MOVES2010 Highway Vehicle

Population and Activity Data

United States
Environmental Protection
Agency

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Assessment and Standards Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

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EPA-420-R-10-026
November 2010

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1. Introduction

The Environmental Protection Agency's MOVES (Motor Vehicle Emission Simulator) is a new set of modeling tools for estimating emissions produced by on-road (cars, trucks, motorcycles, etc.) and, eventually, nonroad (backhoes, lawnmowers, etc) mobile sources. MOVES2010 estimates greenhouse gases (GHG), criteria pollutants and selected air toxics from highway vehicles. MOVES2010 replaces MOBILE6.2 as the model for use in official state implementation plan (SIP) submissions to EPA and for transportation conformity analyses outside of California

MOVES calculates emissions for running exhaust, start exhaust, a number of evaporative processes and several other emission processes. In general, MOVES calculates these emissions by multiplying emission rates by emission activity and applying correction factors as needed. The emission rates and activity in MOVES are distinguished at much finer level than in MOBILE6. For example, most running emissions are categorized into one of 25 operating modes, depending on vehicle speed and vehicle specific power (VSP). Start emissions are distinguished based on the time a vehicle has been idle prior to start, and evaporative emissions modes are defined based on whether the vehicle is operating or has recently been operating. Vehicles are categorized into narrow subtypes or "source bins" with similar fuels, engine sizes and other emission-related characteristics.

MOVES is distributed with a default database of MOVES input data. The "domain" for the default database is the entire United States. MOVES users may create other domains for the model by supplying replacement data. In particular, EPA has issued "Technical Guidance on the Use of MOVES2010 for Emission Inventory Preparation in State Implementation Plans and Transportation Conformity[1]" for information on developing appropriate local inputs for SIP and conformity MOVES runs.

This report describes the default database information on vehicle population and vehicle activity as distributed in MOVES2010 and MOVES2010a (MOVESDB20091221 and MOVESDB20100830). Generally, the fleet & activity values in the MOVES2010a database are identical to those in MOVES2010. Where this is not true, the differences are explained in the text of this report. Emission rates and correction factors values in the default databases are described in other MOVES technical reports.[2]

1.1. Default Inputs and Fleet and Activity Generators

Much of the fleet & activity data used in the MOVES "core model" are calculated from inputs that are in format that is condensed or more readily available. MOVES uses "generators" to populate Core Model Input Tables (CMITS) from user inputs and MOVES defaults.

The Total Activity Generators (TAGs) estimates activity hours by taking base-year vehicle miles travelled (VMT) estimates, growing the VMT to the analysis year, and using speed information to transform VMT into source hours operating (SHO). The default database for MOVES2010 has two base years: 1990 and 1999. Other types of vehicle activity are generated by growing vehicle populations and applying appropriate conversions. For national inventory runs, annual national activity is distributed in time and geography using distribution factors. A separate version of the TAG creates inputs for emission rate runs.

The Source Bin Distribution Generator (SBDG) uses information on gasoline/diesel fractions, weightclass distributions and similar information to estimate the number of vehicles belonging to each narrow sourcebin as a function of sourcetype and vehicle model year.

The Operating Mode Distribution Generators use information on speed distributions and driving patterns to develop operating mode fractions for each sourcetype, roadtype and time of day.

The details of each these generators and other MOVES2010 algorithms are described in the MOVES Software Design and Reference Manual.[3]

This paper documents the sources and calculations used to produce the default population and activity data in the MOVES2010 database used to compute national level emissions based on defaults for individual counties, months, daytypes and hours of the day. In particular, this paper will describe the data used to fill the tables and fields listed in Table 1-1.

Table 1-1. MOVES Database Elements Covered in This Report

Database Table Name	Fields	Content*	Report Sections
AvgSpeedDistribution	avgSpeedFraction	Distribution of time among average speed bins	Section 10
DayVMTFraction	dayVMTFraction	Distribution of VMT between weekdays and weekend days	Section 12
DriveSchedule	averageSpeed	Average speed of each drive schedule	Section 11
DriveScheduleAssociation	sourceTypeID roadTypeID driveScheduleID isRamp	Mapping of which drive schedules are used for each combination of sourcetype and roadtype.	Section 11
DriveScheduleSecond	speed	Speed for each second of each drive schedule.	Section 11
FuelEngFraction	fuelEngFraction**	Joint distribution of vehicles with a given fuel type and engine technology. Sums to one for each sourcetype & model year	Section 4
HourVMTFraction	hourVMTFraction	Distribution of VMT among hours of the day	Section 12
HPMSVtypeYear	HPMSBaseYearVMT baseYearOffNetVMT VMTGrowthFactor	Base Year VMT by HPMS vehicle types and annual VMT growth factors.	Section 8
MonthGroupHour	AC Activity Terms (A, B & C)	Coefficients to calculate air conditioning demand as a function of heat index.	Section 15
MonthVMTFraction	monthVMTFraction	Distribution of annual VMT among months.	Section 12
PollutantProcessModelYear	modelYearGroupID	Assigns model years to appropriate model year groups. These vary with pollutant/process.	Section 4
RegClassFraction	regClassFraction**	Fraction of vehicles in a given "Regulatory Class." Sums to one for each sourceType, modelYear and fuel/engtech combination.	Section 4
RoadTypeDistribution	roadTypeVMTFraction	Distribution of VMT among roadtypes	Section 9
SampleVehicleDay	dayID sourceTypeID	Identifies vehicles in SampleVehicleTrip	Section 13
SampleVehiclePopulation	stmyFuelEngFraction stmyFraction	Incorporates the fractions found in the FuelEngFraction, RegClassFraction, SizeWeightFraction and SCCVTypeDistribution tables, but also expected fractions for vehicles that do not exist in the existing fleet. The expected values are used with the Alternative Vehicle Fuel & Technology Strategy inputs to generate alternate future vehicle fleet source bins.	Section 4

Database Table Name	Fields	Content*	Report Sections
SampleVehicleTrip	priorTripID keyontime keyOffTime	Trip start and end times; used to determine vehicle start and soak times.	Section 13
SCCVTypeDistribution	SCCVTypeFraction	Distribution of sourcetypes to EPA Source Classification Codes	Section 4
SizeWeightFraction	sizeWeightFraction**	Joint distribution of engine size and weight. Sums to one for each sourceType, modelYear and fuel/engtech combination.	Section 4
SourceBinDistribution	sourceBinActivityFraction	Distribution of population among different vehicle sub-types (sourcebins)	Section 4
SourceTypeAge	survivalRate relativeMAR functioningACFraction	Rate of survival to subsequent age; relative mileage accumulation rates and fraction of air conditioning equipment that is functioning	Section 6 & Section 15
SourceTypeAgeDistribution	ageFraction	Fraction of vehicle population at each age.	Section 5
SourceTypeHour	idleSHOFactor	Ratio of extended idle time to driving time, by hour.	Section 14
SourceTypeModelYear	ACPenetrationFraction	Prevalence of air conditioning equipment	Section 15
SourceTypePolProcess	isSizeWeightReqd isRegClassReqd isMYGroupReqd	Indicates which pollutant-processes the source bin distributions may be applied to and indicates which discriminators are relevant for each source type and pollutant/process.	Section 4
SourceTypeYear	sourceTypePopulation salesGrowthFactor migrationRate	Vehicle counts and growth factors	Section 3
SourceUseType	rollingTerm rotatingTerm dragTerm sourceMass	Road load coefficients for each SourceType, used to calculate Vehicle Specific Power.	Section 7
Zone	idleAllocFactor startAllocFactor SHPAllocFactor	Allocation of activity to zone (county).	Section 14
ZoneRoadType	SHOAllocFactor	Allocation of driving time to zone (county) and roadtype.	Section 14

* These summary descriptions are not intended to fully describe the input for each field. See the associated section for a full description.
** These tables are used outside MOVES to generate the SampleVehiclePopulation table, but they are not used by the MOVES2010 model and are included in the default database only for reference.

1.2. MOVES SourceTypes

The primary vehicle classification in MOVES is "SourceType." (Also sometimes called "SourceUseType"). This name was selected because when MOVES eventually incorporates nonroad equipment, the sourcetypes will include many emission sources that are not vehicles.

sourcetypes are derived from DOT's HPMS vehicle classes and are intended to be groups of vehicles with similar activity patterns. The MOVES2010 sourcetypes are listed in Table 1-2, along with the associated DOT Highway Performance Monitoring System (HPMS) vehicle classes.

Table 1-2. MOVES2010 SourceTypes

SourceType ID	SourceType	HPMS Vehicle Class
11	Motorcycles	Motorcycles
21	Passenger Cars	Passenger Cars
31	Passenger Trucks (primarily personal use)	Other Two-Axle/Four Tire, Single Unit
32	Light Commercial Trucks (other use)	Other Two-Axle/Four Tire, Single Unit
41	Intercity Buses (non-school, non-transit)	Buses
42	Transit Buses	Buses
43	School Buses	Buses
51	Refuse Trucks	Single Unit
52	Single Unit Short-haul Trucks	Single Unit
53	Single Unit Long-haul Trucks	Single Unit
54	Motor Homes	Single Unit
61	Combination Short-haul Trucks	Combination
62	Combination Long-haul Trucks	Combination

In MOVES, "long-haul" trucks are defined as trucks for which most trips are 200 miles or more.

2. Data Sources

A number of organizations collect data relevant to this report. The most important sources used to populate the vehicle population and activity portions of 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.

2.1. VIUS(and TIUS)

Until 2002, the U.S. Census Bureau conducted the Vehicle Inventory and Use Survey (VIUS)[4] to collect data on the physical characteristics and activity of U.S. trucks every five years. The survey is a sample of private and commercial trucks that were registered in the U.S. as of July of the survey year. The survey excludes automobiles, motorcycles, government-owed vehicles, ambulances, buses, motor homes and nonroad equipment.

For MOVES, VIUS provides information to characterize trucks by sourcetype and to estimate age distributions, diesel fractions, and regulatory class distributions. MOVES2010 uses data from both the 1997 and 2002[5] surveys. Before 1997, VIUS was known as TIUS (Truck Inventory and Use Survey). To populate the 1990 base year, we used data from the 1992 TIUS.[6]. While the survey includes a large number of vehicles and was designed to be representative of the U.S. 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 Census Bureau has discontinued the VIUS survey. We are investigating alternate data sources and approaches for determining truck populations in the future.

2.2. Polk NVPP® and TIP®

R.L. Polk & Co. is a private company providing automotive information services. The company maintains two databases relevant for MOVES: the National Vehicle Population Profile (NVPP®)[7] and the Trucking Industry Profile (TIP®Net) Vehicles in Operation database.[8] The first focuses on light-duty cars and trucks, the second focuses on medium and heavy-duty trucks. Both compile data from state vehicle registration lists.

For MOVES2010, EPA used the 1999 NVPP® and TIP®. Polk data was used in determining vehicle populations, diesel fractions, engine size fractions and vehicle weight class fractions.

2.3. FHWA *Highway Statistics*

Each year the U.S. 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 states and other sources.

For MOVES210, we used data on vehicle populations (registrations) and vehicle miles traveled (VMT), as summarized in four tables. [9] [10] [11] [12]. Hereafter, references will be to FHWA MV-1, MV-10, VM-1, and VM-2. For the 1999 base year, we used the 1999 statistics; for the 1990 base year, we used 1990 numbers.

2.4. FTA National Transit Database

The U.S. DOT, Federal Transit Administration (FTA) summarizes financial and operating data from U.S. mass transit agencies in the National Transit Database (NTD).[13]

For MOVES2010, we used 1999 data from the report, "Age Distribution of Active Revenue Vehicle Inventory: Details by Transit Agency," to determine age distributions and diesel fractions for transit buses.

2.5. School Bus Fleet Fact Book

The School Bus Fleet 1999 Fact Book includes estimates, by state, of number of school buses and total miles traveled.[14] The Fact Book is published by Bobit Publications.

Information from the 1999 and 1990 School Bus Fleet Fact Book was used in estimating school bus vehicle populations. School bus mileage accumulation rates came from the 1997 Fact Book by way of MOBILE6.

2.6. MOBILE6

MOBILE6 was a precursor to MOVES used to estimate highway vehicle emissions. In some cases, we have used data from MOBILE6 modelwith only minor adaptation. In particular, we used MOBILE6 data for mileage accumulations, air conditioning rates, school bus diesel fractions, urban speed distributions, and many 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."[15] Additional MOBILE6 documentation is available on the web at http://www.epa.gov/otaq/m6.htm

2.7. Annual Energy Outlook & National Energy Modeling System

The Annual Energy Outlook (AEO) [16,17] 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 projections. For MOVES2010 we used *AEO2006* to forecast VMT growth and vehicle sales growth for most vehicles, but updated the passenger car, passenger truck and light commercial truck with information from AEO2009. For MOVES2010a we used AEO2010 to update VMT and sales growth estimates for heavy and medium duty trucks.

2.8. Transportation Energy Data Book

Each year, Oak Ridge National Laboratory produces the DOE Transportation Energy Data Book (TEDB). This book summarizes transportation and energy data from a variety of sources.

For MOVES we used TEDB information in estimating vehicle population, sales, and survival fractions. Beginning with MOVES2004, we relied on Edition 22, published in September 2002[18] and Edition 23, published in October 2003.[19] We later updated 1990 values using Edition 13, published in 1993. For MOVES2010 we updated sales growth based on Edition 27, published in 2008.[20] MOVES2010a includes heavy- and medium-duty sales growth updates from Edition 28, published in 2009.[21]

2.9. Oak Ridge National Laboratory Light-duty Vehicle Database

Oak Ridge National Laboratory Center for Transportation Analysis has compiled a database of light-duty vehicle information which combines EPA Test vehicle data and Ward's Automotive Inc. data spanning 1976 – 2001.[22] We used this database to determine weight distributions for light trucks by model year.

3. Vehicle Population Data by Calendar Year

The SourceTypeYear table stores three data fields—**SourceTypePopulation, SalesGrowthFactor**, and **Migration Rate**. SourceTypePopulation stores the total population of vehicles by sourcetype for MOVES base years. SalesGrowthFactor field stores a multiplicative factor indicating the change in sales by sourcetype for calendar years after the base year. Migration Rate is not used in MOVES2010. Each field is described below in terms of what information it contains, the sources of the data used for the field, and, when applicable, certain data points used in determining the field parameters.

3.1. 1999 SourceTypePopulation

In the MOVES default database, the SourceTypePopulation field stores the total population of vehicles in entire United States in 1990 and 1999 by sourcetype. Some of the values are taken directly from the indicated sources; other values needed to be derived from the available data.

SourceTypePopulation values are used for base years and provide the basis for Total Activity Generator calculation of populations in calendar years after the base year. These populations are, in turn, used to generate travel fractions by age and sourcetype and to allow allocation of VMT by age.

The primary sources for calendar year 1999 vehicle population data are the FHWA *Highway Statistics* Tables MV-1 and MV-10 and the Polk NVPP® and TIP® databases. The Transportation Energy Data Book (TEDB) explains three factors that account for differences between the two sources:

1. Polk data includes only vehicles that were registered on July 1 of 1999. FHWA data includes all vehicles that have been registered at any time throughout the year and thus may include vehicles that were retired during the year or may double count vehicles registered in two or more states.
2. Polk and FHWA may differ in how they classify some minivans and SUVs as trucks or automobiles. (This difference is less important since 1990).
3. FHWA includes all non-military Federal vehicles. Polk data includes only those Federal vehicles that are registered within a state.

Also, FHWA data is available for Puerto Rico, but Puerto Rico does not appear to be included in our Polk data set. MOVES will cover Puerto Rico and the Virgin Islands. In addition, Polk collects data on Gross Vehicle Weight (GVW) class 3 vehicles in both the NVPP® and TIP® databases, but the values are not the same. Polk staff recommended using the TIP® values.[23] Finally, our 1999 Polk data set includes school buses and motor homes (which can be counted separately), but does not include "non-school buses."

Motorcycle population estimates were available from both FHWA registration data and from the Motorcycle Industry Council. The MIC estimate is based on 1998 sales estimates, adjusted to subtract noped sales (nopeds are similar to mopeds, but lack pedals) and to account for scrappage.

The Department of Transportation's National Household Transportation Survey (NHTS) combines the previous National Personal Transportation Survey and the American Travel Survey to collect data on personal travel patterns and includes data on motorcycles, personal trucks and automobiles.[24] Data from the 2001 survey is included in Table 3-1, but was not used in MOVES because it is two years newer than the base year, and it excludes non-household vehicles. Values from the five data sources are compared in Table 3-1.

Table 3-1. Vehicle Population Comparisons 1999

Data Source	Motorcycles	Automobiles	Trucks (total)	Buses (total)	Motor Homes
FHWA MV-1 (w Puerto Rico and publically ownedvehicles)	4,173,869	134,480,432	83,178,092	732,189	
FHWA MV-1 (w/o Puerto Rico and publically owned vehicles)		131,076,551	81,060,369[a]		
Polk NVPP® & TIP®		126,868,744	80,323,528*		902,949
NHTS (2001)	4,951,747	115,914,908	80,499,939		1,446,469
MIC (1998)[25]	4,605,439				

*Excluding motor homes and NVPP® GVW3 trucks.

For automobiles and trucks, it is possible to do a direct comparison of Polk and FHWA data. To estimate the MOVES population, we adjust the FHWA data to account for double-counting by multiplying the total FHWA population by the ratio of the Polk population to the FHWA population without public vehicles and Puerto Rican vehicles.

$$\text{Adjusted Population} = \text{FHWA}_{\text{w public \& PR}} * (\text{Polk}/\text{FHWA}_{\text{w/o public \& PR}})$$

This leads to the values in Table 3-2.

Table 3-2. Adjusted Vehicle Populations

	Population
Automobiles	130,163,354
Trucks (total)	83,007,993

For MOVES, total trucks are sub-classified into seven sourcetypes. The proportion of total trucks in each sourceType was estimated using VIUS responses for Axle Arrangement, Primary Area of Operation, Body Type and Major Use as detailed in Table 3-3 and Table 3-4.

With these definitions and with vehicles that lack AREAOP codes assigned proportionally to the corresponding sourcetypes, we computed the distributions in Table 3-5.

[a] In our peer review, we learned that this number was recorded incorrectly. The correct number is 81,090,659, but this was not remedied prior to MOVES release. This causes a discrepancy of less than 0.04% in the national total truck population and will have no impact on runs using local population inputs.

These distributions were multiplied by the total truck population from Table 3-2 to derive population values for MOVES.

Table 3-3. VIUS 1997 Codes Used for Distinguishing Truck SourceTypes.

SourceType	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 (BODTYP=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

Table 3-4. VIUS 2002 Codes Used for Distinguishing Truck SourceTypes.

SourceType	Axle Arrangement	Primary Area of Operation	Body Type	Operator Classification
Passenger Trucks	axle_config in (1,6,7,8)	any	any	opclass=5
Light Commerical Trucks	axle_config in (1,6,7,8)	any	any	opclass<>5
Refuse Trucks	axle_config in (2,3,4,5,9,10,11,12,13,14,15,16,17,18,19,20)	trip_primary in (1,2,3,4)	bodytype=21	any
Single Unit Short-Haul Trucks	axle_config in (2,3,4,5,9,10,11,12,13,14,15,16,17,18,19,20)	trip_primary in (1,2,3,4)	Any except bodytype=21	any
Single Unit Long-Haul Trucks	axle_config in (2,3,4,5,9,10,11,12,13,14,15,16,17,18,19,20)	trip_primary in (5,6) Long Range	any	any
Combination Short-Haul Trucks	axle_config>=21	trip_primary in (1,2,3,4)	sample_strata=5 Combination Trucks	any
Combination Long_Haul Trucks	axle_config>=21	trip_primary in (5,6) Long Range	sample_strata=5 Combination Trucks	any

Table 3-5. 1999 Truck SourceType Distribution and Populations

SourceType	Percent	Population
Passenger Trucks	68.90%	57,190,192
Light Commercial Trucks	23.02%	19,106,257
Refuse Trucks	0.11%	88,607
Single Unit Short-haul Trucks	5.39%	4,470,798
Single Unit Long-haul Trucks	0.32%	264,435
Combination Short-haul Trucks	1.31%	1,084,366
Combination Long-haul Trucks	.97%	803,337
Total	100.00%	83,007,993

For buses, we needed to distribute the total buses from FHWA to the three MOVES classes. Additional information on bus numbers was available from the FTA NTD, Polk TIP®, and the School Bus Fleet Fact Book, the American Public Transit Association, and the American Bus Association "Motorcoach Census 2000".[26] The FTA NTD provides population numbers for a variety of transit options. To determine the number of transit buses, we summed their counts for Articulated Motor Buses, Motor Bus Class A, B & C, and Double Decked buses.

Table 3-6. 1999 Bus Population Comparisons

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[b]				594,800
FTA NTD			55,706	
APTA[27] ***			75,087	
Polk TIP®				460,178
School Bus Fleet Fact Book				429,086
Motorcoach Census**		44,200		

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

As Table 3-6 shows, estimates of bus populations vary. We chose to use the FHWA value because it includes church and industrial buses that we believe have activity patterns more similar to school buses than to intercity buses. To calculate the number of buses for the categories needed for MOVES, we used the FHWA school bus value and the FTA transit bus

[b] Peer review suggested adjusting the MV-10 values to account for Puerto Rico. This approach should be considered for future databases. In 1999, this change would slightly increase the number of school buses and, more importantly, would decrease the number of intercity buses to 81, 683, a change of about three percent.

value. We assigned the remaining total FHWA buses (732,189-592,029-55,706 = 84,454) to the intercity category.

For motorcycles we used the 1999 FHWA value from table MV-1. For comparison, Table 3-1 also shows the 1998 population as estimated by the Motorcycle Industry Council based on sales and estimated scrappage rates, and the 2001 population estimated by the 2001 NHTS. The FHWA population estimates are noticeably lower than the other estimates.

For motor homes we used the population from the Polk TIP® database. In Table 3-1, this value is compared to the estimate from the 2001 NHTS. As for motorcycles, the FHWA registration count is noticeably lower than the household survey estimate. This could reflect population growth in the years between the estimates, or it may reflect difference in the way motor homes are defined in the two studies, or be an artifact of the method used to extrapolate from the NHTS sample to the national population estimate. If time and resources allow, EPA may investigate this further for future versions of the MOVES model.

Table 3-7 summarizes the 1999 vehicle populations used in MOVES2010.

Table 3-7. 1999 SourceType Populations in MOVES2010

SourceType ID	SourceType	1999 Population
11	Motorcycles	4,173,870
21	Passenger Cars	130,163,000
31	Passenger Trucks	57,190,200
32	Light Commercial Trucks	19,106,300
41	Intercity Buses	84,454
42	Transit Buses	55,706
43	School Buses	592,029
51	Refuse Trucks	88,607
52	Single Unit Short-haul Trucks	4,470,800
53	Single Unit Long-haul Trucks	264,435
54	Motor Homes	902,949
61	Combination Short-haul Trucks	1,084,370
62	Combination Long-haul Trucks	803,337

3.2. 1990 SourceTypePopulation

Because some State Implmentation Plans require estimates of 1990 emissions, the MOVES database includes a 1990 base year. The SourceTypePopulation inputs for 1990 were developed using methods and data similar to those used for 1999.

The primary sources for calendar year 1990 vehicle population data are the FHWA Highway Statistics Tables MV-200, VM- 201A, MV-10 and the Polk NVPP® databases. As in 1999, the FHWA and Polk data differ in how vehicles are counted. (See previous section.) Additionally, the 1990 Polk data does not include buses and motor homes. The National Personal Transportation Survey includes data on personal trucks, automobiles and motorcycles.

Data on motorcycles were also obtained from the Motorcycle Statistical Annual published by the Motorcycle Industry Council. Values from all four sources are compared in Table 3-1.

Registration data on vehicles registered in Puerto Rico for year 1990 was obtained from FHWA's Highway Statistics 1990.

Table 3-8. 1990 Vehicle Population Comparisons

Data Source	Motorcycles	Automobiles	Trucks (total)	Buses (total)	Motor Homes
FHWA(w/ Puerto Rico and Publicly owned vehicles)[1]	4,278,286	135,022,124	54,673,458	629,943	na
FHWA (w/o Puerto Rico and w/ Publicly owned vehicles)[2]	4,259,461	133,700,497	54,470,430	626,987	na
Polk NVPP®	na	123,276,600	56,023,000[3]	na	na
NPTS (1990)[4]	2,089,523	120,712,000	37,110,000	na	821,000
Motorcycle Industry Council[5]	4,310,000	na	na	na	na

[1] Data on Puerto Rico was obtained from Highway Statistics 1990, published by the FHWA.
[2] For these numbers, we used data from FHWA Highway Statistics TableVM-201A, April 1997 and Table MV-200 (state motor vehicle registrations, by years 1990-1995).
[3] As published in TEDB edition 23. Does not include Puerto Rico and publicly –owned vehicles.
[4] 1990 NPTS special report on travel modes- Chapter 3, the Demography of the US Vehicle Fleet. The motorcycle number is calculated using the appendix table and the proportion of MCs from Table 20 of the 2001 NHTS Summary of Travel Trends.
[5] The Motorcycle number was obtained as a sum of on-highway and dual motorcycles for year 1990 as published in the 1999 Motorcycle Statistical Annual.

For MOVES, total trucks are sub-classified into seven sourcetypes. The proportion of total trucks in each subtype was estimated using TIUS92 responses for Axle Arrangement, Primary Area of Operation, Body Type and Major Use as detailed in Table 3-9.

With these definitions and with vehicles that lack AREAOP codes assigned proportionally to the corresponding sourcetypes, we computed the distributions in Table 3-10. These distributions were multiplied by the Polk total truck population in Table 3-8 to derive population values for MOVES.

Table 3-9. TIUS92 Codes Used for Distinguishing Truck SourceTypes.

SourceType	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 (BODTYP=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

Table 3-10. 1990 Truck SourceType Distribution and Populations

SourceType	Percent	Population
Passenger Trucks	67.32%	37,713,840
Light Commercial Trucks	24.07%	13,483,198
Refuse Trucks	0.11%	59,037
Single Unit Short-haul Trucks	6.12%	3,426,459
Single Unit Long-haul Trucks	0.23%	128,776
Combination Short-haul Trucks	1.35%	758,091
Combination Long-haul Trucks	0.81%	453,599
Total	100.00%	56,023,000

For buses, we needed to distribute the total buses from FHWA to the three MOVES classes. Additional information on bus numbers was available from the American Public Transit Association (APTA) Fact Book, the School Bus Fleet Fact Book, and the Transportation Energy Data Book.

Table 3-11. 1990 Bus Population Comparisons

Data Source	Total Buses	Intercity Buses	Transit Buses	School Buses
FHWA (w/o PR and with Publicly-owned Vehicles)*	626,9871	20,6802		545,7223
FHWA (w/o PR and w/o Publicly-owned Vehicles)	275,4931			
APTA Historical Tables[28]			58, 714	
TEDB**		58,141	59,753	508,261
School Bus Fleet Fact Book***				391,714

* FHWA Highway Statistics, Summary to 1995, Table MV-200
** Transportation Energy Data Book : Edition 13, March 1993, Table 3.29. 1990 buses. "Intercity Buses" is sum of "Intercity Bus" and "Other;" "School Buses" includes other non-revenue buses.
*** Average of school years 1989-90 and 1990 -91, School Bus Fleet Fact Books 1990 and 1991.

Table 3-12 summarizes the 1990 vehicle populations used in MOVES2010. For motor homes we used the only available data from NPTS. We used the TEDB data for buses. For trucks the TIUS data was used; the remaining values were based on FHWA data.

Table 3-12. 1990 SourceType Populations in MOVES2010

SourceType ID	SourceType	1990 Population
11	Motorcycles	4,278,286
21	Passenger Cars	135,022,124
31	Passenger Trucks	37,713,840
32	Light Commercial Trucks	13,483,198
41	Intercity Buses	58,141
42	Transit Buses	59,753
43	School Buses	508,261
51	Refuse Trucks	59,037
52	Single Unit Short-haul Trucks	3,426,460
53	Single Unit Long-haul Trucks	128,776
54	Motor Homes	821,000
61	Combination Short-haul Trucks	758,091
62	Combination Long-haul Trucks	453,599

3.3. SalesGrowthFactor

The SalesGrowthFactor field stores a multiplicative factor indicating changes in sales by sourcetype for calendar years after the base year. It determines the number of new vehicles added to the vehicle population each year, and is expressed relative to the previous year's sales. For example, "1" means no change from previous year sales levels, "1.02" means a two percent increase in sales, and "0.98" means a two percent decrease in sales. SalesGrowthFactor is used in the Total Activity Generator calculation of source type populations for calendar years after the base year-- in MOVES2010, years 2000 through 2050.

Note that the sales growth factors are not used in the calculation of county-level or project level emissions, where users must input local vehicle populations for each year that is modeled.

The data sources and methodologies by source type are described below:

- **Passenger Cars, Passenger Trucks and Light Duty Commercial Trucks:** SalesGrowthFactors for calendar year 2000 through 2007 were derived from total sales numbers reported in the TEDB28 Table 4.5 and 4.6. Factors for calendar years 2008 through 2030 were derived from new vehicle sales estimates presented in *AEO2009Supplemental Table 57*, generated by NEMS[c]. A constant annual growth rate of 0.76% was used for years 2031-2050. 0.76% is consistent with the value used in Draft MOVES2009 for passenger cars, and significantly lower than the value used for trucks in Draft MOVES2009. This decrease in future sales is consistent with the overall decrease in truck sales predicted in AEO2009. Note that the growth factor in each year is relative to the preceding year's sales. 1999 sales are calculated from the 1999 population after applying the Age 0 age fraction and survival fraction. They are slightly different that the sales numbers shown in the TEDB. Also, with no data to distinguish sales of passenger trucks and light duty commercial trucks, EPA assumed the same sales growth rates for both.
- **Motorcycles:** SalesGrowthFactors for calendar year 2000 and 2008 were computed from information from the Motorcycle Industry Council and from Polk registration data from 2008. More details are available in a contractor report on the analysis.[29] In MOVES2010, SalesGrowthFactors for years 2008 through 2050 were inadvertently unchanged from Draft MOVES2009, where they had been set equal to passenger car growth factors (ie, based on AEO2006). In MOVES2010a, the sales growth was updated for years 2009 and later as indicated in the contractor report.
- **Buses, Single Unit Trucks & Motor Homes:** For MOVES2010 these estimates were unchanged from previous versions of the model. Calendar years 2000-2001 were based on sales as reported in TEDB23 Table 5.3 (gross weight range 10,000-33,000 lbs). Years 2004 through 2030 were calculated from medium-duty truck sales projections from *AEO2006*Supplemental Table 55. For MOVES2010a, calendar

[c] AEO2009 predates the Model Year 2011 CAFE rule, and the related redefinitions of cars and trucks, so it is consistent with the definitions used in MOVES2010.

years 2000-2007 were based on sales reported in TEDB28 and calendar years 2008 and later were based on values in AEO2010 Table 67.

- **Combination Trucks, Refuse Trucks**: For MOVES2010,these estimates were unchanged from previous versions of the model. Calendar years 2000-2001 were based on sales as reported in TEDB23 Table 5.3 (gross weight range 33,001 and greater pounds). Years 2004 through 2030 were calculated from heavy-duty truck sales projections found in *AEO2006* Supplemental Table 55. For MOVES2010a, calendar years 2000-2007 were based on sales reported in TEDB28 and calendar years 2008 and later were based on values in AEO2010 Table 67.

The resulting SalesGrowthFactors by source type are shown in Table 3-13 and Table 3-14.

Table 3-13. MOVES2010 SalesGrowthFactor by Calendar Year and Source Type

Calendar Year	Motorcycles	Passenger Cars	Passenger and Light Commercial Trucks	Buses, Single Unit Trucks & Motor Homes	Combination Trucks
2000	1.244	1.049	1.087	0.963	0.809
2001	1.178	0.952	1.037	0.850	0.660
2002	1.109	0.962	1.001	0.882	0.923
2003	1.055	0.939	1.026	1.067	1.042
2004	1.111	0.991	1.047	1.170	1.310
2005	1.108	1.023	0.991	1.082	1.130
2006	1.073	1.013	0.936	1.001	1.010
2007	0.992	0.974	0.975	1.001	0.940
2008	1.040	0.895	0.671	1.003	0.990
2009	0.985	0.892	0.792	1.026	1.000
2010	0.980	1.192	1.419	0.992	1.000
2011	1.005	1.137	1.089	0.997	0.990
2012	0.996	1.091	1.025	0.986	1.000
2013	0.991	1.065	1.037	1.000	1.010
2014	0.989	1.055	1.007	1.029	1.020
2015	0.994	1.101	0.986	1.035	1.020
2016	1.001	1.000	0.970	1.025	1.020
2017	1.002	0.995	0.979	1.015	1.020
2018	1.005	1.026	0.978	1.010	1.000
2019	1.004	1.024	0.983	0.995	0.980
2020	1.007	1.021	0.980	0.997	0.980
2021	1.007	1.000	0.986	1.006	1.000
2022	1.009	1.004	0.990	1.012	1.010
2023	1.009	1.014	1.005	1.015	1.010
2024	1.009	1.018	1.013	1.018	1.020
2025	1.008	1.020	1.019	1.018	1.020
2026	1.010	1.015	1.008	1.016	1.020
2027	1.008	1.007	1.005	1.012	1.010
2028	1.007	1.008	0.998	1.006	1.000
2029	1.008	1.011	0.992	1.010	1.010
2030	1.008	1.012	1.015	1.013	1.010
2031+	1.008	1.008	1.008	1.013	1.010

Table 3-14. MOVES2010a SalesGrowthFactor by Calendar Year and Source Type

Calendar Year	Motorcycles	Passenger Cars	Passenger and Light Commercial Trucks	Buses, Single Unit Trucks & Motor Homes	Combination Trucks
2000	1.244	1.049	1.087	0.980	0.980
2001	1.178	0.952	1.037	0.902	0.902
2002	1.109	0.962	1.001	0.850	0.850
2003	1.055	0.939	1.026	1.128	1.128
2004	1.111	0.991	1.047	1.232	1.232
2005	1.108	1.023	0.991	1.238	1.238
2006	1.073	1.013	0.936	0.991	0.991
2007	0.992	0.974	0.975	0.991	0.991
2008	1.040	0.895	0.671	0.967	0.967
2009	0.500	0.892	0.792	0.908	0.908
2010	1.340	1.192	1.419	1.041	1.041
2011	1.240	1.137	1.089	1.086	1.086
2012	1.200	1.091	1.025	1.071	1.071
2013	1.000	1.065	1.037	1.048	1.048
2014	1.000	1.055	1.007	1.036	1.036
2015	1.000	1.101	0.986	1.036	1.036
2016	1.000	1.000	0.970	1.036	1.036
2017	1.000	0.995	0.979	1.034	1.034
2018	1.000	1.026	0.978	1.032	1.032
2019	1.000	1.024	0.983	1.030	1.030
2020	1.000	1.021	0.980	1.029	1.029
2021	1.000	1.000	0.986	1.024	1.024
2022	1.000	1.004	0.990	1.022	1.022
2023	1.000	1.014	1.005	1.026	1.026
2024	1.000	1.018	1.013	1.028	1.028
2025	1.000	1.020	1.019	1.028	1.028
2026	1.000	1.015	1.008	1.028	1.028
2027	1.000	1.007	1.005	1.028	1.028
2028	1.000	1.008	0.998	1.027	1.027
2029	1.000	1.011	0.992	1.028	1.028
2030	1.000	1.012	1.015	1.028	1.028
2031	1.000	1.008	1.008	1.027	1.027
2032	1.000	1.008	1.008	1.027	1.027
2033	1.000	1.008	1.008	1.028	1.028
2034	1.000	1.008	1.008	1.028	1.028
2035+	1.000	1.008	1.008	1.028	1.028

3.4. MigrationRate

The MigrationRate field stores a yearly multiplicative factor that could be used to estimate how many vehicles join or leave the population of a sourcetype in the given domain in a given year. When MOVES was initially designed, we expected this field would be useful when modeling emissions on relatively small geographic scale where vehicle populations might change due to factors other than sales and scrappage. This field is currently not used and is populated with a migration rate of 1, indicating no migration of vehicles.[d]

4. Emission-Related Vehicle Characteristics (Source Bins)

The sourcetypes in MOVES are defined based on large scale, easily observable characteristics such as number of axles, and activity characteristics (such as long-haul vs. short haul). But to estimate emissions, MOVES must also know the emission-related characteristics of the vehicle such as the type of fuel that it uses and the emission standards it is subject to. Thus, in MOVES, we group vehicles into SourceBins that classify a vehicle by discriminators relevant for emissions and energy calculations: fuel and engine technology, average vehicle weight and engine displacement, model year group, and regulatory class.
SourceBin information in MOVES is stored in the SampleVehiclePopulation Table. This table also stores information to link each sourcebin to a Source Classification Code (SCC) for use if a user requests output by SCC.

The MOVES Source Bin Generator code determines which discriminators are relevant for a given pollutant/process combination and multiplies the relevant fractions from the tables listed above to determine the detailed SourceBinDistribution for each combination of Pollutant, Process, sourcetype, and Model Year. In general, fueltype and model year group are relevant for all emission calculations. Regulatory class is relevant for most pollutants and processes, except some energy calculations in MOVES2010, which rely on engine size and vehicle weight. MOVES2010a does not use engine size and vehicle weight classifications in any calculation.

For some uses, particularly the preparation of national inventories, modelers will need to produce output aggregated by EPA's Source Classification Codes (SCC). The EPA's highway vehicle SCC were derived from MOBILE5 and MOBILE6 and do not directly correspond to the MOVES sourcetypes. For example, depending on its fuel and Gross Vehicle Weight (GVW) limits, a vehicle in the MOVES Passenger Truck category may be coded with one of eight SCCs—including the SCC for a Light-Duty Gasoline Truck 1, a Light-Duty Gasoline Truck 2, a Heavy-Duty Gasoline Truck, a Light-Duty Diesel Truck, or one of the four codes for Heavy-Duty Diesel Vehicle.

[d] For motorcycles, the migration rate was mistakenly populated for some years in MOVES2010. We fixed this in MOVES2010a.

Table 4-1. Data Tables Used to Allocate SourceType to SourceBin

Generator Table Name	Key Fields**	Additional Fields	Notes
SourceTypePolProcess	SourceTypeID PolProcessID	isSizeWeightReqd isRegClassReqd isMYGroupReqd	Indicates which pollutant-processes the source bin distributions may be applied to and indicates which discriminators are relevant for each sourceType and polProcess (pollutant/process combination)
FuelEngFraction*	SourceTypeID ModelYearID FuelTypeID EngTechID	fuelEngFraction	Joint distribution of vehicles with a given fuel type and engine technology. Sums to one for each combination of sourceType & modelYear
SizeWeightFraction*	SourceTypeID ModelYearID FuelTypeID EngTechID WeightClassID EngSizeID	sizeWeightFraction	Joint distribution of engine size and weight. Sums to one for each sourceType, modelYear and fuel/engine technology combination.
RegClassFraction*	SourceTypeID ModelYearID FuelTypeID EngTechID RegClassID	regClassFraction	Fraction of vehicles in a given "Regulatory Class." Sums to one for each sourceType, modelYear and fuel/engine technology combination.
PollutantProcessModelYear	PolProcessID ModelYearID	modelYearGroupID	Assigns model years to appropriate model year groups.
SCCVtypeDistribution*	SourceTypeID ModelYearID FuelTypeID SCCVtypeID	SCCVtypeFraction	Fraction of vehicles in a given SCC vehicle class. Sums to one for each sourceType, modelYear and fuelType combination.
SampleVehiclePopulation	SourceTypeID ModelYearID FuelTypeID EngTechID RegClassID WeightClassID EngSizeID SCCVTypeID	stmyFuelEngFraction stmyFraction	Includes the fractions found in the FuelEngFraction, RegClassFraction, SizeWeightFraction and SCCVTypeDistribution tables, but also for combinations that do not exist in the existing fleet. This table is also used with the Alternative Vehicle Fuel & Technology Strategy inputs to generate alternate future vehicle fleet source bins.

* These tables are used outside the model to generate the SampleVehiclePopulation table, but they are not used by the MOVES2010 model and are included in the default database only for reference.
** In these tables, the SourceTypeID and ModelYearID are combined into a single SourceTypeModelYearID.

The MOVES model is designed to aggregate emissions to the user's choice of sourcetype or SCC using information from the SCCVTypeDistribution table. For each combination of sourcetype, Model Year and FuelType, the SCCVTypeDistribution table lists IDs for the possible SCC and the fraction of vehicles assigned to each SCC. The full SCC also includes a suffix that indicates roadway type. This is a mapping from the MOVES roadtype on which the emissions occur to the HPMS Facility Type used in the SCC codes. This mapping is captured in the SCCRoadTypeDistribution table described in Section 9.2.

The fractions described here are intended to represent national averages. Because the distribution of vehicle characteristics varies geographically, local inputs should be used for local runs when available.

More detailed descriptions of the SourceBin Distribution and SCC inputs for each sourcetype follow.

4.1. Motorcycles

Motorcycle characteristics were assigned based on information from EPA motorcycle experts and from the Motorcycle Industry Council.

4.1.1. FuelEngFraction

We assume all motorcycles are powered by conventional gasoline engines.

4.1.2. SizeWeightFraction

The SizeWeightFraction is used for calculating energy consumption in MOVES2010, but not in MOVES2010a. 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 4-2.

Table 4-2. 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

4.1.3. RegClassFraction

All Motorcycles were assigned to the "Motorcycle" (MC) regulatory class.

4.1.4. SCCVtypeDistribution

All Motorcycles were assigned to the "Motorcycle" SCC (prefix 2201080).

4.2. Passenger Cars

For base year 1999, passenger car distributions were derived from the 1999 Polk NVPP®. The national files for domestic and imported cars were consolidated into a single file.

7.2.1. FuelEngFraction

The FuelEngFraction table assigns fractions of each source type and model year to all relevant combinations of fuel type bin and engine technology bin. For MOVES2010 defaults, the only engine technology used was "conventional internal combustion." Fuel fractions were computed from the Polk data car counts and fuel classifications. The fractions were edited to remove the small fractions of non-diesel, non-gasoline fuels and renormalized. For 2000-and-later a diesel fraction of 0.38% was used for each model year. This is an average of the diesel fractions reported in Ward's Automotive Yearbook for model years 1998-2007[30].

4.2.2. SizeWeightFraction

The SizeWeightFraction is used for calculating energy consumption in MOVES2010, but not in MOVES2010a. The Polk cubic displacement values were converted to liters and assigned to the MOVES engine size bins. The weight ID 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.

4.2.3. RegClassFraction

All Passenger Cars were assigned to the "Light-Duty Vehicle" (LDV) regulatory class.

4.2.4. SCCVtypeFraction

All gasoline Passenger Cars were assigned to the Light Duty Gas Vehicle (LDGV) SCC (prefix 2201001). All other Passenger Cars were assigned to the Light Duty Diesel Vehicle SCC (prefix 2230001). If the Alternative Vehicle Fuels and Technologies control strategy is used to assign vehicles to the "Electric" fueltype, those vehicles are mapped to "LDGV" because there is no SCC for electric vehicles.

4.3. General Trucks

This section describes how default Source Bin information was compiled for Passenger Trucks, Light Commercial Trucks, Single-Unit Short-haul and Long-haul Trucks, and Combination Short-haul and Long-haul Trucks. Source Bin information for Buses, Refuse Trucks, and Motor Homes are described in separate sections following.

The Vehicle Inventory and Use Survey (VIUS) conducted by the Census Bureau was the primary source for information on truck distributions. Information from the 1997 and 2002 VIUS was supplemented with information from MOBILE6 and from the Oak Ridge National Laboratory Light Duty Vehicle database.

VIUS records were assigned to sourcetypes as described previously in Table 3-3 and 3-4. Not all sourcetypes had data for all model years, and no data was available beyond model year 2002. For years where no vehicles or only a few vehicles were surveyed by VIUS, we duplicated fractions from the nearest available model year. The 2002 VIUS was used for 1986 and later model years and 1997 VIUS information was only used for the older model years not surveyed in the 2002 VIUS. In the MOVES2010 release, the oldest model year observed diesel fractions were applied to the older model years for combination trucks only. These older model years for the other truck categories were assumed to have no diesel trucks.

4.3.1. FuelEngFraction

Most trucks were assigned to conventional internal combustion engines. In MOVES2010, some passenger trucks and light commercial trucks were assigned to "advanced internal combustion" in order for the model to correct phase-in improvements in energy consumption. The model-year engine technology fractions were back-calculated to match mile-per-gallon values. These fractions do not impact emissions of other pollutants. In MOVES2010a, the energy consumption rates for all light duty vehicles were revised and all trucks were assigned to the "conventional internal combustion" class.

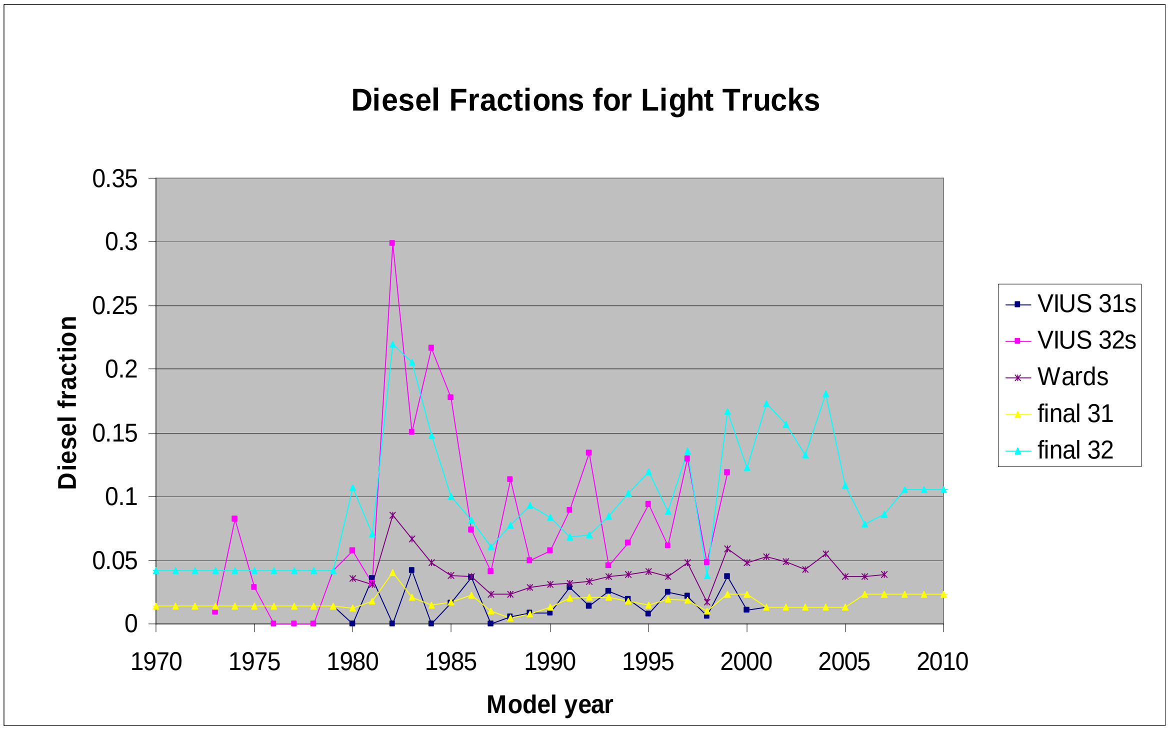
VIUS data was our primary source for fuel information, though we also used AEO2009 data for future years. The VIUS ENGTYP field was converted to the MOVES FuelTypeID. For MOVES2010, all non-gasoline trucks were assigned to diesel fuel, so that the default fleet contains only gasoline and diesel fuel trucks.It was not possible to identify the fuel used for the VIUS category "Other." Vehicles in this category were omitted from the analysis and model year results were renormalized.

As noted in peer review, the original truck diesel fractions were quite erratic, so the MOVES2010 values were smoothed to reduce year-to-year variability.

For MOVES2010, we smoothed the diesel fractions for the passenger trucks and recalculated the diesel fractions for the light commercial trucks by adding a new source of information: Ward's sales data from 1980 through 2007.[31] Assuming that the Ward's data was correct for the total of passenger trucks and light commercial trucks, we back-calculated the diesel fractions for the light commercial trucks. Specifically, we recalculated each passenger truck fraction as a 3-year weighted rolling average of the VIUS passenger truck results for model years 1980-1999 and used the 1999 result of 2.3% for all post-1999 model years. To avoid an extreme value for the light commercial trucks, we also changed the 1982 value for passenger trucks from 1.9% to 4%. We then assumed a 3:1 ratio of passenger trucks to light commercial trucks (as was true in 1999) and used the formula (Ward's percent-0.75*Avg VIUS)/0.25 to estimate the diesel sales fractions for light commercial trucks. For model years beyond 2007 we assumed the average Ward's result of 4.37%. For model years prior to 1979, the 1979 diesel fractions are used. For model years after 2007, the 2007 fractions are used.

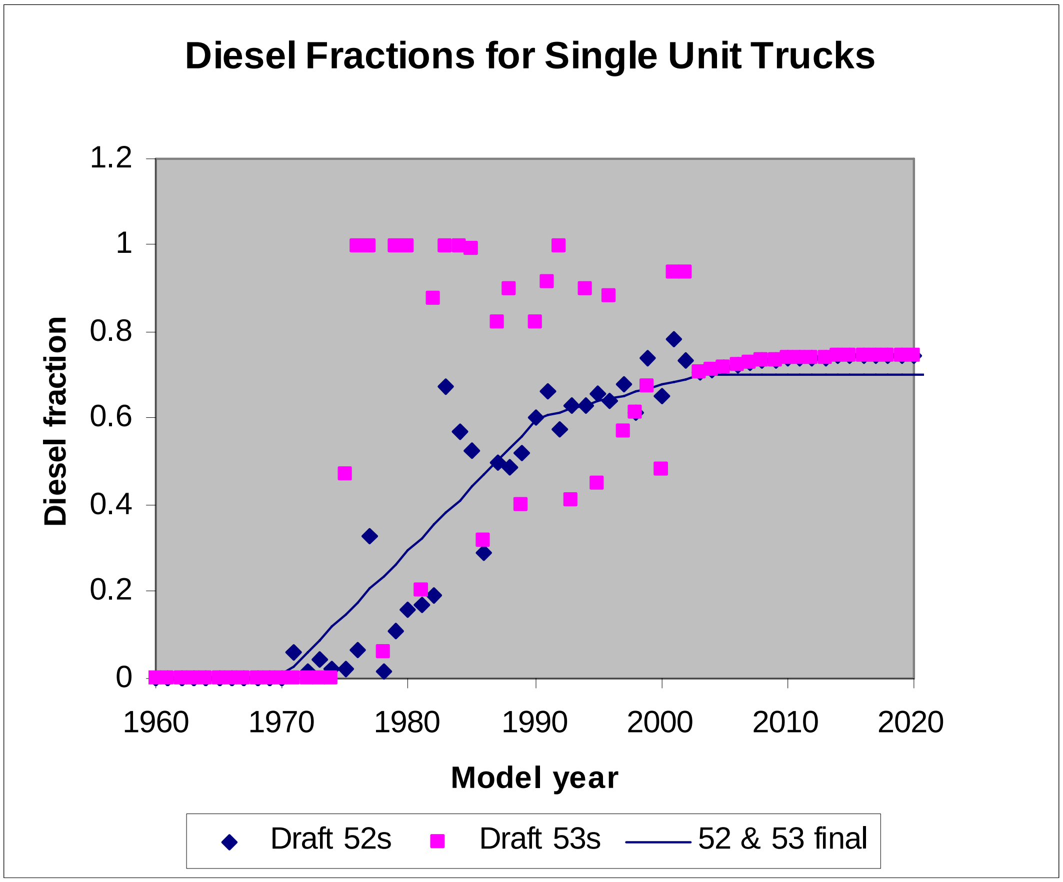
The inputs and results of this analysis are illustrated in Figure 4-1. While the diesel fractions continue to exhibit year-to-year variability, they no longer have the unrealistic extreme values found in the original data.

Figure 4-1. Diesel Fractions for Light Trucks



Diesel fraction values were also smoothed for the other trucks. For the single-unit short-haul trucks (52s), the minimum recorded fraction (0.01) was used for model years 1970 and earlier. The VIUS value of 0.6 was used for 1990 and and the AEO2009 value of 0.70 was used for 2003-and-later. We used linear interpolation to establish values in the years between these established years, and assigned the same fractions to the less abundant single-unit long-haul trucks (53s). This is illustrated in Figure 4-2.

Figure 4-2. Diesel Fractions for Single Unit Trucks



Combination long-haul trucks are virtually all diesel, so we set the fraction to 1 for all model years. Combination short-haul trucks were also mostly diesel, except in model years prior to 1990 when a small fraction of gasoline trucks appeared in the VIUS data. The VIUS values are used for model years 1984+, but given the small sample size for 1983-and-earlier, we assigned the 1984 fraction to these model years. Table 4-3 summarizes the diesel fractions for MOVES general truck categories by model year. The gasoline fractions can be calculated as one minus the diesel fractions listed here.

Table 4-3. Diesel Fractions for Trucks

Source Type	Passenger Trucks 31	Light Commercial Trucks 32	Single-Unit Short-haul Trucks 52	Single-Unit Long-haul Trucks 53	Combination Short-haul Trucks 61	Combination Long-haul Trucks 62
Model Year						
1979 and earlier	0.0139	0.0419	0.2655	0.2655	0.9146	1.0000
1980	0.0124	0.1069	0.2950	0.2950	0.9146	1.0000
1981	0.0178	0.0706	0.3245	0.3245	0.9146	1.0000
1982	0.0400	0.2200	0.3540	0.3540	0.9146	1.0000
1983	0.0209	0.2053	0.3835	0.3835	0.9146	1.0000
1984	0.0145	0.1484	0.4130	0.4130	0.9146	1.0000
1985	0.0172	0.1003	0.4425	0.4425	0.8985	1.0000
1986	0.0222	0.0814	0.4720	0.4720	0.9628	1.0000
1987	0.0105	0.0606	0.5015	0.5015	0.9940	1.0000
1988	0.0049	0.0773	0.5310	0.5310	0.9855	1.0000
1989	0.0076	0.0931	0.5605	0.5605	1.0000	1.0000
1990	0.0134	0.0838	0.6000	0.6000	1.0000	1.0000
1991	0.0200	0.0680	0.6077	0.6077	1.0000	1.0000
1992	0.0207	0.0698	0.6154	0.6154	1.0000	1.0000
1993	0.0212	0.0846	0.6231	0.6231	1.0000	1.0000
1994	0.0180	0.1021	0.6308	0.6308	1.0000	1.0000
1995	0.0149	0.1192	0.6385	0.6385	1.0000	1.0000
1996	0.0198	0.0887	0.6462	0.6462	1.0000	1.0000
1997	0.0187	0.1360	0.6538	0.6538	1.0000	1.0000
1998	0.0100	0.0380	0.6615	0.6615	1.0000	1.0000
1999	0.0232	0.1665	0.6692	0.6692	1.0000	1.0000
2000	0.0232	0.1225	0.6769	0.6769	1.0000	1.0000
2001	0.0130	0.1730	0.6846	0.6846	1.0000	1.0000
2002	0.0130	0.1570	0.6923	0.6923	1.0000	1.0000
2003	0.0130	0.1330	0.7000	0.7000	1.0000	1.0000
2004	0.0130	0.1810	0.7000	0.7000	1.0000	1.0000
2005	0.0113	0.1011	0.7000	0.7000	1.0000	1.0000
2006	0.0137	0.0609	0.7000	0.7000	1.0000	1.0000
2007+	0.0099	0.0592	0.7000	0.7000	1.0000	1.0000

4.3.2. SizeWeightFraction

The SizeWeightFraction is used for calculating energy consumption in MOVES2010, but not in MOVES2010a. Engine size distributions for trucks were determined using the VIUS 1997 and 2002 database. The VIUS database categorizes engine size by fuel type and the categories do not exactly match the MOVES categories. We mapped from the VIUS engine size categories to the MOVES engine size categories as described in Table 4-4. For comparison, the engine size ranges for both the VIUS and MOVES categories are listed in cubic inches displacement.

Table 4-4. Mapping VIUS Engine Size Categories to MOVES EngSizeID

Fuel Type	VIUS Fuel_CID code	VIUS CID Range	MOVES EngSizeID Code	MOVES CID Range
Gasoline	1,2	1-129	20	1-122
Gasoline	3,4	130-149	2025	122-153
Gasoline	5,6	150-179	2530	153-183
Gasoline	7,8	180-209	3035	183-214
Gasoline	9,10	210-239	3540	214-244
Gasoline	11,12	240-299	4050	244-305
Gasoline	13-18	300 & Up	5099	305 & Up
Diesel	20	1-249	3540	214-244
Diesel	21	250-299	4050	244-305
Diesel	22-36	300 & Up	5099	305 & Up
Propane	38-41	All	5099	305 & Up
Alcohol	43	1-229	3035	183-214
Alcohol	44	230-269	3540	214-244
Alcohol	45	270-339	4050	244-305
Alcohol	46	340 & Up	5099	305 & Up
Other	48	1-99	20	1-122
Other	49	100-149	2025	122-153
Other	50	150-199	2530	153-183
Other	51	200-249	3540	214-244
Other	52	250-299	4050	244-305
Other	53-56	300 & Up	5099	305 & Up
Fuel Not Reported	58-61	All	5099	305 & Up
Vehicle Not In Use	63-66	All	5099	305 & Up
All	19,37,42,47,57,62,67	Unknown	0	Unknown

Determining weight categories for light trucks was fairly complicated. The VIUS 1997 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 the Oak Ridge National Laboratory (ORNL) light-duty vehicle database to correlate engine size with vehicle weight distributions by model year.

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

- VIUS 1997 trucks of the sourcetype in Strata 3, 4, and 5 were assigned to the appropriate MOVES weight class based on VIUS detailed average weight information.
- VIUS 1997 trucks of the sourcetype in Strata 1 and 2 were identified by enginesizeID and broad average weight category.
- Strata 1 and 2 trucks in the heavier (10,001-14,000 lbs, etc) VIUS 1997 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 VIUS 1997 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 VIUS 1997 average weight of 6,000 lbs or less, we multiplied the VIUS 1997 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 VIUS 1997 average weight of 6,001-10,000 lbs. Instead these were distributed equally among the MOVES WeightClassIDs 70, 80, 90 and 100.

Source Types 52 and 53 (Long- and Short-haul Single Unit Trucks) also included some trucks in VIUS 1997 Strata 1 and 2, thus a similar algorithm was applied.

- VIUS 1997 trucks of the SourceType in Strata 3, 4, and 5 were assigned to the appropriate MOVES weight class based on VIUS 1997 detailed average weight information.
- VIUS 1997 trucks of the SourceType in Strata 1 and 2 were identified by enginesizeID and broad average weight category.
- Strata 1 and 2 trucks in the heavier (10,001-14,000 lbs, etc) VIUS 1997 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 VIUS 1997 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 VIUS 1997 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 VIUS 1997 average weight of 6,001-10,000 lbs were distributed equally among the MOVES weight classes 70, 80, 90 and 100.

Sourcetypes 61 and 62 (Long- and Short-haul combination trucks) did not include any vehicles of VIUS 1997 Strata 1 or 2. Thus we used the detailed VIUS 1997 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 VIUS 2002 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. Table 4-5 shows the weight ranges used for each weightClassID. 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 (sourceTypeID = 31, 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.

Table 4-5. Mapping VIUS Average Weight to MOVES WeightClassID

Where WeightAvg is not zero:	
weightClassID	**WeightAvg Range**
20	1-2000
25	2000-2499
30	2500-2999
35	3000-3499
40	3500-3999
45	4000-4499
50	4500-4999
60	5000-5999
70	6000-6999
80	7000-7999
90	8000-8999
100	9000-9999
140	10000-13999
160	14000-15999
195	16000-19499
260	19500-25999
330	26000-32999
400	33000-39999
500	40000-49999
600	50000-59999
800	60000-79999
1000	80000-99999
1300	100000-129999
9999	130000 & Up
Where WeightAvg is zero:	
weightClassID	**WeightAvgCK**
140	4 (10000-14000)
160	5 (14000-16000)
195	6 (16000-19500)

4.3.3. RegClassFraction

Regulatory classes are used to group vehicles subject to similar emission standards. The regulatory classes used in MOVES are summarized in Table 4-6 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 and Light Duty Vehicle regulatory classes have a one-to-one correspondence with sourcetype. Other sourcetypes are allocated between regulatory classes based on gross vehicle weight rating (GVWR) (the maximum weight that a truck is designed to carry), the regulatory definition of urban buses, and an internal MOVES rule that only passenger trucks and light commercial trucks may be assigned to regulatory classes 41 and 42, while only buses, single unit and combination trucks are assigned to regulatory classes 46 and higher.[e]

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[e] This final condition is necessary because of a change in the way Scaled Tractive Power was calculated for heavy trucks. See Section 7 for more information.

Table 4-6. Regulatory Classes in MOVES

Reg Class ID	Reg Class Name	Reg Class Description
0	Doesn't Matter	Doesn't Matter
10	MC	Motorcycles
20	LDV	Light Duty Vehicles
30	LDT	Light Duty Trucks
41	LHD<=14k	Light Heavy Duty (8500 lbs < GVWR <= 14K lbs)
42	LHD45	Light Heavy Duty (14K lbs < GVWR <= 19.5K lbs)
46	MHD	Medium Heavy Duty (19.5K lbs < GVWR < =33K lbs)
47	HHD	Heavy Heavy Duty (GVWR > 33K lbs)
48	Urban Bus	Urban Bus (see CFR Sec. 86.091_2)

In particular, we used the VIUS response "PKGVW" in VIUS 1997 and ADM_GVW in VIUS 2002 and the Davis & Truit report on Class 2b Trucks[32] to determine GVW fractions by fuel type. The VIUS fields are intended to identify the Polk weight class. Work for MOBILE6 using the VIUS precursor, TIUS 1992 indicated that the PKGVW measure in VIUS is problematic. TIUS PKGVW is taken from the truck VIN, but is not always consistent with the indicated average and maximum weight. (For example, the reported "maximum weight" often exceeded the PKGVW.) These problems were also seen in VIUS. However, "maximum weight" was not available for smaller trucks, and the other measures of weight reported in VIUS were not consistent with the need for an indicator of the relevant emission standards. When the PKGVW led to unusual results, for example, particularly high fraction of LDT among combination trucks, we checked additional VIUS fields to determine if the PKGVW was mistaken. In some cases, the PKGVW was manually revised to a higher value and fractions were recomputed. In other cases, the PKGVW was consistent with the other fields, and the difference reflected the fact that our sourcetype categories are based on axle counts and trailer configurations rather than weight. For example, a 6-tire ("dually") pickup that regularly pulls a trailer is classified as a "Combination Truck," although, by weight, it would be in the LDT regulatory class. Some model years had relatively high fractions of such trucks. It is likely these high values indicate a problem with small sample size for the model year. For MOVES2010, all the light heavy duty (<195,000 lbs) combination and short haul trucks were assigned to the medium heavy duty regulatory class.

Also, because the split between the LDT and LHD<=14K regulatory class is at 8500 lbs, it was necessary to split the Polk GVW Class 2 into class 2a (6001-8500 lbs) and class 2b (8501-10,000 lbs). Davis & Truitt[33] report that, on average, 23.3 percent of Class 2 trucks are in Class 2b; 97.4 percent of Class 2a trucks are powered by gasoline, and 76 percent of Class 2b trucks are powered by gasoline. From this information, we estimate that 19.2 percent of gasoline-powered Class 2 trucks are Class 2b and that 73.7 percent of diesel-powered class 2 trucks are Class 2b.

Table 4-7. Light Truck Class 2 Weight Distribution

	Class 2a	Class 2b	
Fuel Type	**6001-8500 lbs. GVWR**	**8501-10000 lbs. GVWR**	**Class 2b Fraction**
Gasoline	74.7%	17.7%	19.2%
Diesel	2.0%	5.6%	73.7%
Any	76.7%	23.3%	

The regulatory class fractions for trucks are listed below in Tables 4-8, 4-9 and 4-10. All 1986 and newer model year data was obtained from VIUS 2002. The pre-1986 model year values are from VIUS 1997.

Table 4-8. Passenger & Light Commercial Truck Regulatory Class Percents

	Passenger Trucks					Light Commercial Trucks					
	Gasoline		Diesel			Gasoline			Diesel		
Model Year	**LDT**	**LHD <=14K**	**LDT**	**LHD <=14K**	**LHD >14K***	**LDT**	**LHD <=14K**	**LHD >14K**	**LDT**	**LHD <=14K****	**LHD>14K**
1966 and earlier	81%	19%	38%	29%	33%	24%	6%	71%	7%	0%	93%
1967	90%	10%	38%	29%	33%	72%	17%	11%	7%	0%	93%
1968	88%	12%	38%	29%	33%	67%	1%	32%	7%	0%	93%
1969	100%	0%	38%	29%	33%	91%	0%	9%	7%	0%	93%
1970	99%	1%	38%	29%	33%	80%	12%	9%	7%	0%	93%
1971	96%	3%	38%	29%	33%	94%	4%	2%	7%	0%	93%
1972	96%	4%	38%	29%	33%	75%	5%	20%	7%	0%	93%
1973	95%	5%	38%	29%	33%	59%	9%	32%	7%	0%	93%
1974	95%	5%	38%	29%	33%	65%	9%	26%	7%	0%	93%
1975	97%	3%	38%	29%	33%	72%	17%	10%	7%	0%	93%
1976	95%	5%	38%	29%	33%	88%	8%	4%	7%	0%	93%
1977	89%	11%	38%	29%	33%	79%	13%	7%	7%	0%	93%
1978	85%	15%	38%	29%	33%	81%	16%	3%	7%	0%	93%
1979	87%	13%	38%	29%	33%	78%	9%	13%	7%	0%	93%
1980	90%	10%	38%	29%	33%	74%	17%	9%	40%	0%	60%
1981	96%	4%	38%	29%	33%	89%	5%	6%	12%	0%	88%
1982	94%	6%	38%	29%	33%	72%	12%	16%	27%	0%	73%
1983	95%	5%	38%	29%	33%	90%	6%	4%	23%	0%	77%
1984	94%	6%	38%	29%	33%	87%	9%	4%	24%	0%	76%
1985	94%	6%	38%	29%	33%	87%	12%	1%	23%	0%	77%
1986	93%	7%	38%	29%	33%	82%	11%	7%	35%	42%	23%
1987	95%	5%	38%	29%	33%	90%	10%	0%	9%	49%	42%
1988	95%	5%	38%	29%	33%	89%	9%	2%	21%	63%	16%
1989	95%	5%	26%	74%	1%	89%	10%	1%	14%	46%	39%
1990	95%	5%	26%	74%	1%	91%	7%	2%	6%	27%	67%
1991	96%	4%	26%	74%	0%	89%	10%	2%	18%	52%	30%
1992	95%	5%	26%	74%	1%	91%	9%	1%	22%	63%	15%
1993	95%	5%	26%	74%	1%	91%	8%	1%	15%	47%	38%
1994	95%	5%	30%	70%	0%	87%	12%	1%	16%	50%	34%
1995	95%	5%	31%	68%	0%	88%	11%	1%	20%	56%	24%
1996	95%	5%	29%	70%	0%	86%	13%	1%	21%	48%	31%
1997	95%	5%	26%	74%	0%	88%	11%	1%	36%	52%	12%
1998	95%	5%	26%	74%	0%	89%	10%	1%	14%	44%	42%
1999	93%	7%	26%	73%	0%	87%	12%	1%	21%	58%	21%
2000	94%	6%	36%	63%	0%	88%	11%	0%	22%	50%	29%
2001	94%	6%	23%	76%	0%	88%	12%	0%	34%	54%	11%
2002+	95%	5%	28%	72%	0%	89%	10%	0%	26%	62%	12%

*Note, the relatively high fraction of 42s for pre-1989 diesel passenger trucks is an error, but this has a very small impact on emissions because these are a small portion of the fleet, and for most pollutants, the emission rates for regulatory classes 41s and 42s are identical.

**In the future, the 1985-and-earlier diesel light commercial trucks could be split between regulatory classes 41 and 42, but the impact of this change would be negligible for most pollutants.

Table 4-9. Percentage of Medium Heavy-Duty Trucks among Diesel-fueled Single-Unit and Combination Trucks*

Model year	Refuse Trucks 51	Single Unit Trucks 52&53	Motor Homes 54	Short-haul Comb. Trucks 61	Long-haul Comb. Trucks 62
1972 and earlier	100%	0%	100%	0%	0%
1973	100%	3%	100%	8%	0%
1974	0%	6%	100%	30%	0%
1975	0%	14%	100%	3%	0%
1976	0%	44%	100%	13%	0%
1977	0%	43%	100%	31%	0%
1978	0%	36%	100%	18%	0%
1979	0%	34%	100%	16%	0%
1980	0%	58%	100%	29%	5%
1981	0%	47%	97%	31%	6%
1982	0%	66%	95%	14%	0%
1983	0%	90%	96%	28%	17%
1984	37%	59%	98%	56%	63%
1985	30%	65%	98%	36%	30%
1986	19%	51%	98%	16%	5%
1987	29%	64%	99%	25%	3%
1988	26%	62%	99%	18%	4%
1989	42%	68%	99%	20%	6%
1990	21%	72%	98%	27%	21%
1991	48%	78%	98%	19%	8%
1992	30%	66%	96%	25%	8%
1993	25%	74%	96%	15%	17%
1994	25%	73%	97%	20%	7%
1995	19%	73%	97%	17%	7%
1996	15%	74%	97%	21%	9%
1997	13%	77%	97%	12%	6%
1998	13%	70%	96%	18%	7%
1999	16%	77%	97%	17%	4%
2000	22%	76%	97%	15%	2%
2001	3%	78%	97%	11%	4%
2002+	3%	73%	97%	22%	5%

*Among these sourcetypes, all remaining trucks are in the heavy-heavy-duty regulatory class.

Table 4-10. Percentage of Medium Heavy-Duty Trucks among Gasoline-fueled Single-Unit and Combination Trucks*

Model year	Refuse Trucks & Motor Homes 51	Single Unit Trucks 52&53	Short-haul Comb. Trucks 61
1985 and earlier	100%	100%	100%
1986	100%	95%	79%
1987	100%	100%	79%
1988	100%	100%	79%
1989	100%	99%	#N/A
1990	100%	100%	#N/A
1991	100%	99%	#N/A
1992	100%	99%	#N/A
1993	100%	99%	#N/A
1994	100%	96%	#N/A
1995	100%	98%	#N/A
1996	100%	96%	#N/A
1997	100%	96%	#N/A
1998	100%	98%	#N/A
1999	100%	94%	#N/A
2000	100%	96%	#N/A
2001	100%	92%	#N/A
2002+	100%	96%	#N/A

*Among these sourcetypes, all remaining trucks are in the heavy-heavy-duty regulatory class.

4.3.4. SCCVtypeFraction

Trucks span a wide range of GVWs and, thus, a wide range of SCCs. We used VIUS values for GVW to determine the truck SCC fractions by model year. To separate Light-Duty Trucks 1 and Light-Duty Trucks 2, which are distinguished by Loaded Vehicle Weights, we used information from the Oak Ridge National Laboratory Light-Duty Vehicle database. And to separate Class 2a and 2b trucks, we used information from Davis and Truitt.[34]

The resulting truck mappings are too complex to summarize here, but are available in the MOVES database. If the Alternative Vehicle Fuels and Technologies control strategy is used to assign vehicles to the "Electric" fueltype, those vehicles are mapped to "LDGV" because there is no SCC for electric vehicles.

4.4. Buses

Because buses are not included in VIUS and because the Polk data we had for school buses was incomplete, the source bin fractions for buses is based on a variety of data sources and assumptions. Values for transit buses, school buses, and intercity buses were calculated separately.

7.4.1. FuelEngFraction

All buses were assigned to EngTechID “1" (conventional internal combustion).

We followed the Energy Information Administration (EIA) in assigning all intercity buses to conventional diesel engines (*AEO2006, Supplemental Table 34*).

The National Transit Database (NTD) responses to form 408 (Revenue Vehicle Information Form) included information classifying transit buses to a variety of fuel types by model year. The mapping from NTD fuel types to MOVES fuel types is summarized in Table 4-11. The associated fractions by model year are summarized in Table 4-12.

Table 4-11. Mapping National Transit Database Fuel Types to MOVES Fuel Types

NTD code	NTD description	MOVES Fuel ID	MOVES Fuel Description
BF	Bunker fuel	na	
CN	Compressed natural gas	3	CNG
DF	Diesel fuel	2	diesel
DU	Dual fuel	2	diesel
EB	Electric battery	9	electric
EP	Electric propulsion	9	electric
ET	Ethanol	5	ethanol
GA	Gasoline	1	gasoline
GR	Grain additive	na	
KE	Kerosene	na	
LN	Liquefied natural gas	3	CNG
LP	Liquefied petroleum gas	4	LPG
MT	Methanol	6	methanol
OR	Other	na	

Table 4-12. National Transit Database Implied Fuel Fractions for Transit Buses

Model Year	Gasoline	Diesel	CNG	LPG	Ethanol	Methanol	Electric
1978-and earlier	0	1	0	0	0	0	0
1979	0.033981	0.966019	0	0	0	0	0
1980	0	1	0	0	0	0	0
1981	0.002088	0.997912	0	0	0	0	0
1982	0.001894	0.992424	0	0	0	0	0.005682
1983	0	1	0	0	0	0	0
1984	0.001603	0.998397	0	0	0	0	0
1985	0	0.999565	0.000435	0	0	0	0
1986	0.00079	0.996447	0.002764	0	0	0	0
1987	0.001402	0.998598	0	0	0	0	0
1988	0.002377	0.997623	0	0	0	0	0
1989	0.00113	0.998306	0	0	0.000565	0	0
1990	0.002941	0.990271	0.006787	0	0	0	0
1991	0.003134	0.978064	0.018106	0	0	0	0.000696
1992	0.010769	0.933903	0.046417	0.000743	0	0.005941	0.002228
1993	0.003061	0.918707	0.07551	0.00068	0.001361	0	0.00068
1994	0.010711	0.900625	0.084796	0.000893	0	0	0.002975
1995	0.009555	0.835108	0.153153	0	0	0	0.002184
1996	0.017963	0.881825	0.097613	0.000709	0	0	0.001891
1997	0.012702	0.810162	0.174365	0.000462	0	0	0.002309
1998	0.012003	0.838409	0.1487	0	0	0	0.000889
1999	0.005998	0.878041	0.113296	0	0	0	0.002666

For MOVES2010, most alternative fuels were removed from the model. However, because the number of compressed natural gas (CNG) transit buses was high for some model years, CNG was retained as an option for transit buses, and the default database includes a CNG for some model years, as summarized in Table 4-13 below. For each model year, one percent of the transit bus fleet was assigned to gasoline engines and the remaining, (non-gasoline, non-CNG) fraction was assigned to diesel.

Table 4-13. Transit Bus Fuel Fractions in MOVES2010

Model Year	Gasoline	Diesel	CNG
1989-and-earlier	1.0%	99.0%	0%
1990	1.0%	98.3%	0.7%
1991	1.0%	97.2%	1.8%
1992	1.0%	94.4%	4.6%
1993	1.0%	91.4%	7.6%
1994	1.0%	90.5%	8.5%
1995	1.0%	83.7%	15.3%
1996	1.0%	89.2%	9.8%
1997	1.0%	81.6%	17.4%
1998	1.0%	84.1%	14.9%
1999	1.0%	87.7%	11.3%
2000+	1.0%	93.0%	6.0%

The available Polk data excluded fuel information on school buses and we were unable to locate any other source for bus fuel fractions. (The Union of Concerned Scientists estimated that about one percent of school buses are fueled by either CNG or propane, but does not provide estimates by model year.[35]) Thus we used the diesel fractions from MOBILE6, which were derived from Polk 1996 and 1997 data. We assigned non-diesel buses to gasoline. These fractions are summarized in Table 4-14. In the future it would be desirable to obtain up-to-date, detailed fuel information for school buses from Polk or some other source.

Table 4-14. School Bus Fuel Fractions in MOVES2010

Model Year	Gasoline	Diesel
1975-and-earlier	0.991272	0.008728
1976	0.99145	0.00855
1977	0.976028	0.023972
1978	0.970936	0.029064
1979	0.95401	0.04599
1980	0.94061	0.05939
1981	0.736056	0.263944
1982	0.674035	0.325965
1983	0.676196	0.323804
1984	0.615484	0.384516
1985	0.484507	0.515493
1986	0.326706	0.673294
1987	0.265547	0.734453
1988	0.249771	0.750229
1989	0.229041	0.770959
1990	0.124036	0.875964
1991	0.089541	0.910459
1992	0.010041	0.989959
1993	0.120539	0.879461
1994	0.147479	0.852521
1995	0.114279	0.885721
1996+	0.041539	0.958461

4.4.2. SizeWeightFraction

The SizeWeightFraction is used for calculating energy consumption in MOVES2010, but not in MOVES2010a. While the vast majority of buses of all types have engine displacement larger than five liters (EngSizeID=5099), it was difficult to find detailed information on average bus weight.

For intercity buses, we used information from Table II-7 of the FTA 2003 Report to Congress[36] that specified the number of buses in various weight categories. This information is summarized in below in Table 4-15. 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 4-15. FTA Estimate of Bus Weights

Weight (lbs)	MOVES Weight ClassID	MOVES Weight Range (lbs)	Number 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	

Using our 1999 bus population estimates (in Table3-6), 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[37]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[38] provided information on number of vehicles by gross vehicle weight class and fuel as detailed in Table 4-16.

Table 4-16. California School Buses

	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 4-17.

Table 4-17. 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			

4.4.3. RegClassFraction

For buses, the same regulatory class fractions were used for all model years. All gasoline buses were assigned to the medium-heavy-duty regulatory class. Diesel intercity buses were assigned to the heavy-heavy-duty class. Diesel transit buses were assigned to the urban bus class. Diesel school buses were split using the California survey data and MOVES assignment rules, with 36 percent assigned to the medium-heavy-duty class and 64 percent assigned to the heavy-heavy-duty class.

4.4.4. SCCVtypeFraction

For most buses, the mapping to SCCVtype was straightforward. These mappings are summarized in Table 4-18.

Table 4-18. SCC Mappings for Buses

Source Type ID	SourceType	Fuel Type	SCC-ID	SCC prefix	Abbreviated Description
41	Intercity Bus	gasoline	4	2201070	HDGV&B
41	Intercity Bus	other	12	2230075	HDDB
42	Transit Bus	gasoline	4	2201070	HDGV&B
42	Transit Bus	other	12	2230075	HDDB
43	School Bus	gasoline	4	2201070	HDGV&B
43	School Bus	other	12	2230075	HDDB

If the Alternative Vehicle Fuels and Technologies control strategy is used to assign buses to the “Electric” fueltype, those vehicles are mapped to “HDGV&B” because there is no SCC for electric vehicles.

4.5. Refuse Trucks

Values for Refuse Trucks (Source Type 51) were computed from information in VIUS.

4.5.1. FuelEngFraction

All Refuse Trucks were assumed to have conventional internal combustion engines. Because the VIUS sample was small and the fuel fractions by model year were quite erratic, we calculated an average gasoline fraction (4.0%) and applied it in all model years.

4.5.2. SizeWeightFraction

The SizeWeightFraction is used for calculating energy consumption in MOVES2010, but not in MOVES2010a. Because the sample of Refuse Trucks in VIUS was small, the SizeWeight distributions were calculated for model year groups rather than individual model years. As for other trucks, the EngineSize group was determined from the VIUS engine size categories and the WeightClass was determined from the VIUS reported average weight.

Table 4-19. 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**

4.5.3. RegClassFraction

Using the VIUS data on gross vehicle weight, diesel Refuse Trucks were classified as Heavy-Heavy-Duty Trucks or Medium-Heavy-Duty trucks, as detailed in the truck Table 4-9. above. Using VIUS data and MOVES regulatory class assignment rules, gasoline Refuse Trucks were all assigned to the Medium-Heavy-Duty class.

4.5.4. SCCVtypeFraction

We used VIUS data on gross vehicle weight to determine fractions for diesel Refuse Trucks. They were classified as Heavy-Heavy-Duty Diesel Vehicles or Medium-Heavy-Duty Diesel Vehicles, as detailed in Table 4-20, below. All gasoline Refuse Trucks were all assigned to the Heavy-Duty Gasoline Vehicle and Bus class.

Table 4.20. SCC Mappings for Diesel Refuse Trucks

Model Year	MHHDDV	HHDDV
1973-and-earlier	1	0
1974-1983	0	1
1984	0.3740	0.6259
1985	0.2963	0.7036
1986	0.1850	0.8150
1987	0.2861	0.7139
1988	0.2563	0.7437
1989	0.4164	0.5836
1990	0.2109	0.7891
1991	0.4799	0.5201
1992	0.3034	0.6966
1993	0.2543	0.7457
1994	0.2536	0.7464
1995	0.1868	0.8132
1996	0.1496	0.8504
1997	0.1256	0.8744
1998	0.1331	0.8669
1999	0.1565	0.8435
2000	0.218	0.782
2001	0.0324	0.9676
2002+	0.0298	0.9702

4.6. Motor Homes

Determining source bin distribution for Motor Homes required a number of assumptions and interpolation due to the lack of detailed information. For each field, the following describes the information available, assumptions made, and how data points were determined.

4.6.1. FuelEngFraction

Detailed information on motor home fuel distribution was not available. Staff of the Recreational Vehicle Industry Association (RVIA) told us that the fraction of diesel motor homes had been relatively constant at 10 to 20 percent for many years.[39] This fraction began to increase steadily and was about 50% in 2009[40]. Based on this information, we interpolated to determine the diesel fractions listed in Table 4-21. The remaining 1999-and-earlier motor homes are assumed to be gasoline-fueled. We assigned all motor homes to the conventional internal combustion engine type.

Table 4-21. Diesel Fractions for Motor Homes.

Model Year	Percent Diesel
1993-and-earlier	15%
1994	18%
1995	21%
1996	23%
1997	26%
1998	29%
1999	32%
2000	34%
2001	37%
2002	40%
2003	41%
2004	43%
2005	44%
2006	46%
2007	47%
2008	49%
2009	50%
2010+	50%

4.6.2. SizeWeightFraction

The SizeWeightFraction is used for calculating energy consumption in MOVES2010, but not in MOVES2010a. 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 4-22 and Table 4-23.

Table 4-22. 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 4.23. 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

4.6.3. RegClassFraction

Based on Polk data and MOVES regulatory class assignment rules, we assigned all gasoline motor homes and most diesel-powered motorhomes to the medium-heavy-duty regulatory class. A small fraction of diesel-powered motorhomes were assigned to the heavy-heavy-duty class as detailed in Table 4-9 above.

4.6.4. SCCVtypeDistribution

We assigned all gasoline motor homes to the HDGV class. Based on Polk data, we assigned most diesel-powered motorhomes to the medium-heavy-duty diesel class, as detailed in Table 4-24 below.

Table 4-24. SCCVtype Distributions for Diesel Motor Homes by Model Year

Model Year	MHHDDV	HHDDV
1980-and-earlier	1.000	0.000
1981	0.972	0.028
1982	0.947	0.053
1983	0.958	0.042
1984	0.979	0.021
1985	0.977	0.023
1986	0.981	0.019
1987	0.987	0.013
1988	0.986	0.014
1989	0.987	0.013
1990	0.982	0.018
1991	0.979	0.021
1992	0.956	0.044
1993	0.962	0.038
1994	0.969	0.031
1995	0.974	0.026
1996	0.968	0.032
1997	0.971	0.029
1998	0.96	0.04
1999+	0.971	0.029

5. Age Distributions

The age distribution for each sourcetype is stored in the SourceTypeAgeDistribution table. Because sales are not constant, these distributions vary by calendar year. MOVES uses age distributions for the base year combined with sales and scrappage information to compute the age distribution in the calendar year selected for analysis.

This section describes how the age distributions were determined for the primary default base year of 1999, and the 1990 base year. Age distributions for the 1999 base year are summarized in Table 5-1. Age distributions for the 1990 base year are available in the MOVES2010 default database SourceTypeAgeDistribution table.

5.1. Motorcycles

To determine the 1999 age fractions for motorcycles, a contractor analyzed Polk registration data from 2008. These were normalized and input as age distributions for 1999.[41],

The 1990 fractions were determined earlier and were not updated. For these, we began with 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.

5.2. Passenger Cars

We considered three approaches to determine 1999 age fractions for passenger cars.

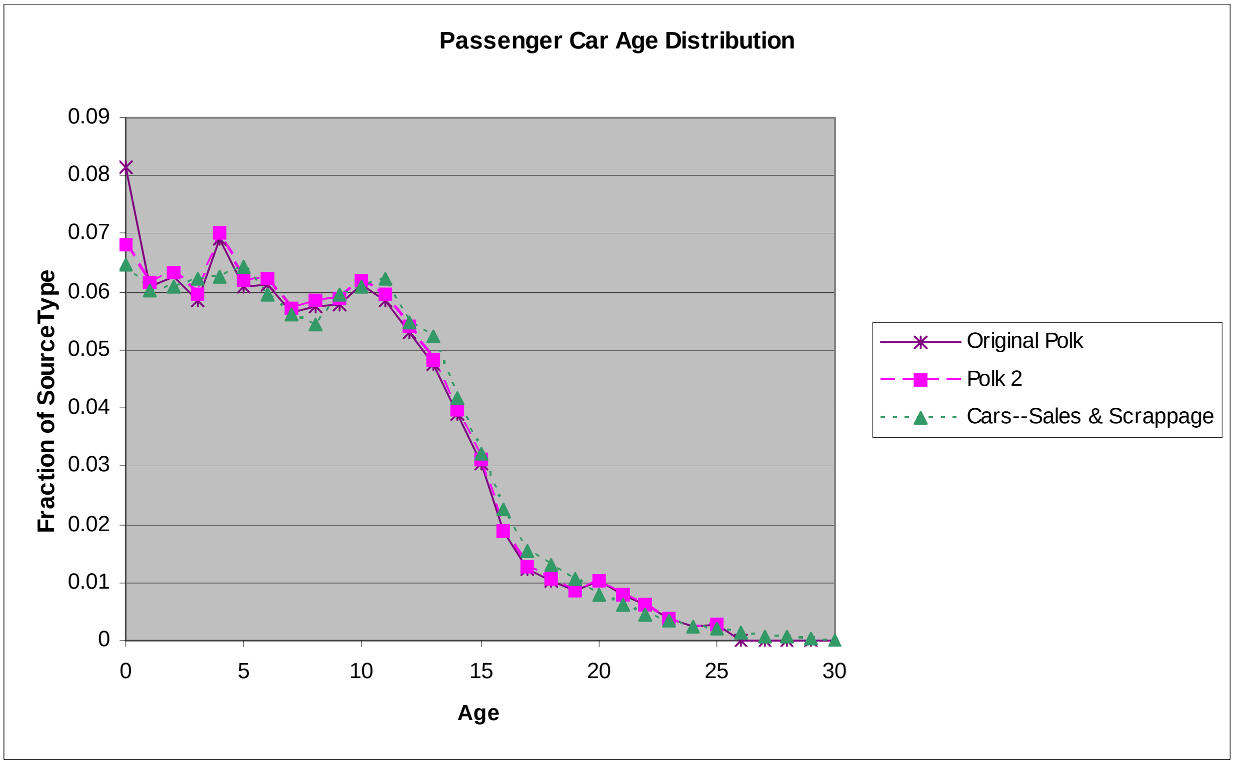
Our original approach (used for MOVES2004 and MOVES Demo) began with Polk NVPP® 1999 data on car registration by model year. This data presents a snapshot of registrations on July 1, 1999, and we needed age fractions as of December 31, 1999. To adjust the values, we used monthly data from the Polk new car database to estimate the number of new cars registered in the months July through December 1999. Model Year 1998 cars were added to the previous estimate of “Age 1” cars and Model Year 1999 and 2000 cars were added to the “Age 0” cars. We then computed fractions by age. However, because this method counts both Model Year 1999 and Model Year 2000 as "Age 0", the Age 0 age fraction is inflated. When the MOVES Total Activity Generator applies growth factors, the number of cars in future years is inflated, and the fraction of passenger cars compared to other source types is skewed. Thus, we rejected this approach.

A second approach was similar to the first, but with only Model Year 1999 vehicles counted as "Age 0" in 1999.

Our third approach used passenger car sales data from Table 4.5 of the TEDB[42] and applied the NHTSA survival fractions, extrapolated to age 30 and shifted such that NHTSA age n = MOVES age n+1. Survival fractions for MOVES age 0 and 1 were interpolated as described in Section 5.1.

Not surprisingly, the age distributions resulting from the three approaches are very similar, as illustrated in Figure 5-1. All show a fairly flat age distribution in the first eleven years followed by a steep decline and a leveling off. The third approach provides a slightly more generic age distribution than the second approach because the direct Polk data approach is for a single year and the NHTSA survival fractions were derived by regression through many years of data. For the MOVES2010 default database, we selected the age distributions generated with the third approach. For future versions of MOVES, we are considering updating these values to better account for more recent data.

Figure 5-1. 1999 Age Distributions for 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.

5.3. Trucks

To determine 1999 age fractions for refuse trucks, short-haul and long-haul single unit trucks and short-haul and long-haul combination trucks, we used data from the VIUS database. Vehicles in the VIUS database were assigned to MOVES source types as summarized in Table 3-3 and Table 3-4.

VIUS 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 MOBILE6 and determined the model year for some of the older vehicles by using the responses to the VIUS questions "How did you obtain this vehicle?" (VIUS field "OBTAIN" in VIUS 1997 or "ACQUIREHOW" in VIUS 2002) and "When did you obtain this vehicle?"

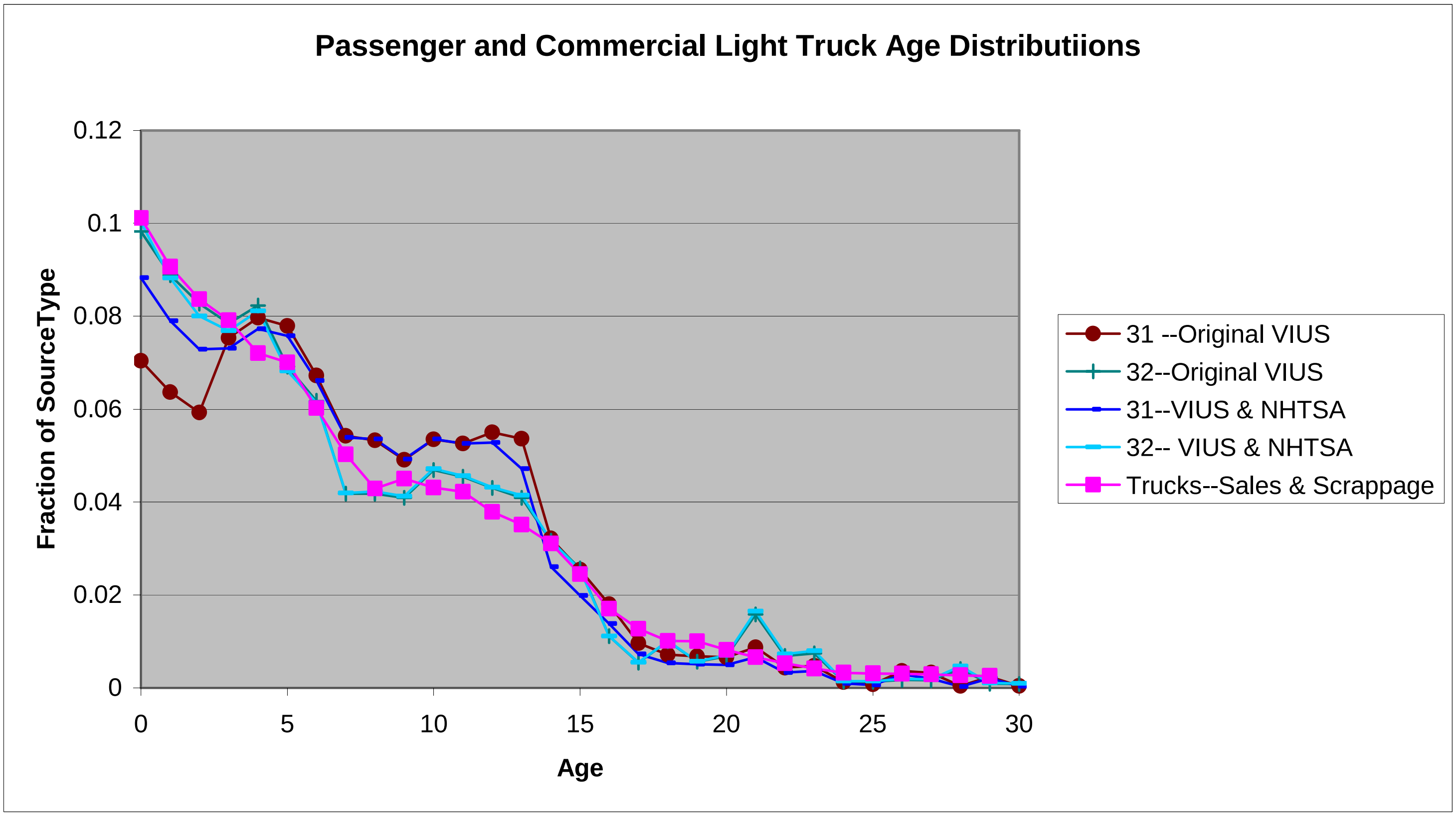
(VIUS field “ACQYR” in VIUS 1997 or "ACQUIREYEAR" in VIUS 2002) to derive the model year of the vehicles that were obtained new. These derived model years also were used for much of the source bin distribution work described elsewhere in this report.

To calculate age fractions, it was important to account for the inconsistent methodologies used for the older and newer vehicles. Thus, for each source type, 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.” This created an array of adjusted vehicle counts by model year for calendar year 1997. This 1997 array may overestimate the fraction of mid-aged vehicles since the fraction of vehicles purchased new likely declines with time; however, we believe the procedure is reasonable given the limited data available.

We then used the sales growth for 1997 and 1998 from TEDB22 Tables 7.6 and 8.3 and the scrappage rates from TEDB22 Tables 6.10 and 6.11 to grow the population to the 1999 base year and then we calculated age fractions.

Initially, we determined the 1999 age fractions for passenger trucks and commercial trucks in the same way as other trucks. However, when the NHTSA survival rates for light duty trucks became available in 2006, we reexamined this approach. We compared (1) our original approach with VIUS data for 1997 and the TEDB scrappage rates, (2) a similar approach using VIUS data and NHTSA survival rates, and (3) a "sales and scrappage" approach similar to that used for passenger cars, combining passenger trucks and commercial light trucks and using TEDB sales data. The results of the three approaches are illustrated in Figure 5-2.

Figure 5-2. 1999 Age Distributions for Passenger and Light Commercial Trucks



Use of the original VIUS data leads to low values for age 0-3 passenger trucks that is not reflected by vehicle sales data. The other approaches all create similar trends of fairly steep declines in age fractions until about age 7, a brief leveling off, another steep decline from about age 12 to 17 and a final leveling off. For the MOVES default database, we selected the age distribution generated with the "Sales and Scrappage" approach, which will be applied to both passenger trucks and light commercial 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 3-3.

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.”

5.4. Intercity Buses

For 1990 and 1999 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 the 1999 and 1990 age distributions that were derived for short-haul combination trucks, as described above.

5.5. 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 also used for 1990

5.6. Transit Buses

To determine the 1999 age fractions for Transit Buses, we used data from the Federal Transit Administration database. In particular, we used responses to 1999 Form 408, which included counts of in-use vehicles by year of manufacture.

To properly account for the fraction of Age 0 vehicles at the end of 1999, it was necessary to adjust the counts for model-year-1999 vehicles to account for the different reporting periods of the various transit organizations. The counts were adjusted proportionally depending on the month in which the fiscal year ended. The adjusted counts were used to calculate the age fractions.

For 1990 Transit Bus age distributions, we used the MOBILE 6 age fractions since 1990 data on transit buses was not available from the Federal Transit Administration database.

Table 5-1. 1999 Age Fractions for MOVES Source Types

source type	11	21	31& 32	42	43	51	52	53	54	61 & 41	62
age											
0	0.1118	0.0646	0.1011	0.0624	0.0794	0.0498	0.0622	0.1697	0.0737	0.0843	0.1668
1	0.0993	0.0602	0.0906	0.0771	0.0660	0.0398	0.0520	0.1419	0.0456	0.0672	0.1331
2	0.0950	0.0610	0.0837	0.0742	0.0647	0.0340	0.0412	0.1124	0.0739	0.0576	0.1140
3	0.0833	0.0624	0.0791	0.0727	0.0594	0.0767	0.0466	0.0585	0.0487	0.0506	0.1140
4	0.0627	0.0626	0.0720	0.0627	0.0798	0.0926	0.0559	0.0609	0.0605	0.0693	0.1186
5	0.0722	0.0642	0.0700	0.0576	0.0406	0.0604	0.0572	0.1017	0.0608	0.0562	0.0804
6	0.0588	0.0597	0.0603	0.0504	0.0511	0.0544	0.0434	0.0783	0.0441	0.0488	0.0643
7	0.0492	0.0562	0.0502	0.0461	0.0435	0.0243	0.0344	0.0185	0.0408	0.0379	0.0403
8	0.0390	0.0543	0.0429	0.0492	0.0585	0.0696	0.0351	0.0138	0.0320	0.0453	0.0304
9	0.0316	0.0596	0.0450	0.0759	0.0696	0.0625	0.0435	0.0686	0.0442	0.0535	0.0315
10	0.0234	0.0608	0.0431	0.0609	0.0419	0.0514	0.0578	0.0748	0.0602	0.0560	0.0320
11	0.0198	0.0622	0.0422	0.0506	0.0526	0.0730	0.0531	0.0517	0.0563	0.0550	0.0290
12	0.0196	0.0549	0.0379	0.0489	0.0556	0.0610	0.0460	0.0129	0.0574	0.0597	0.0080
13	0.0163	0.0522	0.0351	0.0434	0.0512	0.0796	0.0580	0.0031	0.0447	0.0528	0.0087
14	0.0137	0.0419	0.0311	0.0394	0.0464	0.0442	0.0430	0.0064	0.0501	0.0487	0.0115
15	0.0122	0.0320	0.0244	0.0320	0.0374	0.0479	0.0251	0.0067	0.0531	0.0400	0.0062
16	0.0089	0.0226	0.0170	0.0321	0.0144	0.0145	0.0409	0.0000	0.0363	0.0167	0.0013
17	0.0069	0.0155	0.0127	0.0181	0.0111	0.0169	0.0220	0.0032	0.0221	0.0147	0.0011
18	0.0071	0.0129	0.0100	0.0082	0.0136	0.0156	0.0219	0.0024	0.0127	0.0133	0.0035
19	0.0079	0.0105	0.0100	0.0231	0.0138	0.0040	0.0239	0.0000	0.0017	0.0180	0.0012
20	0.0075	0.0080	0.0081	0.0071	0.0118	0.0043	0.0190	0.0002	0.0138	0.0112	0.0010
21	0.0096	0.0060	0.0066	0.0032	0.0104	0.0043	0.0225	0.0101	0.0191	0.0090	0.0006
22	0.0147	0.0045	0.0053	0.0007	0.0107	0.0000	0.0088	0.0006	0.0267	0.0099	0.0010
23	0.0130	0.0034	0.0041	0.0013	0.0073	0.0092	0.0112	0.0011	0.0169	0.0038	0.0000
24	0.0103	0.0026	0.0032	0.0009	0.0092	0.0027	0.0115	0.0005	0.0045	0.0048	0.0009
25	0.0127	0.0019	0.0031	0.0009	0.0000	0.0070	0.0125	0.0000	0.0000	0.0048	0.0003
26	0.0171	0.0014	0.0030	0.0002	0.0000	0.0001	0.0130	0.0021	0.0000	0.0040	0.0003
27	0.0133	0.0008	0.0029	0.0004	0.0000	0.0000	0.0265	0.0000	0.0000	0.0036	0.0000
28	0.0152	0.0006	0.0027	0.0003	0.0000	0.0000	0.0059	0.0000	0.0000	0.0026	0.0002
29	0.0152	0.0005	0.0026	0.0001	0.0000	0.0000	0.0032	0.0000	0.0000	0.0006	0.0000
30	0.0323	0.0000	0.0000	0.0002	0.0000	0.0000	0.0026	0.0000	0.0000	0.0000	0.0000

6. Vehicle Characteristics that Vary by Age

Three fields comprise the SourceTypeAge table in MOVES2010: **SurvivalRate, Relative MAR**, and **FunctioningACFraction**. The first two are described below, including data sources and some relevant data points used in the model. The third is described in Section 15 with other air conditioning inputs.

6.1. SurvivalRate

The SurvivalRate field describes the fraction of vehicles of a given sourcetype and Age that remain on the road one year to the next. SurvivalRate is used in the Total Activity Generator in the calculation of source type populations by age in calendar years after the base year. In MOVES, a separate SurvivalRate is applied to each age in each sourcetype fleet. The SurvivalRates in MOVES are used for all model years in a sourcetype in all calendar years.

SurvivalRates for Motorcycles were calculated based on a smoothed curve of retail sales and 2008 registration data as described in a contractor report.[f,43]

Survival rates for Passenger Cars, Passenger Trucks and Light Commercial Trucks came from NHTSA's survivability Table 3 and Table 4.[44] These survival rates are based on a detailed analysis of Polk vehicle registration data from 1977 to 2002. We modified these rates to fit them into the MOVES format:

- NHTSA rates for Light Trucks were used for both MOVES Passenger Trucks and MOVES Light Commercial Trucks.

- MOVES calculates emissions to age 30 for both cars and trucks, but NHSTA car rates were available only to age 25, so 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 MOVES ages < 2, the survival rates for age 0 and age 1 were interpolated using a linear interpolation and assuming that the survival rate prior to age 0 is 1.

- 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-line year. MOVES calculations

[f] For motorcycles, the survival rates in MOVES2010 were calculated relative to initial sales rather than previous year population. This causes very aggressive scrappage and significantly reduces the MOVES2010 motorcycle population for calendar years after the base year. This error does not impact county-level runs where the analysis year and base year are the same. We fixed this error in MOVES2010a.

require a value that is the ratio of a given year to the previous year, so we transformed the NHTSA rates to MOVES rates using this ratio.

Because MOVES ageid= 30 is intended to represent all ages 30-and-greater, the survival rate for ageid=30 was set to 0.3. The MOVES algorithm eventually transfers all vehicles to this age group and requires a low survival rate to assure that the population of very old vehicles does not grow excessively. The actual survival rates of these age 30+ vehicles is unknown.

- Quantitatively the formula used to derive the MOVES Survival rates was:

MOVES Survival Rate (ageid =0) = 1 - (1-NHTSA Survival Rate (age =2)/3)
MOVES Survival Rate (ageid =1) = 1 - (1- 2* NHTSA Survival Rate (age =2)/3)
MOVES Survival Rate (age = 2 through 29) =
NHTSA Survival Rate (age = n-1)/ NHTSA Survival Rate (age = n-2)
MOVES Survival Rate (age = 30) = 0.3

The data for all other sourcetypes came from the Transportation Energy Data Book We used the Heavy-Duty rates for the 1980 model year (TEDB22, Table 6.11, same as TEDB26 Table 3.10). The 1990 model year rates were not used because they were significantly higher than the other model years in the analysis (e.g. 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 include scrappage rates for GVWR 10,000-26,000 vehicles, so it was necessary to apply the Heavy-Duty rates to predominantly Medium-Duty use types.

The TEDB survival rates were transformed into MOVES format in the same way as the NHTSA rates. Survival rates for all "age 30" sourcetypes[g] were set to 0.3. This is set to keep the fraction of oldest vehicles from growing excessively.

SurvivalRates used in MOVES2010 are shown in Table 6-1.

[g]Except motorcycles, where in MOVES2010 we used the rates developed by our contractor. The 0.3 value was used in MOVES2010a.

Table 6-1. SurvivalRate by Age and SourceType

Age	Motorcycles MOVES2010	Motorcycles MOVES2010a	Passenger Cars	Passenger Trucks Light Comm. Trucks	All Other SourceTypes
0	1.000	1.000	0.997	0.991	1.000
1	0.979	0.979	0.997	0.991	1.000
2	0.920	0.940	0.997	0.991	1.000
3	0.864	0.940	0.993	0.986	1.000
4	0.812	0.940	0.990	0.981	0.990
5	0.763	0.940	0.986	0.976	0.980
6	0.717	0.940	0.981	0.970	0.980
7	0.674	0.940	0.976	0.964	0.970
8	0.633	0.940	0.971	0.958	0.970
9	0.595	0.940	0.965	0.952	0.970
10	0.559	0.940	0.959	0.946	0.960
11	0.525	0.940	0.953	0.940	0.960
12	0.493	0.940	0.912	0.935	0.950
13	0.464	0.940	0.854	0.929	0.950
14	0.436	0.940	0.832	0.913	0.950
15	0.409	0.940	0.813	0.908	0.940
16	0.385	0.940	0.799	0.903	0.940
17	0.361	0.940	0.787	0.898	0.930
18	0.340	0.940	0.779	0.894	0.930
19	0.319	0.940	0.772	0.891	0.920
20	0.300	0.940	0.767	0.888	0.920
21	0.282	0.940	0.763	0.885	0.920
22	0.265	0.940	0.760	0.883	0.910
23	0.249	0.940	0.757	0.880	0.910
24	0.234	0.940	0.757	0.879	0.910
25	0.220	0.940	0.754	0.877	0.900
26	0.206	0.940	0.754	0.875	0.900
27	0.194	0.940	0.567	0.875	0.900
28	0.182	0.940	0.752	0.873	0.890
29	0.171	0.940	0.752	0.872	0.890
30	0.161	0.300	0.300	0.300	0.300

6.2. Relative Mileage Accumulation Rate

The Relative Mileage Accumulation Rate (Relative MAR) is listed for each MOVES sourcetype and Age. The Relative MAR is computed as the annual MAR divided by the highest MAR within the HPMS vehicle class. This allows MOVES to maintain a constant MAR ratio between ages and between the sourcetypes that make up each HPMS vehicle type even as vehicle populations and the total VMT for an HPMS vehicle class changes over time. Table 1-2 (previous) lists the groupings of the MOVES sourcetypes within the six HPMS Vehicle Classes. The following discussion refers to the Source Type ID numbers found in this table.

For many sourcetypes, the annual MARs were derived from the MARs developed for MOBILE6. These were mapped from the MOBILE6 Vehicle Classes to the MOVES sourcetypes. We then used regression to smooth these initial MARs and to extend the MARs from 25 to 30 ages.

The MAR values described below were then used to calculate the "relative MARs" by computing the ratio of the value for each sourcetype and age to the highest value within the HPMS class. For example, all of the bus values are relative to each other. The relative MARs for all sourcetypes are illustrated in Figure 6-1

6.2.1. Motorcycles

The MARs for motorcycles (category 11) were updated by a contractor 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.[45]

6.2.2. Passenger Cars, Passenger Trucks and Light Commerical Trucks

The MARs for passenger cars, passenger trucks and light commercial trucks (categories 21, 31 & 32) were taken from the NHTSA report on survivability and mileage schedules.[46] In the NHTSA analysis, annual mileage by age was determined for cars and for trucks using data from the 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 cubic regression to smooth the VMT by age estimates.

We used NHTSA's regression coefficients to extrapolate mileage to ages not covered by the report. We divided each age's mileage by the NHTSA "age 1" mileage to determine a relative MAR. For consistency with MOVES age categories, we then shifted the relative MARs such that the NHTSA "age1" 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.

6.2.3. Other Trucks

The initial MARs for truck categories 51, 52, 53, 61, and 62 in MOVES were calculated based on weighting fractions assigned to the MOBILE6 truck classes. We used VIUS 1997 values for Gross Vehicle Weight (PKGVW) to determine weighting fractions by model year. To separate Light-Duty Trucks 1 and Light-Duty Trucks 2, which are distinguished by Loaded Vehicle Weights, we used information from the Oak Ridge National Lab Light Duty Vehicle database. To separate Class 2a and 2b trucks, we used information from the Oak Ridge National Laboratory Report by Davis and Truitt.[47] The initial MARs for the MOVES truck categories were then calculated as the product of the weighting fractions and the MARs from MOBILE6. In order to smooth the data and to extend the MARs from the 25 ages in MOBILE6 to the 30 ages in MOVES, we used statistical regression to determine the curves that best fit the data for years starting in 1997 and going back to 1973 (ages 1 to 25).

6.2.4. Buses

For the School Buses (category 43) the initial MARs were taken from the MOBILE6 value for diesel school buses (HDDBS). As in MOBILE6, the same annual MAR was used for each age. The MOBILE6 value of 9,939 miles per year came from the 1997 School Bus Fleet Fact Book.

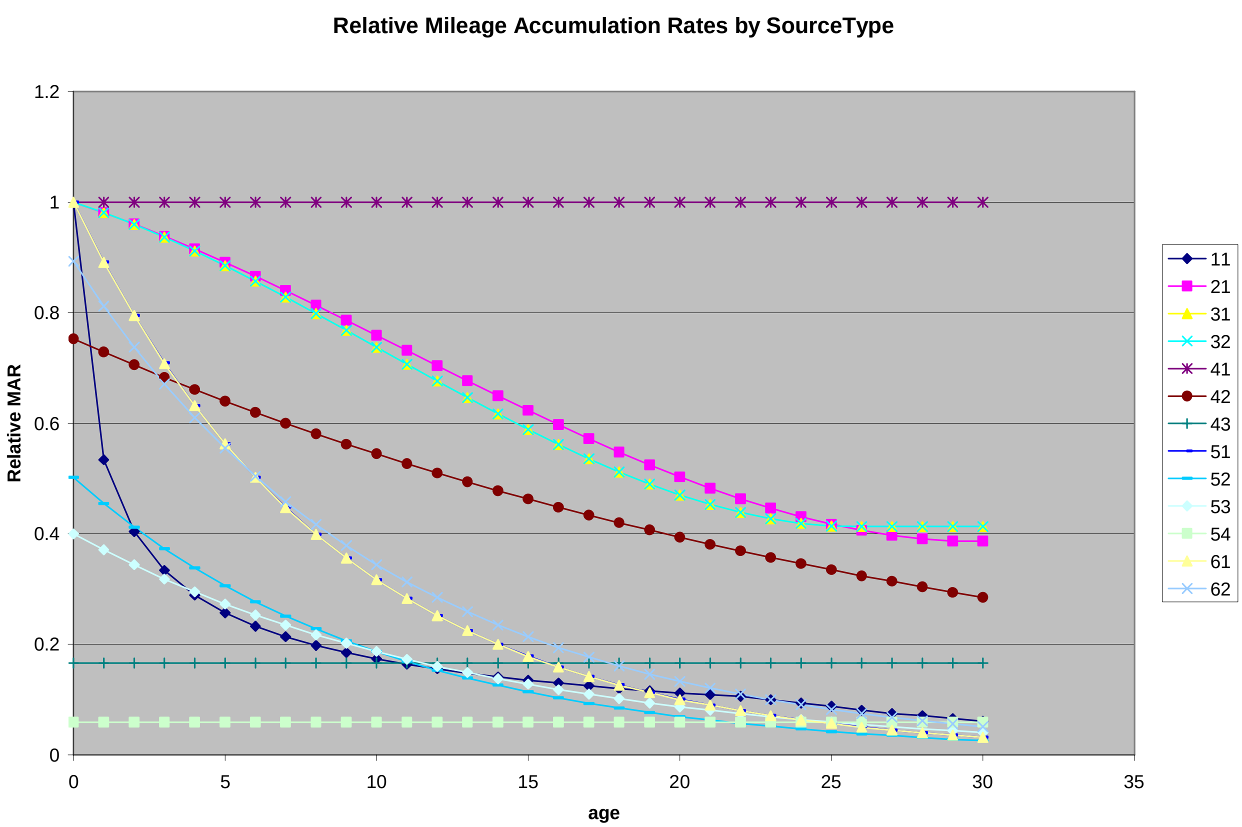
For Transit Buses (category 42), the initial MARs were taken from the MOBILE6 values for diesel transit buses (HDDBT). This mileage data was obtained from the 1994 Federal Transportation Administration survey of transit agencies. [48] The MOBILE6 equation was also applied to ages 26 through 30.

For Intercity Buses (category 41), the initial MARs were taken from Motorcoach Census 2000.[49] The data did not distinguish vehicle age, so the same MAR was used for each age. This MAR is high compared to transit and school buses.

6.2.5. Motor Homes

For motor homes (category 54), the initial MARs were taken from an independent research study[50] 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.

Figure 6-1. Relative Mileage Accumulation Rates in MOVES2010



7. Vehicle-Specific-Power Characteristics by SourceType

The MOVES model calculates emissions by calculating a weighted average of emisisons by operating mode. For running exhaust emissions, the operating modes are defined by Vehicle Specific Power (VSP) or the related concept, Scaled Tractive Power (STP). Both VSP and STP are calculated based on a vehicle's speed and acceleration. They differ in how they are scaled. The VSP equation is used for light duty vehicles (sourcetypes 11-32) and the STP equation is used for heavy-duty vehicles (sourcetypes 41-62).

The SourceUseType table describes the vehicle characteristics needed for the VSP and STP calculations. In particular, this table lists average vehicle mass, fixed mass factor and three average road load coefficients for each SourceType. These are averaged over all model years and ages. The mass is listed in metric tons. The road load coefficients are a rolling term "A," a rotatating term "B," and a drag term "C."

MOVES uses these coefficients to calculate VSP and STP for each source type according to the equation:

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

where A, B, and C are the road load coefficients in units of (kiloWatt second)/(meter), (kiloWatt second^2)/(meter^2 , and (kiloWatt second^3)/(meter$^{3)}$, respectively. The detenominator term, *m* is the fixed mass factor for the sourcetype in *metric tons*, *g* is the acceleration due to gravity (*9.8 meter/ second^2*), *v* is the vehicle speed in *meter/second*, *a* is the vehicle acceleration in *meter/second^2*, and sin θ is the (fractional) road grade.

The values in the SourceUseType table were averaged from values in the Mobile Source Observation Database (MSOD). The values were weighted using the age and sourcebin distributions described elsewhere in this report. In particular, the average values were computed using the equation:

$$weightedvalue = \frac{\sum_{i=1,\, total\,\#of\ ages} \left\{ \beta_i \cdot \left(\frac{\sum_{j=1,\, total\,\#of\ sourcebins} \alpha_j \cdot unweightedvalue}{\sum_{j=1,\, total\,\#of\ sourcebins} \alpha_j} \right) \right\}}{\sum_{i=1,\, total\,\#of\ ages} \beta_i}$$

where the "unweighted value" was either the vehicle mid-point mass or one of the three different road load coefficients determined from the road load–vehicle mass relations described below: α_j were the sourceBinActivityFractions in the MOVES database and β_i were the ageFractions in the MOVES database. Age fractions were matched to model years for calendar year 1999 (i.e., Model Year 1999 corresponds to vehicle ageID of 0; Model Year1969 corresponds to ageID of 30.) Only sourcebins and ages with vehicles in the MSOD were used in these weightings. Thus, the "total number of sourcebins" in the MSOD and "total number of ages" in the MSOD were used to normalize the results.

7.1. SourceMass and Fixed Mass Factor

MOVES2010 includes both a SourceMass and a fixedMassFactor. The SourceMass represents the average weight of a given sourcetype. One can model changes in average weight of a sourcetype by changing this factor. The fixedMassFactor is the value that was used to calculate the relevant power measure used to define operating modes for running emissions, that is, VSP or STP. Note for motorcycles, cars, and light trucks, the default database is populated with a fixedMassFactor that was calculated as the mean for that sourcetype. This differs from the factor used in the actual calculation of the emission rates which was the measured weight for each vehicle. For other sourcetypes, the fixedMassFactor represents a scaling factor to bring the numerical range of tractive power into the same numerical range as the VSP values when assigning operating modes, hence scaled tractive power (STP). The fixedMassFactor of 17.1 is roughly equivalent to the average running weight (in metric tons) of all heavy-duty vehicles. It was also used in the development of the heavy-duty emission rates.

The SourceMass was computed as the weighted average of the “mid-point” mass for the Weight Class associated with each sourcebin. Sourcebins not represented in the MSOD were excluded.

Table 7-1. MOVES Weight Classes

Weight ClassID	**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

7.2. Road Load Coefficients

The information available on road load coefficients varied by regulatory class.

Motorcycle road load coefficients are typically parameterized with mass dependent A and C terms which take into account rolling resistance and aerodynamic drag. Parameters adopted here are from the United Nations report[51,52]:

$A = 0.088M$ and
$C= 0.26 + 1.94x10-4M$

where M is the inertial mass of the motorcycle (SourceMass) and driver and has units of metric tons.

For vehicles with a weight of 8500 lbs or less, the road load coefficients were derived from the track road load horspower ($TRLHP_{@50mph}$) recorded in the MSOD.[53] The calculations applied the following empirical equations:[54]

$$A = 0.7457*(0.35/50*0.447) * TRLHP_{@50mph}$$
$$B = 0.7457*(0.10/(50*0.447)^2) * TRLHP_{@50mph}$$
$$C = 0.7457*(0.55/(50*0.447)^3) * TRLHP_{@50mph}$$

Where 0.447 is a conversion from mile per hour to meters per second.

For the heavier vehicles, no road load parameters were available in the MSOD. Instead EPA used the relationships of road load coefficent to vehicle mass from a study done by V.A. Petrushov,[55] as shown in Table 7-2. The mid-point mass for the sourcebin was used as the vehicle mass.

Table 7-2. Road Load Coefficients for Heavy-Duty Trucks, Buses, and Motor Homes

<table>
<tr><th></th><th>8500 to 14000 lbs (3.855 to 6.350 metric ton)</th><th>14000 to 33000 lbs (6.350 to 14.968 metric ton)</th><th>>33000 lbs (>14.968 metric ton)</th><th>Buses and Motor Homes</th></tr>
<tr><td>A(kW*s/m)/ M(metric ton)</td><td>0.0996</td><td>0.0875</td><td>0.0661</td><td>0.0643</td></tr>
<tr><td>B(kW*s^2/m^2)/ M(metric ton)</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td rowspan="2">C(kW*s^3/m^3) /M(metric ton)</td><td>3.40×10^{-4} (mass is the average mass of the weight category)</td><td>1.97×10^{-4} (mass is the average mass of the weight category)</td><td>1.79×10^{-4} (mass is the average mass of the weight category)</td><td rowspan="2">$\frac{3.22}{mass(kg)} + 5.06 \times 10^{-5}$</td></tr>
<tr><td>$\frac{1.47}{mass(kg)} + 5.22 \times 10^{-5}$</td><td>$\frac{1.93}{mass(kg)} + 5.90 \times 10^{-5}$</td><td>$\frac{2.89}{mass(kg)} + 4.21 \times 10^{-5}$</td></tr>
</table>

In both cases, values of A, B, and C were computed for each SourceBin-associated vehicle in the MSOD and a weighted average was computed as described above. The final SourceMass, FixedMassFactor and road load coefficients for all sourcetypes are listed in Table 7-3.

Table 7-3. SourceUseType Characteristics

Source TypeID	HPMS Vtype ID	SourceType Name	Rolling TermA (kW-s/m)	Rotating TermB ($kW\text{-}s^2/m^2$)	Drag TermC ($kW\text{-}s^3/m^3$)	Source Mass (metric tons)	FixedMass Factor (metric tons)
11	10	Motorcycle	0.0251	0	0.000315	0.285	0.285
21	20	Passenger Car	0.156461	0.002002	0.000493	1.4788	1.4788
31	30	Passenger Truck	0.22112	0.002838	0.000698	1.86686	1.86686
32	30	Light Commercial Truck	0.235008	0.003039	0.000748	2.05979	2.05979
41	40	Intercity Bus	1.29515	0	0.003715	19.5937	17.1
42	40	Transit Bus	1.0944	0	0.003587	16.556	17.1
43	40	School Bus	0.746718	0	0.002176	9.06989	17.1
51	50	Refuse Truck	1.41705	0	0.003572	20.6845	17.1
52	50	Single Unit Short-haul Truck	0.561933	0	0.001603	7.64159	17.1
53	50	Single Unit Long-haul Truck	0.498699	0	0.001474	6.25047	17.1
54	50	Motor Home	0.617371	0	0.002105	6.73483	17.1
61	60	Combination Short-haul Truck	1.96354	0	0.004031	29.3275	17.1
62	60	Combination Long-haul Truck	2.08126	0	0.004188	31.4038	17.1

8. VMT by Year and Vehicle Type

For national level calculations, MOVES uses national VMT by vehicle type to determine source operating hours. The model's Total Activity Generator takes a default VMT for a base year and uses growth factors to estimate VMT in later analysis years. Three fields comprise HPMSVTypeYear in MOVES2010: HPMSBaseYearVMT, BaseYearOffNetVMT, and VMTGrowthFactor.

8.1. HPMSBaseYearVMT

The HPMSBaseYearVMT field stores the base year VMT for each HPMS Vehicle Type. This VMT was calculated from the FHWA VM-1 and VM-2 tables by summing over HPMS Vehicle Class.

The resulting values for 1999 and 1990 by HPMS Vehicle Class are listed in Table 8-1.

Table 8-1. 1999 VMT by HPMS Vehicle Class

HPMS Vehicle Class	1990 VMT	1999 VMT
Motorcycles	9,557,000,000	10,579,600,000
Passenger Cars	1,408,270,000,000	1,568,640,000,000
Other 2 axle - 4 tire vehicles	574,571,000,000	900,735,000,000
Buses	5,726,000,000	7,657,000,000
Single unit trucks	51,901,000,000	70,273,700,000
Combination trucks	94,341,000,000	132,358,000,000

8.2. BaseYearOffNetVMT

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 roadtypes. This field 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 MOVES2010 national defaults, the BaseYearOffNetVMT is zero for all vehicle types.

8.3. VMTGrowthFactor

The VMTGrowthFactor field stores a multiplicative factor indicating changes in total vehicle miles for calendar years after the base year. Total VMT data are reported according the HPMS vehicle classes discussed previously, i.e. passenger car, other 2-axle / 4-tire vehicle, single-unit truck, combination truck, bus and motorcycle. VMTGrowthFactor is expressed relative to the previous year's VMT; for example, 1 means no change from previous year VMT, 1.02 means a two percent increase in VMT, and 0.98 means a two percent decrease in VMT.

VMTGrowthFactor is used in the Total Activity Generator calculation of VMT for calendar years after the base year, meaning calendar years 2000 through 2050 in MOVES2010. It is important to note that VMTGrowthFactor is a key component for estimates of future activity in MOVES, because the level of total activity in future years for many emission processes is derived from projections of total VMT. For these processes, projections of future populations based on sales growth, survival rates, etc. are only used to allocate total VMT.

For motorcycles, default growth factors for years 2000 through 2008 were derived from Highway Statistics Table VM-1. Growth factors for years 2009-and-later were borrowed from a previous (AEO2006-based) estimate for passenger cars.

For passenger cars, passenger trucks and light commercial trucks, growth factors for historical years 2000 through 2007 were derived from estimates of total VMT data as reported in the Transportation Energy Data Book. For these years the growth factors are simply total VMT for the applicable vehicle class for the calendar year divided by total VMT from the previous year. For 2008-2020, we used values from AEO2009. Unlike TEDB, AEO does not break VMT out by cars and trucks. Consequently, EPA developed a formula to apportion the projected AEO light duty VMT between cars and trucks.

VMT = Previous Year VMT x (1+percent change in class) x per-vehicle growth rate

Where

Previous year VMT =	the VMT of the previous year, starting with TEDB in 2007
Percent change in Class =	the percent change in car or truck population relative to the previous year, derived by applying scrappage and sales to the previous year fleet.
Per vehicle growth rate =	a constant growth rate that is used to reflect the increase in per-vehicle annual VMT that is commonly observed.

The per vehicle growth rate was kept identical and constant between cars and trucks during the years 2008-2030. The per-vehicle growth rate was raised in the years 2030 to 2050 so that the total annual growth in light duty VMT was consistent with the average for the time period (1.7% annual growth in total LD VMT). 0.3% annual growth in per vehicle VMT was assumed in 2008-2030, while 1% change in per-vehicle growth was assumed in the years 2030-2050

In MOVES2010, the default VMTGrowthFactor estimates for other sourcetypes were taken from FHWA *Highway Statistics Table VM-1* for 2000 through 2004, and from AEO2006 for years 2005-and-later. VMT projections are provided for total Medium-Duty and total Heavy-Duty in *AEO2004* Supplemental Table 55. The growth factors derived from the *AEO2006* Medium-Duty VMT estimates were applied to the single-unit truck and bus HPMS vehicle classes. The growth factors derived from the *AEO2006* Heavy-Duty VMT estimates were applied to the combination truck vehicle class.

In MOVES2010a, the default VMTGrowthFactor estimates for the heavy sourcetypes were taken from VM-1 for 2000 through 2008 and values from AEO2009 Table 67 were used for years 2009-and-later.

Table 8-2. VMT Growth Factors in MOVES2010

Year	Motorcycles	Passenger Cars	Passenger & Light Comm. Trucks	Buses	Single Unit Trucks	Combination Trucks
2000	0.990	1.020	1.025	0.992	1.004	1.021
2001	0.909	1.018	1.022	0.920	1.025	1.003
2002	1.002	1.019	1.024	0.968	1.048	1.015
2003	0.999	1.008	1.019	0.991	1.025	1.010
2004	1.061	1.017	1.044	0.979	1.043	1.037
2005	1.064	1.005	1.014	0.998	0.998	1.022
2006	1.119	0.990	1.040	1.007	1.007	1.034
2007	1.130	0.988	1.027	1.016	1.016	1.033
2008	1.131	0.988	1.006	1.013	1.013	1.025
2009	1.012	0.983	0.993	1.018	1.018	1.025
2010	1.012	0.993	1.008	1.021	1.021	1.026

Year	Motorcycles	Passenger Cars	Passenger & Light Comm. Trucks	Buses	Single Unit Trucks	Combination Trucks
2011	1.007	1.002	1.011	1.025	1.025	1.025
2012	1.006	1.009	1.011	1.023	1.023	1.023
2013	1.006	1.014	1.012	1.022	1.022	1.022
2014	1.007	1.019	1.010	1.023	1.023	1.022
2015	1.007	1.028	1.008	1.024	1.024	1.023
2016	1.007	1.028	1.005	1.025	1.025	1.023
2017	1.008	1.027	1.003	1.026	1.026	1.025
2018	1.009	1.029	1.001	1.026	1.026	1.025
2019	1.009	1.031	1.000	1.025	1.025	1.021
2020	1.008	1.032	0.998	1.025	1.025	1.020
2021	1.008	1.031	0.997	1.026	1.026	1.020
2022	1.009	1.031	0.997	1.027	1.027	1.021
2023	1.009	1.030	0.997	1.027	1.027	1.021
2024	1.009	1.030	0.997	1.027	1.027	1.022
2025	1.009	1.029	0.998	1.027	1.027	1.023
2026	1.010	1.027	0.999	1.028	1.028	1.024
2027	1.010	1.025	0.999	1.027	1.027	1.024
2028	1.010	1.023	0.999	1.027	1.027	1.023
2029	1.010	1.021	0.999	1.027	1.027	1.023
2030	1.010	1.020	1.000	1.026	1.026	1.023
2031	1.010	1.026	1.007	1.026	1.026	1.023
2032	1.010	1.025	1.008	1.026	1.026	1.023
2033	1.010	1.023	1.009	1.026	1.026	1.023
2034	1.010	1.023	1.010	1.026	1.026	1.023
2035	1.010	1.022	1.010	1.026	1.026	1.023
2036	1.010	1.021	1.011	1.026	1.026	1.023
2037	1.010	1.021	1.012	1.026	1.026	1.023
2038	1.010	1.020	1.014	1.026	1.026	1.023
2039	1.010	1.020	1.016	1.026	1.026	1.023
2040	1.010	1.019	1.015	1.026	1.026	1.023
2041	1.010	1.019	1.015	1.026	1.026	1.023
2042	1.010	1.019	1.015	1.026	1.026	1.023
2043	1.010	1.018	1.015	1.026	1.026	1.023
2044	1.010	1.018	1.016	1.026	1.026	1.023
2045	1.010	1.018	1.016	1.026	1.026	1.023
2046	1.010	1.018	1.016	1.026	1.026	1.023
2047	1.010	1.018	1.017	1.026	1.026	1.023
2048	1.010	1.018	1.017	1.026	1.026	1.023
2049	1.010	1.018	1.017	1.026	1.026	1.023
2050	1.010	1.018	1.017	1.026	1.026	1.023

Table 8-3. VMT Growth Factors in MOVES2010a

Year	Motorcycles	Passenger Cars	Passenger & Light Comm. Trucks	Buses	Single Unit Trucks	Combination Trucks
2000	0.990	1.020	1.025	0.992	1.004	1.021
2001	0.909	1.018	1.022	0.920	1.025	1.003
2002	1.002	1.019	1.024	0.968	1.048	1.015
2003	0.999	1.008	1.019	0.991	1.025	1.010
2004	1.061	1.017	1.044	0.979	1.043	1.037
2005	1.064	1.005	1.014	1.026	1.001	1.012
2006	1.119	0.990	1.040	1.002	1.023	0.991
2007	1.130	0.988	1.027	0.998	1.021	1.016
2008	1.131	0.988	1.006	1.019	1.024	0.989
2009	1.012	0.983	0.993	0.908	0.908	0.891
2010	1.012	0.993	1.008	1.041	1.041	0.998
2011	1.007	1.002	1.011	1.086	1.086	1.043
2012	1.006	1.009	1.011	1.071	1.071	1.046
2013	1.006	1.014	1.012	1.048	1.048	1.034
2014	1.007	1.019	1.010	1.036	1.036	1.024
2015	1.007	1.028	1.008	1.036	1.036	1.018
2016	1.007	1.028	1.005	1.036	1.036	1.017
2017	1.008	1.027	1.003	1.034	1.034	1.018
2018	1.009	1.029	1.001	1.032	1.032	1.022
2019	1.009	1.031	1.000	1.030	1.030	1.023
2020	1.008	1.032	0.998	1.029	1.029	1.020
2021	1.008	1.031	0.997	1.024	1.024	1.013
2022	1.009	1.031	0.997	1.022	1.022	1.011
2023	1.009	1.030	0.997	1.026	1.026	1.014
2024	1.009	1.030	0.997	1.028	1.028	1.017
2025	1.009	1.029	0.998	1.028	1.028	1.017
2026	1.010	1.027	0.999	1.028	1.028	1.017
2027	1.010	1.025	0.999	1.028	1.028	1.015
2028	1.010	1.023	0.999	1.027	1.027	1.013
2029	1.010	1.021	0.999	1.028	1.028	1.012
2030	1.010	1.020	1.000	1.028	1.028	1.013
2031	1.010	1.026	1.007	1.027	1.027	1.012
2032	1.010	1.025	1.008	1.027	1.027	1.011
2033	1.010	1.023	1.009	1.028	1.028	1.013
2034	1.010	1.023	1.010	1.028	1.028	1.013
2035	1.010	1.022	1.010	1.028	1.028	1.015
2036	1.010	1.021	1.011	1.028	1.028	1.015
2037	1.010	1.021	1.012	1.028	1.028	1.015
2038	1.010	1.020	1.014	1.028	1.028	1.015
2039	1.010	1.020	1.016	1.028	1.028	1.015
2040	1.010	1.019	1.015	1.028	1.028	1.015

Year	Motorcycles	Passenger Cars	Passenger & Light Comm. Trucks	Buses	Single Unit Trucks	Combination Trucks
2041	1.010	1.019	1.015	1.028	1.028	1.015
2042	1.010	1.019	1.015	1.028	1.028	1.015
2043	1.010	1.018	1.015	1.028	1.028	1.015
2044	1.010	1.018	1.016	1.028	1.028	1.015
2045	1.010	1.018	1.016	1.028	1.028	1.015
2046	1.010	1.018	1.016	1.028	1.028	1.015
2047	1.010	1.018	1.017	1.028	1.028	1.015
2048	1.010	1.018	1.017	1.028	1.028	1.015
2049	1.010	1.018	1.017	1.028	1.028	1.015
2050	1.010	1.018	1.017	1.028	1.028	1.015

Note that MOVES uses a single national growth factor by vehicle class, thus it does not capture variations in growth across roadtypes and counties. Therefore, for local calculations, locally available data will often better represent local VMT.

9. Roadtypes, VMT Distribution among Roadtypes, and Mappings to SCC

MOVES will calculate emissions separately for each road type and for “off-network” activity. The road type codes used in MOVES are listed in Table 9-1. The MOVES road types are aggregations of the HPMS functional facility types that are also used for reporting in EPA Source Classification Codes (SCCs).

Table 9-1. Road Type Codes in MOVES

RoadTypeID	Description	HPMS functional Types	SCCRoadTypeID
1	Off Network	Off Network	1
2	Rural Restricted Access	Rural Interstate	11
3	Rural Unrestricted Access	Rural Principal Arterial, Minor Arterial, Major Collector, Minor Collector & Local	13, 15, 17, 19, 21
4	Urban Restricted Access	Urban Interstate & Urban Freeway/Expressway	23, 25
5	Urban Unrestricted Access	Urban Principal Arterial, Minor Arterial, Collector & Local	27, 29, 31, 33

The number of default roadtypes in MOVES was limited to reduce database size and to help improve model performance. 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 roadtypes or may run MOVES at project level where emissions can be calculated for individual links.

9.1. RoadTypeVMTFraction

For each sourcetype, the **RoadTypeVMTFraction** field stores the fraction of total VMT for each vehicle class that is traveled on each of the 5 roadway types. For MOVES2010, we used data from 1999 FHWA Highway Statistics, Tables VM-1 and VM-2. VM-1 provides detail on VMT by vehicle type; VM-2 provides detail by HPMS functional type. At the time of the analysis, VM-1 (October 2000) had not been updated, but VM-2 was updated in January 2002. We used the total values from VM-2 to distribute VMT by HPMS facility type and allocated this VMT to vehicle class in proportion to the values in VM-1. We then calculated facility type VMT fractions for each HPMS Vehicle Type. We later aggregated the values to the five MOVES road types and mapped from HPMS Vehicle Type to MOVES Sourcetype.

The FHWA Highway Statistics is currently considered the best available source for national information regarding vehicle miles traveled. However, there are problems and constraints associated with using the (mostly) state-reported data in Highway Statistics. In many cases, locally derived VMT data may be more accurate when modeling local areas.

The VMT distributions in Table 9-2 assume that all VMT reported by HPMS is accumulated on one of the 12 HPMS roadway types and thus one of the four "on-network" MOVES roadtypes. No VMT is currently assigned to the "off-network" category in the national defaults. See the discussion of BaseYearOffNetVMT in Section 8.2.

Table 9-2. Sourcetype VMT distribution among Road Types

RoadType ID	Road type Description	Motorcycles	Passenger Cars	Other 2axle - 4tire vehicles	Buses	Single unit trucks	Combination trucks
1	Off Network	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	Rural Restricted Access	0.1040	0.0834	0.0846	0.1268	0.1149	0.3247
3	Rural Unrestricted Access	0.3161	0.2891	0.3055	0.4821	0.3972	0.2941
4	Urban Restricted Access	0.2177	0.2097	0.2031	0.1385	0.1715	0.2075
5	Urban Unrestricted Access	0.3623	0.4178	0.4068	0.2526	0.3165	0.1737
Total		1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

We are currently assuming identical VMT distributions for all sourcetypes within an HPMS Vehicle Type. However the MOVES model is designed to allow roadway type allocation by sourcetype and one would expect the different sourcetypes to have different roadway type allocations. For example, the long-haul trucks generally would have a greater fraction of travel on rural restricted access roadways than the short-haul trucks. While national data to quantify these distinctions is not currently available, users may find information available at the local level to apply different distibutions at the source type level.

9.2. SCCRoadTypeDistribution

Each SCC includes a suffix that indicates the HPMS Facility Class on which the emissions occur. Because MOVES calculations are done for MOVES roadtypes, the **SCCRoadTypeFraction** is needed to allocate emissions on each MOVES roadtype to the appropriate SCCRoadTypes.

Table 9-3. SCC RoadTypes

SCCRoadTypeID	SCCRoadTypeDesc
11	Rural Interstate
13	Rural Principal Arterial
15	Rural Minor Arterial
17	Rural Major Collector
19	Rural Minor Collector
21	Rural Local
23	Urban Interstate
25	Urban Freeway/Expressway
27	Urban Principal Arterial
29	Urban Minor Arterial
31	Urban Collector
33	Urban Local
1	Off-Network

Because roadtype distributions vary geographically, the mapping of MOVES roadTypes to SCCRoadTypes varies by zone (in this case, county). For SCCRoadTypeDistribution we determined the proportion of hours of operation on a given MOVES roadtype within a county that occurred on each SCCRoadType. Hours of operation were estimated by dividing the 1999 National Emission Inventory (NEI) VMT by the 1999 NEI average speed. Both measures were documented by Pechan & Associates.[56] The NEI VMT estimates are based on the Highway Performance Monitoring System (HPMS) data collected by the Federal Highway Administration[57] for use in transportation planning and vehicle type breakdowns from the EPA MOBILE6 Emission Factor model.[58] The VMT estimates were obtained from the NMIM database for each county and HPMS facility type. The average speed estimates are taken from Table 8 of the NEI documentation.

The SCCRoadType fractions were calculated using the following formula, where i refers to the county, j refers to the MOVES roadtype, k refers to the SCCRoadType within a MOVES road type, and m refers to the VMT for each source type.

SCCRoadTypeFraction(i,j,k) = Sum(j,j,k)(VMT(k,m)/Average Speed(k,m)) /
Sum(i,j)((VMT(k,m)/AverageSpeed(k,m))

In cases where a county had no VMT for a given roadtype, the average values were used. The SCCRoadTypeFraction for OffNetwork travel was set to 1 (mapping all "off-network" emissions to this new roadtype. The SCCRoadType fractions for each roadway type will sum to one for each county. Although the data is from 1999 calendar year estimates, the same allocations will be used for all calendar years.

10. 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. Also, MOVES2010 uses average speeds 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, MOVES2010 uses a distribution of average speeds. The AvgSpeedDistribution table lists the default fraction of driving time for each sourcetype, Road Type, Day, Hour, in each average speed bin. The fractions sum to one for each combination of sourcetype, Road Type, Day, and Hour.

For MOVES2010, the average speed fractions for urban roads were derived from the default speed distributions (SVMT) in MOBILE6[59]. These fractions do not vary by vehicle type. The MOBILE6 speed fractions were adapted to MOVES by converting the fraction of miles travelled to the fraction of time used, and by mapping from the MOBILE6 road types to the MOVESroad types, with the MOBILE6 "freeway" values mapped to the MOVES "urban restricted" roadtype and the MOBILE6 "arterial" values mapped to the MOVES "urban unrestricted" roadtype. The time fractions were normalized to sum to one for each hour of the day over all 14 speed bins. The values for the off-network roadway type were set to null. The detailed distributions are available in the MOVES default database.

For rural road average speed distributions, we relied on light-duty driving data collected in California under studies performed for the California Department of Transportation (Caltrans). Under these Caltrans driving studies, instrumented "chase cars" were equipped with laser rangefinders mounted behind the front grill of each chase car. The studies were performed in the Sacramento area, the San Francisco Bay area and the San Joaquin Valley. Another driving study was also conducted in the South Coast (i.e., Los Angeles Basin), but was conducted entirely in urbanized areas. Thus, this data was not used for the rural area analysis. A contractor report describes the analysis done to develop speed distributions from the Caltrans datasets.[60] In post-processing, the driving data was grouped by HPMS functional class. The urban area travel in these datasets was discarded for this analysis. The average speed was calculated over each one-way driving traverse of a roadway link. Once the average speed was calculated for each link traverse, the VMT was allocated into one of sixteen speed bins defined by EPA for the purpose of calculating speed distributions for use in MOVES. The MOVES speed bins are shown in Table 10-1.

Table 10-1. 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

To import this information into MOVES, we started with the contractor-provided values of "Time-weighted Distributions (% of time) of California Rural Chase Car Driving Data by Average Link Speed for each HPMS Functional Class."[61] These values were used directly for the rural restricted access roadtype (2). For the MOVES rural unrestricted access roadtype, the calculation required consolidating values on the five HPMS functional road classes to the single MOVES roadtype. This was done separately for each HPMS Vehicle Class. For each vehicle class, we used the roadtype VMT distribution (see preceding section) to calculate the fraction of VMT on each road class. We then changed to a time-basis by calculating the average speed on each road class, dividing by the average speed and re-nomalizing. We then computed a sum-product of the speed bin fractions and the road class distributions to calculate the weighted-average speed bin distribution for each vehicle class and assigned this distribution to each sourcetype in the HPMS vehicle class.

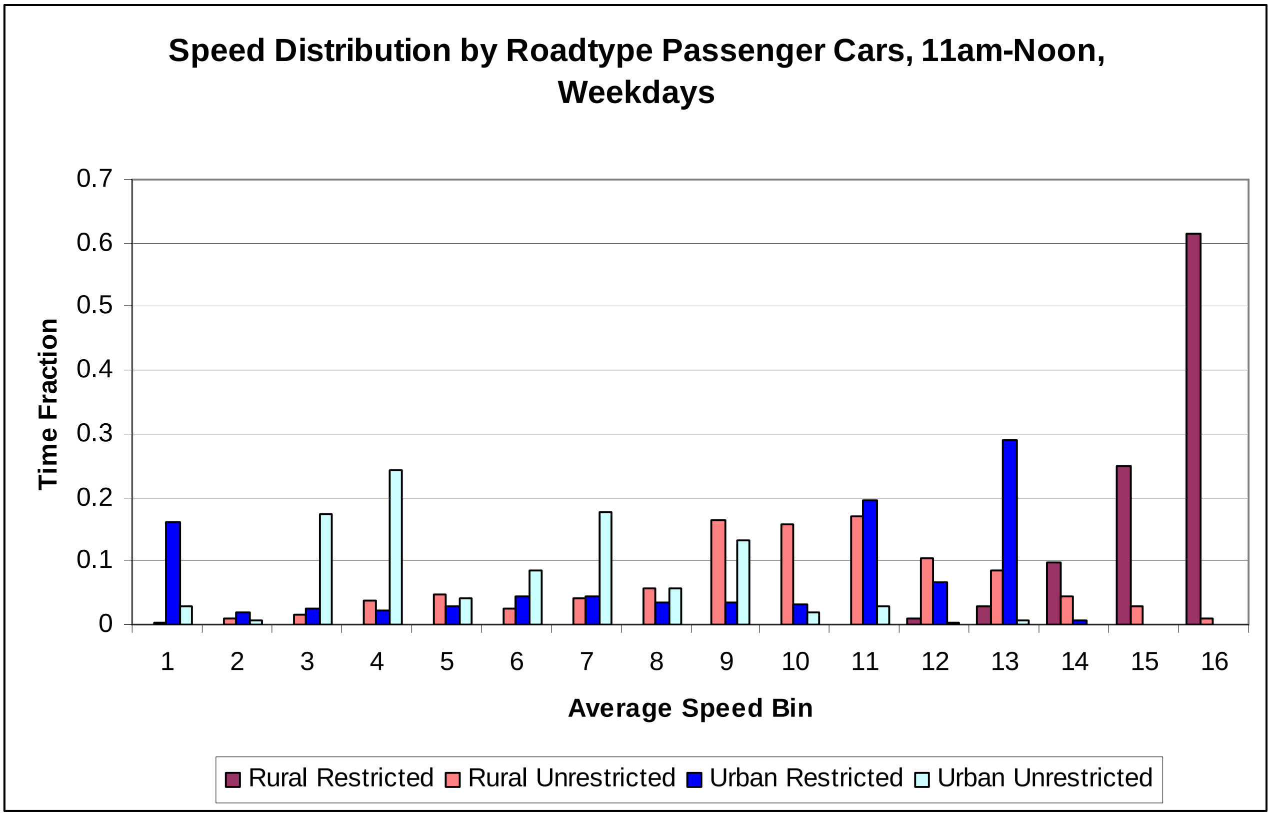
Our calculations of default average speed distributions required a number of assumptions and extrapolations. For both urban and rural road types, the same speed data was used for all sourcetypes.[h] Also the existing data from the rural studies used in this analysis were collected entirely in California. Using these California results to represent national rural speed distributions implicitly assumes that average speeds on rural roadways, within each HPMS functional class, do not significantly vary across the U.S. And the same rural speed distributions were used for all hours of the day. Because of these extrapolations, local data on speed

[h] While the underlying speed data used in MOVES2010 does not vary by sourcetype, the speed distributions in MOVES2010 do. This is because they were originally calculated on twelve roadtypes. When the roadtypes were combined to four, the road type weighting used to calculate the new speed distributions varied by sourcetype, leading, in some cases, to small variations in the associated speed distributions.

distributions often will be more accurate than our national defaults.

National default speed distributions are available in the default database for each roadtype, sourcetype and hourday, and are not provided here. However, for illustration, Figure 10-1 shows the speed distributions on different roadtypes for passenger cars for the time period 11 am. to noon on weekdays.

Figure 10-1 Example Speed Distribution by Roadtype



11. Driving Schedule Tables

DriveSchedule refers to a second-by-second vehicle speed trajectory. A drive schedule typically includes both driving and idling time. Drive schedules are used in MOVES to determine the operating mode distribution for most MOVES running process emissions and for energy consumption.

A key feature of MOVES is the capability to accommodate any number of drive schedules to represent driving patterns across source type, roadway type and average speed. For the national default case, MOVES2010 employs 47 drive schedules, mapped to specific source types and roadway types. In brief, the average speed of a driving schedule is used to determine the weighting of that schedule for a given roadtype and sourcetype, based on the average speed distribution. For each speed bin in the speed distribution, the MOVES model selects the two associated driving cycles with average speeds that bracket the speed bin's average speed. The Vehicle Specific Power (VSP) distributions determined for each bracketing driving schedule are averaged together, weighted by the proximity of the speed bin average speed to the driving schedule average speeds. In this way, the VSP distribution of any roadtype's speed distribution is determined from the available driving schedules. For more details, see the Operating Mode Distribution Generator sections in the MOVES Software and Design Reference Manual.[62] This approach is, of course, imprecise. Users with more information about driving activity may choose to model at the project level where users can enter specific driving cycles or operating mode distributions.

MOVES stores drive schedule information in four database tables. **DriveSchedule** provides the drive schedule name, identification number, and the average speed of the drive schedule. **DriveScheduleAssoc** defines the set of schedules which are available for each combination of source use type and road type. **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. **RoadOpModeDistribution** lists operating mode distributions used for ramps for each source use type, road type and speed bin.

Tables 11-1 through 11-5 list the driving schedules used for different sourcetypes. The freeway and non-freeway driving cycles are intended to cover most of the driving on these respective roadtypes. However, some speed distributions for non-freeway roadtypes will include average speeds faster than the fastest non-freeway cycles. The reverse will be true for some freeway speed distributions. In these cases, the model will use appropriate average speed drive schedules from a different roadtype. This mapping is appropriate since, when the average speed is very low or very high, the roadtype has little impact on the driving pattern.

The driving schedule tables also include light-duty, medium-duty and heavy-duty ramp driving schedules, but these are not used directly in MOVES2010. Instead, for inventory calculations[i] the ramp schedules were transformed into a set of driving cycles consistent with

[i] When MOVES2010 is used to calculate "Emission Rates," ramps are not included in the rates, but "Inventory" calculations in MOVES2010 use the ramp operating mode distribution that matches the average speed as calculated from the average speed distribution. The ramp methodology for both inventory and rate calculations was revised in MOVES2010a such that the emission rate calculations include ramp operating modes appropriate for each identified speed bin, and the inventory calculations use a weighted average of the ramp operating mode distributions for all the speeds in the average speed distribution for that sourcetype, roadtype, day and hour. See the MOVES Software Design and Reference Manual for more information.

connecting to and from a freeway with the given average speed. The cycles were then converted to operating mode distributions, which are stored in **RoadOpModeDistribution**.

Table 11-1. Driving Cycles for Motorcycles, Cars, Passenger Cars and Light Commercial Trucks

ID	Cycle Name	Average Speed	Non-Freeway		Freeway	
			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 FC12LOSD	20.6		X		
1020	Final FC11LOSE	46.1			X	X
1011	Final FC02LOSDF	49.1	X			
1025	Final FC12LOSE	46.1		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 11-2. Driving Cycles for Intercity Buses, Single-Unit Trucks and Motor Homes

ID	Cycle Name	Average Speed	Non-Freeway		Freeway	
			Rural	Urban	Rural	Urban
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

Table 11-3. Driving Cycles for Combination Trucks

ID	Cycle Name	Average Speed	Non-Freeway		Freeway	
			Rural	Urban	Rural	Urban
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

Table 11-4. Driving Cycles for Transit and School Buses

ID	Cycle Name	Average Speed	Non-Freeway		Freeway	
			Rural	Urban	Rural	Urban
201	MD 5mph Non-Freeway	4.6			X	X
202	MD 10mph Non-Freeway	10.7			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

* This speed represents average of traffic the bus is traveling in, not the average speed of the bus, which is lower due to stops.

Table 11-5. Driving Cycles for RefuseTrucks

ID	Cycle Name	Average Speed	Non-Freeway		Freeway	
			Rural	Urban	Rural	Urban
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

The default drive schedules listed in the tables above were developed from several sources. "LD LOS E Freeway" and "High Speed 1" were retained from MOBILE6 and are documented in report M6.SPD.001.[63] "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. "High Speed 3" was developed for MOVES to represent very high speed freeway driving. It is a 580-second segment of freeway driving from an in-use vehicle instrumented as part of EPA's On-Board Emission Measurement "Shootout" program,[64] with an average speed of 76 mph and a maximum speed of 90 mph. In MOVES2010, other historical cycles have been removed and replaced with 15 new light duty cycles developed by a contractor based on urban and rural data collected in California in 2000 and 2004.[65] The new cycles were selected to best cover the range of roadtypes and average speeds that need to be modeled in MOVES.

Medium-Duty and Heavy-Duty schedules were 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."[66] ERG analyzed data from 150 medium and heavy-duty vehicles instrumented to gather instantaneous speed and GPS measurements. ERG segregated the driving into freeway and non-freeway 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. ERG characterized representative driving within each speed range, using distributions of vehicle specific power (VSP), speed and acceleration. Driving schedules were then developed for each speed bin by creating combinations of idle-to-idle "microtrips" until the representative target metrics were achieved. The schedules developed by ERG are, thus, not contiguous schedules which would be run on a chassis dynamometer, but are made up of non-continguous "snippets" of driving meant to represent target distributions. For use in MOVES, the highway heavy-duty schedules developed by ERG were modified to isolate operation on freeway ramps. The segments of freeway microtrips identified by ERG as taking place on on-and off-ramps were extracted and used to create medium-duty and heavy-duty ramp schedules (299 and 399). Thus, the schedules which represent on-freeway driving do not contain ramp operation. Another minor modification to the schedules for use in MOVES was made to the time field in order to signify, within a drive schedule, when one microtrip ended and one began. The time field increments two seconds instead of one when each new microtrip begins. This two second increment signifies that these should not be regarded by the model as contiguous operation.

The two higher-speed transit bus driving cycles were developed based on Ann Arbor Transit Authority buses instrumented in Ann Arbor.[67] Non-contiguous snippets of driving were used to develop cycles with the desired average speeds. The "Low Speed Urban" bus cycle is the last 450 seconds of the standard New York Bus Driving Cycle. The Refuse Truck cycle represents refuse truck driving with many stops and a maximum speed of 20 mph.

12. Temporal Distributions of VMT and Hourly Extended Idle Activity

MOVES can estimate emissions for every hour of every day of the year. For national scale runs ("macroscale") annual VMT estimates and extended idle time need to be allocated to months, days, and hours.

A 1996 report from the Office of Highway Information Management (OHIM)[68] describes analysis of a sample of 5,000 continuous traffic counters distributed through the United States. EPA obtained the data used in the report and used it to generate VMTinputs in the form needed for MOVES2010.

The report does not specify VMT by sourcetype or Vehicle Type. Thus, we currently use the same value for all sourcetypes. We hope to update this in future versions of MOVES, perhaps using data from the U.S. Vehicle Travel Information System (VTRIS).

In MOVES, Extended Idle activity is calculated as proportional Source Hours Operating (SHO) and thus is derived in the model from the VMT and speed distributions. However, the proportions used in MOVES vary by hour of day, as decribed below.

The temporal distribution of start and evaporative emissions is described in Section 13.

12.1. MonthVMTFraction

For MonthVMTFraction, we use the data from the OHIM report, Figure 2.2.1 "Travel by Month, 1970-1995," but modified to fit MOVES specifications.

The figure shows VMT/day, normalized to January=1. For MOVES, we need the fraction of total VMT per month, with different values for leap year and non-leap year. We computed the fractions using the report values and the number of days in each month.

Table 12-1. MonthVMTFraction

Month	Normalized VMT/day	MOVES not Leap Year	MOVES Leap Year
January	1.0000	0.0731	0.0729
February	1.0560	0.0697	0.0720
March	1.1183	0.0817	0.0815
April	1.1636	0.0823	0.0821
May	1.1973	0.0875	0.0873
June	1.2480	0.0883	0.0881
July	1.2632	0.0923	0.0921
August	1.2784	0.0934	0.0932
September	1.1973	0.0847	0.0845
October	1.1838	0.0865	0.0863
November	1.1343	0.0802	0.0800
December	1.0975	0.0802	0.0800

12.2. DayVMTFraction

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 for both 1992 and 1995. The data obtained from the OHIM report is not disaggregated by month or sourcetype. The same values will be used for every month and sourcetype. We used 1995 data (which is very similar to 1992) as it is displayed in Figure 2.3.2 of the OHIM report.

For the DayVMTFraction needed for MOVES, we first summed the reported percentages for each day of the week and converted to fractions. Note, the report explains that data for “3am” refers to data collected from 3am to 4am. Thus data labeled “midnight” belongs to the upcoming day. Because MOVES2009 classifies days into two types of days, "weekdays" and "weekend," we then summed the daily fractions to compute fractions for each type of day.

Table 12-2. DayVMTFractions

	Rural	Urban
Weekday	0.2788	0.2376
Weekend	0.7212	07624

We assigned the “Rural” fractions to the rural Roadtypes and the “Urban” fractions to the urban Roadtypes. The correct distribution for “Off network” VMT is unknown. Since the majority of U.S. travel is urban, the default DayVMTFraction for "Off network" will be assigned the urban fractions. Note the MOVES2009 default VMT on “Off-network” roadtypes is zero.

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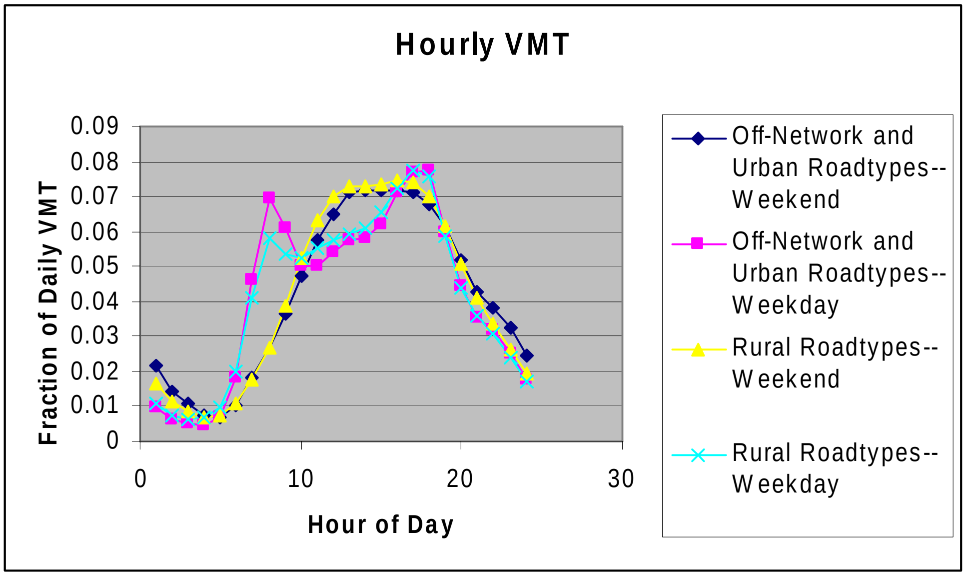
12.3. HourVMTFraction

For HourVMTFraction we used the same data as for DayVMTFraction. We converted the OHIM report data to percent of day by dividing by the DayVMTFraction.

There are separate sets of HourVMTFractions for "Urban" and "Rural" road types. Road types were assigned as for DayVMTFraction. All sourcetypes use the same HourVMTFraction distributions. The Off-Network roadtype was assigned the “Urban” fractions. Figure 12-1 graphs the hourly VMT fractions.

Figure 12-1 Hourly VMT Fractions in MOVES2010



12.4. Extended Idle Activity by Hour

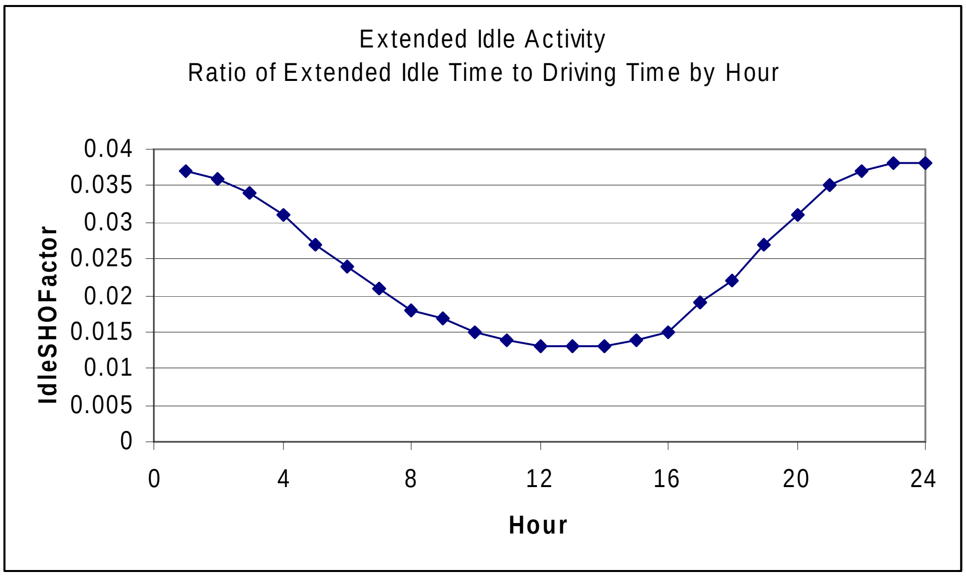
Extended idling, also referred to as "hoteling," is defined as any long period of discretionary idling that occurs during long distance deliveries by heavy-duty trucks. While MOVES includes short-term idling (such as at stop-lights) in the default driving cycles, the emissions from extended idling are modeled separately. In MOVES2010, only the long haul combination truck sourcetype is assumed to have hoteling activity.

The IdleSHOFactor field in the SourceHour table is the number used to determine the number of hours of extended idling for each hour of the day. All source use types other than long haul combination trucks have hoteling activity fractions set to zero.

Federal law limits the number of hours which long haul truck drivers can operate each day. These regulations are described in the Federal Register.[69] Using the distribution of truck hoteling duration times (shown in Figure 1 of the Lutsey, et al. paper[70]) and assuming that long haul truck drivers travel an average of 10 hours a day when engaged in hoteling behavior, we can estimate the average duration of hoteling as 5.9 hours for every 10 hours of long-haul truck driving.

However, for MOVES we need the fraction of hours spent hoteling versus hours of vehicle operation by time of day. This value can be derived from the known truck activity. In particular, the report, "Roadway-Specific Driving Schedules for Heavy-Duty Vehicles,"[71] combines data from several instrumented truck studies. The data contains detailed information about truck driver behavior; however, none of the trucks in any of the studies was involved in long haul, interstate activity. We assumed that all long haul truck trips have the same hourly truck trip distribution as the heavy heavy-duty trucks in the instrumented studies and that all long haul trips are 10 hours long, and thus deduced an hourly distribution of long haul trip ends. The distribution of hoteling durations from the Lutsey report was applied to these trip-end distributions. From these calculations, we estimated the number of hours of truck operation and hours of truck hoteling. For MOVES, we then calculated the ratio of hoteling hours to truck operation hours for each hour of the day. Weekday data was used for both weekday and weekend fractions.

Figure 12-2 Extended Idle Activity Ratio



Note that the MOVES2010 defaults assume no anti-idling measures or truck-stop-electrification efforts. MOVES2010a includes a "generic importer" intended to make it easier for users to modify the inputs of extended idling behavior to account for new or locally available data on such activity.

13. Vehicle Starts and Parking Activity

To estimate start and evaporative emissions, it is important to estimate the number of starts by time of day, and the duration of time between vehicle trips. (This between-trip duration is often called "soak time.") To determine typical patterns of trip starts and ends, MOVES uses information from instrumented vehicles. This data is stored in two tables: SampleVehicleDay and SampleVehicleTrip.

The first table, SampleVehicleDay, lists a "sample population" of vehicles, each with an identifier (vehID), an indication of vehicle type (sourceTypeID), and a "dayID" that indicates whether the vehicle is part of the weekend or weekday vehicle population.

The second table, SampleVehicleTrip, lists the trips made by each of these vehicles. 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 (keyOnTime and keyOffTime, each recorded in minutes since midnight of the day of the trip). To account for overnight soaks, many first trips reference a prior trip with a null value for keyOnTime and a negative value for keyOffTime. And, to account for vehicles that sit for one or more days without driving, the SampleVehicleDay table includes some vehicles that have no trips in the SampleVehicleTrip table.

The data and processing algorithms used to populate these tables are detailed in two contractor reports.[72,73] The data comes from a variety of instrumented vehicle studies, summarized in Table 13-1. This data was cleaned, adjusted, sampled and weighted to develop a distribution intended to represent average urban activity across the U.S. For vehicle classes that were not represented in the available data, the contractor synthesized trips using trip-per-operating hour information from MOBILE6 and soak time and time-of-day information from sourcetypes that did have data. The application of synthetic trips is summarized in Table 13.2. The resulting trip per day estimates are summarized and compared to MOBILE6 in Table 13.3. Note, for some sourcetypes, there are hours with no recorded trip starts.

Table 13-1. Source Data for Sample Vehicle Trip Information

Study	Study Area	Study Years	Vehicle Types	Number of Vehicles
3-City	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**	**Heavy, heavy duty diesel dump trucks**	**4**

Table 13-2. Synthesis of Sample Vehicles for Source Types Lacking Data

SourceType	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

Table 13-3. Starts per Day by SourceType

SourceType	MOVES2010 Weekday	MOVES2010 Weekend	MOBILE6*
Motorcycles	0.78	0.79	1.35
Passenger Cars	5.89	5.30	6.75
Passenger Trucks	5.80	5.06	7.38
Light Commercial Trucks	6.05	5.47	7.38
Intercity Buses	2.77	0.88	6.88
Transit Buses	4.58	3.46	6.88
School Buses	5.75	1.26	6.88
Refuse Trucks	3.75	0.92	6.88
Single-unit short-haul trucks	6.99	1.28	6.88
Single-unit long-haul trucks	4.29	1.29	6.88
Motor homes	0.57	0.57	6.88
Combination short-haul trucks	5.93	1.16	6.88
Combination long-haul trucks	4.29	1.29	6.88

* Note, MOBILE6 distinguished "starts" and "trips." MOVES does not, but MOVES does include some very short "trips."

14. Geographical Allocation of Activity

MOVES is designed to model activity at a "domain" level and then to allocate that activity to "zones." The MOVES2010 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. While geographic allocations clearly change over time, the MOVES defaults were developed for 1999 and are used for all years. If users doing national-level runs have geographical information by year, this can be handled by doing each year as a separate run, with different, user-input, allocations. County- and Project-level calculations do not use the default geographical allocation factors. Instead, they 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.

14.1. SHOAllocFactor

The **SHOAllocFactor** field in the ZoneRoadType table is used to determine the hours of vehicle operation in each zone on each of the MOVES roadway types.

The national source hours of operation (SHO) are calculated from estimates of VMT and speed.

The estimate for the VMT by county comes from the 1999 National Emission Inventory (NEI) analysis documented by Pechan & Associates.[74] These estimates are based on the Highway Performance Monitoring System (HPMS) data collected by the Federal Highway Administration[75] for use in transportation planning and vehicle type breakdowns from the EPA MOBILE6 Emission Factor model.[76] The NEI VMT estimates were incorporated into the National Mobile Inventory Model (NMIM) county database.

To calculate default inputs for MOVES2010, the 1999 NEI VMT estimates were obtained from the NMIM database for each county and HPMS facility type. The average speed estimates were taken directly from Table 8 of the NEI documentation. VMT estimates for each MOVES road type(i) were determined for each county(j) in the nation and the allocation was calculated using the following formula, where k refers to the HPMS facility types within a MOVES road type, and m refers to the VMT for each source type.

$$\text{CountyAllocation}(i,j) = (\text{Sum}(j)((\text{CountyVMT}(i,j,k,m)/\text{Average Speed}(k,m))) / (\text{Sum}(ij)((\text{CountyVMT}(i,j,k,m)/\text{AverageSpeed}(k,m)))$$

The county allocation values for each roadway type sum to one for the nation. Although the data is from 1999 calendar year estimates, the same allocations are used for all calendar years.

14.2. StartAllocFactor and SHPAllocFactor

The StartAllocFactor in the Zone table distributes the domain-wide estimates of the number of trip starts to the zones. In the default database for MOVES2010, the domain is the nation and the zones are counties. There is no national data on the number of trip starts by county, so for MOVES2010, we have used VMT to determine this allocation.

The estimate for the VMT by county comes from the 1999 National Emission Inventory (NEI) analysis.[77] The NEI estimates are based on the Highway Performance Monitoring System (HPMS) data collected by the Federal Highway Administration[78] for use in transportation planning and vehicle type breakdowns from the EPA MOBILE6 Emission Factor model.[79] The NEI VMT estimates have been incorporated into the National Mobile Inventory Model county database.

The VMT estimates were obtained from the NMIM database. VMT estimates for each county in each state and the allocation calculated using the following formula, where “i” represents each individual county.

$$\text{CountyAllocation(i)} = (\ \text{CountyVMT(i)} / \text{Sum(CountyVMT(i)}\ )$$

The county allocation values sum to one for the nation. Although the data is from 1999 estimates, the same allocations will be used for all calendar years.

The SHPAllocFactor in the same table, distributes to the zones the domain-wide estimates of the number of hours that vehicles are parked, No national data is available, so for MOVES2010, this estimate was set to equal the StartAllocFactor.

For national level runs, where starts and parking must be allocated to all 3222 counties, we believe that VMT is an adequate surrogate for start and parking distributions and one of the few measures that is readily available on a national basis for every county and that includes both household and non-household vehicles. To test how well this approach compared to other methods, we computed fractions of vehicles for each county using information from the U.S.Census Bureau's 2005-2007 American Community Survey[80], three-year estimates of aggregate number of household vehicles available by county. While the survey was lacking data for more than 1000 counties (this elevates fractions),and came from different years than the MOVES data, the aggregate household vehicle based estimates for the counties available correlated well with the VMT-based estimates (a simple regression of MOVES defaults to ACS values had a linear coefficient of 1.03 and an R^2 of 0.96). Some counties where the VMT approach greatly exceeded the census approach were rural counties with heavy freeway traffic (for example, Caroline County, Virginia and St. Francis County, Arkansas). Counties where the household vehicle approach estimates greatly exceeded the VMT-based estimates included some Chicago suburbs and a large number of counties in Puerto Rico.

14.3. IdleAllocFactor

The IdleAllocFactor field in the Zone table stores the factor used to determine the hours of extended idling in each zone in each calendar year.

No sources exist that directly measure extended idling in order to geographically allocate the hours of extended idling estimated for heavy-duty trucks. However, extended idling (or hoteling) occurs primarily on long-haul trips across multiple states, which suggests that travel on rural and urban interstates would best represent long-haul trips. Extended idling mainly occurs among the largest (Class 8) trucks, which are now almost exclusively diesel. Since we have estimates for the amount of rural and urban interstate VMT by Class 8 heavy-duty diesel trucks in each county of the nation, we can use this estimate to create a national allocation factor for extended idling hours.

We did this calculation in two steps. First, the actual total demand for overnight parking by trucks has been estimated by the Federal Highway Administration on a state by state basis.[81] These estimates were used to determine the allocation to each State(i) using the following formula:

$$\text{StateAllocation(i)} = \text{StateParkingDemand(i)} / \text{Sum(}\ \text{StateParkingDemand(i)}\ )$$

The State allocation values will sum to one for the entire United States. This method results in no idling in Washington, D.C., Hawaii, Virgin Islands, or Puerto Rico, which make sense, since none of these areas have VMT associated with rural or urban interstates.

We then allocated the state values to county. The estimate for the VMT from Class 8 heavy-duty diesel trucks by county comes from the 1999 National Emission Inventory (NEI) analysis.[82] The NEI estimates are based on total VMT from the Highway Performance Monitoring System (HPMS) data collected by the Federal Highway Administration[83] for use in transportation planning and proportions by vehicle type from the EPA MOBILE6 Emission Factor model.[84] The NEI VMT estimates have been incorporated into the National Mobile Inventory Model (NMIM) county database.

The VMT estimates were obtained from the NMIM database. VMT estimates for Class 8 heavy-duty diesel trucks on rural and urban interstates were determined for each county in each state and the allocation calculated using the following formula where "j" refers to the counties in each particular state.

IdleAllocFactor(i) = StateAllocation(i) * (CountyVMT(j) / Sum(CountyVMT(j))

The county allocation values will sum to one for the entire United States. The sum of the county allocations for a given state will equal the state allocation for that state.

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 airconditioning sytem 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.[85]

15.1. ACPenetrationFraction

The ACPenetrationFraction is a field in the SourceTypeModelYear table. Default values, by sourcetype and model year were taken from MOBILE6. [86] 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% was placed on cars and 95% on trucks under the assumption that there will always be vehicles sold without air conditioning, more likely on trucks than cars. No data was available on heavy-duty trucks. While VIUS asks if trucks are equipped with airconditioning, "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 sourcetypes (except motorcycles, for which AC penetration is assumed to be zero).

Table 15-1. AC Penetration Fractions in MOVES2010

	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 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 airconditioning system failure by age reported in a consumer study and assumptions about repair frequency during and after the warranty period[87] 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 Use Types Except Motorcycles)

Age	FunctioningAC Fraction
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

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."[88] 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).

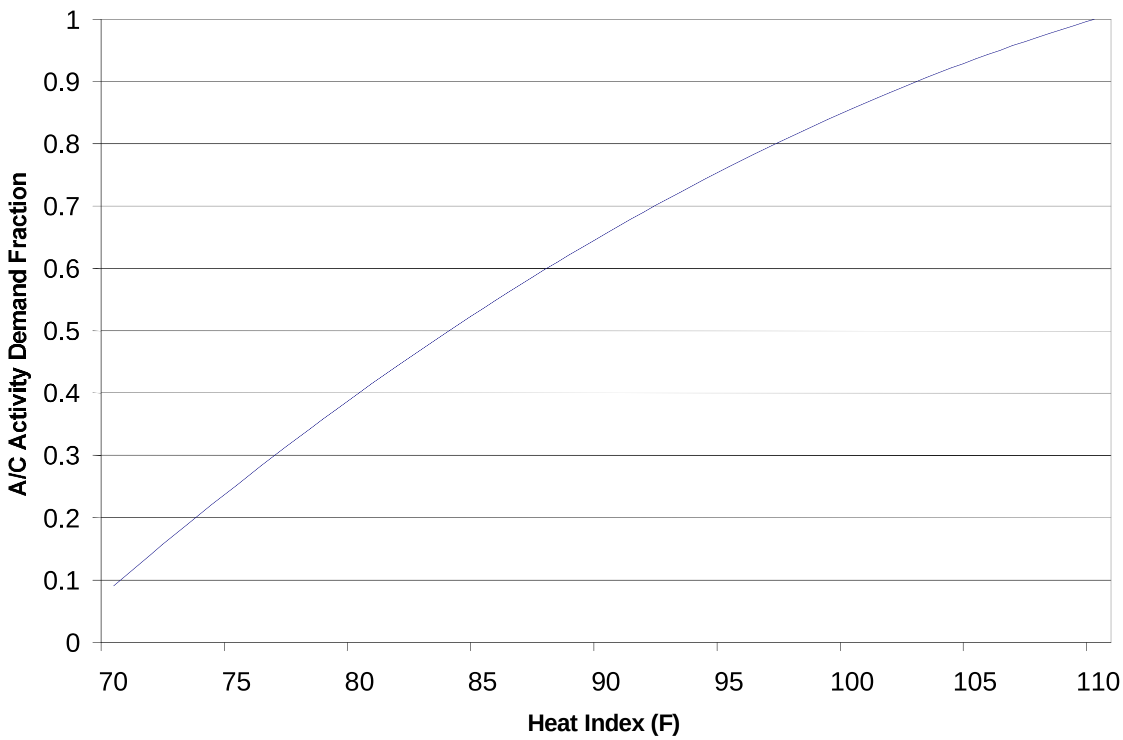
However, for MOVES2010, the default data uses one set of coefficients for all MonthGroups and Hours. These default coefficients represent an average A/C activity demand function over the course of a full day. The coefficients are listed in Table 15-3.

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

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 MOVES2010 and MOVES2010a 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. The emission characteristics for the most 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 data can contribute significant uncertainty in resulting emission estimates. In particular, when modellers estimate emissions for specific geographic locations, it is often appropriate to replace many of the MOVES fleet and activity defaults with local data. This is especially true for inputs that vary geographically and for inputs where local data is more detailed or up-to-date than that provided in the MOVES defaults. EPA's Technical Guidance[89] provides more information on customizing MOVES with local inputs.

The fleet and activity defaults also are limited by the necessity of forecasting future emissions. The inputs for MOVES2010 and MOVES2010a were developed for a 1999 base year, and much of the source data is from 1999-and-earlier. This information needs to be updated to assure that the model defaults reflect available information on the U.S. 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 In-Use Survey, has been discontinued. As the data gathered from the last survey (2002) ages, it will become more and more important to find substitutes that can be used to provide age distributions, fuel distributions, weight class distributions and other essential data. Without such a data source, future MOVES calculations may need to be simplified.

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 large-scale budget choices.

In addition to these general limitations, there are also specific data elements in MOVES2010 and MOVES2010a that could be improved with additional research. Such areas include extended idle activity, vehicle-type distinctions in temporal activity, heavy truck and bus daily trip activity patterns (particularly at night), characterization of refuse trucks and motorhomes, classification of passenger and commercial trucks into "light" and "heavy" regulatory classes, and information on the prevalence of alternative fueled vehicles.

Future updates to fleet and activity defaults will need 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 sourcetypes or roadtypes) might make noticeable improvements in run time.

At the same time, the fundamental MOVES assumption that vehicle activity varies by sourcetype and not by fueltype or other sourcebin characteristic may be challenged by the growing market share of electric vehicles and other vehicles that may have distinct activity patterns.

As we progress with MOVES, development of fleet and activity inputs will continue to be an essential area of research.

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Appendix A. Response to Peer Review Comments (A)

Draft MOVES2009 Highway Vehicle Population and Activity Data
Peer Review Comments & EPA Response

Professor Lisa Aultman-Hall

As part of the MOVES2010 Peer Review process, EPA solicited comments from Professor Lisa Aultman-Hall on the July 2009 draft of report Draft MOVES2009 Highway Vehicle Population and Activity Data

Professor Aultman-Hall is the faculty director of the University of Vermont Transportation Research Center. She is a full professor in the School of Engineering and her three degrees are all in civil engineering specializing in transportation. Her research involves travel data collection and statistical analysis of this travel data. The majority for funding for the Transportation Research Center is derived from the US DOT. Her research has been funded by the US DOT, several state DOTs and NSF. The Center includes a Transportation Air Quality Lab where graduate students collect second-by-second vehicle activity and tailpipe emissions data from light duty and hybrid vehicles. Staff in the Center work with travel demand forecasting models that generate trip rates and length distributions related to the activity data in MOVES. At the time of her review, she was Principal Investigator of a research project that involves estimation of start and soak activity for typical personal travel from GPS data. While her staff and graduate students have run MOBILE and MOVES, she does not. One previous Ph.D. student and one current Ph.D. student study vehicle activity and tailpipe emissions using real-world on-road data. Based on this combination of experience, she is familiar with the concepts, models and approaches discussed in the document reviewed, but claims no explicit detailed experience with the MOVES model itself.

Professor Aultman-Hall's comments are copied below, with EPA response in italics.

I must open by stating that the task of estimating vehicle population and activity for the nation, or zones within the nation, is huge. I understand the authors have made, by necessity, assumptions and used older data from limited sources. I know they would prefer more accurate or timely measures but that these simply do not exist in many cases. Furthermore, the authors have done an excellent job especially given their limited resources. My requests and suggestions for changes are made while thoroughly understanding the project resources and timeline will not allow all changes to be made. When I am particularly concerned about a modeling approach or data source I have noted that extra concern in my comments below. I have divided my comments according to specific requests in Mr. Koupal's correspondence. I have shown these questions in bold below. Finally, there are edits and small wording changes that I have circled on my copy of the report that I have provided in pdf.

Overall Comments:

The authors have done the best they can with very limited data. However, given the level of emissions, energy use and environmental damage stemming from mobile source tailpipe emissions there is a critical need for more robust data on vehicle population and activity including forecasts. The necessity of relying on relatively weak secondary data for this important task is inappropriate. Support for dedicated data resources and forecasts is important.

I categorize the data sources in this report into my own three broad classes: 1) vehicle population; 2) total travel (VMT) by roadway location and 3) operational patterns (operating modes or driving schedules/cycles). In the later case, operating mode, data are understandably limited as this approach is new and the methods to collect robust representative data limited. In fact I was impressed by the efforts already undertaken to fill this data gap for MOVES. New field studies and use of traffic simulation models will improve this data source in the 5 year time horizon. VMT by location, my second broad class, is estimated and described in this report. The methods and data sources are reasonable and might be improved by use of different disaggregations (replacing the urban/rural types with design speed and volume to capacity ratios; addition of holiday as a day type for example) but for the most part methods are good. However, in the first class, vehicle population, as well as the total VMT per year by vehicle type, the data sources available to the authors were of un-acceptable quality. Given that vehicles require government licenses and that mileage on vehicles is tracked during inspection or upon sale, resources to tabulate better data in the appropriate categories from at least a representative sample of states should be made available and should be a national transportation/environment data priority.

We agree that vehicle population and VMT data in MOVES are not ideal. We did not have the time to update these values for MOVES2010, but we plan to update this data for future versions of MOVES. Note that these defaults are most important for runs where national defaults are used. For State Implementation Plans and conformity determinations, we expect local values to be used in place of national defaults.

While it may seem easy to compile state registration data, differences between states in the way vehicles and fuels are counted and classified make determining vehicle populations and mileage accumulations with the level of detail needed for MOVES quite challenging. And the discontinuation of the Census Bureau's Vehicle Inventory and Use Survey makes it more difficult to estimate truck populations in the categories needed for MOVES. Unfortunately, EPA does not have the resources to generate this data directly. For the future, we are budgeting funds and resources to purchase and analyze more recent existing population and mileage accumulation data, but we expect to use similar data sources to those used for Draft MOVES2009. We expect the values will be more up-to-date, but otherwise of similar quality.

In terms of report style, it was developed assuming a level of knowledge of MOVES or MOBILE and the associated modeling approaches. I believe, the introduction must include basic information and context for the new analyst. It is my hope to use this manual and others in teaching undergrads and grads whom we hope will join the ranks of an increasing number of new professionals using MOVES. I think if the authors think of these graduate student readers as their target reader it will help them add this background information. It is so clear that the authors "live and breath" MOBILE and MOVES. They know it inside out and with my experience I can follow what they are talking about in most cases, but in many sections more context would be very useful to inexperienced professional readers.

The introduction should start with a general description of how MOVES will calculate emissions – very general for those who do not know yet. Things like MOVES combines second-by-second vehicle specific power (VSP) for different sources or types of vehicles when they travel on different roads types by time of day, day of week and month of year.

By midway through chapter 3, it is starting to be confusing regarding timelines – 1990, 1999 and future years. This gets even more confusing for a new reader in Table 4-1 when AC data goes back to 1972 and in chapter 7 when fuel fractions are introduced. These will seem like arbitrary divisions for those not aware of regulatory history or requirements. Ideally, all these concepts including both the data needed as well as the timelines associated with each type of data should be included in the introduction. I also believe the subsections dealing with <1999 and >2000 can be combined with single tables for each variable for all years.

A conclusion chapter should be written. This chapter can summarize the authors' knowledge of data source limitations and also provide a ranking of the most critical data gaps that must be filled. This would set a context for research.

We have substantially revised the introduction, reorganized material, and edited the text to make the report clearer.

Are the data sources appropriate? Are important data sources missing? Are there alternative data sources?

I assess that for the most part that appropriate assumptions and estimations have been made with limited data in this report. However, the data sources while the best available are not always optimal. As I suggest above, a dedicated vehicle population dataset with appropriate classifications could be obtained from a subset of 6-10 state DMV offices. A similar approach is used in highway safety in the Highway Safety Information System (HSIS). I recommend this as a long-term improvement requiring policy support and program funding. Resources invested in proper documentation of vehicle population and total VMT activity would more than likely substantially increase MOVES accuracy.

We have begun investigating whether using detailed data from a sample of states would be a worthwhile approach for MOVES purposes, perhaps in addition to our current data sources.

The lack of alternative fuel vehicle (AFV) data and accurate projections for market penetration and travel is concerning. I believe national policy makers may look to MOVES for important alternative scenario evaluations for AFVs and the model data will limit the usefulness of results. An effort to pursue these data should not delay release of MOVES2009 but should be a top priority for data improvement.

In the future, MOVES may become an important tool for analyzing emissions from AFVs. However, because AFV modeling is not a primary concern for State Implementation Plans, conformity determinations, EPA rulemakings or EPA inventories, we have removed most AFV options from MOVES2010. Removing these fuels from the user interface makes it clearer that modeling alternative fuels is currently outside the intended scope for MOVES.

That said, the algorithms for modeling alternative fuels still exist in the model and if EPA priorities change, the model could easily be updated. Or an interested user could develop the required inputs to do this analysis.

The data on intercity buses might be improved by using the American Bus Association or the United Motorcoach Association (established in 1926 and 1971 respectively).

We used data from the American Bus Association for Draft MOVES2009 and MOVES2010. We plan to request more recent data for MOVES updates, and will also request information from the United Motorcoach Association.

Although I find the agreement of methods reassuring in Figures 6-1 and 6-2, the methods/data especially for truck age distribution is weak. The dated TIUS and the importance of trucks to emissions suggest a need to seek funding to repeat or replace this survey.

We agree that this data is essential, but implementing a full VIUS replacement is outside the scope of work for our office. We are exploring other options for substitute data.

The California School bus data (Table 7-15) is dated. Although I am unaware of a source, I cannot believe Department of Education or Energy sources do not have more up to date information.

The data used was the best available at the time. We are investigating more up to date sources of data on school bus weights and fueltypes.

When VMT is divided by day type, weekday and weekend are used. Many research studies have found Saturday is different from Sunday and that holidays are unique. More than two categories of day may be considered in future versions.

In designing MOVES we considered treating each day separately (because Fridays are also quite different from other weekdays), or treating all days as the same. Choosing to use two day types was a compromise intended to improve model run-time when compared to the seven-day option and to optimize file size and local data entry requirements, while still accounting for the substantial differences in traffic patterns that are found when comparing weekdays and weekends. To model different day-type categories than those chosen in MOVES2010, a user could re-populate the appropriate data tables describing daily traffic variation.

I note the important addition of higher speed freeway drive schedules as important. This may have a definable impact when MOVES starts being used for project level analysis.

The average speeds listed in Table 14.2 of the draft report indicate that MOVES2009 (and MOVES2010) use driveschedules with average speeds up to 76.0 mph. The draft report does not detail that many of the driveschedules include significant speed variations, with maximum instantaneous speeds up to 90 mph. The final version of the report will make this clear. Of course, if users wish to model a project where <u>average</u> speeds are greater than 76 mph, the users would need to provide their own appropriate driving schedule or VSP distribution.

Should the modeling or data for soak times be included in this report? Would it not flow directly from the drive schedules for vehicles? Chapter 20 presents only start data for urban areas only.

The soak time data does not come from drive schedules, instead it comes from "key-off," "key-on"data from a collection of vehicle studies. The data and its analysis are detailed in a contractor report that will be posted on the EPA website. It is true that most of the data is from vehicles based in urban areas. It is possible that a study with a rural focus would see different patterns.

Although you state that no default values for migration rate between zones are provided because this version is estimating national emissions, it would be very straightforward to estimate vehicle migration based on population increases and decreases which are available back further than the timeline required here and at the county level.

The migration rate discussed here is at the national level, so it would refer to vehicles entering the U.S. though mechanisms other than new vehicle sales. We will clarify. At the national level, vehicle sales data are sufficient to estimate the national vehicle population.

The reviewer's actual concern is the distribution of population between zones, which is handled by the various "AllocFactors" in the Zone and ZoneRoadType tables, described later in the report. While these allocations clearly do change over time, MOVES2010 simplifies with a single value for each zone. While entering allocations by year would vastly increase table size, this is an area we are considering revising in future versions of the model. Note, however, that it is not an issue for State Implementation Plan and conformity analysis because EPA's guidance requires users to enter specific county-level population for each calendar year.

Are the default values for vehicle population and activity appropriate for national use?

I believe these are the best estimates available. My most significant concern regarding use of the model for national estimates is the inability to evaluate the impact of AFVs market penetration.

I am concerned that the report suggests that idling is only considered for heavy duty trucks. Idling is a policy concern that may be evaluated at any study area level for any vehicle type. Is idling perhaps indirectly incorporated for all vehicles in the drive schedules? If yes, this should be explicitly mentioned in Chapter 15.

Yes, idling is incorporated in the drive schedules. We will clarify. The "Extended Idling" emission process for heavy duty trucks differs from the in-cycle idling because it is typically a high-speed idle designed to run accessories for several hours

Were assumptions and extrapolations appropriate? How could they be improved?

While the default data are likely appropriate for national use, the move to smaller zones will require a future effort to develop methods to construct driving schedules from simulated traffic data from microscopic traffic simulation models. One long term improvement I believe should be pursued is the provision of speed distributions, not just as a function of road type and average speed, but also by volume to capacity ratio (V/C). This might be a better approach than rural versus urban which are not causal variables (acknowledged indirectly on page 85 when Table 14-1 is discussed) but rather surrogates whose limitations are now widely recognized within transportation. The authors might acknowledge this limitation when road classes are introduced.

We will revise the paper to be more explicit about the limitations of roadtype in determining appropriate driveschedules and/or operating mode distributions. Users who have more detailed information on driving activity may instead choose to use the MOVES project-level option where they can input this information directly.

On page 23, it is unclear why 0.3 was selected as a survival rate for age 30 years and older. The modeled survival rate for 29 years is so much higher for all vehicle types. This suggests 0.3 is too low.

The survival rate for age-30-and-older is not the survival rate for the year after age 29, but an average for all cars 30-years an older. A simple one-year extrapolation of the survival rate leads to a ballooning population of very old cars, not supported by data. Instead, we chose a low survival rate that leads to reasonable age distributions. More research in this area could certainly improve our value for this number, but is unlikely to have a significant impact on fleet-wide emission results. Our revised report will explain this more clearly.

It is unclear on page 69 why the rolling resistance was multiplied by a factor of 5.

That statement was incorrect. The equation is correct as written. We will fix this in the final report.

On page 70, it is unclear why if you are conducting sensitivity analysis by varying weights that you should not change all vehicle weight terms in the equation.

The "Fixed Mass Factor" is not a true mass, but a value used in the emission rate calculations to transform measured emissions into VSP-specific rates. We will revise this explanation to clarify.

The county allocation on page 91 section 17 could be tested by checking against population and employment which are available by county (by year).

While we would expect some correspondence between VMT and population or employment, we would not consider this a reliable check of the VMT estimates. Public transit can reduce VMT per person in urban counties, while major freeways can increase VMT per person in rural counties. Patterns in non-passenger vehicle traffic, especially long-haul vehicles, are unlikely to match employment or population distributions.

In chapter 3, the differences between the distribution of truck types in 1990 is so similar to 1999 that I am not sure why both datasets are needed. The difference is well below what I expect the error level is.

The MOVES activity generator assumes that base year vehicle populations are independent, so the model expects a separate set of values for each base year.

Overall are the fleet and activity inputs described here adequate for calculating national highway emissions inventories?

I have reasonable confidence in past and current emissions estimates. But future projections (described in section 3.3, 7.7 and elsewhere) are very dependent on AOE estimates. At the very least, this merits a more complete discussion of what their projections are based on, levels of errors expected and what factors affect these estimates. I am concerned that the information regarding different vehicle technologies, fuels and efficiencies into the future are not accurate and that this will affect the accuracy of policy scenario evaluation. As an example, the aging baby boomers and their retirement makes me doubt levels of increasing sales growth. How do demographics fit into AOE projections?

We will provide better citations to AEO methods, including the NEMS Transportation Demand Module. This module projects light-duty passenger vehicle sales based on income per capital, fuel prices and average predicted vehicle prices.

As indicated above, I am concerned about the inclusion of alternatively fueled vehicles. It is unclear to me in sections 7.2 and 7.7 if data exists to be able to model these and I suspect MOVES will be called upon to help evaluate emissions benefits from AFVs. As an example on page 55, CNG and LPG refuse trucks are coded as diesel. In section 7.7 AFVs are discussed but then in 7.7.2 and subsection tables they are not included at all.

As explained in the response above, modeling alternative fuels is currently outside the intended scope for MOVES.

I am concerned the data regarding AC discussed in chapter 4 and elsewhere are not fully appropriate. For example, treating all trucks and buses the same in Table 4-1 and neglecting regional differences especially in older models and for previous year estimates is a source of error. It is impossible for me to assess the level of error without running the model and assessing the impact of AC on the ultimate emissions rates.

In our testing of the model, we saw a small impact of air conditioning on the fuel consumption from heavy duty diesel trucks. In the warmest months, we saw a fleet average air conditioning effect on fuel consumption of less than 10 percent. The fuel consumption change also results in a proportional increase in refueling hydrocarbon emissions and SO2 and SO4 emissions. Other pollutants were unaffected.

We have attempted to find other data sources on air conditioning in heavy trucks, but have not found a reliable source. However, discussions with EPA trucking industry experts suggest that the current fraction of trucks equipped with air conditioning is quite high. It is certainly possible that we are overestimating or underestimating the number of older trucks with air conditioning, but as these older vehicles are scrapped from the fleet, the potential impact of errors here will decline.

In Table 7-4, I cannot understand why the diesel fractions bounce up and down by so much for individual truck types. The discrepancies are large enough to make me question the data or procedures. Note the one non-1.0 number for source type 62.

While we do not have a better source for this data, we agree that some of the large variations don't make sense. In some of these cases, we have smoothed the inputs used in MOVES. The details will be described in the final report.

It is unclear how empty hauls are handled in the truck weight distributions. An explicit discussion could be added, perhaps in section 7.3.2.

The average weight was intended to include a mix of full and empty trucks. We will explain this in the final report.

Appropriateness and completeness of the literature discussed

It might be prudent in terms of building the case for better vehicle population and activity data in the US to provide a review of what other countries do. Do they have better direct sources?

I am concerned about the web references as a long-term reference. In addition to the weblink I prefer to have enough information to use a search engine to find the report or data if the specific web link is dead. Some references are very brief and non-specific as circled in my pdf of the report.

We will improve the references in the final report.

Integration of Information from multiple areas

This is very challenging and the report achieves very good integration for experienced modelers. However, this report and MOVES will be used at the intersection of diverse professional disciplines. I recommend considering the new professional analysts or graduate students as the target reader and defining all jargon for their consumption. Examples are as simple as "vehicle source type" clarifying "source type" or requiring more complete discussion of a driving schedule.

Our technical reports are intended primarily for specialists, but we will work to make them clearer.

Clarity of Presentation

A list of all acronyms at the front or back of the report would be very helpful.

(page 6) A third column should be added to Table 1-2 that describes in lay words the brief definition of the data table. For example, sourceusetype is Emission Model Variables or Variables for Vehicle Specific Power Equation. Similarly, a fourth column could provide the report section numbers where the data table is described.

(page 6) Define activity. Here and throughout, it would be easier for new analysts if the word "vehicle" was inserted before "population" and "source".

(page 6) Change "the sources and calculations" to "the data sources, assumptions, and calculation procedures"

Throughout the report the U.S. DOT and its Administrations and Offices are not referred to consistently. I would recommend searching and replacing throughout with U.S. DOT and providing office names in parenthesis.

(page 9 and 10) In some sections of chapter 2 the document indicates "what" the data are used for and in others it does not. For example it does not say what Polk or FTA is used for.

(page 11) sourcetypeyear is not an appropriate section or chapter heading for the whole set of target readers. Throughout it seems that variable names are used as section titles. I would recommend changing chapter 3 to something like "The Vehicle Source Type and Age".

(page 11) bullet #2 – why are the differences less important since 1990. Can an example be provided for bullet #3. I believe information like this that is known well to the authors can be useful in educating diverse future users of MOVES.

(page 11) "Also, FHWA data is…" I think this point is actually a bullet #4.

(page 12) Table 3-1 – It is unclear the difference between a blank and an "na"

(page 12 and throughout but especially chapter 8) equation numbers would be very helpful.

(page 12 and 15) Table 3-2 There are several places where it is unclear whether this is the documentation for DRAFTMOVES2009 or FinalMOVES2009. This table (and Table 3-4) suggested to me that the report was about final MOVES but later sections suggest otherwise. Should Table 3-6 have final MOVES populations too. I think the number cited for refuse trucks is for final MOVES not Draft. Table 3-6 could have a total row.

(page 12) Table 3-2 Why not include all source types in this table?

(page 13) Table 3-3a and 303b could have the same column widths which would help a reader compare. Use of AXLRE, axle_config, and AREAOP has no meaning to the reader.

Table 3-8 could also have the same column widths.

(page 13) Table 3-5 Should APTA be added to the data sources in chapter 2.

(page 15) For both motorcycles and motor homes the lower option is selected without justification.

(page 16) In Table 3-7 and others it might be helpful to very lightly shade the cells which contain the value used.

(page 17) The text on the bottom of the page regarding bus population could be expanded with a few more details including reference to Table 3-10. Table 3-10 includes some extra digits in columns 1 and 2.

(page 19) Table 3-11 – the population numbers for the three types of buses are slightly different from Table 3-10.

(page 21) Table 3-12 Motorcycles and cars are the same for 2000 and 2001 – is this correct?

(page 21) Section 3-3 – Clearly define migration rate.

(page 22) The data related to functioning air conditioning could be included here from 5.3.

(page 11-24) Sections 3 through 5.1 are all about vehicle populations. This could be grouped as one chapter. Section 5.2 is about vehicle activity or travel and belongs back with those sections in chapter 11 or 12?

(page 23 and 25) MAR needs an explicit definition up front for the new reader. It is still unclear in section 5.2 whether this is mileage in year x as a function of year x-1 or as a function of mileage in the first year. This needs to be made explicit for Figure 5-2 as well. On page 25 state why it is desirable to keep MAR constant.

(page 26) Why was the MAR for motorcycles set equal to the MOBILE value. Simply say why for the new reader.

(page 28) The reader needs source type names in Figure 5.1 to be able to interpret the graph.

(page 30) Another example of the need for lay-word titles. I would propose Chapter 6 be called "Vehicle Age Distributions for Base Year". But Chapter 6 is also another example of what might be considered in re-organizing the report. This is no longer data source descriptions but rather calculation with the data to get age distributions of the fleet. The general procedure could be outlined at the beginning of this section as population by vehicle age is calculated as age distribution for the base year plus sales and minus survival. Chapter 6 is also the only place a rejected method is described in detail.

(page 34) Table 6-1 Use both sourcetype number and names.

(pages 35-36) The information from sections 6.7 through 6.12 could be easily, and more effectively, addressed in sections 6.1-6.6. This would also allow the authors to explain the context and need for different base years.

(page 37) Sourcebindistribution needs a name new analysts and policy makers will understand – perhaps Vehicle Sub-types. It is also important that a discussion of context be added as this chapter opens explaining how emissions vary by these different vehicle characteristics and that MOVES will have different emissions rates for each type. This is implied but needs to be stated explicitly especially for the new reader. There is also a need to explicitly describe in the first section of 7.0 that the system of delineating source bins is different pre-2000 and post-2000.

(page 37) Post 2000 is all in section 7.7 yet pre-2000 is in sections 7.1 through 7.6. I would suggest putting both <2000 and >2000 in a single section by vehicle type and producing a single table for all years. The discussion could then explicitly discuss any discrepancies at the timeline breakpoint.

(page 38) Table 7-1 Row 1 is unclear, rows 2 and 3 are very clear, row 4 is less clear and may need an example, rows 5 and 6 do not seem to fit with the others. Some additional explanation of what these variables are used for could be added to the second paragraph of Chapter 7 on page 37. (Same comments for paragraph that follows Table 7-1 – the variable name jargon will be hard for new users to follow).

(page 40) Table 6-3 should read Table 7-3.

(page 41) Is Table 7-4 for final MOVES or DraftMOVES? Sentence above the table may contribute to confusion.

(page 48) Is Table 7-8 referenced from the text.

(page 49 and 50) Tables 7-9 and 7-10 illustrate two options that could be considered for many of the tables. First, minimizing decimal places would allow the reader to more easily see trends (it also helps authors edit and see errors). Second, all tables could go from start year (1967 or 1970) completely through to 2009 regardless of the source of the data or the estimation procedures used. This would make each Table a comprehensive look up source. For several items, one needs to look to different sections or different tables for the same data for different years. Why are 2000 and 2001 mostly missing from both sets of tables?

(page 51) Last sentence above Table 7-11 should read Table 7-12 not Table 7-10.

(page 54) When you have a very small section such as 7.4.3 or 7.6.3 could the information not be included in the introduction to the main sub-section – in this case in section 7.4 or 7.6.

(page 56) Tables 7-17 and 7-18 are not referred to or discussed in the text.

(page 60) Will methanol and hydrogen be in final MOVES?

(page 61) Honda and Toyota – I would not mention specific manufacturers in this document.

(page 63) The Table naming changes from #-# to #.#

(page 67) Should chapter 8 be called Emissions Model Variables or Emissions Model Constants

(page 67) As chapter 8 opens VSP should be defined. The equation should be referenced. A, B and C might better be called constants than terms. Take care to avoid confusion about the rolling constant/term and rolling resistance – the constant verses the whole term in the VSP equation. There may not be enough context for someone unfamiliar with VSP to follow this section.

(page 67) I think that the second equation in this section is the weight for a given vehicle class and age in the whole fleet in a given year but I am unsure. I would recommend more explanation in this section.

(page 68) Table 8-1 – You could add the mass M in kg that is actually used in the VSP equation as a fourth column.

(page 68) Section 8.2 The "UN Report" is not referenced and not in section 2.0. The equation is really two – one for A and one for C – place on different lines and use unique equation numbers. It is unclear in the paragraph that opens "For vehicles with a weight…" which source categories this applies to.

Chapter 8 – The constants could be subscripted with the source type and weight class.

Chapter 9 – Title could be Distribution of VMT by Road Type

(page 70) "fixed mass factor" This paragraph is very hard to accept. Why if you are changing the mass of the vehicle fleet would some, but not all, of the mass terms be changed in the model. Would use of an equation here help explain this situation?

(page 71) – The Highway Statistics are not self reported – are they perhaps state-reported?

(page 72) Table 9-2 – I do not believe these are road type distributions. This seems like VMT Distributions by Road Type.

(page 73) In the paragraph that starts "The average speed was…" it is very hard to follow the logic. Links is introduced. This is fine for me a traffic engineer but I suspect this will get confusing for others. The concept of driving schedules is also hard to follow. I took this to be similar to driving cycles but different because the time sequence is not necessarily continuous or complete.

(page 75) Chapter 11 title – VMT by Vehicle Type per Year? I would recommend the opening sub-section contain a more complete context of why these data are needed and how they will be used in lay language. Note that assuming VMT growth is constant by road type may be limiting for some types of scenario evaluation.

(page 76) Third last line should be 11-2 not 11-3.

(page 79) Is this OHIM the same as the HPMS data source described earlier in the report? Is 1996 the only data? Are more recent estimates not available? In section 12.1 I would explicitly refer to Table 12-1 and state that total VMT by source for the year is allocated to months using these data.

(page 81) Figure 12-1 is useful and would be more useful if bigger. The table might also be presented for consistency with other data charts. It is unclear here and in other places whether these data are for draft MOVES or final MOVES. The text requests input on whether hourly fractions is important for inclusion. I believe it will be more appropriate for inclusion after velocity distributions are provided by V/C ratio by road type.

(page 82) Chapter 13. The authors could be more explicit in distinguishing between vehicle trajectories (the source data), vehicle schedules (the tabulated data) and driving cycles (a traditional sequence of related items used for emissions data collection in labs). It is unclear from the text whether trajectories are actually used or simply a distribution of speed patterns ("snippets") by road type. Are driving schedules dimensionless in time such that they map to any mileage of a given road type?

(page 82) This section introduces for the first time in this report the important road type of ramps. It appears that drive schedule distributions are generated for ramps but the VMT information by vehicle sources is not provided that way. How can this discrepancy be explained? Are a set proportion of ramps associated with a unit length of freeway?

(page 84) No new chapter - 14 can be included in 13. Some of the description of what drive schedules are from this section could be more useful to reader if it came at the start of chapter 13.

(page 86) Table 14-2 is unclear and contains jargon. I was expecting a list of average speeds / road class combinations without their own drive cycle and the road class and speed combination used instead. I think that this information is there, but expressed as file names or data table names instead of words.

(page 88) This chapter could be entitled Idling.

(page 90-92) Chapter 16 and 17 should be reversed in order.

(page 91) The zone change in MOVES is important and should be included in the introduction where the general form of the model is outlined.

(page 91) Should this chapter be called Vehicle Starts, Idling and Parks? Is this information only provided for class 8 trucks? How are soak emissions estimated for all vehicle types? Soaks are a function of activity and drive schedules and might be appropriately handled in this report.

(page 93) This chapter could be named "Creating Output by EPA's Source Category Codes"

(page 94) There are 2 Table 18-1s. The text indicates that Table 18-1 will contain the proportions of vehicles by delineation but it does not.

(page 96) Chapter 19 could better follow chapter 13. I would suggest different names for variables A B and C here to avoid confusion with VSP equation terms. Can an equation be provided for air condition activity demand? It is unclear how Figure 19-1 is used in combination with yearly distribution data. Does this vary by region with temperature?

(page 97) Should chapter 20 be called "Start and Soak Emissions". Table 20-1. Can references to reports on these data be provided? If the number of days of data collection is known it would be a good addition to Table 20-1.

(page 98) The big differences in Table 20.2 need to be addressed in the text.

These are helpful suggestions. We have tried to address them in the revised text. Note the references listed in the comments refer to the original page numbers, chapters and tables.

Appendix B. Response to Peer Review Comments (B)

Draft MOVES2009 Highway Vehicle Population and Activity Data
Peer Review Comments & EPA Response

Dr. Kanok Boriboonsomsin

As part of the MOVES2010 Peer Review process, EPA solicited comments from Dr. Kanok Boriboonsomsin on the July 2009 draft of report Draft MOVES2009 Highway Vehicle Population and Activity Data

Dr. Boriboonsomsin is an Assistant Research Engineer (research faculty) at the College of Engineering -Center for Environmental Research and Technology, University of California at Riverside. He is also a registered Traffic Engineer in the state of California. His areas of expertise include transportation planning, vehicle emissions modeling, vehicle activity analysis, transportation conformity, traffic simulation, and GIS applications in transportation. He has published extensively in these research areas, and has served as a Principal Investigator (PI) or Co-PI on a number of research projects funded by various air and transportation agencies. He is also a member of the Transportation Research Board's Transportation and Air Quality Standing Committeewe.

Dr. Boriboonsomsin's comments are copied below, with EPA response in italics.

Introduction

This is a review of the *Draft MOVES2009 Highway Vehicle Population and Activity Data* report prepared by the EPA's MOVES team. The reviewer is charged with a set of questions designed to focus the review on specific areas of the report. These questions are answered in the "Overall Comments" section. Also, the reviewer is asked to comment on four elements of the report. Therefore, I organize the "Specific Comments/Questions" section according to these elements. Finally, the reviewer is requested to give special attention to whether there are alternate data sources or approaches that would better allow the model to estimate national default values. In response to this request, the dedicated "Potential Data Sources" section is provided at the end of this review.

Overall Comments

1. **What are your recommendations for improving how we model fleet and activity in MOVES and how we populate the associated national default input data?**

In Draft MOVES2009, the national default values for highway vehicle population and activity data have been updated and improved from the previous version in MOVES2004 in many areas. To name a few, the SourceTypeAgeDistribution of passenger cars and trucks has been improved with the methodology that combines sales and scrappage information. Also, the SalesGrowthFactor of future years beyond the horizon year has been updated with a more realistic assumption. Instead of setting it to 1 (in MOVES2004), indicating no growth in sales, it is now set to the value of the horizon year (in Draft MOVES2009), indicating the same growth rate thereafter.

To improve the national default values in Draft MOVES2009 further, several recommendations are made with regards to the methodologies for better estimating the AvgSpeedDistribution and the StartAllocFactor, the use of other data sources to reinforce the existing estimates, and the consideration of other idle types besides extended idle, among others. These are discussed in more details in the "Specific Comments/Questions" section.

2. Are the data sources used to populate the MOVES default values appropriate? Are we missing any important data sources?

Almost all the critical data sources that exist have been gathered and used in preparing the national default values. A few data sources that can be used to improve the estimate of extended idling activity are suggested in the "Specific Comments/Questions" section. In addition, potential data sources for longer-term consideration are listed at the end of this review.

3. Given your knowledge of U.S. vehicle populations and activity, are the default values summarized in the report reasonable?

Most of the default values in the report are reasonable. There are some default values that could be based on more updated data or data from multiple sources. These are discussed in more detail in the "Specific Comments/Questions" section.

4. Data was not always available where it was needed. In these cases, were the assumptions and extrapolations used to populate the model appropriate? How could they be improved?

The majority of the assumptions and extrapolations used are appropriate, although a few of them need a validation or a better justification, especially the assumptions made when estimating the average speed distributions. Detailed comments are provided in the "Specific Comments/Questions" section below.

5. Overall, are the fleet and activity inputs described here adequate for calculating national highway vehicle emission inventories?

In their current form, the fleet and activity inputs described in the report are considered to be adequate for calculating national highway vehicle emission inventories. Of course, these inputs should continue to be updated with newer and better data once they become available. Note that the many updated tables in the Draft MOVES2009 highway vehicle population and activity data not only provide better information about vehicle fleet and activity in the U.S., but also reflect the benefits of the modular design of MOVES architecture that allows for an easy update of any specific model inputs.

Specific Comments/Questions

1. Clarity of the Presentation

    - Page 9: The term "base year" is abruptly introduced here. In Draft MOVES2009, there are now two base years—1990 and 1999. A paragraph describing this in the Introduction section will be helpful (such description is provided in the MOVES2004 report, but is excluded in this Draft MOVES2009 report).

    - Page 68: In Table 8-1, should the Midpoint Weight for the Weight ClassID 5 be 250 instead of 350?

- Page 73: In Table 10-2 from a mathematical point of view, should the Average Speed for the Average Speed Range of < 2.5 mph be 1.25 instead of 2.5?

- Page 75: What are the "other twelve categories" mentioned in Section 11.2?

- Page 76: The calculation described in the paragraph prior to the last is too complex to be understood in plain text. Supplemental equations would be helpful.

- Page 88: It is not clear how the data from the Lutsey report was used to calculate the hourly distribution of hoteling activity. Additional explanation or some equations will be helpful.

- There are some errors in the report, e.g.
    - Page 20: In the Commercial Trucks bullet, "Factor for Calendar year 2002 through 2030…" should read "Factor for Calendar year 2006 through 2030…"
    - Page 18: There are errors (likely to be typos) in the numbers of buses in Table 3-10. Please check accordingly.
    - Page 40: The last sentence in the paragraph above Section 7.2.2 is incomplete.
    - Page 95: There are errors in the equations. Indexes *i* and *j* seem to be missing from the variable VMT.

- There are a few occasions of incorrect call-out of table numbers, i.e.
    - Table 1-2 on Page 25. It should be Table 1-1.
    - Table 11-3 on Page 76. It should be Table 11-2.
    - Also, Table 20-2 on Page 98 is listed twice.

These are helpful suggestion; we will improve the table references and clarify the text.

2. Integration of Information from Multiple Areas

- Page 12: As indicated in the footnote, the value of total trucks in Table 3-2 needs to be corrected. In doing so, please be cautioned that the current value of the total number of trucks (w/o Puerto Rico and publically owned vehicles) shown in Table 3-1 (i.e. 81,060,369) does not match up with the value from the 1999 Highway Statistics (i.e. 81,090,659). Using the value from the 1999 Highway Statistics and the equation provided, the calculated total truck population is 82,391,214.

The reviewer is correct; we mistakenly subtracted the Puerto Rican truck population. This causes a discrepancy of less than 0.04% in the national total truck population. This error was not fixed for MOVES2010, but should be fixed when default national populations are updated in the future. Note, the error should not impact SIP or conformity estimates which are required to use local population data.

- Page 14: The number of school buses could be adjusted to account for Puerto Rican school buses using the ratio of School and Other Buses to Private and Commercial Buses in MV-10. Then, multiply this ratio to the Puerto Rican Private and Commercial Buses in MV-1. As a result, the calculated number of intercity buses will also be reduced.

The reviewer is correct; this approach would cause a small percentage increase in the number of school buses and would reduce the national population of intercity buses by about 3 percent. This approach was not used for MOVES2010, but should be considered when default national populations are updated in the future.

- Page 72: In the estimation of the AvgSpeedDistribution for urban driving, it is unclear why the available data from other driving studies (e.g. South Coast, St. Louis, etc.) are not used in conjunction with the MOBILE6 default? Also, why are the MOBILE6 “ramp” values not included in the MOVES “urban restricted access” road type? Similarly, why are the MOBEILE6 “local” values not included in the MOVES “urban unrestricted access” road type?

MOBILE6 does not have speed distributions for ramps or local roads, instead these were modeled at a single speed. Adding them to the distribution would have created artificial peaks at these two speeds. Computing national average rural speed distributions, as was done for MOVES, is a relatively easy task only because so little data is available. For urban areas, there is a wealth of information from chase cars studies, traffic models and other sources, so the challenge is collecting the data, analyzing it, and weighting it into a national average distribution appropriate for national-scale modeling (SIP and conformity modelers are required to input local speed data). This was a massive undertaking for MOBILE6, and it is an area where EPA should invest resources when next updating MOVES activity inputs.

- Page 85: Care should be exercised when mixing drive schedules from different road types. Although it may be true often than not that, as assumed in the report, when the average speed is very low or very high, the road type has little impact on the driving pattern. However, there are some cases that warrant investigation. For example, the Freeway LOS E schedule (average speed of 30.5 mph), which involves driving speed of up to 60 mph plus frequent acceleration/deceleration events, is not likely to be a good representative of the driving on an urban street with a 30 mph average speed. Based on the available data in hand, statistical tests could be performed to validate the assumption (see e.g. [Boriboonsomsin et al., 2009]).

Between draft MOVES2009 and final MOVES2010, we made substantial revisions to the drive schedule mapping provided in the MOVES default to improve representativeness and continuity. The Freeway LOS E schedule mentioned in the comment is now assigned only to the urban and rural restricted roadtypes (ie freeways).

- Page 91: For the StartAllocFactor, VMT is probably not the best surrogate for vehicle start. Other trip generation-related indicators such as the number of vehicles per household are better ones.

For local and regional runs, we expect county vehicle population will be used to estimate starts at the county level. If users choose to allocate emissions to sub-counties, vehicle population (perhaps computed as the product of number-of-households and vehicles-per-household) could be used to determine StartAllocFactor.

For national level runs, where starts must be allocated to 3222 counties, we believe that VMT is an adequate surrogate for start distributions and one of the few measures that is readily available on a national basis for every county. To test how well this compares to other methods, we computed fractions of vehicles for each county using information from the U.S.Census Bureau’s 2005-2007 American Community Survey, three-year estimates of aggregate number of vehicles available per housing unit by county (B25046). While the survey was lacking data for more than 1000 counties (this elevates fractions),and comes from different years, the estimates for the counties available correlated well with the VMT-based estimates (a simple regression of MOVES defaults to ACS values had a linear coefficient of 1.03 and an R^2 of 0.96). Some counties where the VMT approach greatly exceeded the census approach were rural counties with heavy freeway traffic (for example, Caroline County, VA and St. Francis County, AR). Counties where the household vehicle approach estimates greatly exceeded the VMT-based estimates included Chicago suburbs and a very large number of counties in Puerto Rico.

3. Appropriateness and Completeness of Literature Discussed

- Page 26: The mileage accumulation rate for school buses could be taken from the more updated 1999 School Bus Fleet Fact Book, as it is already available to the EPA.
- Page 79: Data from existing traffic monitoring systems such as the Freeway Performance Measurement System or PeMS (https://pems.eecs.berkeley.edu/) in California could be useful in estimating the temporal distributions of VMT.
- Page 85: The data used for developing the 45 light-duty drive schedules is biased toward California driving. Incorporating additional data from other regions of the country would be desirable.
- Page 88: There is another survey related truck idling conducted by the American Transportation Research Institute [Tunnell and Dick, 2006]. A recently published paper [Frey et al., 2008] also examines the idling activity of long-haul trucks. The EPA may consider incorporating the results from these sources into the default estimate of truck idling activity. Furthermore, the National Cooperative Freight Research Program is sponsoring a research project to characterize truck idling at the regional and national level (http://144.171.11.40/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=2671). Once completed, it could be another source of truck idling activity in MOVES.
- Page 89: The American Transportation Research Institute survey [Tunnell and Dick, 2006] also has data on the anti-idling measures in use. The National Deployment Strategy for Truck Stop Electrification (TSE) (http://tse.tamu.edu/) has data on existing TSE sites in the U.S.
- Page 92: The National Truck Stop Directory (http://www.truckstops.com/) lists truck stops by city. Therefore, it should enable a direct determination of IdleAllocFactor by county.

These are good suggestions, but we did not have time to pursue them for MOVES2010 or MOVES2010a. We will add them to the list of possible data sources for future fleet and activity updates.

4. Appropriateness of the Resulting Data for Use in National-Level Highway Vehicle Emissions Modeling

- Page 73: In the estimation of the AvgSpeedDistribution for rural driving based on the chase car data sets, it is described that for each link the average speed is first calculated, and then the driving time is allocated to one of the speed bins defined in Table 10-2. This approach, although sounds reasonable in a general sense, suffers from the lost of data variability. For instance, a driving snippet on a rural unrestricted access link consists of 10 seconds at 30 mph and another 10 seconds at 0 mph (idle at a traffic light). Using the current approach, this 20-second driving snippet will be allocated to Speed Bin 4 (12.5 mph <= speed < 17.5 mph). However, it is more appropriate to allocate a half of the snippet to Speed Bin 1 and the other half to Speed Bin 7. Since the data sets used in this analysis already contain HPMS Functional Class designation on a second-by-second basis, it is recommended that the speed distributions be estimated directly from the second-by-second data for each MOVES road type. Furthermore, if the data sets have time stamp information, then the analysis can be performed for each hour of day, resulting in different rural speed distributions by time of day.

This comment indicates that the report needs to explain the MOVES algorithm more clearly. The reviewer is correct that, in his example, the snippet would be allocated to Speed Bin 4. However, that does not mean that the driving associated with this snippet would be modeled as a constant 15 mph. Instead, it would be modeled as a weighted average of the operating modes from two driving schedules; in this case, a small fraction of driving schedule 101 (average speed of 2.5, minimum speed of 0, and maximum speed of 10 mph) and a larger fraction of schedule 1041 (average speed of 18.5, minimum *speed of 0 and maximum speed of 50.3 mph). Thus, the average speed distribution is used to map to the MOVES drive schedules, but does not restrict activity to the average speeds. Of course, to exactly model a single drive schedule, the user would have to enter the desired drive schedule or operating mode directly.*

- Page 74: Using the speed distributions of light-duty vehicles to represent those of heavy-duty vehicles is not appropriate, especially for the restricted access road types. In many states, the freeway speed limits for trucks are different than those for cars (see http://en.wikipedia.org/wiki/Speed_limits_in_the_United_States). Therefore, it is recommended that the speed distributions of heavy-duty vehicles be derived from available measured truck activity data (e.g. [Battel, 1999]). In addition, the speed limits for cars also vary by state. Hence, it is recommended that an adjustment be made to the speed distributions of light-duty vehicles derived from the California data. This may be performed by synthesizing the speed distributions for each state by shifting the California distributions according to the differences in speed limits. Then, the national speed distributions can be calculated by weighting the speed distributions for each state by VMT.

These are good suggestions, but we did not have time to pursue them for MOVES2010 or MOVES2010a. We will add them to the list of recommendations for future fleet and activity updates.

Note that SIP and conformity users are expected to enter local speed distributions directly and can account for state and local speed limits directly.

Also note that even when light and heavy duty vehicles are modeled with the same average speed distribution, they do not have the same driving schedules. For example, the highest speed driveschedule for heavy duty trucks has an average speed of 72, a maximum speed of 81 and a minimum speed of 63mph. For light duty vehicles, the highest speed driveschedule has an average speed of 76, a maximum of 90, and a minimum of 66 mph.

- Page 81: I believe that the hourly VMT fractions for heavy-duty trucks, especially for long-haul trucks, would be significantly different from those for cars. This could be important for air quality modelers as different hourly VMT fractions for heavy-duty trucks would affect the diurnal NO_x and PM profiles.

We agree. We did not have time to incorporate this for MOVES2010, but we encourage local modelers to use local data on differences in hourly VMT fractions by sourcetype and we hope to differentiate these distributions in future MOVES updates.

- Page 84: In Table 14-1, there is only the Refuse Truck Urban schedule (average speed of 2.2 mph) for refuse trucks on unrestricted access road types. This may not be sufficient and Heavy Heavy-Duty Non-Freeway schedules may be needed to help supplement the driving at higher speeds.

This is a good point. We have added additional cycles to account for higher speed refuse truck travel.

- Page 88: MOVES now only models extended idle of long-haul trucks. However, other types of idle may also worth consideration, such as idle while loading/unloading (buses and commercial trucks), idle while in operation (parcel trucks and refuse trucks), idle in parking lots or at drive-thru restaurants (mostly light-duty vehicles), etc. For these types of idle, while each occurrence may not be long in duration, their frequent occurrences could still add up to a significant amount of idling time.

This comment indicates that the report needs to explain the MOVES algorithm more clearly. Idling in normal operation is included in the driving cycles. So, for example, the LD Low Speed 1 cycle (cycle 101) has 602 seconds; 280 seconds at 0 mph. Modelers wishing to model specific operation with a high percentage of idle time may use the project-level modeling approach and enter their own driveschedules or operating mode distributions. Heavy-duty extended idle differs from this regular idle because it is characterized by a higher engine speed, and thus higher emissions. We will attempt to explain this more clearly in the final report.

Potential Data Sources

- International Registration Plan (http://www.irponline.org/) and International Fuel Tax Agreement (http://www.iftach.org/): These are programs that facilitate commercial vehicle registration and fuel tax reporting across multiple jurisdictions though a single system. Participating fleets are required to log Individual Vehicle Distance Record (IDVR), which includes information regarding distance traveled in each jurisdiction for each vehicle in the fleets. The IDVR could be useful in estimating the age distribution, relative mileage accumulation rate, and possibly SHOAllocFactor of intercity buses and long-haul trucks.

- Truck Engine Control Units (ECUs): The ECUs of heavy-duty diesel engines are capable of monitoring and storing a variety of engine operation data such as fuel consumption, time at idle, active fault codes (i.e. problems in the engine), the amount of time that a truck spent in various speed bins, etc. The information is typically kept for the time period following the last ECU reset and can span the life of the engine. Once downloaded, the information can be used for several analyses such as the estimation of temporal distribution of VMT [Barth et al., 2009].

- Fleet Management Systems: Many trucking companies equip their truck fleets with a fleet management system that has tracking and telematics capabilities so that engine operating parameters (from ECU) as well as positioning information (from GPS) can be wirelessly transmitted to a computer server on a periodic basis. The data from these trucking companies are then compiled by data aggregators into very large databases such as the Highway Visibility System (http://www.calmartelematics.com/hivis.php). If accessible, these databases along with proper fleet characterization will be useful in developing many of the MOVES highway vehicle activity data tables.

- Traffic Information Providers: In order to get real-time traffic info, traffic information providers maintain a network of probe vehicles (i.e. GPS-enabled) traveling around the country, for example, the Smart dust Network (http://www.inrix.com/techdustnetwork.asp). These probe vehicles encompass not only passenger cars, but also other variety of vehicle types including commercial fleet, delivery, and taxi vehicles. If accessible, these probe vehicle data along with proper vehicle characterization will be useful in developing many of the MOVES highway vehicle activity data tables.

- Traffic Monitoring Systems: Many transportation agencies have developed and maintain a traffic monitoring system for their jurisdiction. Examples include California's Freeway Performance Measurement System or PeMS (https://pems.eecs.berkeley.edu/) and Houston TranStar (http://www.houstontranstar.org/). Although the spatial coverage of these systems is not as wide as that of the HPMS, they provide data with better resolution (both spatially and temporally) than the HPMS for the areas they cover. Thus, their data can be used to supplement the HPMS data.

- Weigh-In-Motion: This data source was mentioned in the MOVES2004 peer review. It is worth mentioning again that it could be useful for estimating heavy-duty truck activity on freeways.

These are good suggestions, but we did not have time to pursue them for MOVES2010. We will add them to the list of recommendations for future fleet and activity update.

References

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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.

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