	Transit Bus (42)	School Bus (43)	Refuse Truck (51)	Single Unit Short-Haul (52)	Single Unit Long-Haul (53)	Motor Home (54)	Combination Short-Haul (61)	Combination Long-Haul (62)
2012	8571	128033	86859	21393	18	69	617	185	6194	260	1559	1191	1280
2013	8687	129764	87924	21791	19	72	643	195	6525	274	1643	1234	1332
2014	8706	130054	88014	21960	20	74	663	203	6777	285	1708	1258	1377
2015	8747	130666	88345	22167	21	77	691	213	7093	299	1788	1306	1439
2016	8844	132117	89259	22492	22	80	720	223	7392	312	1863	1354	1503
2017	8943	133583	90198	22803	22	82	740	230	7589	322	1915	1380	1555
2018	9018	134715	90934	23043	23	84	753	235	7709	328	1946	1390	1600
2019	9098	135907	91718	23279	23	86	766	239	7824	333	1977	1400	1645
2020	9178	137105	92513	23508	23	87	780	243	7953	335	2012	1410	1690
2021	9260	138317	93324	23730	24	88	794	247	8093	340	2053	1422	1737
2022	9337	139471	94098	23939	24	90	809	252	8242	345	2095	1437	1783
2023	9416	140653	94892	24150	25	92	824	256	8385	351	2134	1453	1828
2024	9498	141880	95725	24361	25	93	838	260	8510	352	2168	1466	1872
2025	9585	143179	96598	24591	26	95	853	264	8638	357	2204	1482	1918
2026	9680	144593	97557	24833	26	97	867	267	8752	362	2239	1495	1964
2027	9781	146100	98575	25092	27	98	879	269	8846	366	2266	1505	2005
2028	9888	147713	99664	25368	27	99	889	272	8927	371	2288	1514	2040
2029	9996	149317	100741	25649	27	100	900	274	9017	375	2312	1527	2073
2030	10103	150922	101823	25925	28	101	912	277	9114	376	2340	1546	2104
2031	10215	152591	102952	26209	28	103	922	280	9209	377	2368	1567	2131
2032	10328	154280	104098	26493	28	104	931	283	9286	381	2385	1585	2152
2033	10439	155930	105216	26772	28	105	942	286	9378	385	2405	1609	2174
2034	10538	157420	106225	27024	29	106	956	290	9493	391	2432	1639	2203

Year	Motorcycle (11)	Passenger Car (21)	Passenger Truck (31)	Light Comm. Truck (32)	Intercity Bus (41)	Transit Bus (42)	School Bus (43)	Refuse Truck (51)	Single Unit Short-Haul (52)	Single Unit Long-Haul (53)	Motor Home (54)	Combination Short-Haul (61)	Combination Long-Haul (62)
2035	10633	158833	107181	27263	29	108	969	293	9599	396	2457	1669	2232
2036	10724	160194	108102	27494	30	109	983	296	9698	401	2482	1701	2260
2037	10813	161523	109001	27720	30	111	996	299	9795	405	2508	1733	2288
2038	10901	162835	109888	27944	30	113	1009	301	9887	409	2532	1766	2315
2039	10983	164062	110717	28153	31	114	1021	304	9968	413	2553	1794	2342
2040	11055	165135	111441	28338	31	115	1034	306	10051	416	2573	1822	2371
2041	11155	166628	112449	28594	32	117	1047	309	10147	420	2596	1849	2402
2042	11256	168135	113466	28852	32	118	1060	312	10243	424	2620	1876	2435
2043	11357	169655	114490	29115	32	120	1074	315	10342	428	2646	1901	2470
2044	11460	171189	115523	29380	33	121	1087	318	10442	432	2672	1925	2507
2045	11564	172737	116567	29647	33	123	1101	321	10543	436	2698	1950	2544
2046	11668	174299	117620	29916	34	124	1115	324	10646	440	2725	1975	2581
2047	11774	175875	118683	30187	34	126	1129	328	10749	445	2751	2001	2619
2048	11880	177465	119756	30460	34	127	1143	331	10853	449	2778	2028	2656
2049	11988	179069	120838	30735	35	129	1158	334	10958	453	2805	2055	2695
2050	12096	180688	121931	31013	35	131	1172	337	11064	458	2832	2083	2733

18 Appendix B: Fuel Type and Regulatory Class Fractions for 1960-1981

As noted in the text, the fuel type and regulatory class distributions in the SampleVehiclePopulation table for model year 1981 and earlier have not changed from MOVES2010b. Those fuel type distributions between 1960 and 1981 for each source type have been summarized in Table 18-1 and Table 18-2. Many of the data sources for the fuel type fractions are the same in MOVES2010b and MOVES2014. Truck diesel fractions in Table 18-1 are derived using a MOVES2010b sample vehicle counts dataset—similar to the MOVES2014 one—but with 1999 Polk vehicle registrations and the 1997 VIUS, except for refuse trucks and motor homes. We assumed 96 percent of refuse trucks were manufactured to run on diesel fuel in 1980 and earlier according to the average diesel fraction from VIUS across all model years. We also assumed that 15 percent of these motor homes are diesel powered based on information from the Recreation Vehicle Industry Association (RVIA), as noted above in Section 6.2.2.5.

Table 18-1 Diesel fractions for truck source types*

	Source Type						
Model Year	**Passenger Trucks (31)**	**Light Commercial Trucks (32)**	**Refuse Trucks (51)**	**Single Unit Trucks (52 & 53)**	**Motor Homes (54)**	**Short-Haul Combination Trucks (61)**	**Long-Haul Combination Trucks (62)**
1960-1979	0.0139	0.0419	0.96	0.2655	0.15	0.9146	1.0000
1980	0.0124	0.1069	0.96	0.2950	0.15	0.9146	1.0000
1981	0.0178	0.0706	0.96	0.3245	0.15	0.9146	1.0000

* All other trucks are assumed to be gasoline powered

As in MOVES2010b, lacking both emission rate and population data, we assume in MOVES2014 that all motorcycles will be gasoline powered, all intercity buses will be diesel powered over all model years, and all transit buses will be run on diesel from 1960 to 1981. School bus fuel type fractions are reused from MOBILE6, originally based on 1996 and 1997 Polk data. Passenger cars are split between gasoline and diesel for 1960-1981 using the MOVES2010b sample vehicle counts dataset.

Table 18-2 Diesel fractions for non-truck source types*

	Source Type				
Model Year	**Motorcycles (11)**	**Passenger Cars (21)**	**Intercity Buses (41)**	**Transit Buses (42)**	**School Buses (43)**
1960-1974	0	0.0069	1.000	1.000	0.0087
1975	0	0.0180	1.000	1.000	0.0087
1976	0	0.0165	1.000	1.000	0.0086
1977	0	0.0129	1.000	1.000	0.0240
1978	0	0.0151	1.000	1.000	0.0291
1979	0	0.0312	1.000	1.000	0.0460
1980	0	0.0467	1.000	1.000	0.0594
1981	0	0.0764	1.000	1.000	0.2639

* All other vehicles are assumed to be gasoline powered

The 1960-1981 regulatory class distributions have been derived from the MOVES2010b sample vehicle counts dataset. Motorcycles (sourceTypeID 11 and regClassID 10) and passenger cars (sourceTypeID 21 and regClassID 20) have one-to-one relationships between source types and regulatory classes for all model years for both MOVES2010b and MOVES2014. Passenger trucks (sourceTypeID 31) and light commercial trucks (sourceTypeID 32) are split between fuel type and regulatory class (regClassID 30 and 40) as shown in Table 18-3.

Table 18-3 Percentage by regulatory class and fuel type for passenger trucks (sourceTypeID 31) and light commercial truck (sourceTypeID 32)

	Passenger Trucks (31)				Light Commercial Trucks (32)			
	Gasoline		Diesel		Gasoline		Diesel	
Model Year	LDT (30)	LHD (40)	LDT (30)	LHD (40)	LDT (30)	LHD (40)	LDT (30)	LHD (40)
1960-1966	81%	19%	38%	62%	24%	76%	7%	93%
1967	90%	10%	38%	62%	72%	28%	7%	93%
1968	88%	12%	38%	62%	67%	33%	7%	93%
1969	100%	0%	38%	62%	91%	9%	7%	93%
1970	99%	1%	38%	62%	80%	20%	7%	93%
1971	96%	3%	38%	62%	94%	6%	7%	93%
1972	96%	4%	38%	62%	75%	25%	7%	93%
1973	95%	5%	38%	62%	59%	41%	7%	93%
1974	95%	5%	38%	62%	65%	35%	7%	93%
1975	97%	3%	38%	62%	72%	28%	7%	93%
1976	95%	5%	38%	62%	88%	12%	7%	93%
1977	89%	11%	38%	62%	79%	21%	7%	93%
1978	85%	15%	38%	62%	81%	19%	7%	93%
1979	87%	13%	38%	62%	78%	22%	7%	93%
1980	90%	10%	38%	62%	74%	26%	40%	60%
1981	96%	4%	38%	62%	89%	11%	12%	88%

The bus and motor home source types each have a single regulatory class distribution for all model years, as described in Section 6. The 1960-1981 regulatory class distributions for diesel-fueled single unit and combination trucks have been summarized in Table 18-4 below. All 1960-1981 gasoline-fueled single unit and combination trucks fall into the medium heavy-duty (MHD) regulatory class (regClassID 46).

Table 18-4 Percentage of MHD trucks (regClassID 46) among diesel-fueled single unit and combination trucks*

	Source Type			
Model Year	**Refuse Trucks (51)**	**Single Unit Trucks (52&53)**	**Short-Haul Comb. Trucks (61)**	**Long-Haul Comb. Trucks (62)**
1960-1972	100%	0%	0%	0%
1973	100%	3%	8%	0%
1974	0%	6%	30%	0%
1975	0%	14%	3%	0%
1976	0%	44%	13%	0%
1977	0%	43%	31%	0%
1978	0%	36%	18%	0%
1979	0%	34%	16%	0%
1980	0%	58%	29%	5%
1981	0%	47%	31%	6%

*For these source types, all remaining trucks are in the HHD regulatory class (regClassID 47).

19 Appendix C: 1990 Age Distributions

19.1 Motorcycles

The motorcycle age distributions are based on Motorcycle Industry Council estimates of the number of motorcycles in use, by model year, in 1990. However, data for individual model years starting from 1978 and earlier were not available. A logarithmic regression curve (R^2 value = 0.82) was fitted to available data, which was then used to extrapolate age fractions for earlier years beginning in 1978.

19.2 Passenger Cars

To determine the 1990 age fractions for passenger cars, we began with Polk NVPP® 1990 data on car registration by model year. However, this data presents a snapshot of registrations on July 1, 1990, and we needed age fractions as of December 31, 1990. To adjust the values, we used monthly data from the Polk new car database to estimate the number of new cars registered in the months July through December 1990. Model Year 1989 cars were added to the previous estimate of "age 1" cars and Model Year 1990 and 1991 cars were added to the "age 0" cars. Also the 1990 data did not detail model year for ages 15+. Hence, regression estimates were used to extrapolate the age fractions for individual ages 15+ based on an exponential curve (R^2 value =0.67) fitted to available data.

19.3 Trucks

For the 1990 age fractions for passenger trucks, light commercial trucks, refuse trucks, short-haul and long-haul single unit trucks and short-haul and long-haul combination trucks, we used data from the TIUS92 (1992 Truck Inventory and Use Survey) database. Vehicles in the TIUS92 database were assigned to MOVES source types as summarized in Table 19-1. Like VIUS97, TIUS92 does not include a model year field and records ages as 0 through 10 and 11-and-greater. Because we needed greater detail on the older vehicles, we followed the practice used for the 1999 fractions and determined the model year for some of the older vehicles by using the responses to the questions "How was the vehicle obtained?" (TIUS field "OBTAIN") and "When did you obtain this vehicle?" (TIUS field "ACQYR") and we adjusted the age-11-and-older vehicle counts by dividing the original count by model year by the fraction of the older vehicles that were coded as "obtained new."

Table 19-1 VIUS1997 codes used for distinguishing truck source types

Source Type	Axle Arrangement	Primary Area of Operation	Body Type	Major Use
Passenger Trucks	2 axle/4 tire (AXLRE= 1,5,6,7)	Any	Any	personal transportation (MAJUSE=20)
Light Commercial Trucks	2 axle/4 tire (AXLRE= 1,5,6,7)	Any	Any	any but personal transportation
Refuse Trucks	Single Unit (AXLRE=2-4, 8-16)	Off-road, local or short-range (AREAOP <=4)	Garbage hauler (BODTYPE=30)	Any
Single Unit Short-Haul Trucks	Single Unit (AXLRE=2-4, 8-16)	Off-road, local or short-range (AREAOP<=4)	Any except garbage hauler	Any
Single Unit Long-Haul Trucks	Single Unit (AXLRE=2-4, 8-16)	Long-range (AREAOP>=5)	Any	Any
Combination Short-Haul Trucks	Combination (AXLRE>=17)	Off-road, local or medium (AREAOP<=4)	Any	Any
Combination Long-Haul Trucks	Combination (AXLRE>=17)	Long-range (AREAOP>=5)	Any	Any

19.4 Intercity Buses

For 1990, we were not able to identify a data source for estimating age distributions of intercity buses. Because the purchase and retirement of these buses is likely to be driven by general economic forces rather than trends in government spending, we will use the1990 age distributions that were derived for short-haul combination trucks, as described above.

19.5 School Buses and Motor Homes

To determine the age fractions of school buses and motor homes, we used information from the Polk TIP® 1999 database. School bus and motor home counts were available by model year. Unlike the Polk data for passenger cars, these counts reflect registration at the end of the calendar year and, thus, did not require adjustment. We converted model year to age and calculated age fractions. Because we did not have access to 1990 data, these fractions were used for 1990.

19.6 Transit Buses

For 1990 Transit Bus age distributions, we used the MOBILE6 age fractions since 1990 data on transit buses was not available from the Federal Transit Administration database. MOBILE6 age fractions were based on fitting curves through a snapshot of vehicle registration data as of July 1, 1996, which was purchased from R.L. Polk Company. To develop a general curve, the 1996 model year vehicle populations were removed from the sample because it did not represent a full year, and a best-fit analysis was performed on the remaining population data. The best-fit analyses resulted in age distribution estimates for vehicles ages 1 through 25+. However, since the vehicle sales year begins in October, the estimated age 1 population was multiplied by 0.75 to account for the fact that approximately 75 percent of the year's sales will have occurred by July 1st of a given calendar year.

Both Weibull curve fitting and exponential curve fitting were used to create the age distributions. The nature of the Weibull curve fitting formula is to produce an "S" shaped curve, which is relatively flat for the first third of the data, decreases rapidly for the next third, and flattens again for the final third. While using this formula resulted in a better overall fit for transit buses, the flatness of the final third for each curve resulted in unrealistically low vehicle populations for the older vehicle ages. For this reason, the original Weibull curve was used where it fit best, and exponential curves were fit through the data at the age where the Weibull curves began to flatten. Table 19-2 presents the equations used to create the age distribution and the years in which the equations were used.

Table 19-2 Curve fit equations for registration distribution data by age

Vehicle Age	Equation
1-17	$y = 3462 * \mathrm{e}^{-\left(\left(\frac{\mathrm{age}}{17.16909475}\right)^{12.53214119}\right)}$
18-25+	$24987.0776 * \mathrm{e}^{-0.2000 * \mathrm{age}}$

20 Appendix D: Detailed Derivation of Age Distributions

20.1 2012-2050 Age Distribution Projections

The base algorithm for forecasting age distributions is as follows:

1. Starting with the base population distribution ($\overrightarrow{P_y}$), remove the number of vehicles that did not survive ($\overrightarrow{R_y}$) at each age level.
2. Increase the population age index by one (for example, 3 year old vehicles are reclassified as 4 year old vehicles).
3. Add new vehicle sales ($\overrightarrow{N_{y+1}}$) as the age 0 cohort.
4. Combine the new age 30 and 31 vehicles into a single age 30 group.
5. This results in the next year population distribution ($\overrightarrow{P_{y+1}}$). If this algorithm is to be repeated, $\overrightarrow{P_{y+1}}$ becomes $\overrightarrow{P_y}$ for the next iteration.

This is mathematically described with the following equation (reprinted from Section 7.1.2.2 for reference):

$$\overrightarrow{P_{y+1}} = \overrightarrow{P_y} - \overrightarrow{R_y} + \overrightarrow{N_{y+1}} \qquad \text{Equation 10}$$

Unfortunately, as described in Section 7.1.2.1, the only survival information we have is a single snapshot. Because vehicle populations and new sales change differentially (for example, the historic populations shown in Section 5.1 level off during the recent recession; at the same time, sales of most vehicle types plummeted), it is important to adjust the survival curve in response to changes in population and sales. We did so by defining a scalar adjustment factor k_y that can be algebraically calculated from population and sales estimates. Its use in determining the population of vehicles removed and its relationship to the generic survival rate $\overrightarrow{S_0}$ is given by Equation 27. Note that the open circle operator ($\circ$) represents entrywise product; that is, each element in an array is multiplied by the corresponding element in the other one, and it results in an array with the same number of elements.

$$\overrightarrow{R_y} = k_y \cdot \left(1 - \overrightarrow{S_0}\right) \circ \overrightarrow{P_y} \qquad \text{Equation 27}$$

Substituting Equation 27 into Equation 10 yields Equation 28:

$$\overrightarrow{P_{y+1}} = \overrightarrow{P_y} - k_y \cdot (1 - \overrightarrow{S_0}) \circ \overrightarrow{P_y} + \overrightarrow{N_{y+1}} \qquad \text{Equation 28}$$

Since both the value of the scalar adjustment factor and the actual distribution of the next year's population are unknown, Equation 28 can't be used yet. However, by using an estimate of next year's total population, it can be transformed into Equation 29:

$$P_{y+1} = P_y - k_y \sum\nolimits_a \left(\left(1 - \overrightarrow{S_0}\right) \circ \overrightarrow{P_y}\right) + N_{y+1} \qquad \text{Equation 29}$$

This was algebraically solved for k_y and evaluated for each HPMS category[1] using the following information:

- Total populations P_y and $P_{\square+1}$ by HPMS category. For analysis year 2011, this information is described source type in Section 5.1 and simply needs to be summed by HPMS category for use here. For years 2012+, this information is described in Section 5.2
- Survival $\overrightarrow{S_0}$ by HPMS category, which is described in Section 7.1.2.1.
- Population distribution $\overrightarrow{P_y}$ by HPMS category. For analysis year 2011, this information came from combining the total populations described in Section 5.1 with the age distributions described in Section 7.1.1.2 and summing by HPMS category. For years 2012+, this comes from $\overrightarrow{P_{y+1}}$ of the previous year.
- New vehicle sales N_{y+1} by HPMS category, which are derived from AEO2014. The projection of sales was calculated as a percentage of the total population using the vehicle category mapping discussed in Section 4.2; this is converted to the number of new vehicles by multiplying by the HPMS category population.

After determining k_y by HPMS category, Equation 28 was used with the following information to compute the next year's population and then age distribution by source type:

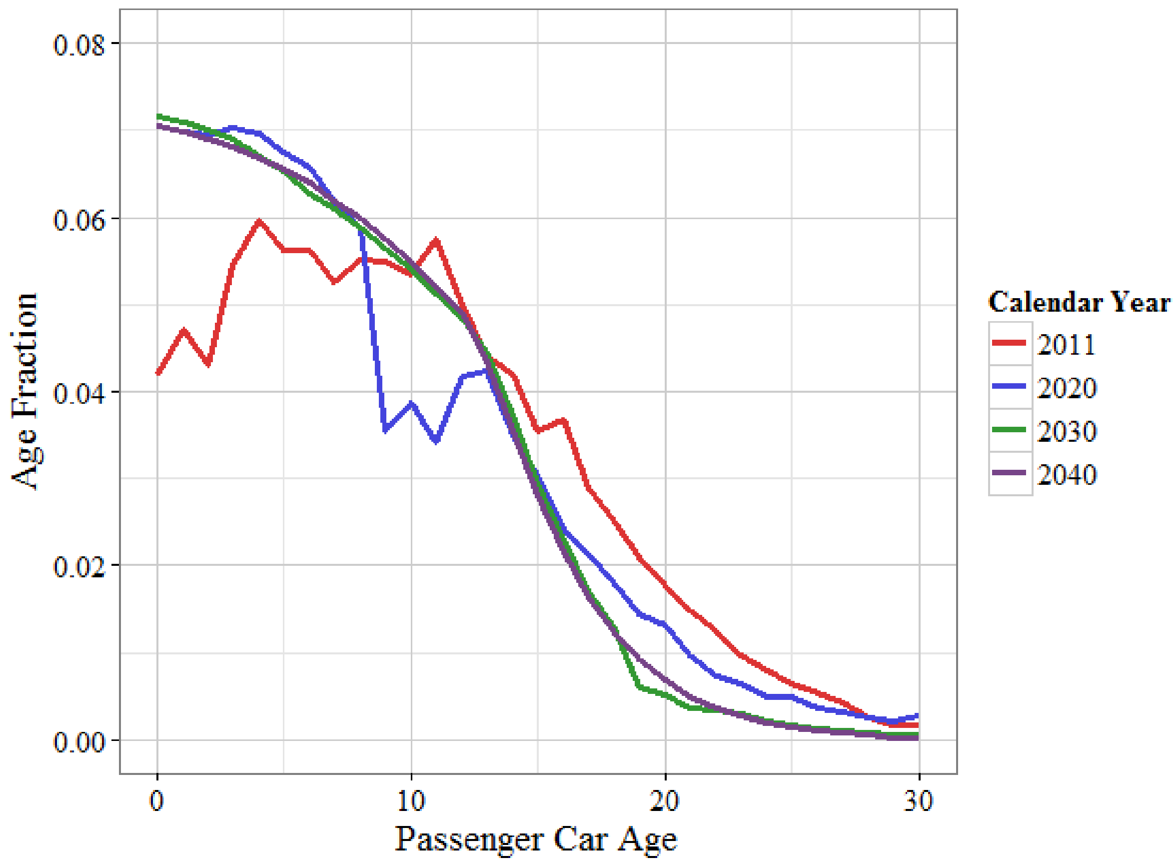
- Population distribution $\overrightarrow{P_y}$ by source type. For analysis year 2011, this information came from combining the total populations described in Section 5.1 with the age distributions described in Section 7.1.1.2. For years 2012+, this comes from $\overrightarrow{P_{y+1}}$ of the previous year.
- The scalar adjustment factor k_y and generic survival rate $\overrightarrow{S_0}$ applied by source type using the HPMS to source type mapping described by Table 2-1. Please note that limits were placed on the $k_y(1-\overrightarrow{S_0})$ term of Equation 28: the value of this term for each age was restricted to being between 0 and 1.
- New vehicle sales $\overrightarrow{N_{y+1}}$ determined as a percentage of the total population in AEO2014 as discussed above; this is converted to the number of new vehicles by multiplying by the total source type population.

With all of this information, the population distributions were algorithmically determined for years 2012-2050. The resulting total source type populations (P_y) are stored in the SourceTypeYear table of the default database. The resulting age distributions are stored in the SourceTypeAgeDistribution table. An illustration of passenger car age distributions is presented in Figure 20-1. For clarity, only four years are shown: 2011, 2020, 2030, and 2040. The effects

[1] Because vehicle survival rates use the categories of motorcycles, passenger cars, light-duty trucks, buses, single unit trucks, and combination trucks, these were the categories used for determining the scalar adjustment factor. Since these are essentially the HPMS categories used by MOVES with the additional subcategories of passenger car and light-duty trucks, the term "HPMS category" is used here for simplicity.

of the 2008-2009 recession are visible in the 0-3 year old cars in the 2011 age distribution. By 2020, the recession dip is moved to the 9-11 year old cars as expected.

Figure 20-1 Selected age distributions for passenger cars in MOVES2014



20.2 1999-2010 Age Distributions

The base algorithm for forecasting age distributions is as follows:

1. Starting with the base population distribution ($\overrightarrow{P_y}$), remove the age 0 vehicles ($\overrightarrow{N_y}$).
2. Decrease the population age index by one (for example, 3 year old vehicles are reclassified as 2 year old vehicles).
3. Add the vehicles that were removed in the previous year ($\overrightarrow{R_{y-1}}$).
4. This results in the previous year population distribution ($\overrightarrow{P_{y-1}}$). If this algorithm is to be repeated, $\overrightarrow{P_{y-1}}$ becomes $\overrightarrow{P_y}$ for the next iteration.

This is mathematically described with the following equation (reprinted from Section 7.1.2.3 for reference):

$$\overrightarrow{P_{y-1}} = \overrightarrow{P_y} - \overrightarrow{N_y} + \overrightarrow{R_{y-1}} \qquad \text{Equation 30}$$

However, without detailed historical data for every year, we needed to estimate vehicle removals. The equation governing vehicle removal discussed the previous section is also applicable here. Taking careful note of the subscripts, Equation 27 and Equation 30 can be combined into Equation 31:

$$\overrightarrow{P_{y-1}} = \overrightarrow{P_y} - \overrightarrow{N_y} + k_{y-1} \cdot \left(1 - \overrightarrow{S_0}\right) \circ \overrightarrow{P_{y-1}} \qquad \text{Equation 31}$$

As in the forecasting situation, the value of the scalar adjustment factor and the actual distribution of the previous year's population are unknown. With a similar strategy of using the previous year's known total population, Equation 31 can be transformed into Equation 32:

$$P_{y-1} = P_y - N_y + k_{y-1} \sum_a \left(\left(1 - \overrightarrow{S_0}\right) \circ \overrightarrow{P_{y-1}}\right) \qquad \text{Equation 32}$$

However, this still leaves a $\overrightarrow{P_{y-1}}$ term, which is unavoidable because the total number of vehicles removed is dependent on the age distribution of those vehicles. To properly solve Equation 32 for k_{y-1} and $\overrightarrow{P_{y-1}}$, a numerical method of approximation could be employed. However, due to lack of resources, $\overrightarrow{P_y}$ was used as a simple approximation of $\overrightarrow{P_{y-1}}$ on the left hand side of Equation 32. The following sources were used to determine k_{y-1} by HPMS category:

- Total populations P_y and P_{y-1} by HPMS category. For all historic analysis years, this information is described source type in Section 5.1 and simply needs to be summed by HPMS category across all ages for use here.
- Survival $\overrightarrow{S_0}$ by HPMS category, which is described in Section 7.1.2.1.
- Population distribution $\overrightarrow{P_y}$ by HPMS category. For analysis year 2011, this information came from combining the total populations described in Section 5.1 with the age distributions described in Section 7.1.1.2 and summing by HPMS category. For other years, this comes from $\overrightarrow{P_{y-1}}$ of the previous iteration.
- New vehicle sales N_{y+1} data, which was collected by source type from a variety of sources. Each of these was summed by HPMS category. Motorcycles sales comes from the Motorcycle Industry Council; sales data for passenger cars, passenger trucks, light commercial trucks, refuse trucks, short-haul and long-haul single unit trucks, and short-haul and long-haul combination trucks comes from TEDB and VIUS; transit buses production estimates are based on EPA certification data; and school bus sales came from the *School Bus Fleet Fact Book*. No sales data were available for intercity buses, so the other bus categories were used as a surrogate. That is, the total transit bus production and school bus sales as a percentage of the transit and school bus populations in each year were applied to the intercity bus populations to estimate their sales. Similarly, no sales data were available for motor homes, so a sales fraction was estimated by averaging the sales of refuse, short-haul, and long-haul single unit trucks as a fraction of their total population.

After determining k_{y-1} by HPMS category, Equation 31 was used with the following information to compute the previous year's age distribution by source type:

- Population distribution $\overrightarrow{P_y}$ by source type. For analysis year 2011, this information came from combining the total populations described in Section 5.1 with the age distributions described in Section 7.1.1.2. For other years, this comes from $\overrightarrow{P_{y-1}}$ of the previous iteration.
- The scalar adjustment factor k_{y-1} and generic survival rate $\overrightarrow{S_0}$ applied by source type using the HPMS to source type mapping described by Table 2-1. As with before, limits were placed on the $k_y(1-\overrightarrow{S_0})$ term, such that the value of this term for each age was restricted to being between 0 and 1. Also, the $\overrightarrow{P_{y-1}}$ term used when calculating the number of vehicles removed was approximated by $\overrightarrow{P_y}$.
- New vehicle sales $\overrightarrow{N_{y+1}}$, from the sources listed above and applied by source type.

With all of this information, the population distributions were algorithmically determined for years 1999-2010. The resulting age distributions are stored in the SourceTypeAgeDistribution table.

21 Appendix E: SCC Mappings

21.1 SCC Mappings between MOVES2014 and MOVES2010b

The SCC values used in MOVES2010b and earlier versions of MOVES and MOBILE do not have a one-to-one correspondence with the MOVES2014 SCC values. This makes it difficult to compare results from MOVES2014 to those from earlier models. While MOVES2014 allows output by fuel type and regulatory class (which were the primary identifiers for the earlier SCCs), there are complications that prevent developing a simple mapping from the old to the new. The most important complication is that the distribution of regulatory classes and fuel types for each source type varies by model year, while typical inventories aggregate across model years. This means any mapping would have to vary with calendar year and with user vehicle population inputs. In addition, regulatory class groupings for light and light heavy-duty trucks do not line up exactly with the GVWR groupings used in the earlier SCCs. Table 21-1 below compares MOVES2014 classification by fuel type and regulatory class to the older SCCs.

Table 21-1 Comparison of MOVES2014 Fuel Types and Regulatory Classes to MOVES2010b Source Classification Code (SCC) Vehicle Classes

Fuel Type	MOVES2014 Regulatory Class (RegClassID)	MOVES2010b Source Classification Code (SCC)
Gasoline	Motorcycles (10)	Motorcycles (01080)
	Passenger Cars (20)	Passenger Cars (01001)
	Light-Duty Trucks (0-8500 lbs GVWR) (30)	Light-Duty Trucks (0-6000 lbs GVWR) (01020)
		Light-Duty Trucks (6001-8500 lbs GVWR) (01040)
	Heavy-Duty Trucks and Buses (40, 41, 42, 46 & 47)	Heavy-Duty Trucks and Buses (01070)
Diesel	Passenger Cars (20)	Passenger Cars (30001)
	Light-Duty Trucks (30)	Light-Duty Trucks (30060)
	Heavy-Duty Vehicles 2b (8501-10000 lbs GVWR) with four tires (40)	Heavy Duty Vehicles 2b (8501-10000 lbs GVWR) (30071)
	Heavy-Duty Vehicles 2b with 6 tires or more (8501-10000 lbs GVWR)	Light Heavy-duty Vehicles (10001-19500 lbs GVWR) (30072)
	Heavy-duty Vehicles (10001-14000 lbs GVWR) (41)	
	Heavy-duty Vehicles (14001-19500 lbs GVWR) (42)	
	Medium Heavy-Duty Vehicles (19501-33000 lbs GVWR) (46)	Medium Heavy-Duty Vehicles (19501-33000 lbs GVWR) (30073)
	Heavy Heavy-Duty Vehicles (33001+ lbs GVWR) (47)	Heavy Heavy-Duty Vehicles (33001+ lbs GVWR) (30074)
	Transit Buses (48)	Diesel Buses (30075)

21.2 2011 SCC VMT Conversions

The source classification code (SCC) used before MOVES2014 do not cleanly map to the source types used by MOVES. In the 10-digit SCC, the first seven digits (SCC7) indicate the vehicle classification. The SCC vehicle classifications were mapped to the source types used by MOVES by calculating the fraction VMT for each source type found in each SCC classification result in a national MOVES2010b run for calendar year 2011. The factors calculated from the MOVES2010b run are shown in Table 21-2.

Table 21-2 Mapping of previous SCC vehicle classifications to MOVES source types for calculation of road type distributions

SCC (7 digits)	Description	Source Type	Description	2011 Fractions
2201001	Gasoline Light-Duty Vehicles (Passenger Cars)	21	Passenger Car	1.000000
2201020	Gasoline Light-Duty Trucks (0-6,000 lbs. GVWR)	31	Passenger Truck	0.779270
2201020	Gasoline Light-Duty Trucks (0-6,000 lbs. GVWR)	32	Light Commercial Truck	0.220730
2201040	Gasoline Light-Duty Trucks (6,001-8,500 lbs. GVWR)	31	Passenger Truck	0.779269
2201040	Gasoline Light-Duty Trucks (6,001-8,500 lbs. GVWR)	32	Light Commercial Truck	0.220731
2201070	Gasoline Heavy-Duty Gasoline Vehicles (8501 lbs. and greater GVWR)	31	Passenger Truck	0.450274
2201070	Gasoline Heavy-Duty Gasoline Vehicles (8501 lbs. and greater GVWR)	32	Light Commercial Truck	0.267803
2201070	Gasoline Heavy-Duty Gasoline Vehicles (8501 lbs. and greater GVWR)	42	Transit Bus	0.000664
2201070	Gasoline Heavy-Duty Gasoline Vehicles (8501 lbs. and greater GVWR)	43	School Bus	0.002476
2201070	Gasoline Heavy-Duty Gasoline Vehicles (8501 lbs. and greater GVWR)	51	Refuse Truck	0.000509
2201070	Gasoline Heavy-Duty Gasoline Vehicles (8501 lbs. and greater GVWR)	52	Single Unit Short-Haul Truck	0.221958
2201070	Gasoline Heavy-Duty Gasoline Vehicles (8501 lbs. and greater GVWR)	53	Single Unit Long-Haul Truck	0.030154
2201070	Gasoline Heavy-Duty Gasoline Vehicles (8501 lbs. and greater GVWR)	54	Motor Home	0.025802
2201070	Gasoline Heavy-Duty Gasoline Vehicles (8501 lbs. and greater GVWR)	61	Combination Short-Haul Truck	0.000359
2201080	Gasoline Motorcycles	11	Motorcycle	1.000000
2230001	Diesel Light-Duty Vehicles (Passenger Cars)	21	Passenger Car	1.000000
2230060	Diesel Light-Duty Trucks (0-8,500 lbs. GVWR)	31	Passenger Truck	0.343599
2230060	Diesel Light-Duty Trucks (0-8,500 lbs. GVWR)	32	Light Commercial Truck	0.656401
2230071	Diesel Class 2b Heavy-Duty Vehicles (8501-10,000 lbs. GVWR)	31	Passenger Truck	0.364691
2230071	Diesel Class 2b Heavy-Duty Vehicles (8501-10,000 lbs. GVWR)	32	Light Commercial Truck	0.635309
2230072	Diesel Class 3, 4 & 5 Heavy-Duty Vehicles (10,001-19,500 lbs. GVWR)	31	Passenger Truck	0.305092
2230072	Diesel Class 3, 4 & 5 Heavy-Duty Vehicles (10,001-19,500 lbs. GVWR)	32	Light Commercial Truck	0.694908
2230073	Diesel Class 6 & 7 Heavy-Duty Vehicles (19,501-33,000 lbs. GVWR)	51	Refuse Truck	0.001726
2230073	Diesel Class 6 & 7 Heavy-Duty Vehicles (19,501-33,000 lbs. GVWR)	52	Single Unit Short-Haul Truck	0.623978
2230073	Diesel Class 6 & 7 Heavy-Duty Vehicles (19,501-33,000 lbs. GVWR)	53	Single Unit Long-Haul Truck	0.086570
2230073	Diesel Class 6 & 7 Heavy-Duty Vehicles (19,501-33,000 lbs. GVWR)	54	Motor Home	0.025294
2230073	Diesel Class 6 & 7 Heavy-Duty Vehicles (19,501-33,000 lbs. GVWR)	61	Combination Short-Haul Truck	0.194650

SCC (7 digits)	Description	Source Type	Description	2011 Fractions
2230073	Diesel Class 6 & 7 Heavy-Duty Vehicles (19,501-33,000 lbs. GVWR)	62	Combination Long-Haul Truck	0.067783
2230074	Diesel Class 8a & 8b Heavy-Duty Vehicles (33,001 lbs. and greater GVWR)	51	Refuse Truck	0.008531
2230074	Diesel Class 8a & 8b Heavy-Duty Vehicles (33,001 lbs. and greater GVWR)	52	Single Unit Short-Haul Truck	0.100296
2230074	Diesel Class 8a & 8b Heavy-Duty Vehicles (33,001 lbs. and greater GVWR)	53	Single Unit Long-Haul Truck	0.013800
2230074	Diesel Class 8a & 8b Heavy-Duty Vehicles (33,001 lbs. and greater GVWR)	54	Motor Home	0.000328
2230074	Diesel Class 8a & 8b Heavy-Duty Vehicles (33,001 lbs. and greater GVWR)	61	Combination Short-Haul Truck	0.323425
2230074	Diesel Class 8a & 8b Heavy-Duty Vehicles (33,001 lbs. and greater GVWR)	62	Combination Long-Haul Truck	0.553619
2230075	Diesel Buses	41	Intercity Bus	0.430859
2230075	Diesel Buses	42	Transit Bus	0.122565
2230075	Diesel Buses	43	School Bus	0.446576

22 Appendix F: Calculation of Combination Truck Average Speed Distributions

The average speed for each roadway type, day type, and hour can be calculated by multiplying the average speed of each bin by the corresponding distribution of time as shown in Equation 33. Here, $\bar{v}$ is the average speed of the distribution, v_i is the average speed of bin i, and ρ_i is the proportion of time spent in bin i.

$$\bar{v} = \sum v_i \cdot \rho_i$$
$$= 2.5 \cdot \rho_1 + 5 \cdot \rho_2 + \cdots + 70 \cdot \rho_{15} + 75 \cdot \rho_{16}$$

Equation 33

To adjust the average speed for heavy-duty combination trucks, we redistributed the proportion of time spent in each speed bin such that its contribution to the average speed was 92 percent of the light-duty speed, as shown in Equation 18. This redistributed proportion of time in each speed bin is given by ρ_i'.

$$\bar{v}_{\text{combination}} = (0.92)\, \bar{v}_{\text{light-duty}}$$
$$= \sum v_i \cdot \rho_i'$$

Equation 34

To perform this redistribution, we defined two new variables, α and β, where α_i is the fraction of ρ_i that is shifted down one speed bin, and β_i is the fraction of ρ_i shifted down two speed bins. The new distribution at speed bin i (given by ρ_i') starts with the original distribution (ρ_i), gains the proportions moved down from the higher speed bins ($\alpha_{i+1} \cdot \rho_{i+1}$ and $\beta_{i+2} \cdot \rho_{i+2}$), and loses the proportion that is moved to a lower speed bin ($\alpha_i \cdot \rho_i$ and $\beta_i \cdot \rho_i$). This is shown in Equation 35:

$$\rho_i' = \rho_i + (\alpha_{i+1} \cdot \rho_{i+1}) + (\beta_{i+2} \cdot \rho_{i+2}) - (\alpha_i \cdot \rho_i) - (\beta_i \cdot \rho_i)$$

Equation 35

For speed bins with an average speed of less than or equal to 60 mph, we only needed to shift distributions using a fraction of one speed bin (or 5 mph). Thus we only calculated α_i and set $\beta_i = 0$. Mathematically, reducing a bin's average speed by a certain fraction (η) can be expressed with Equation 36:

$$(1 - \eta) \cdot v_i = \alpha_i \cdot (v_i - 5) + (1 - \alpha_i) \cdot v_i$$

Equation 36

Essentially, the fraction that is moved to the next slower bin (α_i) is multiplied by the slower speed (note that each of the speed bins are 5 mph apart, so this is $v_i - 5$), and the fraction that remains $(1 - \alpha_i)$ is multiplied by the original speed v_i. Since the average speed of the combination trucks is 92 percent of cars, $(1 - \eta) = 92\%$ and $\eta = 0.08$.

By rearranging terms from Equation 20, and solving for α_i we obtain Equation 37:

$$\alpha_i = \frac{v_i \cdot \eta}{5} \qquad \text{Equation 37}$$

However, for speed bins ≥ 65 mph, Equation 37 yields α_i greater than 1. Since that logically can't happen, some of the distribution needed to be moved to the second next slower speed bin to fully account for the 8 percent speed reduction. This is mathematically shown in Equation 38, which is the logical extension of Equation 36:

$$(1 - \eta) \cdot v_i = \beta_i \cdot (v_i - 10) + \alpha_i \cdot (v_i - 5) + (1 - \alpha_i - \beta_i) \cdot v_i \qquad \text{Equation 38}$$

The difference between Equation 36 and Equation 38 is that an additional fraction (β_i) is removed from the original speed bin and is given the speed of two speed bins slower (or 10 mph slower). With this additional factor, there is an infinite combination of solutions that could satisfy Equation 38. We solved this problem with a linear equation solver by setting Equation 38 to a constraint (see Equation 39), adding the constraint that $\alpha_i + \beta_i$ are less than or equal to 1 (see Equation 40), and choosing the solution that minimized β_i.

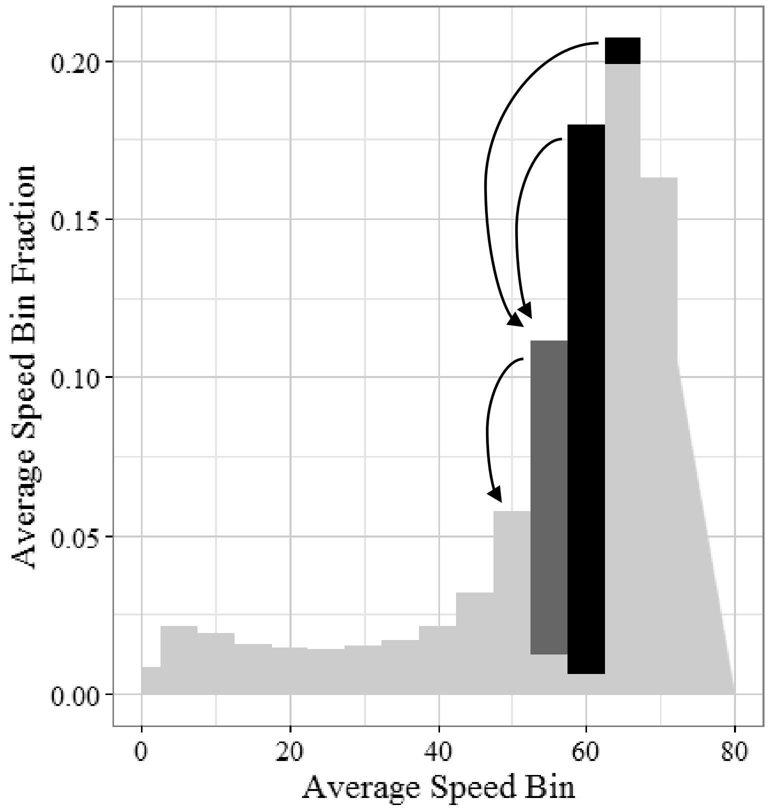
$$\alpha_i \cdot (v_i - 5) + \beta_i \cdot (v_i - 10) + v_i \cdot (\eta - \alpha_i - \beta_i) = 0 \qquad \text{Equation 39}$$

$$\alpha_i + \beta_i \leq 1 \qquad \text{Equation 40}$$

This linear program was used to solve for α_i and β_i for each speed bin between 65 and 75 mph. With α_i and β_i known for each bin, the new distributions ρ_i' were calculated.

An additional adjustment was made for the highest speed bins because we assumed that the maximum speed bin had a triangular distribution with an average speed of 75 mph, see Figure 22-1. In the figure, the original speed distribution is shown in light gray. The darker gray is the proportion of speed bin 55 that is moved out to the slower speed bin 50 mph, and the black areas are the distributions from speed bin 60 and 65 that are moved in to speed bin 55 mph.

Figure 22-1 An illustration of adjustments made to the average speed bin 55 mph for heavy-duty vehicles



In the new distribution, all of the maximum speed bin fraction was redistributed to the 65 and 70 mph bins. Therefore, the new maximum speed bin (70 mph) was also assumed to have a triangular distribution. Geometrically, 1/9th of a triangular distribution averaging 70 mph is faster than 72.5 mph. Since the 75 mph speed bin is defined as any speed ≥72.5 mph, 1/9th of the new 70 mph fraction (ρ'_{15}) was reclassified as the new fraction for the 75 mph bin.

This process was repeated for both short- and long-haul combination trucks on restricted access road types for every hour and day type combination.

23 Appendix G: Driving Schedules

A key feature of MOVES is the capability to accommodate a number of drive schedules to represent driving patterns across source type, roadway type and average speed. For the national default case, MOVES2014 employs 49 drive schedules with various average speeds, mapped to specific source types and roadway types.

Table 23-1 below lists the driving schedules used in MOVES2014. Some driving schedules are used for both restricted access (freeway) and unrestricted access (non-freeway) driving. Some driving schedules are used for multiple source types or multiple road types where vehicle specific information was not available.

Table 23-1 MOVES2014 default driving schedule statistics

drive schedule id	drive schedule name	avg speed	max speed	idle time (sec)	percent of time idling	miles	time (sec)	minutes	hours
101	LD Low Speed 1	2.5	10.00	280	46.5%	0.419	602.00	10.03	0.167
153	LD LOS E Freeway	30.5	63.00	5	1.1%	3.863	456.00	7.60	0.127
158	LD High Speed Freeway 3	76.0	90.00	0	0.0%	12.264	581.00	9.68	0.161
201	MD 5mph Non-Freeway	4.6	24.10	85	29.0%	0.373	293.00	4.88	0.081
202	MD 10mph Non-Freeway	10.7	34.10	61	19.6%	0.928	311.00	5.18	0.086
203	MD 15mph Non-Freeway	15.6	36.60	57	12.6%	1.973	454.00	7.57	0.126
204	MD 20mph Non-Freeway	20.8	44.50	95	9.1%	6.054	1046.00	17.43	0.291
205	MD 25mph Non-Freeway	24.5	47.50	63	11.1%	3.846	566.00	9.43	0.157
206	MD 30mph Non-Freeway	31.5	55.90	54	5.5%	8.644	988.00	16.47	0.274
251	MD 30mph Freeway	34.4	62.60	0	0.0%	15.633	1637.00	27.28	0.455
252	MD 40mph Freeway	44.5	70.40	0	0.0%	43.329	3504.00	58.40	0.973
253	MD 50mph Freeway	55.4	72.20	0	0.0%	41.848	2718.00	45.30	0.755
254	MD 60mph Freeway	60.1	68.40	0	0.0%	81.299	4866.00	81.10	1.352
255	MD High Speed Freeway	72.8	80.40	0	0.0%	96.721	4782.00	79.70	1.328
301	HD 5mph Non-Freeway	5.8	19.90	37	14.2%	0.419	260.00	4.33	0.072
302	HD 10mph Non-Freeway	11.2	29.20	70	11.5%	1.892	608.00	10.13	0.169
303	HD 15mph Non-Freeway	15.6	38.30	73	12.9%	2.463	567.00	9.45	0.158
304	HD 20mph Non-Freeway	19.4	44.20	84	15.1%	3.012	558.00	9.30	0.155
305	HD 25mph Non-Freeway	25.6	50.70	57	5.8%	6.996	983.00	16.38	0.273
306	HD 30mph Non-Freeway	32.5	58.00	43	5.3%	7.296	809.00	13.48	0.225
351	HD 30mph Freeway	34.3	62.70	0	0.0%	21.659	2276.00	37.93	0.632
352	HD 40mph Freeway	47.1	65.00	0	0.0%	41.845	3197.00	53.28	0.888
353	HD 50mph Freeway	54.2	68.00	0	0.0%	80.268	5333.00	88.88	1.481
354	HD 60mph Freeway	59.7	69.00	0	0.0%	29.708	1792.00	29.87	0.498
355	HD High Speed Freeway	71.7	81.00	0	0.0%	35.681	1792.00	29.87	0.498
396	HD High Speed Freeway Plus 5 mph	76.7	86.00	0	0.0%	38.170	1792.00	29.87	0.498
397	MD High Speed Freeway Plus 5 mph	77.8	85.40	0	0.0%	103.363	4782.00	79.70	1.328

Table 23-1 MOVES2014 default driving schedule statistics

drive schedule id	drive schedule name	avg speed	max speed	idle time (sec)	percent of time idling	miles	time (sec)	minutes	hours
398	CRC E55 HHDDT Creep	1.8	8.24	107	42.3%	0.124	253.00	4.22	0.070
401	Bus Low Speed Urban (nominal 15 mph)	3.1	19.80	288	63.9%	0.393	451.00	7.52	0.125
402	Bus 30 mph Flow (nominal 30 mph)	11.5	33.80	109	37.5%	0.932	291.00	4.85	0.081
403	Bus 45 mph Flow (nominal 45 mph)	21.9	47.00	116	28.3%	2.492	410.00	6.83	0.114
404	New York City Bus	3.7	30.80	403	67.2%	0.615	600.00	10.00	0.167
405	WMATA Transit Bus	8.3	47.50	706	38.4%	4.261	1840.00	30.67	0.511
501	Refuse Truck Urban	2.2	20.00	416	66.9%	0.374	622.00	10.37	0.173
1009	Final FC01LOSAF Cycle (C10R04-00854)	73.8	84.43	0	0.0%	11.664	569.00	9.48	0.158
1011	Final FC02LOSDF Cycle (C10R05-00513)	49.1	73.06	34	5.0%	9.283	681.00	11.35	0.189
1017	Final FC11LOSB Cycle (C10R02-00546)	66.4	81.84	0	0.0%	9.567	519.00	8.65	0.144
1018	Final FC11LOSC Cycle (C15R09-00849)	64.4	78.19	0	0.0%	16.189	905.00	15.08	0.251
1019	Final FC11LOSD Cycle (C15R10-00068)	58.8	76.78	0	0.0%	11.922	730.00	12.17	0.203
1020	Final FC11LOSE Cycle (C15R11-00851)	46.1	71.50	1	0.1%	12.468	973.00	16.22	0.270
1021	Final FC11LOSF Cycle (C15R01-00876)	20.6	55.48	23	2.5%	5.179	905.00	15.08	0.251
1024	Final FC12LOSC Cycle (C15R04-00582)	63.7	79.39	0	0.0%	15.685	887.00	14.78	0.246
1025	Final FC12LOSD Cycle (C15R09-00037)	52.8	73.15	12	1.5%	11.754	801.00	13.35	0.223
1026	Final FC12LOSE Cycle (C15R10-00782)	43.3	70.87	0	0.0%	10.973	913.00	15.22	0.254
1029	Final FC14LOSB Cycle (C15R07-00177)	31.0	63.81	27	3.6%	6.498	754.00	12.57	0.209
1030	Final FC14LOSC Cycle (C10R04-00104)	25.4	53.09	41	8.0%	3.617	513.00	8.55	0.143
1033	Final FC14LOSF Cycle (C15R05-00424)	8.7	44.16	326	38.2%	2.066	853.00	14.22	0.237
1041	Final FC17LOSD Cycle (C15R05-00480)	18.6	50.33	114	16.1%	3.659	709.00	11.82	0.197
1043	Final FC19LOSAC Cycle (C15R08-00267)	15.7	37.95	67	7.7%	3.802	870.00	14.50	0.242

24 Appendix H: MOVES2010b Source Masses

Light-duty source masses were unchanged from MOVES2010b. In addition, the heavy-duty source masses originally come from MOVES2010b, although they have been updated as described in Section 14.1.

In MOVES2010b, weight data (among other kinds of information) were used to allocate source types to source bins using a field called weightClassID. As described in Equation 41, each source type's source mass was calculated using an activity-weighted average of their associated source bins' midpoint weights:

$$M = \frac{\sum_a \left\{ f_a \cdot \left(\frac{\sum_b \alpha_b \cdot m}{\sum_b \alpha_b} \right) \right\}}{\sum_a f_a} \qquad \text{Equation 41}$$

where M is the source mass factor for the source type, f_a is the age fraction at age a, α_b is the source bin activity fraction for source bin b, and m is the vehicle midpoint mass. Table 24-1 lists the vehicle midpoint mass for each weightClassID. The source bin activity fraction in MOVES2010b is a calculated value of activity based on fuel type, engine technology, regulatory class, model year, engine size, and weight class. This calculation is outside the scope of this document, but more information can be found in the MOVES2010b SDRM.

Table 24-1 MOVES weight classes

WeightClassID	Weight Class Name	Midpoint Weight
0	Doesn't Matter	[NULL]
20	weight < 2000 pounds	1000
25	2000 pounds <= weight < 2500 pounds	2250
30	2500 pounds <= weight < 3000 pounds	2750
35	3000 pounds <= weight < 3500 pounds	3250
40	3500 pounds <= weight < 4000 pounds	3750
45	4000 pounds <= weight < 4500 pounds	4250
50	4500 pounds <= weight < 5000 pounds	4750
60	5000 pounds <= weight < 6000 pounds	5500
70	6000 pounds <= weight < 7000 pounds	6500
80	7000 pounds <= weight < 8000 pounds	7500
90	8000 pounds <= weight < 9000 pounds	8500
100	9000 pounds <= weight < 10000 pounds	9500
140	10000 pounds <= weight < 14000 pounds	12000
160	14000 pounds <= weight < 16000 pounds	15000
195	16000 pounds <= weight < 19500 pounds	17750
260	19500 pounds <= weight < 26000 pounds	22750
330	26000 pounds <= weight < 33000 pounds	29500
400	33000 pounds <= weight < 40000 pounds	36500
500	40000 pounds <= weight < 50000 pounds	45000
600	50000 pounds <= weight < 60000 pounds	55000
800	60000 pounds <= weight < 80000 pounds	70000
1000	80000 pounds <= weight < 100000 pounds	90000
1300	100000 pounds <= weight < 130000 pounds	115000
9999	130000 pounds <= weight	130000
5	weight < 500 pounds (for MCs)	350
7	500 pounds <= weight < 700 pounds (for MCs)	600
9	700 pounds <= weight (for MCs)	700

The following sections detail how weight classes were assigned to the various source types in MOVES.

24.1 Motorcycles

The Motorcycle Industry Council "Statistical Annual" provides information on displacement distributions for highway motorcycles for model years 1990 and 1998. These were mapped to MOVES engine displacement categories. Additional EPA certification data was used to establish displacement distributions for model year 2000. We assumed that displacement distributions were the same in 1969 as in 1990, and interpolated between the established values to determine displacement distributions for all model years from 1990 to 1997 and for 1999. Values for 2000-and-later model years are based on model year 2000 certification data.

We then applied weight distributions for each displacement category as suggested by EPA motorcycle experts. The average weight estimate includes fuel and rider. The weight distributions depended on engine displacement but were otherwise independent of model year. This information is summarized in Table 24-2.

Table 24-2 Motorcycle engine size and average weight distributions for selected model years

Displacement Category	1969 MY distribution (assumed)	1990 MY distribution (MIC)	1998 MY distribution (MIC)	2000 MY distribution (certification data)	Weight distribution (EPA staff)
0-169 cc (1)	0.118	0.118	0.042	0.029	100%: <= 500 lbs
170-279 cc (2)	0.09	0.09	0.05	0.043	50%: <= 500 lbs 50%: 500lbs -700lbs
280+ cc (9)	0.792	0.792	0.908	0.928	30%: 500 lbs-700 lbs 70%: > 700lbs

24.2 Passenger Cars

Passenger car weights come from Polk. The weightClassID was assigned by adding 300 lbs to the Polk curb weight and grouping into MOVES weight bins. For each fuel type, model year, engine size, and weight bin, the number of cars was summed and fractions were computed. In general, entries for which data was missing were omitted from the calculations. Also, analysis indicated a likely error in the Polk data (an entry for 1997 gasoline-powered Bentleys with engine size 5099 and weight class 20). This fraction was removed and the 1997 values were renormalized. 1999 model year values were used for all 2000-and-later model years.

24.3 General Trucks

24.3.1 Light-Duty Trucks

Determining weight categories for light trucks was fairly complicated. The VIUS1997 data combines information from two different survey forms. The first form was administered for VIUS "Strata" 1 and 2 trucks: pickup trucks, panel trucks, vans (including mini-vans), utility type vehicles (including jeeps) and station wagons on truck chassis. The second form was administered for all other trucks. While both surveys requested information on engine size, only the second form requested detailed information on vehicle weight. Thus for Strata 1 and 2 trucks, VIUS classifies the trucks only by broad average weight category (AVGCK): 6,000 lbs or less, 6,001-10,000 lbs, 10,001-14,000lbs, etc. To determine a more detailed average engine size and weight distribution for these vehicles, we used an Oak Ridge National Laboratory (ORNL) light-duty vehicle database, compiled from EPA test vehicle data and Ward's Automotive Inc.[84] data, to correlate engine size with vehicle weight distributions by model year.

In particular, for source types 31 and 32 (Passenger Trucks and Light Commercial Trucks):

- VIUS1997 trucks of the source type in Strata 3, 4, and 5 were assigned to the appropriate MOVES weight class based on VIUS detailed average weight information.
- VIUS1997 trucks of the source type in Strata 1 and 2 were identified by engine size and broad average weight category.
- Strata 1 and 2 trucks in the heavier (10,001-14,000 lbs, etc) VIUS1997 broad categories were matched one-to-one with the MOVES weight classes.
- For trucks in the lower broad categories (6,000 lbs or less and 6001-10,000 lbs), we used VIUS1997 to determine the fraction of trucks by model year and fuel type that fell into each engine size/broad weight class combination (the "VIUS fraction").

- We assigned trucks in the ORNL light-duty vehicle database to a weightClassID by adding 300lbs to the recorded curb weight and determining the appropriate MOVES weight class.
- For the trucks with a VIUS1997 average weight of 6,000 lbs or less, we multiplied the VIUS1997 fraction by the fraction of trucks with a given weightClassID among the trucks in the ORNL database that had the given engine size and an average weight of 6,000 lbs or less. Note, the ORNL database did not provide information on fuel type, so the same distributions were used for all fuels.
- Because the ORNL database included only vehicles with a GVW up to 8500 lbs, we did not use it to distribute the trucks with a VIUS1997 average weight of 6,001-10,000 lbs. Instead these were distributed equally among the MOVES weightClassID 70, 80, 90 and 100.

24.3.2 Single Unit Trucks

Source types 52 and 53 (long- and short-haul single unit trucks) also included some trucks in VIUS1997 Strata 1 and 2, thus a similar algorithm was applied.

- VIUS1997 trucks of the source type in Strata 3, 4, and 5 were assigned to the appropriate MOVES weight class based on VIUS1997 detailed average weight information.
- VIUS1997 trucks of the source type in Strata 1 and 2 were identified by engine size and broad average weight category.
- Strata 1 and 2 trucks in the heavier (10,001-14,000 lbs, etc) VIUS1997 broad categories were matched one-to-one with the MOVES weight classes.
- For trucks in the lower broad categories (6,000 lbs-or-less and 6001-10,000 lbs), we used VIUS1997 to determine the fraction of trucks by model year and fuel type that fell into each engine size/broad weight class combination (the “VIUS fraction”).
- We did not believe the ORNL light-duty vehicle database adequately represented single unit trucks. Thus, the trucks with a VIUS1997 average weight of 6,000 lbs or less and an engine size less than 5 liters were distributed equally among the MOVES weight classes 20, 25, 30, 35, 40, 45, 50, and 60. Because no evidence existed of very light trucks among the vehicles with larger engines (5 liter or larger), these were equally distributed among MOVES weight classes 40, 45, 50 and 60.
- The trucks with a VIUS1997 average weight of 6,001-10,000 lbs were distributed equally among the MOVES weight classes 70, 80, 90 and 100.

24.3.3 Combination Trucks

Long- and short-haul combination trucks (source types 61 and 62) did not include any vehicles of VIUS1997 Strata 1 or 2. Thus we used the detailed VIUS1997 average weight information and engine size information to assign engine size and weight classes for all of these trucks.

When VIUS2002 became available, we updated values that had been based on VIUS1997. The VIUS2002 contains an estimate of the average weight (vehicle weight plus cargo weight) of

1998-2002 model year vehicle or vehicle/trailer combination as it was most often operated when carrying a typical payload during 2002. These estimates were used to determine the MOVES weightClassID categories for these trucks. Any vehicles with a zero or missing value for the average weight and without a weight classification in the WeightAvgCK field were excluded from the analysis for determining the average weight distributions.

Since there is a smaller number of gasoline trucks among the single unit and refuse trucks, all model years (1998-2002) were combined to determine a single weight distribution to use for these model years. The VIUS1997 based estimates were retained for light-duty trucks (source types 31 and 32) and for all model years prior to 1998.

In cases where distributions were missing (no survey information), distributions from a nearby model year with the same source type was used. Weight distributions for all 2003 and newer model years were set to be the same as for the 2002 model year for each source type.

24.4 Buses

For intercity buses, we used information from Table II-7 of the FTA 2003 Report to Congress[46] that specified the number of buses in various weight categories. This information is summarized in below in Table 24-3. Note the FTA uses the term "over-the-road bus" to refer to the class of buses roughly equivalent to the MOVES intercity bus category. The FTA weight categories were mapped to the equivalent MOVES weight classes.

Table 24-3 FTA estimates of bus weights

Weight (lbs)	MOVES Weight ClassID	MOVES Weight Range (lbs)	Number of buses (2000)	Bus type
0-20,000			173,536	school & transit
20,000-30,000			392,345	school & transit
30,000-40,000	400	33,000-40,000	120,721	school & transit & intercity
40,000-50,000	500	40,000-50,000	67,905	intercity
total			754,509	

Table 24-4 1999 bus population comparisons by data source

Data Source	Total Buses	Intercity Buses	Transit Buses	School Buses
FHWA MV-1	732,189			
FHWA MV-10 (excludes PR)	728,777			592,029*
FHWA adjusted for PR				594,800
FTA NTD			55,706	
APTA[85] ***			75,087	
Polk TIP®				460,178
School Bus Fleet Fact Book				429,086
Motorcoach Census[45]**		44,200		

* Includes some church & industrial buses.
** Includes Canada.
*** Includes trolleybuses.

Using the 1999 bus population estimates in Table 24-4, we were able to estimate the fraction of all buses that were intercity buses and then to estimate the fraction of intercity buses in each weight bin. In particular:

Estimated number of intercity buses in 2000:

754,509 * (84,454/(84,454+55,706+592,029)) = 87,028

Estimated number of intercity buses 30,000-40,000 lbs:

87,028 - 67,905 = 19,123

Estimated intercity bus weight distribution:

Class 400 = 19,123/87,028 = 22%
Class 500 = 67,905/87,028 = 78%

This distribution was used for all model years.

For transit buses, we took average curb weights from Figure II-6 of the FTA Report to Congress[46] and added additional weight to account for passengers and alternative fuels. The resulting in-use weights were all in the range from 33,850 to 40,850. Thus all transit buses were assigned to the weight class "400" (33,000 - 40,000 lbs) for all model years. This estimate could be improved if more detailed weight information for transit buses becomes available.

For school buses, we used information from a survey of California school buses. While this data is older and may not be representative of the national average distribution, it was the best data source available. The California data[86] provided information on number of vehicles by gross vehicle weight class and fuel as detailed in Table 24-5.

Table 24-5 California school bus study weight classes and fuel types

	Gas	Diesel	Other	Total
LHDV	2740	4567	8	7315
MHDV	467	2065	2	2534
HHDV	892	11639	147	12678
Total	4099	18271	157	

To estimate the distribution of average weights among the MOVES weight classes, we assumed that the Light Heavy-Duty (LHDV) school buses were evenly distributed among weightClassIDs 70, 80, 90, 100, and 140. Similarly, we assumed the Medium Heavy-Duty (MHDV) school buses were evenly distributed among weightClassIDs 140, 160, 195, 260, and 330 and the Heavy Heavy-Duty (HHDV) school buses were evenly distributed among weightClassIDs 195, 260, 330, and 440.

The final default weight distributions for buses are summarized in Table 24-6.

Table 24-6 Weight distributions for buses by fuel type

	Intercity Buses (41)	Transit Buses (42)	School Buses (43)	
Weight Class	**Diesel**	**Diesel & Gas**	**Diesel**	**Gas**
70			0.0500	0.1337
80			0.0500	0.1337
90			0.0500	0.1337
100			0.0500	0.1337
140			0.0726	0.1565
160			0.0226	0.0228
195			0.1819	0.0772
260			0.1819	0.0772
330			0.1819	0.0772
400	0.2197	1.0000	0.1593	0.0544
500	0.7800			

24.5 Refuse Trucks

Because the sample of Refuse Trucks in VIUS was small, the weight distributions were calculated for model year groups rather than individual model years, shown below in Table 24-7. As for other trucks, the WeightClass was determined from the VIUS reported average weight.

Table 24-7 Refuse truck SizeWeight fractions by fuel type

Gasoline							
Engine Size	**Weight (lbs.)**	**Pre-1997**	**1997 and Newer**				
3-3.5L	5000-6000	0.009074	0				
>5L	7000-8000	0.148826	0				
>5L	9000-10000	0.070720	0				
>5L	10000-14000	0.135759	0.324438				
>5L	14000-16000	0.199961	0.593328				
>5L	16000-19500	0.055085	0				
>5L	19500-26000	0.205341	0				
>5L	26000-33000	0.022105	0				
>5L	33000-40000	0.153129	0				
>5L	50000-60000	0	0.082234				
Sum		**1.000000**	**1.000000**				
Diesel							
Engine Size	**Weight (lbs.)**	**Pre-1998**	**1998**	**1999**	**2000**	**2001**	**2002 and Newer**
3.5-4L	10000-14000	0.007758	0	0	0	0	0
4-5L	10000-14000	0	0	0	0	0	0.006614
4-5L	14000-16000	0	0	0	0.015505	0	0
4-5L	16000-19500	0	0	0	0	0.011670	0
>5L	9000-10000	0.006867	0.009593	0	0	0	0
>5L	10000-14000	0.011727	0	0	0	0.019438	0
>5L	14000-16000	0.022960	0	0	0	0	0
>5L	16000-19500	0.063128	0	0.011367	0.047200	0	0
>5L	19500-26000	0.099782	0.035378	0.026212	0.052132	0.018329	0.026079
>5L	26000-33000	0.102077	0.019625	0.067419	0.072106	0.043877	0
>5L	33000-40000	0.237485	0.103922	0.088975	0.085991	0.042678	0.046966
>5L	40000-50000	0	0.283642	0.275467	0.165624	0.266357	0.194716
>5L	50000-60000	0.336484	0.338511	0.326902	0.384612	0.315133	0.474469
>5L	60000-80000	0.111730	0.196424	0.193238	0.176831	0.282517	0.224995
>5L	80000-100000	0	0	0.010420	0	0	0.013081
>5L	100000-130000	0	0.012904	0	0	0	0.013081
Sum		**1.000000**	**1.000000**	**1.000000**	**1.000000**	**1.000000**	**1.000000**

24.6 Motor Homes

No detailed information was available on average engine size and weight distributions for motor homes. We assumed all motor home engines were 5 L or larger. As a surrogate for average weight, we used information on gross vehicle weight provided in the Polk TIP® 1999 database by model year and mapped the Polk GVW Class to the MOVES weight bins. These values are likely to overestimate average weight. The Polk TIP® information did not specify fuel type, so we assumed that the heaviest vehicles in the Polk database were diesel-powered and the remainder were powered by gasoline. This led to the weight distributions in Table 24-8 and Table 24-9.

Table 24-8 Weight fractions for diesel motor homes by model year

Polk GVW bin	3	4	5	6	7	8
MOVES weight class	**140**	**160**	**195**	**260**	**330**	**400**
Model Year	**Diesel**					
1975-and-earlier	0.171431	0.792112	0.029828	0	0.006629	0
1976	0.637989	0.340639	0.018755	0.000436	0.002181	0
1977	0.68944	0.292308	0.012168	0.000277	0.005531	0.000277
1978	0.423524	0.574539	0	0.000387	0.00155	0
1979	0.096922	0.899344	0	0.001067	0.002667	0
1980	0.462916	0.537084	0	0	0	0
1981	0	0.941973	0	0.030174	0	0.027853
1982	0	0.868333	0	0.049	0.03	0.052667
1983	0	0.912762	0.000203	0.014845	0.030096	0.042094
1984	0	0.932659	0.000835	0.009183	0.036732	0.020592
1985	0	0.881042	0.001474	0.010761	0.083285	0.023438
1986	0	0.855457	0.013381	0.022962	0.089534	0.018667
1987	0	0.791731	0.085493	0.022498	0.087164	0.013113
1988	0	0.72799	0.148917	0.015469	0.093335	0.014289
1989	0	0.73298	0.128665	0.043052	0.082792	0.012511
1990	0	0.173248	0.614798	0.043628	0.149939	0.018387
1991	0	0	0.619344	0.063712	0.296399	0.020545
1992	0	0	0.551548	0.01901	0.385085	0.044356
1993	0	0	0.345775	0.471873	0.144844	0.037509
1994	0	0	0.45546	0.354386	0.159622	0.030531
1995	0	0	0.635861	0.163195	0.17468	0.026264
1996	0	0	0.553807	0.229529	0.184208	0.032456
1997	0	0	0.666905	0.193167	0.111299	0.028628
1998	0	0	0.267	0.335069	0.357508	0.040423
1999+	0	0	0	0.736656	0.233886	0.029458

Table 24-9 Weight fractions for gasoline motor homes by model year

Polk GVW bin	3	4	5	6	7	8
MOVES weight class	140	160	195	260	330	400
Model Year	Gasoline					
1975-and-earlier	1	0	0	0	0	0
1976	1	0	0	0	0	0
1977	1	0	0	0	0	0
1978	1	0	0	0	0	0
1979	1	0	0	0	0	0
1980	1	0	0	0	0	0
1981	0.747723	0.252277	0	0	0	0
1982	0.732235	0.267765	0	0	0	0
1983	0.714552	0.285448	0	0	0	0
1984	0.641577	0.358423	0	0	0	0
1985	0.692314	0.307686	0	0	0	0
1986	0.720248	0.279752	0	0	0	0
1987	0.606635	0.393365	0	0	0	0
1988	0.459429	0.540571	0	0	0	0
1989	0.551601	0.448399	0	0	0	0
1990	0.543354	0.456646	0	0	0	0
1991	0.612025	0.322022	0.065952	0	0	0
1992	0.54464	0.373999	0.081361	0	0	0
1993	0.583788	0.361277	0.054935	0	0	0
1994	0.481099	0.361146	0.157755	0	0	0
1995	0.52997	0.198479	0.271551	0	0	0
1996	0.435959	0.289453	0.274588	0	0	0
1997	0.221675	0.433334	0.344991	0	0	0
1998	0.288222	0.581599	0.13018	0	0	0
1999+	0.170133	0.392451	0.288411	0.149004	0	0

25 Peer Review of Draft Report

This section contains comments on the draft report of *Population and Activity of On-road Vehicles in MOVES2014* from two peer reviewers and EPA's responses to those comments. The reviewers were selected by a third-party contractor, ICF International, facilitating a peer review of the MOVES2014 technical reports. The submitted peer review comments are publicly available on the EPA Science Inventory database.[87]

25.1 Kanok Boriboonsomsin, PhD, PE

Dr. Boriboonsomsin has been a researcher at the University of California at Riverside since 2005. He currently holds the position of Assistant Research Engineer at the College of Engineering's Center for Environmental Research and Technology (CE-CERT) and received a PhD in Transportation Engineering from University of Mississippi in 2004. Dr. Boriboonsomsin previously reviewed the MOVES2010b Population and Activity Report.

25.1.1 General Comments

This is a review of the *Draft Report on Population and Activity of On-road Vehicles in MOVES2014*, referred to as the "Fleets Report", prepared by the EPA Office of Transportation and Air Quality. I was also a peer reviewer of the *Draft MOVES2009 Highway Vehicle Population and Activity Data*, which helped me identify and understand changes made to the national default values for vehicle population and activity inputs in MOVES2014 during the time of this review.

Overall, the Fleets Report is well written and organized, with sensible use of examples, tables, and figures. I appreciate the addition of Section 2 (MOVES Vehicle and Activity Classifications), which will help readers understand early on the various ways in which vehicles and their activities are classified in the context of MOVES. I find the description of analytical methods and procedures to be sufficiently clear with appropriate use of mathematical equations to help explain complex calculations such as in Section 9.2 (Heavy-Duty Average Speed Distributions) [Now Appendix F: Calculation of Combination Truck Average Speed Distributions]. I also appreciate the list of areas for future research in Section 16 (Conclusion and Areas for Future Research), which informs research directions for improving the vehicle population and activity data inputs in future updates of MOVES.

In terms of the vehicle population and activity inputs, I find that the national default values in MOVES2014 have been appropriately updated by using more recent data from Polk (2011), AEO (2014), and TEDB (2013). Perhaps, the most important development in this vehicle population and activity update is the use of nationwide GPS dataset to develop average speed distributions for light-duty vehicles. This is an exciting time for vehicle activity research due to the increasing availability of large-scale, high-resolution instrumented vehicle data from a variety of sources. As indicated in the Fleets Report, many of the limitations in the current MOVES vehicle activity inputs can be addressed through analysis of such instrumented vehicle data.

25.1.2 Detailed Comments

Detailed comments and suggestions are provided below. These are made with the understanding of the challenges of developing nationally representative default values for MOVES vehicle population and activity inputs under the limited resources that the EPA has.

25.1.2.1 Section 1 – Introduction

An early explanation of the analysis years considered in this Fleets Report (e.g., 2011 being the base year) would be helpful to readers.

Response: A short paragraph has been added to the Introduction to address the possible analysis years and 2011 base year.

25.1.2.2 Section 2.3 – Regulatory Classes

The mapping between multiple vehicle classification schemes has always been a challenging topic. The introduction of a new regulatory class 40 is well thought out, and the rationale for it is well explained.

Response: Further explanation on regulatory class 40 can be found in the MOVES2014 report on emission rates of heavy-duty vehicles.[5]

25.1.2.3 Section 2.4 – Fuel Types

The population of CNG-fueled refuse trucks is growing and emissions test data of these trucks are increasingly available. This source type-fuel type combination may be considered for modeling in future versions of MOVES.

Response: Yes, CNG refuse trucks have a rapidly growing market share. More than half of the refuse trucks sold today are manufactured to run on natural gas[88]*; however, despite this rapid growth, there are about 8,800 natural gas-fueled refuse trucks according to 2014 industry estimates*[88]*, which constitutes less than 10 percent of the US refuse truck fleet. While developing MOVES2014, EPA decided not to include CNG refuse trucks but will consider adding them to future versions of MOVES. Report text has been edited to mention CNG refuse trucks.*

25.1.2.4 Section 2.8 – Allowable Vehicle Modeling Combinations

Tables Table 2-6 and Table 2-7 provide a very good summary of allowable vehicle modeling combinations in MOVES2014.

Where would shuttle buses (e.g., those used to pick up and drop off passengers at airports) fit in Table 2-7?

Response: As discussed in Section 6.1.4, any buses in MOVES not utilized for urban public transit or service to and from a school are considered intercity buses. Since airport shuttles cannot be classified as either transit or school buses, they fall into the MOVES intercity bus source type.

25.1.2.5 Section 4.1 – Historic Vehicle Miles Traveled (1990 and 1999-2011)

Does FHWA publish the methodology used to adjust VMT data for 2000-2006? If not, the average ratio method used appears reasonable.

Response: FHWA did not publish their methodology of adjusting the VMT data. The language in this section has been edited for clarity.

25.1.2.6 Section 4.2 – Projected Vehicle Miles Traveled (2012-2050)

The methods used to project VMT for future years are appropriate.

25.1.2.7 Section 5.1 – Historic Source Type Populations (1990 and 1999-2011)

It is described that "the 2000-2010 distributions among source types within the general truck categories were linearly interpolated between 1999 and 2011". However, the 2000-2010 truck population distributions in Figures Figure 5-2, Figure 5-3, and Figure 5-4 do not show linear trends. Please clarify the linear interpolation that was performed.

Response: We are not interpolating the populations but the fractions of each source type out of its general populations, such as long-haul combination trucks out of total combinations trucks, between 1999 and 2011. Those source type fractions were then multiplied by the general MV-1 populations. Without interpolation of these source type allocations, source type populations would not have necessarily followed the MV-1 populations trends from 1999 to 2011, which would have implied that we knew more about the source type populations than we actually did. We have added clarifying text and Table 5-1 with these 1999-2011 source type population fractions to this section.

25.1.2.8 Section 5.2 – Projected Vehicle Populations (2012-2050)

The use of VMT growth as a surrogate for vehicle population growth is reasonable per the analysis of VMT per vehicle trends shown in [Figure 5-6, previously represented in a table].

25.1.2.9 Section 6.2.1 – Fuel Type and Regulatory Class Distributions

Data on actual fuel type used by E85-capable vehicles are available for 100 vehicles in California, which may be used in future updates, (http://www.dot.ca.gov/research/researchreports/reports/2015/final_report_task_1919.pdf).

Response: The use of E85 fuels varies geographically and is an area of great uncertainty and change. MOVES default values can be considered as our initial national estimate for E85 use. Users should consider using more locally-specific and up-to-date information when running MOVES. A more detailed discussion of E85 use in MOVES2014 can be found in the report on the default fuel supply.[6]

According to AEO2014, hybrid electric and plug-in hybrid electric vehicles are projected to grow from 2.2% of total cars and light truck sales in 2011 to 6.1% in 2040. Would they warrant their own category with respect to fuel type in future versions of MOVES?

Response: Hybrid electric and plug-in hybrid electric vehicles certainly present some modeling challenges in MOVES. We have added text to this section of the report discussing these challenges.

25.1.2.10 Section 8 – VMT Distribution of Source Type by Road Type

In Table 8-2, it is my personal opinion that some numbers are not intuitive. For example, I would think that refuse trucks are operated mostly in urban areas, but they are reported to have about the same VMT fraction in rural and urban areas. In another example, combination long-haul trucks have roughly the same VMT distribution as combination short-haul trucks although I would expect them to have higher VMT fraction on rural restricted access roads. The numbers in Table 8-2 are derived from the 2011 NEI V1, which is probably the most appropriate source of this type of data at this time. These numbers may be compared with numbers derived from large-scale GPS datasets for each source type in the future.

Response: It is difficult to find data on the activity of refuse trucks on a national basis and many states have trouble finding appropriate data for this category. Similarly, it is difficult to distinguish long-haul and short-haul trucks in most data sources. We are considering simplifying our source type categories in future versions of MOVES.

25.1.2.11 Section 9.1 – Light-Duty Average Speed Distributions

It may be of interest to compare some of the average speed distributions derived from TomTom dataset with those derived from traffic monitoring systems. For example, California has the Freeway Performance Measurement System or PeMS (http://pems.dot.ca.gov/). Average speed distributions can be derived using a subset of TomTom data on California freeways and compare to those derived from PeMS. This would help understand potential biases, if any, in TomTom data. It is understood this will incur additional analyses (and costs) by TomTom as the raw data are not provided to ERG and EPA.

Response: Acquiring a California subset of the TomTom data and comparing it to PeMS data is an interesting idea to understand potential inherent bias—oversampling of long-distance trips and trips with routes unfamiliar to the driver. In the hope of making national comparisons, EPA is actively identifying other datasets like PeMS that represent typical driving in the US to compare against TomTom data.

In Figure 9-1, it is observed that the highest average speed fraction for urban unrestricted access road is not in the lowest average speed bin (< 2.5 mph) although one would expect a significant amount of idle time at signalized intersections. This may be due to the length of intersection segments being much longer than a typical length of traffic queue, which causes the zero speed while idling in the queue to be canceled out by relatively higher speeds before joining the queue. I am not sure how much the shift in this average speed distribution would impact emission inventories at the national scale. If the impact would be significant enough, these intersection segments may be divided into shorter segments in future analyses.

Response: Without the raw TomTom data, one can only speculate about the amount of time these GPS-equipped vehicles spent at urban intersections. We will consider how to improve this *information in future data collection efforts. You are correct that the road segments used by MOVES are much larger than what might be used specifically for intersection modeling. All of the low speed driving cycles used in MOVES contain a significant amount of idling time that would reflect the time at idle at signalized intersections.*

25.1.2.12 Section 9.2 – Heavy-Duty Average Speed Distributions

The adjustment made in this section is well done.

Response: We have moved the details of the heavy-duty average speed adjustment to the appendix, and left a summary in the main text.

25.1.2.13 Section 10.2 – Ramp Activity

What data were used to estimate operating mode distributions for ramp activity?

Response: Ramp operating modes in MOVES2014 were not based on data and were carried over from previous MOVES versions. The distributions were derived from existing operating mode distributions using engineering judgement. EPA has begun to analyze data from second-by-second measurements of real world vehicle activity to develop new ramp operating mode distributions for the next major release of MOVES.

The ramp fraction may be determined using either PeMS or TomTom data. It is understood that the latter will incur additional analyses (and costs) by TomTom as the raw data are not provided to ERG and EPA.

Response: TomTom data was not provided with any geospatial coordinates, which would be necessary for identifying ramps, and acquiring this new level of detail would take additional analysis and cost beyond the original data purchase.

25.1.2.14 Section 11.1 – National Default Hotelling Rate

The assumptions made in this section can be validated using large-scale GPS datasets of commercial trucks, for example, the truck GPS dataset maintained by the American Transportation Research Institute (ATRI) (http://atri-online.org/2014/10/28/truck-gps-data-for-tracking-freight-flows/).

Response: Many states are also looking into truck hotelling and may be able to provide local estimates for truck hotelling hours.

25.1.2.15 Section 11.2 – Hoteling Activity Distribution

There are studies that provide data on APU and truck electrification usage that may be considered in future updates. For example:

- Frey, H. C., P.-Y. Kuo, and C. Villa. (2008). Methodology for characterization of long-haul truck idling activity under real-world conditions. *Transportation Research Part D*, 13, 516-523.

- National Renewable Energy Laboratory (NREL)'s Truck Stop Electrification Testing (http://www.nrel.gov/transportation/fleettest_truck_stop_electrification.html).

Response: The current MOVES design does not currently allow for the application of county-by-county control programs that affect the amount of hotelling hours for national scale modeling. However, users may include specific hotelling hour estimates in the HotellingHours table in their county databases (CDBs). County specific CDBs are normally used for most official inventory estimates (such as the National Emission Inventory (NEI) and EPA rules, such as the recent light-duty vehicle Tier 3 rule), so providing appropriate hotelling hour estimates is done on a case-by-case basis using the available information at the time of the MOVES runs. EPA has used data provided by states during the NEI process from sources, such as you cite, to keep the CDBs we use and the inventory estimates generated up-to-date and accurate.

25.1.2.16 Section 12 – Temporal Distributions

Temporal distributions of VMT rely heavily on the 1996 OHIM report. Traffic monitoring systems, such as PeMS, may be considered for use as a source of more recent data, especially for restricted access roads. Note that in the case of PeMS, VMT are estimated separately for cars and trucks, which can be used to represent light-duty source types and heavy-duty source types, respectively.

Response: EPA has begun analyzing data from instrumented vehicles as a source for much of the activity information used by MOVES, including temporal distributions, and would like to use this new data in future versions of MOVES. We also plan to investigate data from traffic monitoring systems, such as PeMS.

25.1.2.17 Section 12.1 – VMT Distribution by Month of the Year

Container volumes at ports around the US may be considered for use as a surrogate of VMT distribution by month of year for short-haul and long-haul combination trucks. For example, https://www.portoflosangeles.org/maritime/stats.asp.

Response: This is a helpful suggestion, but we think instrumented vehicle data and traffic monitoring systems will likely be better sources for national average VMT temporal distributions. We intend to investigate these for a future version of MOVES.

25.1.2.18 Section 12.2 – VMT Distribution by Type of Day

Data from traffic monitoring systems may be used to estimate DayVMTFraction for each month.

Response: States may and often provide their own data for modeling their areas, so updating the national average default distributions has not been a high priority. However, as traffic monitoring and instrumented vehicle data have become more available, we hope to make updates in the future.

25.1.2.19 Section 12.4 – Engine Starts and Parking

More recent instrumented vehicle data are available on NREL's Transportation Secure Data Center website (http://www.nrel.gov/transportation/secure_transportation_data.html) for passenger vehicles and on NREL's Fleet DNA website (http://www.nrel.gov/transportation/fleettest_fleet_dna.html) for commercial vehicles.

Response: EPA has gained access to the NREL FleetDNA dataset but has not yet determined its applicability for MOVES. EPA is also currently analyzing start and soak information for light-duty vehicles using a large telematics dataset.

25.1.2.20 Section 12.5 – Hourly Hotelling Activity

In future updates, the hourly hotelling activity may be estimated from large-scale GPS datasets of long-haul trucks such as ATRI's.

Response: We agree that data from instrumented vehicles will likely provide better estimates of truck hotelling activity than survey or self-reported data. EPA is exploring a variety of heavy-duty vehicle activity datasets, including streams collected from GPS and/or OBD devices, to update MOVES default hotelling information such as hourly rates.

25.1.2.21 Section 14.2 – Road Load Coefficients

The road load coefficients for light-duty vehicles were set to remain constant over time despite the Light-Duty Greenhouse Gas Rule (because the improvements in these coefficients have already been incorporated into the energy and emission rates). However, the road load coefficients for 2014 and later model year heavy-duty vehicles were updated in light of the 2014 Medium and Heavy-Duty Greenhouse Gas Rule. Shouldn't the impact of the 2014 Rule be expected to reflect in [future energy and emission rates]?

Response: Energy rates have been updated to reflect engine efficiency improvements set out in the 2014 Heavy-Duty Greenhouse Gas Rule, as described in the MOVES2014 technical report documenting the heavy-duty vehicle emission rates.[5] Please refer to Chapter 5 of the 2014 HD GHG Rule's Regulatory Impact Analysis (RIA) for further information on modeling emissions from heavy-duty vehicles in future years.[80]

25.1.2.22 Section 16 – Conclusion and Areas for Future Research

The national default values for vehicle population and activity inputs in MOVES2014 were developed for the base year of 2011. It may be of interest to validate the 2012-2014 projections for some of these inputs with actual data that are available for those years. This will allow the assumptions made in the projections to be adjusted if necessary.

Response: In the past EPA has validated MOVES default activity estimates according to fuel volumes reported through tax receipt data from FHWA.[83] We hope to do a similar analysis for MOVES2014.

25.2 Randall Guensler, PhD

Dr. Guensler is a Professor at Georgia Institute of Technology's School of Civil and Environmental Engineering. He has served as chairmen of the Transportation Research Board Committee on Transportation and Air Quality (1997-2002) and as an advisor on EPA's Mobile Sources Technical Review Subcommittee of the Clean Air Act Advisory Committee (1995-2001). Dr. Guensler holds a PhD in Civil Engineering from the University of California at Davis.

25.2.1 General Comments

Thank you for the opportunity to participate in the peer review of the USEPA's *Population and Activity of On-road Vehicles in MOVES2014* Documentation. I have provided suggested edits using revision marks and comments in the margins of the Word document. At various points in the paper, I have suggested edits to move text explaining tables so that the text appears before the table is presented. There are a number of sections in the document that I suggest be summarized in a single paragraph, shipping the detailed text off to an Appendix, to improve readability.

25.2.2 Detailed Comments

The most important issues that I believe could be addressed in the document are summarized below.

25.2.2.1 Section 1 – Introduction

Somewhere up front in this paper a very brief overview of emissions sources and modeling goals should be added. How MOVES works, in a nutshell, and what data are needed to run MOVES. This can also differentiate between baseline emissions by source type and correction factors. VSP can be addressed here as well as internal driving cycles. Then, the document can refer back to the general discussion when needed.

Response: We have updated the introduction to provide better context, to make the function of this report more clear, and to point users to other documents that address many of these questions.

A big picture issue throughout the entire document is to set the stage for the reader as to why they should be using local-specific or regional-specific data. This is a common theme throughout my comments.

Response: This report documents how EPA developed national-scale default data related to fleet characteristics and travel behavior. As explained in the introduction, information on customizing MOVES with local inputs is detailed in the MOVES2014 Technical Guidance.[3]

25.2.2.2 Section 2 – MOVES Vehicle and Activity Classifications

The MOVES Vehicle and Activity Classification section really needs an overview designed to introduce the reader to the content of the Chapter. This overview can help the reader understand that the emission rates need to be properly linked to the concepts of vehicle classes, vehicle source types, regulatory classes, etc.

Response: We have added a paragraph to the beginning of this section describing the purpose of the section and the need to link emission rates to vehicle activity.

The paper could probably use a paragraph or two associated with the difficulty in mapping FHWA vehicle classes and EPA vehicle classes. Papers by Yoon (2006) and Liu (2015) offer some insight into these issues. Yoon discusses these in the context of visual classes for observational data, although that paper would need to be updated. Providing this in an Appendix might prove helpful to users. This applies in [Section] 3 as well.

Response: We have added information in Section 2.2 and Section 6 that discussing the difficulties of vehicle classification for MOVES modeling and have added citations to the papers referenced.

There is a problem with MOVES implementation at a higher level that, if resolved, would significantly improve modeling efforts. As outlined [in Section 2.2] and elsewhere, it is important to structure MOVES for users to enter mutually exclusive technology groups that can be derived from license plate observational data. Anything that can be added to the documentation to help users better classify their vehicle input based upon field observations will be appreciated by users. Comment 8 also suggests the development of a table to instruct users.

Response: Source types cannot be fully resolved using field observations. Text has been added to Section 2.2 describing our use of a combination of field measurements along with survey and registration data. Guidance for users developing local data is provided in the Technical Guidance.[3]

Comment 8: Another table here showing the mutually exclusive lines for source type, regulatory class, and fuel type might be helpful.

Response: Section 2.8 describes the mutually exclusive combinations of source types, fuel types, and regulatory classes that can be modeled in MOVES2014.

I suggest adding a new section to introduce the use of model year distributions.

Response: An introduction to model year groups has been added, see Section 2.7

There are a number of detailed explanations that probably belong in Appendices rather than in the text to improve readability (and initial clarity).

Response: Both before and after this peer review, we have moved certain detailed explanations where appropriate to appendices for improved readability and clarity. In this final report, we have created appendices on SCC mappings between MOVES versions, forecast and backcast algorithms for age distributions, average speed distributions of combination trucks, and responses to peer review comments regarding this report.

The SCC classes are another big picture issue with MOVES, in that these contribute to the mutually exclusive technology groups. The concept is complex and needs to be explained better in the text. I suggest the addition of a table for clarity.

Response: The new SCCs do not add another grouping, but just clearly label the specific combination of technologies. We have changed Section 2.6 to improve the description of the SCC classes. A table has been added to Section 21 (Appendix E: SCC Mappings*) to compare the MOVES regulatory classes to the old SCC categories to help map between them.*

The audience needs a connection between SCC and regulatory class in Section 2.6. At the same time, Table 2-5 loses the audience due to complexity. An overview paragraph would help here. This is one of the most complicated sections and general improvements would help the audience. Specific comments are provided in the document markup.

Response: The new SCCs are not based on regulatory class. The complexity comes when trying to use regulatory class to map back to the old SCCs. We have revised this section and Table 2-5 to make the discussion clearer.

Table 2-8 appears to be the key table for the entire chapter. If the text is rewritten, I would suggest pointing all of the explanations and discussions so that they result in the reader reaching the table with full understanding of the content of that table. A paragraph is needed after Table 2-8 to let the reader know that everything they do from here on out is to generate the data that will be used by the 80 groups represented in this table.

Response: We do not consider Table 2-8 to be of primary importance. We have revised the entire section to make it clearer that the aim of this section is to define MOVES terminology and that later sections talk about how we actually estimate populations and activity for the different categories. Table 2-8 simply identifies the vehicle technology combinations for which we have emissions data.

Table 2-9 [now Table 1-1] is excellent and can be used to organize the presentation of materials before and after. Listing in order of use in the document, rather than alpha order, will help the structure.

Response: We have moved this entire section, including the table to the introduction to help provide context for all of the paper. Listing the MOVES table names in Table 1-1 alphabetically makes it more useful for reference purposes. The table of contents will assist the reader in understanding the order of how topics will appear in the report.

25.2.2.3 Section 3 – Data Sources

Data sources introduction should be expanded significantly to inform the reader about what they need for modeling. Given the sensitivity and capabilities of MOVES, A goal here should be to shift users to locally-sourced data rather than national defaults.

Response: The data sources described in Section 3 were used to develop national default values of activity-related inputs found in the MOVES2014 database. Users are encouraged to incorporate locally-source data for project- or county-scale modeling where possible. As indicated in the report's introduction, there is separate technical guidance that provides details on developing locally-sourced inputs for project- and county-scale modeling.[3] We have now repeated that information at the beginning of Section 3.

25.2.2.4 Section 4 – VMT by Calendar Year and Vehicle Type

As indicated in Comment 34, buses and HD Trucks experience different growth rates. A separate data source should be found for the next set of updates. At the very least, local data should be recommended for buses of all types (these data can be obtained from transit agencies).

Comment 34: This seems a bit shaky. Bus activity growth will not parallel HDV truck growth. There are completely different causal factors in play. Single unit and large trucks are also likely to grow at different rates. Not sure I have a reasonable alternative to propose though. At least the uncertainty should be acknowledged here.

Response: Lacking better information, it is unclear how VMT growth in buses will relate to growth in other heavy-duty vehicle types. We agree that the uncertainty of assuming bus growth follows heavy-duty freight growth should be acknowledged and have added text to that effect.

25.2.2.5 Section 5 – Vehicle Populations by Calendar Year

Changes in vehicle ownership and mileage accrual rates are generally different. These sources can be obtained from registration databases coupled with I/M programs. This would be a worthwhile small study to sponsor.

Response: MOVES does not currently use vehicle registration databases from I/M areas for relative MARs or survival rates of light-duty vehicles. Only using data from a small sample of selected areas may generate issues of representativeness, but we are interested in reassessing the viability of registration data from I/M areas in the future.

25.2.2.6 Section 6 – Fleet Characteristics

The materials presented [in reference to modeling flexible fuel vehicles running on either gasoline or E85 in Section 6.2.1] (Comment 41) are very confusing for the reader and serve to reinforce the need for users to obtain their own regional/local input data. The discussion can be simplified for clarity or expanded with detail for clarity.

Comment 41: This whole paragraph [discussing flexible fuel vehicles] is confusing (and reinforces the need to allow the user to provide direct inputs rather than relying on the internal algorithms for assignment), as noted earlier. If this paragraph remains, it should either be expanded to provide the exact details of the internal method, or reduced to avoid confusion.

Response: The text has been revised to add a footnote that more clearly explain that information on MOVES vehicle fuel consumption comes from two separate fractions. The fuel type fraction delineates whether the vehicle is capable of running on single or multiple fuels and the fuel usage fraction describes how much of the total fuel consumed is a specific fuel, particularly for light-duty flexible fuel vehicles that are using E85 or gasoline. As noted in the text, discussion on fuel usage is in a separate technical report on the MOVES2014 fuel supply.[6] Given the spatial variation of E85 use, user-supplied data would be preferable over national defaults for localized flexible fuel vehicle modeling.

Comment 48 identifies an internal problem in MOVES that causes problems for users in matching local fleet composition.

Comment 48: This is the problem [with the SampleVehiclePopulation table] identified earlier associated with single fixed assignments inside MOVES. The user cannot control these allocations later in the process. See the discussion in Liu et al., 2015.

Response: While the AVFT importer is designed to make it easy for users to change fuel type fractions by model year, we thought it unlikely that many users would have information on regulatory class distributions, so we did not create an importer for this data.

25.2.2.7 Section 7 – Vehicle Characteristics that Vary by Age

The discussion on survival modeling could be significantly improved (see comments) and caveats should be added. A number of comments are also provided on model year distribution values, especially for the oldest vehicle groups. Plus, the detailed text in this section would fit better as an appendix. A focused peer review of this section is probably warranted (see comments).

Comment 55: This is a fairly weak justification…. If a method is applied later, stipulate the method and basis here.

Response: To thoroughly model scrappage in MOVES, we need projections of vehicle retirement by source type and age for every calendar year 2012+. This is the justification for using base survival rates from TEDB and scaling them as necessary based on sales and VMT projections. The text here has been amended to include a more detailed justification.

Comment 56: As noted below, a reader needs to see plots over time here to assess impact of assumptions. This can be done by overlaying future fleets by calendar year. The 30+ group should be growing slightly, or remaining stable, rather than shrinking over time, as folks hold onto vehicles longer. These are 1985 and older vehicles today. Vehicles in today's fleet are more durable. Need to reassure users that the failure rate assumption is reasonable with an independent confirmation.

Response: MOVES2014 has generic survival curves by vehicle classifications independent of model year. With this limited data, we chose to scale these generic survival curves to ensure that changes in population would be evident over time. We do not have enough data to adequately assess how 30+ year old vehicle populations are changing over time, but this is a topic of interest for EPA. We have added a figure towards the end of Section 20.1 (in Appendix D: Detailed Derivation of Age Distributions*) with overlaying future fleets. Due to our assumptions in the national case, most source types do not see an uptick in 30+ vehicles (combination trucks being the exception). However, as noted in the paragraph regarding the user tool, projected local age distributions retain their 30+ population fractions.*

Comment 58: Need to be careful here. Differential retirements in model year groups could represent technology durability/acceptability issues. Need to double-check prior to discounting sources. Caveat whole paragraph by reassuring the audience that you did the best you could and that users can specify their own future fleets and ignore the retirement rates.

Response: We agree that double-checking is necessary before discounting sources, which is why 5-year survival rates derived from VIUS 1992 and 1997 were used to justify our choice. The paragraph is also caveated with the acknowledgement of how limited the data are. We provide user guidance in separate documents.

Comment 60: Showing a survival curve is a good idea. Survival curves can be developed separately for various technology groups if desired.

Response: Vehicle survival rates by age and HPMS class are shown in Table 7-2.

Comment 61: I suggest moving all of the text from this point down to the end of the section into an Appendix. It is not needed here and adds to reader confusion for something that is rarely needed by a user. The bottom line is that you have made adjustments to the rates to try to help the predictions match the data without adjusting rate parameters. You can say that here and refer the user to an appendix.

Response: We agree and have moved the detailed description of implementing the algorithm to Appendix D (Section 20).

Comment 62: Based on this text, it looks like the 0.3 value has been discarded, which is probably a good thing. This needs to be clarified and applicable text in this section corrected as needed.

Response: In the Age Distribution Projection Tool, which users are encouraged to use to project local age distributions into the future, this is correct: the 0.3 value has been discarded. However, this is only true for the tool; the national analysis retains this assumption.

Comment 63: It is not clear why [for] 1999-2010 this needs to be modeled with a survivor model at all, rather than simply interpolated between your 1990 and 2011 data sets, using sales figures for control given that there are no better data in between). Given that survival rates are so different across the country (e.g. New England vs. Arizona), and by technology as it entered the fleet, I'm not convinced that the detailed approach is warranted.

Response: Our chosen approach provides a consistent method for generating age distributions across all analysis years in MOVES. Again, our user guidance encourages the use of local age distributions for regional or state-level analysis.

Comment 64: Given the 140 pages to review, there is not enough time to perform a full technical analysis of Section 7.1. I would suggest that the equations be sent out for a separate and focused peer review… Finally, the users need to be reassured that they can specify the composition of the future fleet off model using their own sales and survival functions.

Response: Thank you for the suggestion. Work on vehicle sales growth and retirement rates was presented as a poster at the 25th Coordinating Research Council (CRC) Real World Emissions Workshop in March 2015. EPA has discussed the possibility of publishing this research in a peer-reviewed journal sometime in the future. Our guidance documents allow users to employ different methodologies to generate age distributions.

Mileage accrual for the older vehicles is also a potential issue (see comments).

Comment 70: You have confounding effects from the recession in Section 7.2. The traffic volumes on freeways declined significantly during that period, but have been on the rise. MARs warrant a double check with post-2009 data. Given the vehicle purchase delays, the accumulation rates will likely vary even more by model year cluster. I don’t have a better answer, but I question the stability assumption.

Response: We agree with the assertion that the 2001 and 2009 data are similar does not address the issue of whether the 2009 data is anomalous in regards to a trend in mileage accumulation. However, without a full analysis of the trend, we are left with the choice of using the 2001 data or the 2009 data. Text has been added to the explanation of our choice to continue to use the 2001 data—since it was unaffected by the 2008-2009 recession—in the report.

Comment 72: These are fairly significant assumptions that cannot be verified from the information provided. Older vehicles are relegated to different service activities, so these are important assumptions to verify, especially given the age of the 1992 TIUS data.

Response: Information about the oldest model years in the fleet are scarce, and due to the smaller number of vehicles, any data will have significant variability. It will be difficult to reduce the uncertainty in the mileage accumulation rates for the oldest vehicles without significant effort. Without clear information that the activity of these older vehicles has changed dramatically in recent years, updating this information will have a low priority.

The Single unit long-haul truck distribution in Figure 7-1 is so different than the other curves that it warrants a detailed explanation.

Response: All the age distributions for single unit trucks were constructed primarily from national registration data, but there was a particular small sample of long-haul trucks in VIUS2002, especially in more current years. Due to this small sample size, the long-haul single unit age distribution is probably affected greatly by minor changes in population.

The Cubic Regression approach [in Section 7.2.2] is not clearly defined.

Response: The text of Section 7.2.2 was updated to state clearly that the regression used was a simple cubic fit and not, for example, a spline fit. Given the very good fit reported by NHTSA and the use of the regression in their model, we did not see a need to reconsider this choice.

Table 7-3 is good. Similar tables should be provided for other classes.

Response: We have added a table to the report with the raw mileage accumulation rates for passenger cars and light-duty trucks copied from the NHTSA reference document.

I could not replicate the data in Table 7-6. Please see comments.

Response: We have updated the text explaining how the data was generated to include more details. The updated method will produce the reported statistics.

25.2.2.8 Section 8 – Average Speed Distributions

I have some expertise in the availability and resolution of TomTom data. The use of these data as outlined in the document appears problematic. Comments are provided throughout Section 9.1 and 9.2I cannot recommend the use of these data in this fashion. I recommend that additional research in this area be undertaken.

Comment 79: You have nailed most of the potential biases in the bullets [in Section 9.1]. This was enough to keep us from using these data for our research efforts. There are significant vehicle class, lane choice, operating condition, and geographic biases that likely result. Given the tremendous sensitivity of MOVES to the selected duty cycle, I am not inclined to recommend the use of the derived average speed for hours or selection of driving cycle weightings without much more information to evaluate this effort and comparative studies with other data sources.

Response: We agree that there are limitations to this dataset, which is why we listed the biases in the report. However, using the default nationally representative average speed distribution from TomTom GPS data is a substantial improvement over the previous default average speed distributions in MOVES2010. We added a sentence in the introduction paragraph of Section 9 that discusses the state of the default average speed distribution in MOVES2010, and a citation to a MOVES FACA work group presentation that included comparisons of the updated the TomTom average speed distributions with the MOVES2010 average speed distributions. The MOVES2010 average speed distributions for urban areas were based on average speed estimates from a survey of urban travel demand models, and the rural speeds were based on chase-car studies conducted in California. Changing the average speed distribution does not always have a large impact on the vehicle emissions. We have added text in Section 9.2 that discusses cases in which MOVES is not strongly sensitive to changes in the average speed distributions.

Comment 80: This [assumption of MOVES average speed distributions based on the average speed in each roadway segment, not second-by-second speed measurements] is even more troubling, because it indicates that the most disaggregate TomTom data were not employed.

Response: The average speed distribution is intended to be the average distribution of the average link speeds within a modeling domain. It is not intended to be the average speed distribution of a collection of second-by-second speeds.

Comment 81: I cannot recommend this [TomTom average speed analysis] or use of the results. Another independent data source is needed to verify these results. Naturalistic driving data [SHRP 2 Naturalistic Driving Study] or ATRI [truck GPS data from the American Transportation Research Institute] data.

Response: We did not have another comparable telematics or data set available to compare the results to the TomTom dataset. We agree this would be a valuable comparison going forward. As we mention in the Introduction and the introductory paragraph of Section 3, local users have the option to (and should wherever possible) replace the default activity inputs, including average speed distributions, with their own local data. Please also see the comments above regarding the sensitivity of average speed distributions on results.

Comment 82: A consistent method at the national level can have a significant bias and still be useful, as long as the bias is consistent over time. That is, you can look at percentage changes over time and even if the magnitude of the predicted value is consistently off by 20%, the results are useful. The problem here [with using TomTom data to represent national default average speed distribution in MOVES] is that regional agencies will likely use the same distributions in county or regional EI development. I would suggest that the guidance here inform regional and project level users that they need to develop their own speed distributions.

Response: The intention of this report is to document the default population and activity in MOVES. Recommended modeling approaches for regional and project level users is contained in the technical guidance documents.[3] For example, in the development of SIP and regional transportation conformity analysis, a local speed distribution is a necessary input.

Comment 83: Trucks operate in the two right-hand lanes. Field studies clearly show that the speed distributions in these lanes are very different than inside lanes, and trucks speed distributions can also differ in these lanes. A more appropriate data source is the ATA data set collected from trucks. I do not recommend "adjusting" the TomTom data for use here. You also do not need to show all of the equations below to tell the audience that you manually adjusted the values by [tell the audience in one paragraph of text]. You would be better off just showing the initial and shifted results in a comparative table. Providing all of these equations is an oversell of the quality of the data and the assumptions made. These equations can be moved to an Appendix if you decide move forward with this method.

Response: We have added text to Section 9.2 that points out that it would be preferable to have heavy-duty specific data on heavy-duty trucks, including combination trucks. We also state that we will prioritize updating the heavy-duty specific average speed data in the future. We have also added information regarding the energy and emissions sensitivity of the average speed adjustment on combination truck speeds. In addition, we have moved the equations and detailed discussion to an appendix.

25.2.2.9 Section 10 – Driving Schedules and Ramps

The use of the driving cycle weighting is an issue in MOVES (see comment 92 and 93). Use of local driving cycles is preferable when such data are available.

Comment 92: All of this assumes that the driving cycles are representative of these average speed cutpoints. I agree that the approach is probably better than the previous approach of using a "closed" cycle, but no compelling argument has been made that the weighting of the cycles employed in the latest algorithms matches real world composite driving for a facility. Some of the cycles were generated to make sure that we have adequate emission rate data for the model bins, not necessarily to be representative of onroad operations. [Tis] is not as big a deal at the national level (provided that all analyses backcast emissions for previous years and do not mix these outputs with the results of previous analyses that employed MOVES2010). However, there is no compelling reason to advocate that this default approach be used in regional or local analyses without corroboration.

Response: The driving schedules used by MOVES are derived from real world driving behavior rather than emission certification cycles, and while it is difficult to assure they are representative of all driving in the associated bin, we feel they are reasonable estimates for national defaults. In addition, MOVES is specifically designed to accept the use of local driving schedules and operating modes when this type of data is available, and EPA guidance explains that this type of data is preferred, especially for project-level analysis.[89]

Comment 93: The creep cycle was designed to assess emission rates for high inertial load lug operations required to get freight loads moving at low speeds (in freight yards as I recall). Matching this by average speed bin, based upon TomTom data, and weighting that bin may be a huge stretch and may even overstate emissions. Unfortunately, the only way to assess whether the method is viable is to do verification data collection, probably by extensive video analysis.

Response: Trucks driving at extremely low speeds (similar to the average speed of the creep cycle) will experience inertial load lug operations similar to those occurring in the creep cycle, due to stop-and-go operation. At the national and regional level, most truck operation will occur at speeds much higher than the creep cycle, so that any differences between the creep cycle and actual low-speed truck behavior will have little effect on overall emission estimates for trucks. In cases where the focus of the analysis is specifically on low speed operation, EPA recommends using project-level analysis with user supplied driving schedules.

It is not clear to users how they should handle activity on weaving and exit lanes. Comments [97-99] address this issue.

Comment 97: It is unclear whether the schedule includes any activity on weaving lanes (lanes that run between an entry ramp and the next exit ramp when ramps are close together). My assumption has always been (based upon Sierra Research presentation years ago) that weaving areas upstream of ramps were part of the freeway activity (and freeway driving cycles) and that ramps began at the gore area. Is there any way to confirm this and state it in the text?

Response: The text in Section 10.2 has been updated to make is clear that the total operation of vehicles on restricted roads (freeways) was divided so that ramp activity could be separated. Activity that occurs on the freeway in anticipation of ramps or occurring after entry is included in the non-ramp freeway.

Comment 98: It would be helpful to establish how these distributions were developed. A clear definition of start and end of ramp is warranted for user application. Perhaps some diagrams would support this. As I recall, the ramp cycles used car following data collected from gore area to the arterial and vice-versa, including any off-freeway weaving areas. It may be important to let the reader know that the HCM "area of influence" (about 450m upstream and downstream of the ramp) is not included in ramp activity but in freeway activity.

Response: The ramp operating mode distributions used in MOVES2014 are not based on data collected from ramp activity. The existing set of operating modes for ramps were selected to represent the different average speed bins. Updating the handling of ramps related to freeway driving is a high priority for future versions of MOVES.

25.2.2.10 Section 12 – Temporal Distributions

Section 12.3 provides defaults for temporal distributions. Again, local data are preferred given the variability noted across urban areas.

Response: EPA guidance generally advocates using local information in preference to MOVES defaults in almost all cases. MOVES specifically includes an importer for user inputs for temporal allocations in the County Data Manager and Project Data Manager to make it easier for users to provide their own data.

26 References

[1] Motor Vehicle Emission Simulator (MOVES) technical reports are available on the US Environmental Protection Agency website (http://www.epa.gov/oms/models/moves/moves-reports.htm). Please refer to the MOVES2009 or 2010 report for any MOVES2014 report that has not been finalized and published.

[2] US Environmental Protection Agency (EPA), Office of Transportation and Air Quality (OTAQ), *Population and Activity of On-road Vehicles in MOVES2014: Draft Report*, EPA Science Inventory, Record ID 309336, Ann Arbor, MI: July 2015, http://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=309336.

[3] US EPA, *MOVES2014 Technical Guidance: Using MOVES to Prepare Emission Inventories for State Implementation Plans and Transportation Conformity*, EPA-420-B-15-007, Ann Arbor, MI: January 2015, http://www.epa.gov/otaq/models/moves/documents/420b15007.pdf.

[4] US EPA, *Exhaust Emission Rates for Light-Duty On-road Vehicles in MOVES2014*, EPA-420-R-15-005, Ann Arbor, MI: October 2015, http://www3.epa.gov/otaq/models/moves/documents/420r15005.pdf.

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