Use of Data from "Development of Emission Rates for the MOVES Model," Sierra Research, March 3, 2010

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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Overview

The report Development of Emission Rates for the MOVES Model, Sierra Research, March 3, 2010, was developed to document inputs provided to the EPA Motor Vehicle Emissions Simulator (MOVES). This cover note provides additional detail on how this data was incorporated into official versions of MOVES, particularly MOVES2010, MOVES2010a and MOVES2010b, as released in 2009, 2010 and 2012.

The Sierra Research report covers a variety of topics, namely:

- Sulfur dioxide (SO2) and SO4 fractions for all vehicles
- Ammonia (NH3) emission rates for all vehicles
- NO2 and NO fractions of NOx for all vehicles
- Motorcycle emission rates for many pollutants
- Motorcycle fleet and activity inputs
- Emission factors/algorithms for a large number of mobile source air toxics.

This note describes how each set of data was incorporated into MOVES.

Sulfur dioxide (SO_2) and Sulfate (SO_4) fractions

Data from the Sierra Research work on sulfur was used to populate the sulfateEmissionRate table in MOVES for all vehicles and fuels. The Sierra inputs were used in MOVES2010, MOVES2010a and MOVES2010b.

Ammonia (NH_3) emission rates for all vehicles

Data from the Sierra Research work on ammonia was used to populate the emisisonRateByAge table in MOVEs. The same inputs were used in MOVES2010, MOVES2010a and MOVES2010b. The report does not discuss crankcase emissions. These are set to zero in MOVES since ammonia emissions are formed in the catalyst and thus do not exist in the crankcase.

NO2 and NO fractions of NOx for all vehicles

Data from the Sierra Research work on nitrogen oxide and nitrogen dioxide ratios was used to populate the nono2ratio table to allocate NO_x emissions between these species.[a] For

[a] Note, the MOVES NOx, NO and NO2 results are all reported in terms of NO2. In MOVES2010, the ratio table was mistakenly populated with modelyeargroupid = 0 for all

MOVES2010b, nitrous acid (HONO) was added to the model. This required a change in the NO2 and NO fractions. The HONO fraction was set to 0.008 for all records.[1] The HONO fraction was subtracted from the MOVES2010a NO2 fraction to create a new NO2 fraction such that the fractions still sum to one across the three pollutants.

Motorcycle emission rates for many pollutants

The Sierra Research motorcycle emission rates were used to populate the exhaust and evaporative emission factor tables in MOVES2010, MOVES2010a and MOVES2010b.

The Sierra Research data was used to populate the EmissionRateByAge and the CrankcaseEmission Ratio tables for motorcycle exhaust emissions of total hydrocarbons (THC), carbon monoxide (CO), oxides of nitrogen (NOx), elemental carbon (EC) and organic carbon (OC). While motorcycle exhaust emissions are in the EmissionRateByAge table, they are constant across all ages. For evaporative emissions, the Sierra data was used to populate the EmissionRateByAge and the CumTVVCoeff table. The vapor venting rates do vary with age for some modelyear groups.

The Sierra report did not address emissions of methane (CH4), nitrous oxide (N2O), tirewear, brakewear or energy consumption rates for motorcycles. These rates were populated in MOVES based on other data sources.

Motorcycle fleet and activity inputs

Vehicle Population and Growth

Motorcycle default population data is stored in the MOVES sourcetypeYear table. This table also includes sales growth rates which are used to grow the population from the base year to the analysis year, and an unused field for "migration rates." In MOVES2010, MOVES2010a and MOVES2010b, the base year motorcycle populations (1990 and 1999) come from FHWA registration data.[2] In MOVES2010a and MOVES2010b, the MOVES default database incorporates the salesgrowth factors indicated in the Sierra Report, including their forecasts for future motorcycle sales growth rates. [b]

Sierra also provided motorcycle migration rates. However, the migrationrate field in MOVES is not used. The Sierra-provided rate was stored in the MOVES2010 default database; however, for clarity, it was replaced with values of "1"in the MOVES2010a and MOVES2010b databases.

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records. This created erroneous NO and NO2 results in the MOVES2010 output. As documented in the MOVES2010 Errata/Information Sheet, the MOVES2010 error was corrected in MOVES2010a and in the intermediate 20100512 MOVES database.

[b] In MOVES2010, the sales growth factors were inadvertently unchanged from Draft MOVES2009, where they had been set equal to passenger car data.

Survival Rates

In MOVES, the survival fraction is multiplied by the population of vehicles of a given age to calculate the population at the next age, thus it indicates the fraction of vehicles that remain from one year to the next. However, the motorcycle survival rate documented in the Sierra report and provided to EPA was the fraction of the initial population that remains at the end of each year.

In MOVES2010, the Sierra survival values were input directly. This overestimated scrappage and led to smaller motorcycle populations than expected. For MOVES2010a (and 2010b), we revised these rates. We calculated the revised scrappage rate in the format needed for MOVES using following equation: New scrappage rate (age i) = Original scrappage rate (age i)/Original scrappage rate (age i-1). Because the initial value was developed from a fitted curve, the revised value was a constant of 0.940 for all ages 2 and greater.

Relative Mileage Accumulation Rates

In MOVES, the relative mileage accumulation rate is a normalized measure of the average number of miles driven by vehicles of each age. The relativeMARS for motorcycles provided by Sierra were used in MOVES2010, MOVES2010a and MOVES2010b.

Age Distribution

Sierra calculated a motorcycle age distribution based on data for calendar year 2008. For MOVES2010, MOVES2010a and MOVES2010b, this was used as the 1999 base-year age distribution in the SourceTypeAgeDistribution table.

Base Year Vehicle Miles Travelled (VMT) and VMT Growth

MOVES2010, MOVES2010a and MOVES2010b used the Sierra-calculated base year VMT and VMT growth factors for motorcycles for years through 2008. The 2009-and-later VMT growth rates were based on AEO2006 projections of VMT growth for cars.

Daily Trip Patterns

MOVES2010, MOVES2010a and MOVES2010b use the Sierra-provided motorcycle information to populate the tables SampleVehicleDay and SampleVehicleTrip. Note the spreadsheet MOVES_MC_SampleVehicleDay.csv lacks seven vehicleids that are in MOVES and are listed in MOVES_MC_SampleVehicleTrip.csv.

Temporal Distribution of Activity

The text of the Sierra report discusses differences between weekend and weekday activity for motorcycles, as well as seasonal differences. This information was used to update the daily trip pattern information (SampleVehicleTrip and SampleVehicleDay), but it was not used to update the values in MonthVMTFraction or DayVMTFraction. The MOVES VMT fractions by month and daytype are the same for all sourcetypes[3].

Driving Cycles

As recommended in the Sierra report, and in absence of better data, MOVES uses driving cycles for passenger cars to represent driving cycles for motorcycles.

Emission factors and algorithms for mobile source toxics

MOVES2010 and MOVES2010a estimate emissions for a short list of mobile source air toxics. MOVES2010b models many more "hazardous air pollutants" (HAPs). Most of these emission rates were developed by EPA staff from available data. [4] The Sierra report was used for the following emission rates for all vehicle types:

1) Exhaust gaseous HAPs for pre-Tier 2 vehicles running on gasoline (E_0) and gasohol (E_{10}).

2) Gas and particle phase polycyclic aromatic hydrocarbon (PAH) allocation factors (but not actual emission rates).

3) Toxics ratios for pre-2007 diesels for 2,2,4-trimethylpentane, hexane, propionaldehyde, and toluene (but not other gaseous HAPs).

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[1] Kurtenbach, R., Becker, K. H., Gomes, J.A.G., Kleffmann, J., Lorzer, J. C., Spittler, M., Wiesen, P., Ackermann, R., Geyer, A., Platt, U., 2001. Investigations of emissions and heterogeneous formation of HONO in a road traffic tunnel. Atmospheric Environment 35, 3385–3394.

[2] U.S. EPA, 2010, "MOVES2010 Highway Vehicle Population and Activity Data," EPA-420-R-10-026, November 2010, http://www.epa.gov/otaq/models/moves/420r10026.pdf

[3] EPA-420-R-10-026

[4] U.S. EPA, 2012, "MOVES 2010b: Additional Toxics Added to MOVES," EPA-420-B-12-029a, May 2012, http://www.epa.gov/otaq/models/moves/documents/420b12029a.pdf

Development of Emission Rates for the MOVES Model

prepared for:

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DEVELOPMENT OF EMISSION RATES FOR THE MOVES MODEL

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DEVELOPMENT OF EMISSION RATES FOR THE MOVES MODEL

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1. INTRODUCTION

This introduction provides a review of the background behind the effort, a brief summary of the key issues and findings, and the organization of the remainder of the report.

1.1 Background

The successor to MOBILE6, MOtor Vehicle Emissions Simulator (MOVES), was released in April 2009 in draft form without certain emission rates included. Emission rates that need to be added include certain nitrogen compounds and toxic air pollutants from cars and trucks and all pollutants and activity rates from highway motorcycles. For some of the missing emissions rates, EPA has data that needed to be analyzed and processed into a form which is appropriate for MOVES. In other areas, additional data needed to be identified. The purpose of this effort was to identify, analyze, and process available data to create estimated emission rates for the above-described pollutants currently missing from MOVES.

Highest priority was assigned to the development of sulfur dioxide (SO_2), ammonia (NH_3), nitrogen dioxide (NO_2), and nitrogen oxide (NO) emissions (or NOx fractions) for all vehicle categories. Currently, the NMIM and/or MOBILE6.2 / PART5 models contain estimates for NO, NO_2 and SO_2 pollutants and processes such as running and start, and in some cases, crank-case and extended idle. Unfortunately, most of these estimates were out of date (some date back to the 1970s), and needed to be updated or at least reviewed.

Second priority was assigned to the development of motorcycle emission and fleet activity rates. Rather than simply carrying forward motorcycle emissions and activity data from MOBILE6 (that were originally developed in MOBILE5), EPA left ―placeholders" in the Draft MOVES2009 model and underlying database structure until more up-to-date emissions and activity data could be analyzed and incorporated into MOVES.

Lower priority was assigned to the development of revised emission factors for an expanded set of mobile source air toxics compounds. Draft MOVES2009 relied on algorithms carried over from MOBILE6.2 and implemented these air toxic emission factors as speciation ratios relative to VOC. These algorithms were derived from U. S. EPA's Complex Model for Reformulated Gasoline, developed in the early 1990s for the

Federal Reformulated Gasoline Rule. Also, Draft MOVES2009 included emission rates for only the following seven air toxic pollutants:

- Benzene,
- 1,3-Butadiene,
- Formaldehyde,
- Acetaldehyde,
- Acrolein,
- Naphthalene and
- Ethanol.

This included the addition of toxic speciation ratios for vehicles running on E-85 fuel. None of the long list of other toxics included in EPA's National Mobile Inventory Model (NMIM)—designated as Additional Hazardous Air Pollutants (HAPS)* throughout the remainder of this report—were inserted into Draft MOVES2009. Thus, assembly of data and development of toxic speciation ratios for these Additional HAPS was the focus of this element of the study.

1.2 Project Summary

Under Contract No. EP-C-05-037, Work Assignments 3-03 and 4-03, Sierra Research, Inc. (Sierra) was contracted to assist EPA in the assembly and development of these emission rates and activity data that had not been included in Draft MOVES2009 but would be implemented in a future release of the model.

The effort was divided into three analytical tasks as follows:

1. Nitrogenous and Sulfur Pollutant Rates;
2. Highway Motorcycle Emission and Activity Rates; and
3. Additional Air Toxic Speciation Ratios.

Data Sources – EPA provided Sierra with a list of existing studies and associated databases that the agency had assembled to support the development of MOVES emission rates and air toxic speciation ratios in each of these three task areas. In addition to these sources, Sierra performed additional literature searches. Key additional sources (which are cited later in the report sections where they were used) included the following:

- Unpublished emission test data (FTP, idle and 50 mph cruise measurements) obtained from the California Air Resources Board (CARB) for a small sample of

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* Table A-l from the Work Assignment contains the complete list of Additional HAPS to be considered under this task. (The exceptions on the list that are not considered Additional HAPS for the purposes of this effort are HC, CO, NOx, SO_2, CO_2, SOA, PM_{10}, $PM_{2.5}$, NH_3, acetaldehyde, acrolein, benzene, formaldehyde, 1,3 butadiene, and MTBE.)

newer model heavy-duty Diesel vehicles with selective catalyst reduction (SCR) and Diesel particulate filter (DPF) after-treatment systems;

- Modal (second-by-second) motorcycle exhaust emissions test data from a 2000 testing program sponsored by CARB;

- Nationwide on-road motorcycle registrations for calendar year 2008 compiled by R.L. Polk and obtained through the Motorcycle Industry Council (MIC); and

- Current highway motorcycle activity and usage data obtained from a recently completed motorcycle owner survey.

<u>Key Issues/Findings</u> – During the course of this effort, several key issues arose in evaluating data sources and assembling the required MOVES emission rates. These key issues and findings are summarized below and described in greater detail in the body of the report.

- *Factors Affecting Ammonia Emission Rates* – Prior studies and test measurements show a clear inverse relationship between ammonia emission rates and NOx emission controls. Catalytic NOx reduction implemented on vehicles beginning in the early 1980s led to increases in ammonia emission rates up until phase in of NLEV and Tier 2 emission standards.

- *Highway Motorcycle Tampering Effects* – In-use emission rates for highway motorcycles are significantly affected by the assumed or estimated level of tampering. Survey and test data indicate that OEM catalyst removal and use of aftermarket exhaust systems are most significant in affecting in-use motorcycle emissions. These types of tampering often occur soon after a motorcycle is sold. Thus, all of the tampering/deterioration effects for motorcycles were assumed to occur within the newest vehicle age group (0-3 years) defined in MOVES.

- *Limited Motorcycle Evaporative Data* – Although exhaust emission data were available for roughly 170 individual motorcycle tests, evaporative emission measurements were more limited. One-hour SHED measurements were available for about 35 vehicles and only a handful of real-time 24-hour evaporative tests were available. This necessitated conversion of the one-hour SHED data to an equivalent 24-hour estimate in order to translate the test results into the new evaporative emission processes defined and employed in MOVES.

- *Processing Required for Air Toxic Speciation Data* – Speciation ratios for Diesel-fueled vehicles were developed from a CRC database for which a number of data processing and validation steps were necessary (e.g., matching emission tests for both the toxic compound and the ―base” criteria pollutant upon which its ratio was based).

- *Hole-Filling Required to Generate MOVES Rates* – Given the highly disaggregated design of most of the MOVES emission rate tables, a fairly extensive amount of extrapolation of “hole-filling” was necessary to populate the data tables, by model year, age group, and operating mode. The report clearly identifies the extent to which hole-filling was performed and the assumptions that were made in doing so.

- *Difficulty in Quantifying Uncertainty* – In the MOVES emission rate tables developed under this effort, Sierra provided estimates of both mean emission rates as well as calculated uncertainty, expressed as the coefficient of variation (COV). However, sample sizes were often small and variance within the available data large so that COVs entered into the MOVES tables were often capped at an upper limit of 0.5 per EPA's direction.

1.3 Organization of the Report

Following this introductory section, the remainder of the report is organized in a manner consistent with the three separate analytical tasks in the effort (Tasks 2 through 4).

Section 2 describes the sources considered and assembly, validation, and processing of various emission test data to develop MOVES emission rate tables for nitrogen- and sulfur-based pollutants not already represented in the model. Separate sub-sections in Section 2 present methods for development of ammonia emission rates, sulfate and sulfur dioxide emission rates, and nitrogen oxide/nitrogen dioxide emission rate ratios.

Section 3 describes the data sources and discusses the step-by-step methodologies used to develop MOVES exhaust and evaporative emission rates (for all criteria pollutants) and fleet activity data for motorcycles. It also includes a separate discussion of how these emission and activity data were tabulated and integrated into the specific table structures employed in the MOVES database.

Section 4 discusses the data sources, data assembly, and validation methods used to develop speciation ratios for an additional list of mobile source air toxic compounds identified by EPA for subsequent implementation in MOVES.

Section 5 contains a list of references cited in the body of the report.

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2. NITROGEN- AND SULFUR-BASED EMISSION RATES

In Draft MOVES2009, priority was placed on developing complete sets of underlying emissions rates for those criteria pollutants and precursors that have significant emissions from on-road vehicles: hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NOx) and particulate matter (PM). The first analytical task under this effort consisted of developing emission rates for three other nitrogenous and sulfur-based pollutants that had not yet been built into MOVES:

1. Ammonia (NH_3);
2. Sulfur dioxide and sulfates; and
3. Nitric oxide (NO) and nitrogen dioxide (NO_2) ratios.

The data sources and methods used to develop these new emission rates and structure them into MOVES-ready database tables are presented in the following three sub-sections.

2.1 Ammonia Emission Rates

Early testing revealed trace ammonia emissions from both gasoline and Diesel-powered Internal Combustion Engines (ICE). Studies in the 1970s and 1980s concluded that the levels of ammonia emissions produced by then-current mobile sources were not a cause for concern, or reason to trigger limiting regulations, but that levels should be monitored in the future.

The early 1980s introduction of vehicles equipped with three-way catalytic converters quickly raised concerns regarding ammonia emissions. Many studies revealed increased levels of ammonia from early examples of such vehicles. Detailed studies revealed an inverse relationship with NOx control: catalytic reduction of NO_x in the exhaust stream resulted in elevated NH_3 levels.

As emissions standards continued to drop and vehicle emission control technology continued to improve, ammonia emissions fell to nearly the levels observed prior to the introduction of the three-way catalyst. In addition, as the early 1980s vehicles aged, NOx emissions rose with catalyst deterioration, and ammonia levels dropped proportionately.

The results of several programs were combined to calculate emission rates for the range of VSP bins used in MOVES.

The most important source of continuous ammonia emissions data was a program performed by the Center for Environmental Research and Technology (CE-CERT) of the University of California, under a Cooperative Agreement with the US EPA (CX827692-01-0). In the program, 39 modern production vehicles received standard Federal Test Procedure (FTP) emission tests that included second-by-second ammonia measurements. The test fleet was designed to represent the in-use fleet in 2001, including such factors as manufacturer, age, engine/emission control technology, and car/truck split. Five of the newest vehicles received additional tests using cycles at lower and higher speeds than the FTP. Results from 35 of the vehicles were retrieved from EPA's Mobile Source Observation Database (MSOD) with enough information to allow transformation of the second-by-second ammonia emissions results into the VSP bins used in the MOVES emissionsRateByAge table. In MOVES, results are stratified by model year and age at time of test.

Table 2-1 summarizes the distribution of the CE-CERT test fleet with respect to model year and age. The MOVES table schema stratifies results into seven age groups, as shown below.

While it is possible to enter individual model year groups into MOVES, the results of this limited program were pooled into model year groups roughly corresponding to the stringency of the emission standards and resulting engine/emission control technology included in the years represented. This averaging was performed to prevent single vehicles from biasing the emission factors for small subgroups. The model year groups

Table 2-1
CE-CERT Ammonia Test Program Vehicle Counts

MY Group	Age Group							Num Vehs
	0-3	4-5	6-7	8-9	10-14	15-19	>=20	
00-01	3							
98-99	10							20
96-97		7						
94-95			2					10
91-93				8				
87-90					4			5
81-87						1		
<81								0

selected were 1981-1990, 1991-1995, and 1996-2001. There were five vehicles in the oldest group, 10 vehicles in the middle group, and 20 vehicles in the newest group.

In MOVES, 23 Operating Mode Bins are defined for running emissions processes. Bins 0 and 1 apply to braking and idle operation, 11-16 to operation at speeds between 0-25 mph, 21-30 to speeds between 25-50 mph, and bins 33-40 to speeds above 50 mph. The bins are defined in terms of vehicle specific power (VSP). VSP was calculated using the procedures described EPA's Draft MOVES2009 documentation.[1*]

Essentially, Track Road Load Horsepower (TRLHP) for each vehicle was allocated to A, B, and C coefficients using default fractions of 0.35, 0.10, and 0.55, respectively. Actual speed and dynamometer inertia weight were then used to compute acceleration and VSP for each second of operation. A specific bin number, as defined in the EPA report, was assigned to each individual second. The grams of ammonia measured during individual seconds were then summed by VSP bin. The overall average ammonia emissions for each bin within the three model year groups was calculated by summing the observed emissions and dividing by the number of seconds included in the sum. Results were then converted from milligrams per second to the grams per hour scale used in MOVES.

The driving schedule used for the FTP test does not include the speed and accelerations required to enter higher VSP bins. Additional testing was performed, however, on five of the vehicles in the 1996-2001 model year group. The US06 test, a component of the Supplemental Federal Test Procedure (SFTP), includes operation at high speeds and rates of acceleration. Results from these US06 tests were used to fill the missing bins (referred to as ―hole-filling" in other EPA documentation).

The US06 results of the five vehicle fleet were scaled to conform to the average FTP results in the 20-vehicle fleet in two steps. First, the US06 results were scaled to match to the corresponding FTP results in the five vehicle subset. Table 2-2 displays the five vehicle FTP and US06 averages for Bins 25-40. An offset was noted between the tests. As only a few seconds of data were collected in bin 28 of the FTP, bin 27 was selected as the ―pivot point" to fill Bins 28, 29, and 30. The ratio between the FTP results for bin 27 and the US06 results for Bin 27 was calculated (12.139/4.487 = 2.705). The US06 results for Bins 28, 29, and 30 were calculated by dividing the original US06 results by 2.705 (12.628/2.705=4.668). Similarly, bin 35 was selected to scale the US06 results for Bins 37, 38, 39, and 40. The results for the five-car fleet were then merged as shown, using the original FTP results for Bins 1-27 and 33-35 and the scaled US06 results for Bins 28-30 and 37-40.

Next the merged results for the five-car fleet were scaled to the averages observed in the twenty-car fleet. The same pivot points were selected (Bins 27 and 35), and the merged five-car results were scaled to the 20-car results. The initial and final transformed results are shown in Table 2-3. The final merged results were used as the average ammonia emission factors for vehicles manufactured between 1996 and 2001 at between 0 and 5 years of age.

[*] Numeric superscripts denote references provided in Section 5.

Table 2-2 VSP Scaling Step 1										
VSP Bin	25	27	28	29	30	33	35	37	38	39	40
FTP	2.126	4.487	2.627			1.684	2.081				
US06	1.680	12.139	12.628	13.840	29.497	8.259	10.485	20.700	28.760	24.776	36.148
Scaling		**2.705**	***4.668***	***5.116***	***10.903***		**5.039**	***4.108***	***5.708***	***4.917***	***7.174***
Merged	2.126	4.487	4.668	5.116	10.903	1.684	2.081	4.108	5.708	4.917	7.174

Table 2-3 VSP Scaling MY 1996-2001											
VSP Bin	25	27	28	29	30	33	35	37	38	39	40
Merged	2.126	4.487	4.668	5.116	10.903	1.684	2.081	4.108	5.708	4.917	7.174
FTP 20	1.782	2.668				1.673	1.941				
Scaling		**1.682**	***2.775***	***3.042***	***6.482***		**1.072**	***3.831***	***5.323***	***4.586***	***6.690***
20 Merge	1.782	2.668	2.775	3.042	6.482	1.673	1.941	3.831	5.323	4.586	6.690

The next group of vehicles included model years 1992 through 1995. Only FTP results were available for this group. Lacking any other source of data, the US06 ammonia results obtained with the first group were scaled to the FTP results obtained with the older cars using the same approach as described above. Results are shown in Table 2-4.

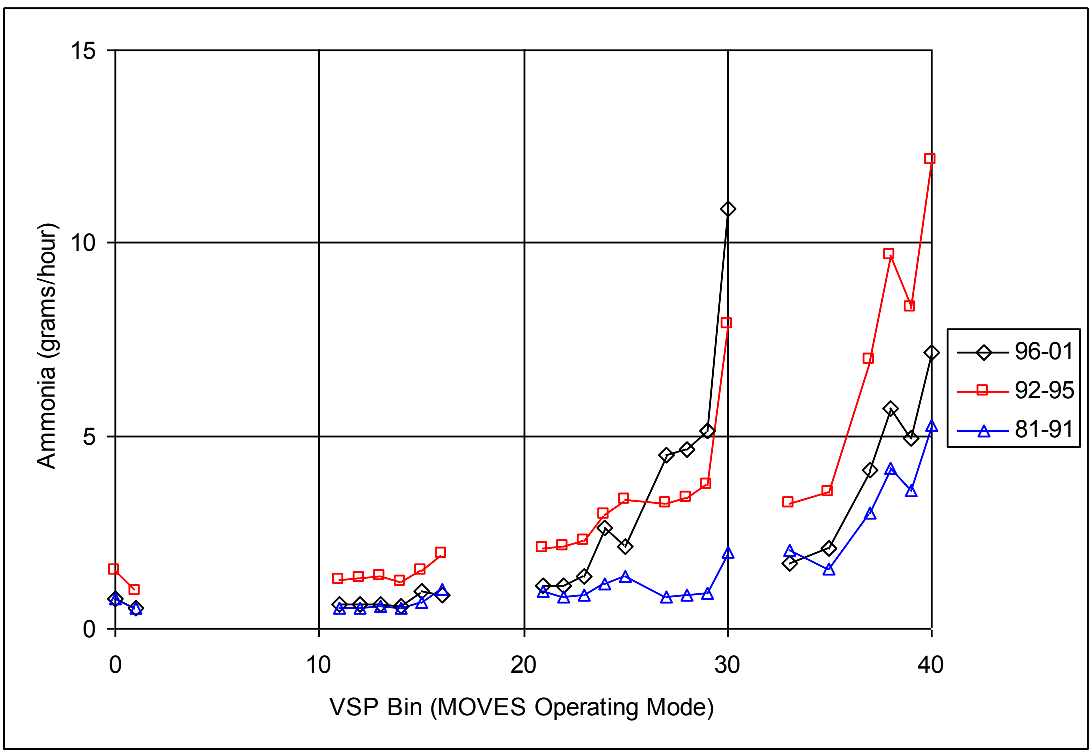
The final group of vehicles in this program included model years 1981 through 1991. The same approach was again applied, with results displayed in Table 2-5.

Table 2-4 VSP Scaling MY 1992-1995											
VSP Bin	25	27	28	29	30	33	35	37	38	39	40
Merged	2.126	4.487	4.668	5.116	10.903	1.684	2.081	4.108	5.708	4.917	7.174
FTP mid	2.929	3.248	2.690			3.236	3.527				
Scaling		**1.381**	***3.379***	***3.704***	***7.893***		**0.590**	***6.964***	***9.675***	***8.335***	***12.161***
MidMerge	2.929	3.248	3.379	3.704	7.893	3.236	3.527	6.964	9.675	8.335	12.161

Table 2-5 VSP Scaling MY 1981-1991											
VSP Bin	25	27	28	29	30	33	35	37	38	39	40
Merged	2.126	4.487	4.668	5.116	10.903	1.684	2.081	4.108	5.708	4.917	7.174
FTP old	1.338	0.823	0.309			2.028	1.524				
Scaling		**5.450**	***0.856***	***0.939***	***2.000***		**1.365**	***3.009***	***4.181***	***3.602***	***5.255***
OldMerge	1.338	0.823	0.856	0.939	2.000	2.028	1.524	3.009	4.181	3.602	5.255

The results from this scaling are summarized in Figure 2-1. The pattern observed is similar to that obtained by EPA for other emissions, with factors within a speed group (<25 mph, 25-50 mph, and >50mph) rising exponentially in the highest VSP bins. The 1992-1995 MY group generally had higher ammonia emissions, while the 1981-1991 group in general had the lowest. Bin 39 for all three groups had an unusual drop, which may be related to the US06 cycle that was used to generate these results.

Figure 2-1
Ammonia Emissions (g/hr) vs. Operating Mode by Model Year Group



Similar EPA analyses generally included thousands of tests. The patterns observed between subgroups were generally much smoother; reflecting the effect of the relatively small sample size used for this analysis.

Other test programs were used to estimate emission factors for earlier (1980 and older) and more modern (2002 and later) vehicles.

CRC program E-60[2] revealed significant reductions in average fleet emissions for current technology vehicles (LEV and better). The CRC program also tested artificially aged catalysts equivalent to 120,000 road miles. The deterioration rate observed in the E-60 fleet was used to project deterioration from the rates observed at low mileage MOVE bins derived in the first CE-CERT program to the aged bins for the complete MOVES database.

A final significant study combining the results of a number of additional studies was reported in SAE paper 830987.[3] This literature survey reports the average and range of ammonia emissions found in several previous testing programs. This 1983 paper includes results from light-duty vehicles without catalyst, with oxidation-only catalysts, and three way catalysts. Also reported are average emissions observed with heavy-duty gasoline trucks and light- and heavy-duty Diesel trucks.

The E-60 and 1983 SAE paper did not, however, report the second-by-second emission results required to develop MOVES database tables corresponding to the vehicles tested. The average emission levels were, however, used to scale the MOVES bins developed in the CE-CERT study to earlier and later vehicles.

The limited number of vehicles included in the primary studies could not directly represent all possible MOVES bins combinations. While it was possible to estimate future and past composite emissions, the second-by-second data required to fill all possible MOVES strata were not available. Simple ratios were used to scale the VSP bin results developed with the CE-CERT data to ―hole fill" the remainder of the MOVES emissionRateByAge table.

The most prevalent unit found in the literature to express average emission rate is mg/mi. Table 2-6 displays the average rates drawn from the three programs described above.

Scaling factors for vehicle deterioration were estimated using the E-60 results. Tests in this program were performed with as-received catalysts and with catalysts that had been artificially aged the equivalent of 120,000 miles. The average as-received emissions for the fleet were 14 mg/mi while the results with the aged catalysts were 21 mg/mi. A factor of 21/14 = 1.5X was used to estimate the effect of aging full useful life. Linear interpolation was used to assign an aging factor of 1.2X for half useful life deterioration. No additional deterioration was assumed for the 20+ year age group.

Table 2-6 Fleet Average Ammonia Emissions (mg/mi)							
Program:	**E-60**	**CE-CERT**			**SAE 830987**		
MY Range:	2002+	96-01	92-95	81-91	81-83	75-80	<1975
Age/							
0-5	**14**	**43**			**101**	**15**	**11**
6-9			**83**			**15**	**11**
10-19	**21**			**37**			**11**
20+							

These deterioration factors were applied to the CE-CERT program to arrive at emission factors for the 1996-2001 model year groups of 43 mg/mi, 1.2X43 for the 6-9 year age group, and 1.5X43 for the 10-20+ year age groups. Assuming some deterioration had already taken place with the 1992-1995 vehicles, an emission factor of 1.1X83 was assigned to the 10-19 year old vehicles and 1.2X83 to the 20+ year old vehicles. No additional deterioration was assigned to the 1981-1991 vehicles in the 10-19 year old age group, leaving the average emission factor of 37 mg/mi for the 20+ year old group.

These average emission rates were then used to scale the VSP bins previously calculated from the CE-CERT results. The 0-5 year VSP averages for the 1996-2001 vehicles remained the same. Each bin in the 0-5 year group was multiplied by 1.2 to arrive at VSP bins for the 6-9 year group. Each bin in the 0-5 year group was multiplied by 1.5 to estimate VSP bins for the 10-19 and 20+ year groups of this model year group. The 1992-1995 model year VSP bin results were multiplied by 1.1 to represent the 10-19 year old results and 1.2 to represent the 20+ year old vehicles. For the 1981-1991 vehicles, the 10-19 year old bins were assigned without correction to the 20+ year old age group.

No second-by-second data were found for the newer vehicles. After reviewing results obtained with large samples for HC, CO, and NOx, it appeared reasonable to scale the newest CE-CERT VSP bin results (1996-2001) to the 2002+ model years, in proportion to the fleet average composite results. Thus the 2002+ model year VSP bins were assigned a value equal to 14/43 times the individual bin results for the 0-5 year old newest vehicles. The deterioration rates were applied to the 0-5 year old bins by again multiplying by 1.2 and 1.5.

The least amount of data was available for the earliest model year vehicles. The literature review SAE paper provided averages and ranges for three groups of vehicles: not-catalyst-equipped; equipped with oxidation-only catalysts; and equipped with three-way catalysts. It was apparent that the oxidation catalyst and non-catalyst vehicles presented substantially lower ammonia emission rates than the newer technology vehicles. Oxidation catalysts came into widespread use in 1975 following nationwide installations of unleaded fuel dispensers. Three-way catalysts were introduced in federal vehicles in 1981 to meet technology-forcing standards (requiring significant NOx reduction). The non-catalyst results were therefore assigned to all model years prior to 1975, and the oxidation catalyst results were assigned to model years 1975-1980. No deterioration results were available for either group. Recognizing the relatively small remaining population of these older vehicles, a single set of VSP emission factors was calculated for the 1975-1980 group by applying the ratio of that group to the 1981-1991 results (15/37 = .405) times the individual 1981-1991 VSP bins. These bins were used for all age groups in the 1975-1980 model year range. Similarly, a factor of 11/37=0.297 was used to scale the 1981-1991 bins to all model years prior to 1975.

One significant group of unfilled strata remained: those representing vehicles at a younger age than were available when the vehicles were tested in 2000-2001. It was not possible to test a MY1985 vehicle at 0-10 years of age in CY2000. This does not present major problems for a run performed in CY2009: all 1985 vehicles are 20+ years old. While it is acknowledged that certain baseline runs representing earlier calendar years are affected by these vehicles, again because of the lack of data, the results collected in the CE-CERT program were applied to the younger vehicle age strata without modification. Table 2-7 repeats the base results from Table 2-6 and summarizes the extrapolation and interpolation used to complete this group of vehicles.

Table 2-7
Extended Fleet Average Ammonia Emissions (mg/mi)

Program:	E-60	CE-CERT			SAE 830987		
MY Range:	2002+	96-01	92-95	81-91	81-83	75-80	<1975
Age/							
0-5	14	43	***83***	***37***	101	15	11
6-9	***17*** ***1.2 X***	***52***	83	***37***		15	11
10-19	21 ***1.5 X***	***65***	***91***	37			11
20+	***21*** ***1.5 X***	***65***	***91***	***37***		***0.405 X*** **81-91**	***0.297 X*** **81-91**

The MOVES EmissionRateByAge table requires identification of the fuel type and the regulatory class of each entry. To this point only gasoline-fueled vehicles have been discussed (fuel type 1). The regulatory classes of the vehicles included are 20 – Light Duty Vehicles and 30 – Light Duty Trucks. Continuing the practice used in other MOVES tables, the factors for gasoline are used when no data are available for ethanol. Ethanol is fuel type 5.

The 1983 SAE paper reported tests of light- and heavy-duty Diesel trucks, and heavy-duty gasoline-powered trucks. While Diesel-powered light and heavy-duty vehicles have been subjected to increasingly stringent emission standards, emission control technology for this class of vehicles has not included closed loop fuel mixture control and three-way catalyst converters. For this effort, the approach used for oxidation and non-catalyst vehicles was continued by applying the ratio of the reported average fleet emissions to the emission bins computed using the 1981-1991 CE-CERT fleet.

Light-Duty Diesel Trucks (LDDT) were reported to have an average ammonia emission rate of 7 mg/mi, which is 7/37 = 0.189 of the 37 mg/mi reported in the CE-CERT program for 1981-1991 vehicles. This factor was used to develop binned VSP factors for all group 20 and 30 Diesel-powered vehicles. Heavy-duty Diesel trucks (HDDT) were reported to produce an average of 27 mg/mi, a ratio of 0.730 of the CE-CERT factor. These results were applied to all group 41, 42, 46, 47, and 48 Diesel-powered vehicles. These results are summarized below in Table 2-8.

Table 2-8
Ammonia Emissions for Diesel and Heavy Duty Vehicles (mg/mi)

Class	mg/km	mg/mi	1981-1991	Ratio
LDDT	4.2	7	37	0.189
HDDT	16.8	27	37	0.730
HDGT	28	45	37	1.216

Significant emission control rule changes have been enacted for Diesel powered vehicles in recent years. Most manufacturers have elected to employ Selective Catalyst Reduction (SCR) emission control technologies including urea injection to achieve the new emission standards. A by-product of SCR is the release of excess ammonia (slip) from the SCR device. Commonly reported SCR systems for on-road vehicles include a final ammonia slip catalyst to minimize this release. These devices are reported to reduce ammonia release to —negligible” levels, with one system reporting 1-3 ppm in the exhaust stream. That level in a large Diesel engine would represent between 1 and 2 grams/hour of ammonia. It would be appropriate to review in-use performance as production SCR systems are placed into service to determine if the ammonia emission factors recommended here should be updated.

The last type of vehicle for which ammonia emission factors were developed was motorcycles (regulatory class 10). No test program including measurement of ammonia with motorcycles was identified. The results of the CE-CERT program were therefore used, with consideration of differing emission standards and emission control technologies applied to the two different types of vehicle. As catalytic converters were not common on motorcycles before 1999, the non catalyst (pre-1975) light-duty vehicle rates were applied to this group. Catalytic converters and feedback fuel control systems became increasing common on motorcycles between 2000 and 2005, so the 1975-1980 light-duty vehicle rates were applied. New standards have been phased in for motorcycles, and three-way catalysts with feedback systems have become the norm. The 1981-1991 light-duty vehicle results were used for 2006 and newer motorcycles. As no significant number of Diesel motorcycles are expected, no ammonia emission factors were developed.

The amount of second-by-second test data, and information regarding changes in ammonia formation with vehicle age, is extremely limited. No information regarding ammonia emissions with the use of ethanol blends was found. The newest technology (LEV) vehicles, on the other hand, were found to produce extremely low levels of ammonia. One remote sensing study[4] attributes more than 20% of total daily ammonia emissions in the South Coast Air Basin to on-road vehicles. Kean reports[5] that heavy-duty Diesel emissions are difficult to measure in a tunnel study because of interference from relatively higher light-duty ammonia emission production, but he does consider the potential impact of ammonia slip. Future studies should be monitored to determine if additional data collection for the purpose of updating the recommended factors is appropriate.

2.2 Sulfur-Based Emission Rates

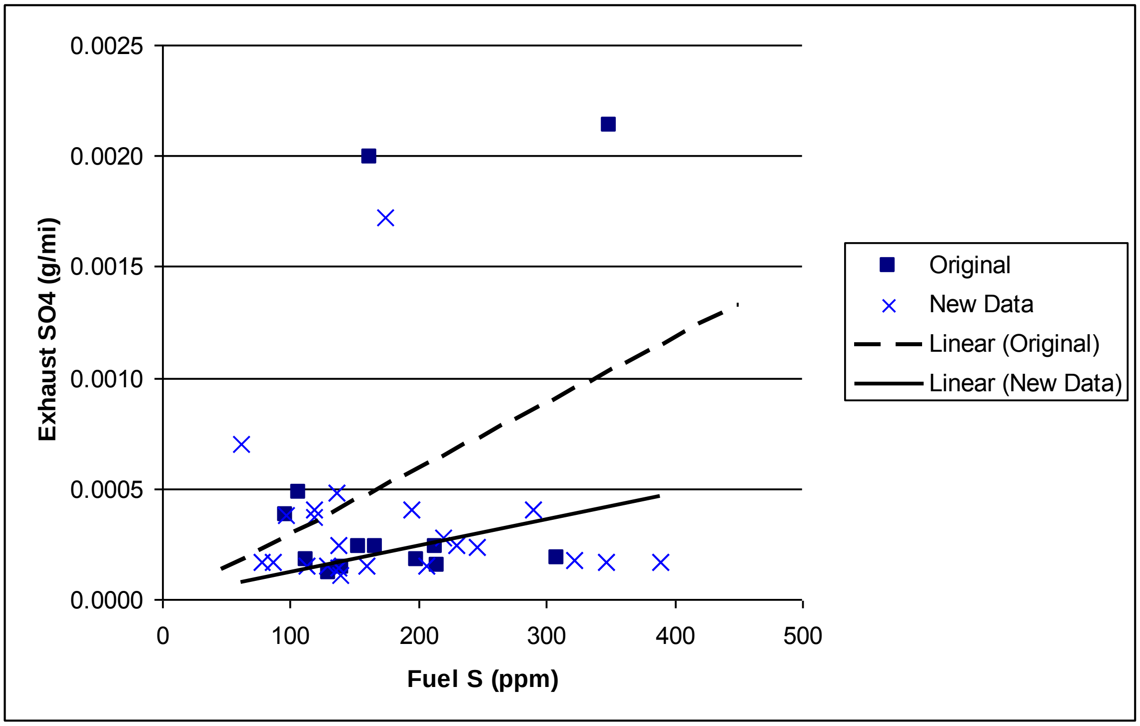
The Draft2009 MOVES model includes the sulfateEmissionRate table. The table was populated using early results from the Kansas City program. A draft report[6] detailing the analytical procedure used was provided with the Work Assignment.

The sample size used in the original analysis was limited because QC review had not been completed and each point required both the exhaust sulfate level and fuel sulfur level. Thirteen points were included in the original analysis. An updated MSOD database including results from Kansas City was provided with the Work Assignment. Forty additional tests with both exhaust sulfate and fuel sulfur were identified in the database. The analytical approach described in the draft report was applied to the combined results.

Figure 2-2 displays the results obtained with 1981 and later vehicles. The solid square points reflect the data initially used, while the –X" points represent the new data. A regression was performed to determine the slope of the equation:

$$SO_4 \text{ (g/mi)} = \text{slope} \times \text{fuel S (ppm)} \text{ (forcing zero intercept)}$$

Figure 2-2
Exhaust SO_4 vs. Fuel S – 1981 and Newer



The newly developed combined slope was slightly more than half of that developed with the original limited sample:

Original	0.000002952
Update	0.000001597

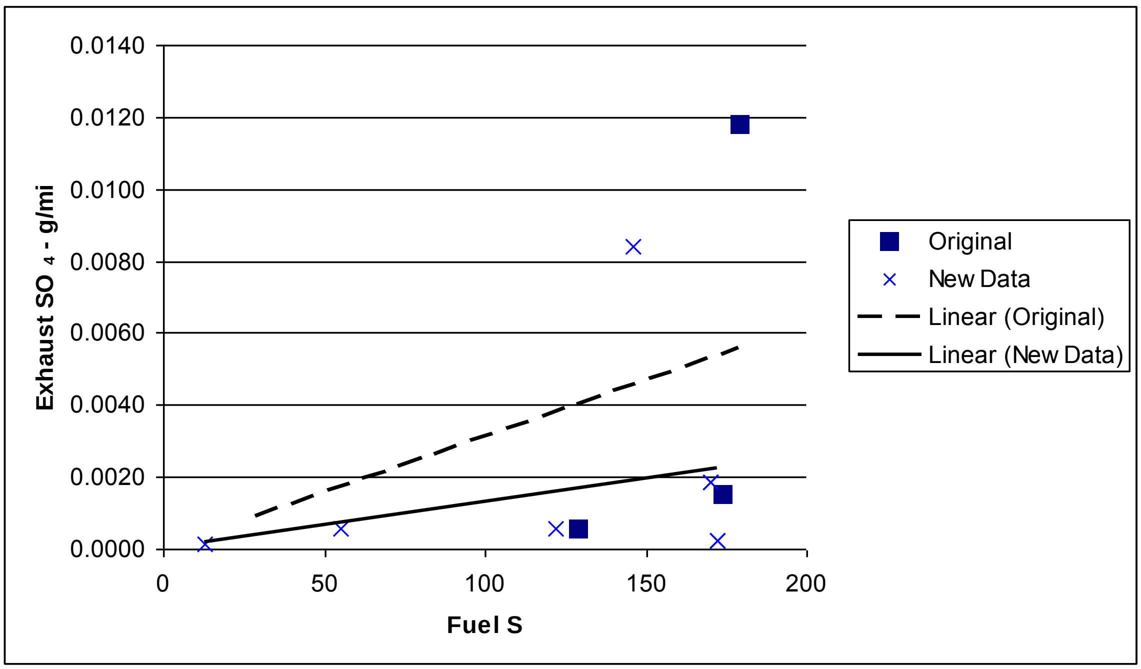
Only four of the more modern vehicles had SO_4 emissions results above 0.0005 g/mi, with little response to varying sulfur level in the fuel.

The average SO_4 emission rate for this group of vehicles was 0.000344.

The results obtained with 1980 and older vehicles were similar and are displayed in Figure 2-3. The original analysis included only three vehicles. The slope was determined by averaging the three Exhaust SO_4 measurements and dividing by the average fuel S for those tests. Several additional tests were found, and a slope was determined using linear regression.

Original	0.00002892
Update	0.00001907

Figure 2-3
Exhaust SO_4 vs. Fuel S – 1980 and Older



The slope developed with the combined data set for older vehicles is more than 10X the slope obtained with the 1981 and newer vehicles.

No additional results were obtained for Diesel vehicles. The same factors were used for ethanol fuel, with the assumption that the sulfur level used as an input will be the level measured in the diluted fuel + ethanol blend used on the road, not just in the blend fuel. Lacking other information, the same factors were used for starting, running, and extended idle.

2.3 Nitrogen Oxide and Nitrogen Dioxide Ratios

NO and NO_2 ratios are to be expressed in MOVES as a fraction of total NOx. The NONO2Ratio table will include the MOVES variables:

> meanBaseNONO2ratio
> NO to NOx ratio for entries including polProcessID 32xx
> NO2 to NOx ratio for entries with polProcessID 33xx
>
> meanBaseRateCV
> Coefficient of Variation (COV) ≅ standard deviation / mean

Results were additionally classified in terms of MOVES variables sourceTypeID (types 11-62), polProcessID (with pollutantID 32 for NO and pollutantID 33 for NO2), fuelTypeID (initially gasoline, Diesel, and ethanol) and modelYearGroupID (including vehicle model years 1960-2050). The ―Datasource" field for entries in the table initially refer to this report with an ID of 8101. A ―chained" calculator will retrieve total NOx and the coefficients in the NONO2Ratio table to compute individual NO and NO_2 results.

A wide range of NO_2 to NOx ratios is reported in the literature. Because NO oxidizes to NO_2 over time, a significant problem is defining when to measure and report results. Values of 1-3% are frequently reported for gasoline-powered vehicles. One study, utilizing nearly instantaneous real-time exhaust emission data, reports an average value of less than 1%.[7] The study continues with the conclusion that CVS bag measurements are questionable because ―fast oxidation of NO to NO_2 occurs when diluted exhaust is sampled in bags." Other studies report NO_2 fractions as high as 30% with certain types of emission control equipment and operating conditions.[8,9,10]

A study including continuous NO and NO_2 results from a representative cross-section of modern gasoline powered vehicles was identified—the CE-CERT study previously used in the development of ammonia emissions factors.[11] EPA's MSOD database contains second-by-second NO and NO_2 results for 20 of the vehicles, providing a representative cross-section of results for vehicles ranging from Tier 0 (1981-1989) through NLEV and ULEV (2001) light-duty cars and trucks. The data allow calculation of both average emission levels and variation of results within groups. No studies reporting individual 1980 and earlier vehicle results were identified. This includes vehicles produced prior to the introduction of catalytic converter (generally 1960-1974), and to vehicles produced with oxidation catalysts (1975-1980). The ―widely accepted assumption" of 2.5% NO_2 to NO_x ratio was used to populate the MOVES tables for 1960 through 1974 vehicles. Results for the remaining groups of gasoline-powered light-duty vehicles were computed using the CE-CERT data, and are summarized in Table 2-9.

Table 2-9 **Gasoline NONO2 Ratios**					
Model Years	Average NOx Level	Running NO_2 ratio	COV	Start NO_2 ratio	COV
1960-1980	-	0.025	-	0.025	-
1981-1990	0.764	0.068	0.094	0.039	0.040
1991-1995	0.824	0.046	0.054	0.013	0.003
1996+	0.107	0.164	0.099	0.049	0.020

For the 1981-1996+ groups, the second-by-second NO and NO_2 readings were summed for each bag of each test in the respective groups, and then the ratios of NO and NO_2 to the total ($NO+NO_2$) were calculated. The average and standard deviation of the ratios within each model year group were then determined. The average NO_2 ratio is reported in the table. (The NO ratio must be 1 minus the NO_2 ratio.) The Coefficient of Variation (COV) is the standard deviation of the individual values divided by their average.

The limited sample sizes yielded a slightly higher average NOx g/mi value from the 1991-1995 than the 1981-1990 vehicle groups. This was not caused by a single outlier vehicle, but rather normal variation found within small samples (six tests versus seven tests). Of greater interest is the consistency found in the NO and NO_2 ratios to the total in their groups—all less than 10%. The most modern cars, with very low average total NOx, resulted in the highest NO_2 ratio (16%); the remaining tests displayed results ranging between 1 and 7%, consistent with the general results reported in the literature.

The model year groups for sourceTypeID's 21, 31, and 32 (light-duty cars and trucks) were assigned the coefficients displayed in Table 2-9. The model year grouping for sourceTypeID 11 (motorcycles) was modified to account for the differences in emission standards and control technologies employed, with 2010+ motorcycles receiving the coefficients assigned to 1991-1995 automobiles. Similarly, assignments to vehicles in sourceTypeIDs ranging between 41-62 (heavy-duty gasoline powered trucks) were aligned with emission standards and technology changes.

No single study of NO/NOx ratios was identified for Diesel powered vehicles. Several SAE papers summarizing testing on individual vehicles were reviewed, and provided reasonably consistent results within technology groups. Earlier technologies had little reported impact on NO/NO_2 ratios, but advanced technologies potentially can have a major influence.

Lanni[12] included measurement of both NO_2 and NOx total emissions, citing research that indicated that retrofit of CRDPFs (Continuously Regenerating Diesel Particulate Filters) had resulted in an increase in NO_2 emissions. The CRDPF in the vehicles studied uses an upstream catalyst that partially oxidizes NO to NO_2, as well as oxidizing HC, CO, and SOF. A downstream particulate filter traps soot particles. The particulate trap is continuously regenerated by combustion of the soot particles with the NO_2 remaining in the exhaust stream. Lanni reports his unmodified test vehicles “agrees well with the 8% average NO_2/NOx volume ratio reported in the literature” and continues that total NOx emissions were not affected by the DPF, but elevated NO_2 emissions resulted in elevated NO_2/NO_x ratios, approaching 50%.

Ayala[13] reported similar results on Diesel-powered buses before and after installation of a retrofit DPF, using parallel analysis of NO and NOx during several test cycles. Unpublished results provided by Dr. Ayala on a Diesel-powered Class 8 tractor was also considered.

Table 2-10 displays the results used to determine average ratios without DPF controls.

Table 2-10
Diesel Without DPF trap NO/NO_2 Ratios

Pollutant or Ratio	SAE 2003-01-0300			SAE 2002-01-1722		Ayala II
	CBD OEM	CBD OEM	NYBDC	CBD OEM	SS OEM	Baseline
NO_2	2.1	1.6	4.6	0.92	2.14	1.26
NO	24.5	22.5	65.70	29.28	22.49	19.87
NOx	26.6	24.1	70.30	30.20	24.63	21.13
NO_2/NOx	**0.079**	**0.066**	**0.065**	**0.030**	**0.087**	0.060
NO/NOx	0.921	0.934	0.935	0.970	0.913	0.940

The average NO_2/NOx ratio observed was 0.065, with a standard deviation of 0.019 and a COV of 0.301.

Table 2-11 displays average results obtained in three programs for Diesel vehicles with DPF traps installed. The average NO_2/NOx ratio for this sample is 0.594, with a standard deviation of 0.406 and COV of 0.193.

Table 2-11 Diesel With DPF trap NONO2 Ratios											
Pollutant or Ratio	SAE 2003-01-0300	SAE 2002-01-1722					Ayala II				
	UDDS	UDDS	CBD	SS	NYBC	UDDS	CRT	VSCRT	ZSCRT	DPX	CCRT
NOx	25.9	22.1	34.4	26.5	52.1	23.1	18.8	5.2	5.7	10.58	8.0
NO	12.8	11.8	17.7	13.8	28.3	14.1	12.9	3.9	4.2	7.75	3.3
NO_2	13.1	10.3	16.7	12.7	23.8	9.0	5.8	1.3	1.5	2.83	4.7
NO/NOx	0.494	0.534	0.515	0.521	0.543	0.610	0.688	0.747	0.731	0.733	0.412
NO_2/NOx	0.506	0.466	0.485	0.479	0.457	0.390	0.312	0.253	0.269	0.267	0.588

Table 2-12 displays results obtained following extended idle. The average NO_2/NOx ratio observed was 0.108, with a standard deviation of 0.070 and COV of 0.645.

Table 2-12 Diesel With DPF trap and Extended Idle NONO2 Ratios					
Pollutant or Ratio	Ayala II				
	CRT	VSCRT	ZSCRT	DPX	CCRT
NO_x		90.50	77.2	43.05	
NO		86.53	69.6	35.18	
NO_2		3.97	7.6	7.86	
NO/NOx		0.956	0.901	0.817	
NO_2/NOx		0.044	0.099	0.183	

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3. HIGHWAY MOTORCYCLE EMISSION RATES AND ACTIVITY FACTORS

Task 3 of this study required the development of emission and activity factors for highway motorcycles. Subtasks included a review and analysis of available emissions data and consultation with the Motorcycle Industry Council (MIC) to obtain retail sales data, registration data, and the results of an owners survey.

This section of the report identifies the data sources for the highway motorcycle emission rates and activity data being developed for MOVES and describes the methods used to process and validate these data and assemble them into MOVES-ready database tables. It is organized into sub-sections that provide an overview of key highway motorcycle characteristics, describe uncontrolled and controlled emission rates, discuss Inspection and Maintenance program effects on emissions, present latest estimates on motorcycle populations and activity levels and finally, describe how the emission rate and activity data were organized into specific MOVES-ready tables.

3.1 Highway Motorcycle Characteristics

The U.S. highway motorcycle fleet encompasses an extremely wide range of vehicles. The variation in available models is actually greater than the variation in passenger cars in terms of engine size, engine power, vehicle weight, and vehicle performance. At one end of the spectrum are small scooters weighing less than 200 pounds and equipped with <50 cc single cylinder engines and CVT transmissions that have inadequate performance for freeway operation. Historically, many of the <50 cc scooters have used 2-stroke engines. At the other end of the performance spectrum are 400–500 pound sport models equipped with 1000–1300 cc, 4-cylinder, 4-stroke engines and 6-speed manual transmissions with performance capabilities exceeding those of high-performance passenger cars. At the other end of the size spectrum are 3-wheeled "trike" configuration vehicles weighing close to 1,500 pounds with automotive V-8 engines exceeding 6 litres displacement.

Excluding the relatively low volume of 3-wheeled vehicles classified as motorcycles, highway motorcycle models are commonly divided into six separate categories: "scooter," "standard," "dual-sport," "sport," "touring," and "cruiser." Some manufacturers use variations on these categories. The term "supersport" is sometimes used to distinguish ultra-high-performance models from lower-powered models of the same basic design. "Sport touring" and "luxury touring" are terms used to describe subcategories of touring motorcycles. (There are also a number of "crossover" models that do not fit neatly into any of the six categories.)

"Scooters" might be considered the motorcycle equivalent of an economy car. They are motorcycles designed primarily for providing low-cost transportation in an easy-to-ride configuration with a "step-through" frame, a relatively low seat, an upright riding position, and an automatic transmission. Most scooters use some form of automatic transmission, making them easier for inexperienced riders to use. They usually have a short wheelbase to facilitate maneuverability in congested urban areas. Almost all scooters have a partial fairing and windscreen to provide wind and weather protection. Scooters have smaller diameter wheels and tires than other motorcycles. There is an extremely wide range of performance within the scooter category, ranging from models that are too slow for freeway driving to more powerful models that have the performance of typical passenger cars.

"Standard" models are conventional motorcycles with an upright riding position and no fairing. They are sometimes referred to as "naked" bikes; however, small windscreens and partial fairings may be standard on some models and available as an option on others. They are seldom equipped with saddlebags, but may have bags available as optional or aftermarket equipment. Standard motorcycles are usually intended to be general-purpose vehicles for all-around riding. Standard models are available in a wide range of performance levels, ranging from barely adequate for freeway travel to ultra-high performance. Representative models include the BMW R1200R and the Suzuki Bandit 1250S.

"Touring" models are the motorcycle equivalent of luxury sedans and sports sedans. They have the upright riding position of a "standard," which is the most comfortable for long distance riding, in combination with a fairing, windscreen, and saddlebags. The distinction between "luxury touring" and "sport touring" models is primarily related to size and performance. Sport touring models tend to be smaller, more nimble, and higher performance. Representative models include the Yamaha FJR1300 and the Kawasaki Concours 14. Pure touring models are larger and designed to provide more room and wind protection for a rider and a passenger. Representative models include the Honda Gold Wing and the BMW K1200LT. The minimum level of performance from touring motorcycles is adequate performance for freeway travel. At the other end of the spectrum, some sport touring models have a level of performance comparable to a typical "sport" bike.

"Sport" motorcycles are designed primarily for exceptional handling and performance. They are the motorcycle equivalent of a "sports car." They generally have a relatively short wheelbase, and narrow, forward-located handlebars that put the rider in a leaning forward position. The footpegs are often set high and to the rear of the motorcycle to provide increased cornering clearance. Most are equipped with full fairings to reduce aerodynamic drag at high speeds, but the fairings are narrow and the windscreens are too short to take the wind off of a rider's head and shoulders unless the rider is in a "tucked" position that most riders would find comfortable only for short periods of time. Most sport models have relatively high-output engines that provide a greater level of performance than is available from most high performance passenger cars. Representative models include the Suzuki GSX750R, the Honda CBR600RR, the Yamaha YZF-R1, and the Kawasaki ZX10R.

"Dual-sport" models are the motorcycle equivalent of a sport-utility vehicle or a "Jeep." They share the upright riding position of a "standard" model but they tend to be "taller" motorcycles with relative long suspension travel to make them suitable for off-road operation, or at least operation off of paved roads. It is particularly important for the footpegs on a dual-sport bike to be located directly under the rider so that they are easy to stand on while riding in rough terrain. Representative models include the BMW R1200GS, the Suzuki V-Strom, and the Kawasaki KLR650.

The design criteria for the "cruiser" category are primarily focused on preservation of a more classic style and sound than on high performance. Most cruisers are equipped with relatively large displacement, V-twin engines that generate maximum horsepower at a relatively low engine speed. These engines produce a distinctly different sound than the high speed, 4-cylinder engines used in most other large motorcycles. Cruiser category motorcycles are also designed to provide a fundamentally different rider position, with higher handlebars and "forward" foot controls (often with floorboards rather than footpegs) and relative low seat height. Cruiser models typically have a relatively long wheelbase and steering geometry that provides increased stability in a straight line at the expense of cornering performance. To preserve a classic visual appearance, cruiser models are equipped with either air-cooled engines or water-cooled engines that are designed to resemble an air-cooled engine. Minimal use of fairings or other body work preserves the visual prominence of the engine, an important aspect of cruiser design. Representative models include the Harley-Davidson Softail, the Honda VTX1800, the Suzuki Boulevard C90, and the Kawasaki Vulcan 900 Classic.

While the differences between a "scooter" and a "touring" bike are extreme, the variations within an individual category are almost as extreme. For example, there are greater than 10:1 variations in engine power among "scooter" models.

Under current EPA regulations, highway motorcycles are divided into three classes based on engine displacement. Class I covers 0–169 cc; Class II covers 170–279 cc; and Class III covers >279 cc. Prior to model year 2006, Class I covered 50–169 cc and motorcycles with <50 cc engines were exempt from emission standards. Motorcycles categorized as "scooters" fall into all three displacement classes. Motorcycles categorized as "dual sport," and "standard" are primarily in Classes II and III. Motorcycles categorized as "sport," "cruiser," and "touring" are primarily in Class III. Prior to calendar year 2000, over 90% of all highway motorcycles were in Class III. Due to a recent increase in the sales of small scooters, Class III motorcycles are currently estimated to be approximately 85% of the highway-legal fleet (as is discussed in more detail below).

3.2 Uncontrolled Emissions Characteristics

Since engine displacement and weight are correlated, Class I motorcycles are the lightest weight, which contributes to inherently low NOx emission levels. Class I motorcycles also have relatively small fuel systems, which contributes to relatively low evaporative emissions. However, the small displacement engines have relatively high surface-to-volume ratios, which contributes to higher HC exhaust emissions. Prior to model year 2006, the lack of emission standards for motorcycles <50 cc allowed for the use of 2-stroke engines, which have much higher HC exhaust emission levels than 4-stroke engines. Prior to 1978, high-emission 2-stroke engines were used on many models with ≥50 cc engines and control of crankcase vent emissions was not required from motorcycles with 4-stroke engines.

Crankcase Emissions – The imperfect sealing of the combustion chamber in a premixed charge, reciprocating engine results in ―blowby” of unburned fuel past the piston rings and into the crankcase. To prevent blowby from pressurizing the crankcase (causing oil leaks) and to prevent unburned gasoline from building up in the crankcase, a crankcase ventilation system is incorporated in 4-stroke engines. (Two-stroke engines use a pressurized crankcase and do not have a crankcase vent.)

Prior to the imposition of emissions control requirements, crankcase ventilation was routinely provided by a road draft tube. Air flow under the vehicle created a slight vacuum which assisted in the removal of blowby gases from the crankcase while also drawing some fresh air through the crankcase breather/vent. Based on block data statements in MOBILE5, uncontrolled crankcase emissions were approximately 4 g/mi of unburned hydrocarbon, nearly half as much as uncontrolled exhaust hydrocarbon emissions. Subsequent versions of EPA's vehicle emissions model assume crankcase emissions are proportional to exhaust emissions, with pre-controlled vehicles having crankcase emissions that are 33% of ―running” exhaust.

For vehicles with crankcase controls, estimated crankcase emissions drop to 1.3% of running exhaust. Actual testing by Sierra Research determined that typical crankcase emissions from passenger cars without Positive Crankcase Ventilation (PCV) systems installed are approximately 2.5 grams per mile over the LA4 driving cycle.[14] Second-by-second data collected by Sierra indicated that crankcase emissions increase with acceleration rate. As a result, actual emissions in customer service are likely to be higher than 2.5 g/mi for uncontrolled cars.

Measurement of uncontrolled motorcycle crankcase emissions was conducted during a study conducted by Southwest Research Institute for EPA.[15] Measurement of blowby emissions was limited to idle, 20 mph road load, and 40 mph road load operation of a 1972 model year, 220 pound, 100 cc, 4-stroke motorcycle. Average emissions were calculated to be 0.421 g/mi, assuming 20% idle. Assuming average crankcase emissions are proportional to fuel consumption, the measured crankcase emissions rate would be increased by 60% to account for the difference between the 80 mpg measured for the 100 cc motorcycle over the LA4 driving cycle and the 50 mpg of the average motorcycle.

It would also be appropriate to account for the expected increase in crankcase emissions during vehicle operation more representative of typical driving. However, analysis of the second-by-second data collected by Sierra Research during its testing of passenger car crankcase emissions indicates that crankcase emissions during a mixture of idle, 20 mph, and 40 mph operation are very close to average emissions over the LA4 driving cycle. Our best estimate of uncontrolled crankcase emissions for the average motorcycle is therefore 0.7 g/mi HC. Assuming crankcase emissions are proportional to fuel consumption, this is consistent with the 2.5 g/mi crankcase emissions rate measured on a full-size passenger car.

Exhaust Emissions – Although physically much smaller than passenger cars and light-duty trucks, the uncontrolled exhaust emissions from highway motorcycles were nearly as high as those of cars and light trucks. This was due to the fact that a significant fraction of the uncontrolled motorcycle fleet was powered by 2-stroke engines with relatively high HC emissions. Based on information available to EPA in 1992, the exhaust emissions of uncontrolled 2-stroke motorcycles were estimated at 15.4 g/mi HC and 27.0 g/mi CO.[16] The same document estimates the emissions of uncontrolled 4-stroke motorcycles at 2.9 g/mi HC and 42.0 g/mi CO.

Regulated Pollutants – Sierra has independently estimated uncontrolled exhaust emissions from motorcycles by analyzing data collected during the previously referenced SwRI study and CARB surveillance testing programs.[17,18,19] Figures 3-1, 3-2, and 3-3 present the FTP results for HC, CO, and NOx as a function of odometer for 35 pre-1978, 4-stroke motorcycles ranging from 90 cc to 1340 cc displacement (average 573 cc). Three of the vehicles were tested only on the LA92 driving cycle rather than the LA4. FTP emission levels were estimated based on the correlation between LA92 and LA4 for 29 motorcycles tested on both cycles during CARB's third (1998) surveillance testing program. As shown in the figures, there is wide variation in the test results. HC emissions range from about 1 g/km to 7 g/km. CO emissions range from just under 6 g/km to 60 g/km. NOx emissions range from 0.04 g/km to 1.9 g/km. Since emissions-related defects were identified in very few of the vehicles, the variation appears to be related to differences between the various models tested. Examination of the detailed information available for each tested vehicle also indicates no significant relationship between emissions and engine displacement. As evidenced by the low coefficient of determination (r^2) values, the relationship between emissions and odometer is not statistically significant.

Average emissions for pre-1978 4-stroke models were 2.92 g/km HC, 31.2 g/km CO, and 0.27 g/km NOx. Given the variability in the available test results, these averages should be applied to all three displacement classes—I, II, and III. The available data do not support any specific deterioration rate and, as discussed below, data on later model vehicles indicate an insignificant increase in emissions as mileage is accumulated.

Figure 3-1
Exhaust Hydrocarbons vs. Odometer
Pre-1978 4-Stroke Models

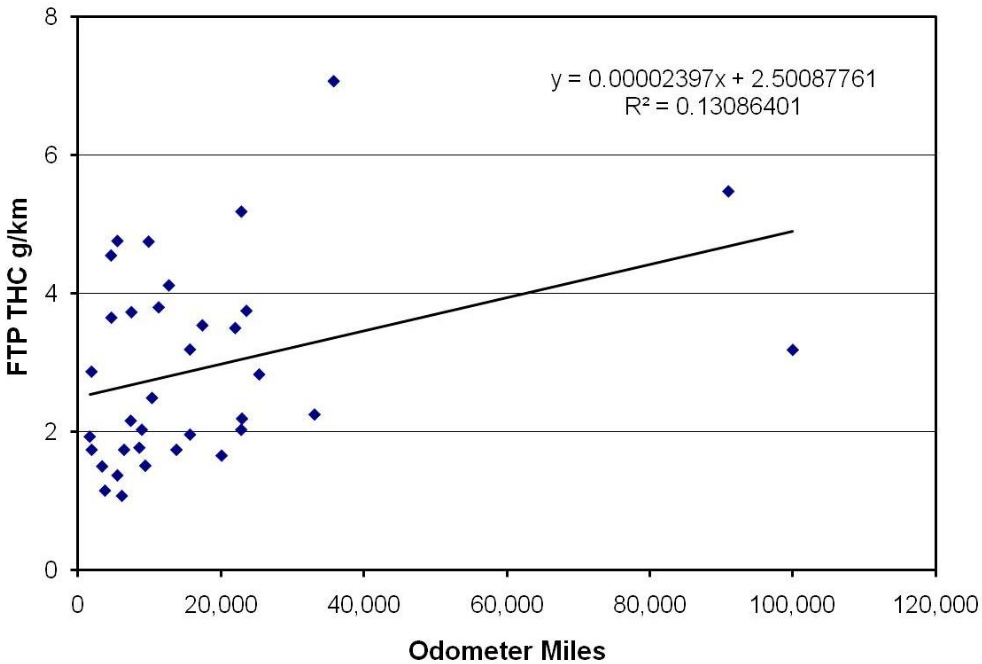


Figure 3-2
Exhaust Carbon Monoxide vs. Odometer
Pre-1978 4-Stroke Models

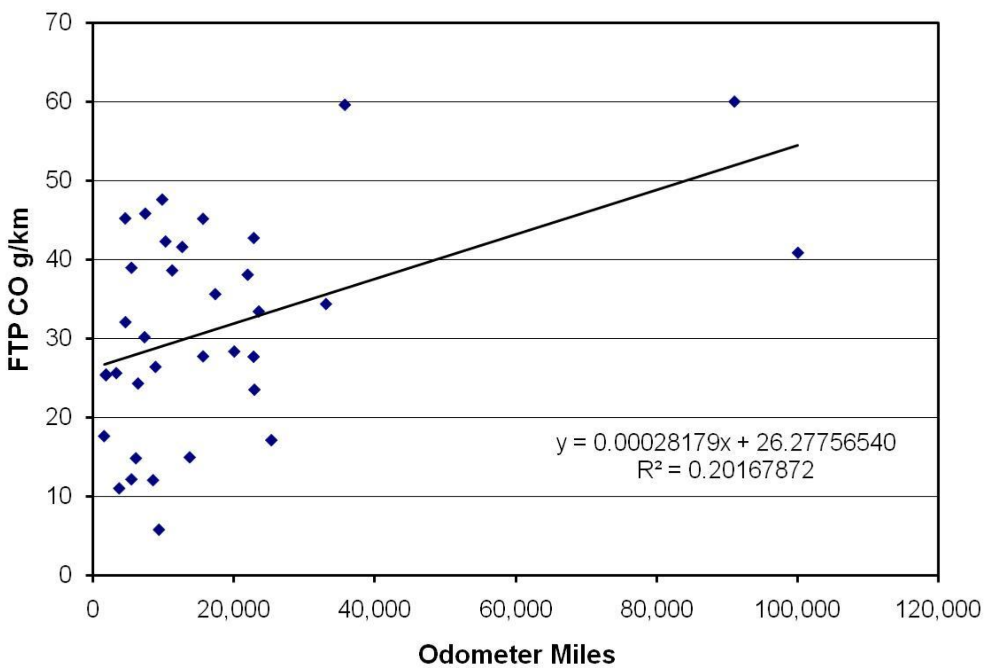
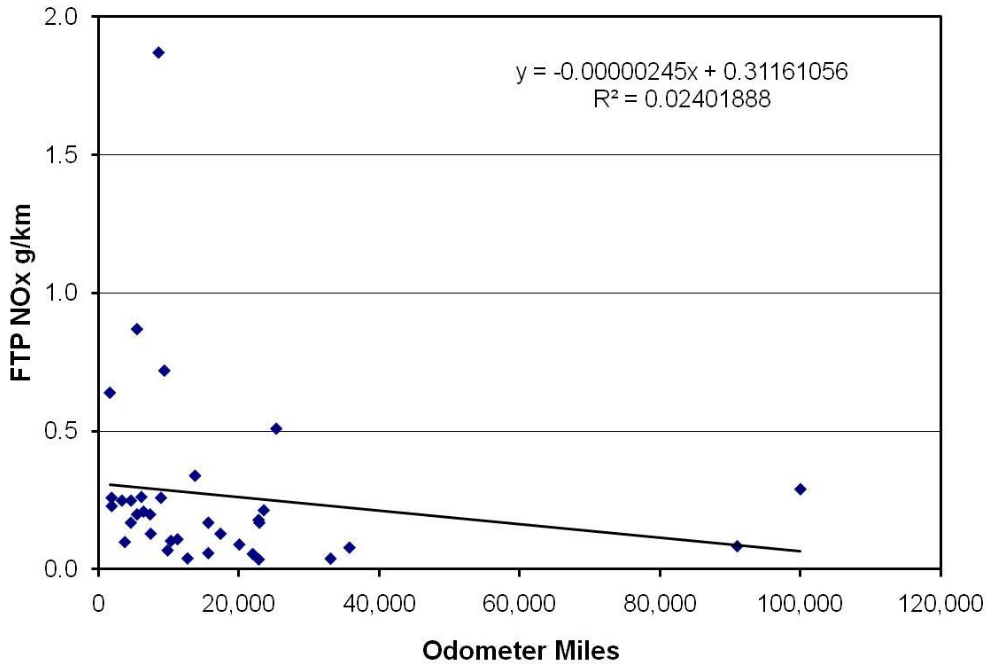


Figure 3-3
Exhaust Oxides of Nitrogen vs. Odometer
Pre-1978 4-Stroke Models



Figures 3-4, 3-5, and 3-6 present the more limited data available for motorcycles with 2-stroke engines. Data were available for only nine vehicles, ranging from 125 cc to 500 cc engine displacement. HC emissions range from about 6 g/km to 24 g/km. CO emissions range from about 5 g/km to 38 g/km. NOx emissions range from 0.0 to 0.1 g/km. As was the case with the 4-stroke models, the variation appears to be related to differences between the various models tested, rather than displacement or odometer.

Average FTP emissions for pre-1978 2-stroke models were 11.94 g/km HC, 19.7 g/km CO, and 0.04 g/km NOx. As in the case of the 4-stroke models, the available data do not support any specific deterioration rate.

Figure 3-4
Exhaust Hydrocarbons vs. Odometer
Pre-1978 2-Stroke Models

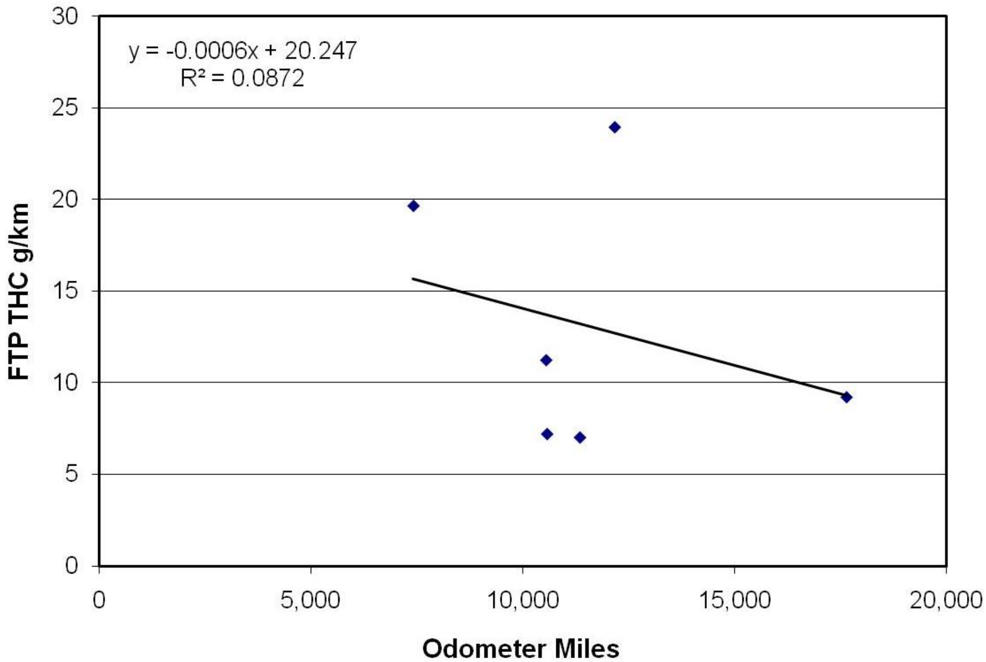


Figure 3-5
Exhaust Carbon Monoxide vs. Odometer
Pre-1978 2-Stroke Models

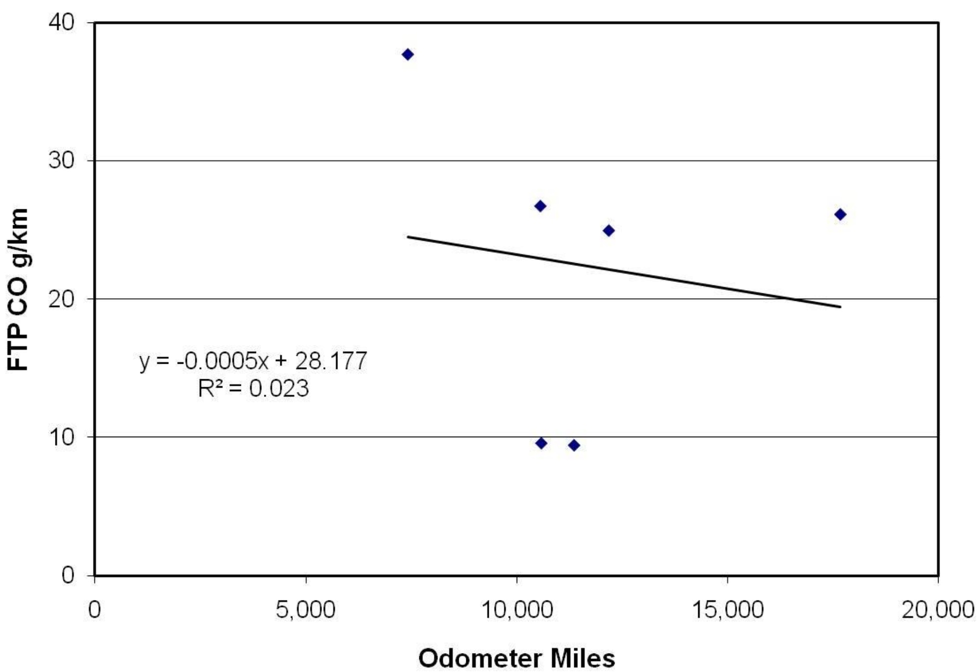
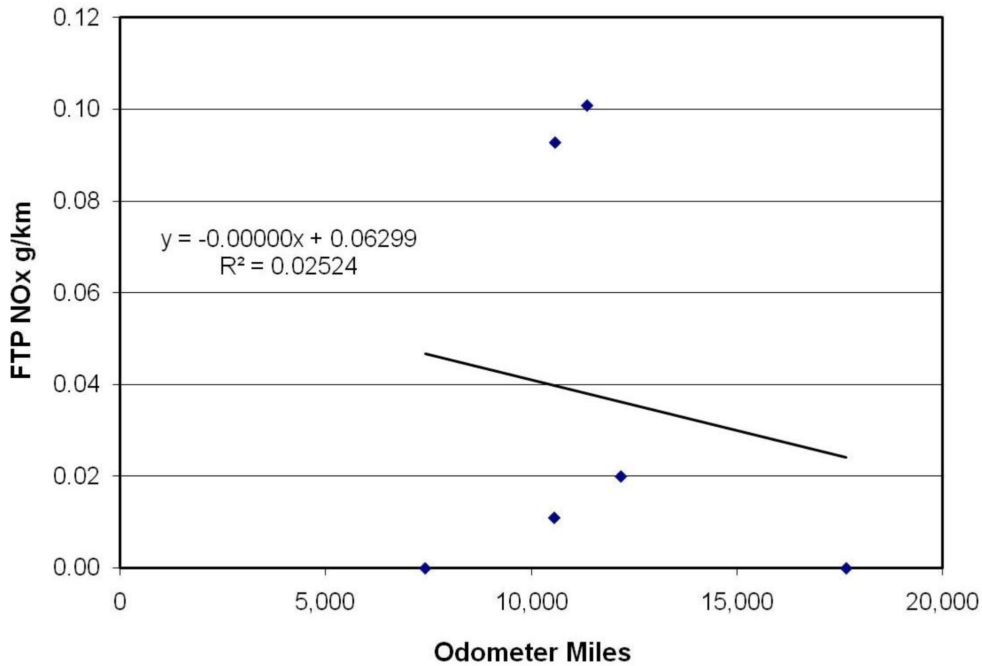


Figure 3-6
Exhaust Oxides of Nitrogen vs. Odometer
Pre-1978 2-Stroke Models



Particulate Emissions – Very limited data are available for particulate emissions from pre-1978 model motorcycles. The above-referenced SAE paper by Hare, et al. provides particulate emissions estimates based on the tests of four 4-stroke and three 2-stroke engines tested on leaded gasoline under steady-state conditions. Translating the steady-state test results to grams per mile, the paper estimates average particulate emissions at 0.048 g/mi for 4-stroke motorcycles and 0.36 g/mi for 2-stroke motorcycles. (However, it should be noted that these estimates are based on the use of fuel containing 3 grams per gallon of tetra-ethyl lead.)

Particulate emissions data more representative of current fuels are available from a 2003 SAE paper by Ricardo.[20] Ten 4-stroke and two 2-stroke motorcycles were tested over three different driving cycles: two versions of the European test cycles and a preliminary version of the transient World Motorcycle Test Cycle (WMTC), which our analysis indicates is reasonably representative of light-duty vehicle operation in the U.S. The 2-stroke models were both 50 cc; the 4-stroke models ranged from 150 to 1300 cc. All of the testing was done on unleaded gasoline. Particulate emissions were measured using the technique specified for Diesel particulate measurement in Europe.

Except for one of the 2-stroke models, particulate emissions were reported to be in the range of 0.001 g/km to 0.013 g/km. As best we can determine from the poor quality graphs in the paper, the average particulate emission rate appears to be approximately 0.007 g/km for the 4-stroke motorcycles tested on the WMTC.

One of the 2-stroke models was a direct injection engine that produced particulate emissions comparable to those of 4-strokes. The more conventional carbureted 2-stroke produced particulate emissions approximately ten times higher than the 4-strokes, i.e., approximately 0.07 g/km.

At the time they were originally sold, the substantially higher particulate emissions associated with the use of leaded fuel were applicable to pre-1978 model motorcycles. However, when pre-1978 models are running on unleaded fuel, the measurements reported by Ricardo are considered to be representative of vehicles currently in operation.

<u>Evaporative Emissions</u> – Uncontrolled evaporative emissions were estimated from three primary sources: (1) surveillance testing of uncontrolled motorcycles by CARB; (2) testing of uncontrolled off-highway motorcycles by ATL; and (3) permeation emission estimates for plastic fuel tanks from EPA's Regulatory Support Document for the regulations for 2006 and subsequent model year highway motorcycles.[21]

Test results for uncontrolled motorcycles tested by ATL[*] and CARB are shown in Table 3-1. All tests were run on California specification fuels at the time of the testing, which ranged from 7 to 9 psi Reid Vapor Pressure. The resting loss portion of the diurnal emissions measured by ATL was calculated from the total emissions that occurred during the period of declining temperatures during a real-time, 24-hour diurnal emissions test. Since the CARB data are available only for the accelerated diurnal test, they are assumed to contain only a small fraction of actual resting loss emissions. Likewise, the CARB test results do not include running loss emissions.

As shown in the first row of Table 1, evaporative emissions measured by ATL averaged 6.83 grams hot soak, 9.47 grams during the heat build portion of the diurnal, 4.00 grams during the declining temperature portion of the diurnal (―resting loss"), and 1.08 g/mi for running loss. The only two vehicles to receive a full complement of evaporative tests were relatively small (200-250 cc) ―off-highway" motorcycles (a Honda XR200R and a Yamaha WR250F). Although it would have been preferable to have had test results for highway models, these were the only tests available with ―real time" evaporative testing (i.e., a 24-hour diurnal test) and running loss measurements.

The resting loss emissions were calculated from the continuous ATL emissions results. Diurnal emissions occurring during the portion of the test when temperatures were decreasing were considered ―resting loss." The calculated resting loss emissions are subtracted from total diurnal emissions to determine the emissions occurring during the ―heat build" portion of the diurnal. It should also be noted that the uncontrolled running loss emissions used in the calculations are based on very limited data. The project manager for the testing program reports that high levels of tank vibration occurred during the testing as the result of the test vehicles being equipped with knobby tires.[22] This

[*] See *http://www.arb.ca.gov/research/apr/past/00-315.pdf*.

		Hot Soak	Diurnal/ Heat Build	Resting Loss	Running Loss	TOTAL
Table 3-1 Uncontrolled Highway Motorcycle Evaporative Emissions						
1.	ATL, Average of 2 Vehicles	6.83 g	9.47 g	4.00 g	1.08 g/mi	-
2.	CARB, Average of 35 Vehicles	8.69 g	8.93 g	n.a.	n.a.	-
3.	Resting Loss Calculation For Vehicle with Plastic Tank	-	-	8.6 g	-	-
4.	Resting Loss Estimate For Vehicle with Metal Tank	-	-	2.0 g	-	-
5.	Resting Loss Calculation For 90% Metal Tanks	-	-	2.66	-	-
6.	Best Estimate of Uncontrolled Evaporative Emissions	8.69 g	8.93 g	2.66 g	1.08 g/mi	-
7.	Grams/mile, assuming 8.5 mi/day, 2 hot soaks/day, Full diurnal emissions ea. day	2.04	1.05	0.31	1.08	4.48
8.	Grams/mile assuming 8.5 mi/day, 4 hot soaks/week Diurnals reduced by 14%	0.58	0.90	0.31	1.08	2.87
9.	Grams/mile assuming 30 mi/day, 2 hot soaks and a full diurnal each day	0.58	0.30	0.09	1.08	2.05

vibration would be expected to contribute to vapor growth. Anecdotal evidence indicates that many motorcycles actually have a net inflow of air to the gasoline tank during normal operation because the effect of decreasing fuel level more than offsets the vapor growth caused by relatively modest fuel heating associated with tanks that are not located in close proximity to exhaust systems.

As shown in the second row of Table 3-1, the average hot soak and diurnal emissions reported by CARB for 35 uncontrolled highway motorcycles were similar to the emissions reported for the two off-highway motorcycles tested by ATL. The individual hot soak emission results contributing to the 8.69 gram average ranged from just under 4 grams to just over 17 grams per test. Individual diurnal emissions results contributing to the 8.93 gram average ranged from 1 to 20 grams per test.

Also shown in Table 3-1 is an estimate of resting loss emissions estimated using the methodology described in EPA's Regulatory Support Document (RSD) for the 2008 model year permeation standards applicable to highway motorcycles. This calculation was done because of the limited amount of resting loss data and the fact that the resting loss emissions measured by ATL may be higher than the highway motorcycle average because both of the vehicles were equipped with plastic tanks.

The RSD estimates permeation emissions from plastic tanks at 1.32 g/gal/day, which is 3.7 grams for the average 2.8 gallon tanks on the vehicles tested by ATL. This is just under the total resting loss emissions estimated from the ATL test results. For the average 5 gallon tank size assumed by EPA, the permeation rate for uncontrolled plastic tanks would be 6.6 grams per day (g/day).

The RSD estimates emissions from "R7"-specification fuel line at 873 $g/m^2/day$ at 29° C and assumes 1.5 feet of hose is used on the average motorcycle. Assuming 5/16" inner diameter fuel lines, this translates to 9.95 grams per day, which is more than double the resting loss emissions calculated from the ATL test data. If 3.7 grams of the resting loss measured by ATL were from plastic tank permeation, the estimate for fuel line permeation is high by a factor of over 30 times. It is also significant to note that CARB evaporative emissions test results on several 1990s vintage motorcycles with evaporative emissions control systems have diurnal emissions in the range of 0.1 grams measured during a 1-hour test. If 100% of the diurnal emissions were from fuel line permeation, daily emissions would be only 2.4 grams.

The available ATL and CARB data make it clear that permeation emissions from motorcycle fuel lines are significantly lower than the estimates based on EPA's assumed emission rate for R7 fuel line. This could be due to the fact that the fuel hose permeation rate assumed by EPA is the upper limit allowed under the SAE R7 standard. Actual emissions for typical fuel hoses, whether R7-spec or not, are obviously much lower. Tests of two commercial R7-spec hoses presented in a 1988 SAE paper indicated emissions as low as 70% below the maximum allowable.[23]

Based on the ATL and CARB test results, it appears that the maximum fuel hose permeation rate for vehicles not subject to the 2006 and later model year permeation standards is at or below 2 g/day. We have assumed this rate applies to pre-2006 models.

Row 3 of Table 3-1 shows that resting losses are estimated at 8.6 g/day for uncontrolled vehicles with plastic tanks. This value is the sum of the 6.6 g/day estimate for a 5 gallon tank and a 2.0 g/day estimate for fuel hose permeation. Row 4 shows the resting loss estimate for uncontrolled motorcycles with metal fuel tanks, which includes only the estimated emissions for fuel hoses. Row 5 shows the resting loss emissions for a fleet of uncontrolled motorcycles with 10% plastic tanks.

Rows 7, 8, and 9 of Table 3-1 show the estimated fleet average evaporative emissions translated into grams per mile. Rows 7 and 8 assume an average daily VMT of 8.5 miles, which is equivalent to about 3,100 miles per year (an estimate supported by activity data described below).

Row 7 shows the results for the assumption that the average motorcycle, like the average car, experiences two hot soaks and one full diurnal per day. As described in the subsequent discussion of motorcycle usage, two hot starts per day is not a reasonable assumption for the average motorcycle. Unlike passenger cars, most motorcycles are not used on a daily basis. Because they are usually stored in garages when not being used, the emissions associated with the full diurnal test also do not occur on a daily basis.

Row 8 shows the results based on the assumption that there are only 4 hot soaks per week (which results in the same number of miles per hot soak as with passenger cars) and that diurnal emissions are reduced by 20% on days when the vehicle is not driven. Table 5.1-6 of EPA's Final Regulatory Impact Analysis done for the Marine SI and Small SI Engines, Vessels, and Equipment rule indicates that diurnal emissions are reduced by 20% when a vehicle is stored in a garage.[24] Survey data obtained by MIC indicate that 83% of motorcycles are stored in garages on days they are not driven.[25] For vehicles driven two days per week, a 20% reduction on the non-drive days results in a 14% reduction in average diurnal emissions.

Row 9 shows the results for those motorcycles that are used like cars and driven about 30 miles per day with 2 hot soaks daily and one full diurnal. By comparing the last column of row 7 with the last column of row 9, it is apparent that how the vehicle is used causes evaporative emissions to vary by more than 100% on a g/mi basis.

Summary of Uncontrolled Emissions – Table 3-2 summarizes the analysis described above with all emissions translated into grams per mile. Due to the extremely high exhaust HC emissions of 2-stroke models, average exhaust HC for uncontrolled motorcycles is about 24% higher than the estimate for uncontrolled passenger cars. In contrast, uncontrolled CO and NOx emissions are significantly lower. Evaporative emissions from motorcycles are about 30% lower than from uncontrolled passenger cars. Uncontrolled crankcase emissions are 90% lower.

Table 3-2
Uncontrolled Highway Motorcycle Emissions (g/mi)
(FTP test conditions, 8.5 mi/day, 4 hot soaks per week, 5 reduced diurnals/week)

Vehicle	Exhaust					Evap	Crankcase	Total
	HC	CO	NOx	PM	HC+NOx			HC+NOx
2-Stroke Motorcycle	19.2	31.7	0.06	0.11	19.26	2.87	0	22.13
4-Stroke Motorcycle	4.7	50.2	0.43	0.01	5.13	2.87	0.7	8.70
Average Motorcycle (45% 2-stroke)	**11.2**	**41.9**	**0.26**	**0.06**	**11.46**	**2.87**	**0.4**	**14.73**
Passenger Car	9.0	90	4.0	-	13.0	4.0	4.0	21.0

Note: Passenger car evaporative emissions based on 30 mi/day, 2 hot soaks per day. PM emissions assume the use of unleaded fuel.

3.3 Controlled Emissions

New highway motorcycles ≥50 cc have been subject to exhaust and crankcase emissions standards since model year 1978, ten years after the first federal standards were applied to passenger cars and light-duty trucks. Conventional evaporative emissions standards have not yet been required for highway motorcycles under federal regulations; however, 2006 and subsequent model year motorcycles are required to use low permeation fuel system components. In addition, evaporative emissions controls required by the State of California since the 1984 model year have been voluntarily applied to some motorcycles sold in other states.

Crankcase Emissions – Beginning with model year 1978, all highway motorcycles ≥50 cc have been required to be designed so that ―no crankcase emissions shall be discharged into the ambient atmosphere.” Although it is likely that some crankcase emissions are emitted as the result of deterioration of breather hoses in customer service, no data were identified on which a non-zero emission rate could be based.

Exhaust Emissions – Table 3-3 summarizes the motorcycle exhaust emissions standards adopted by EPA and CARB. (Unlike the standards applicable to cars and trucks, the motorcycle standards may be met based on each manufacturer's sales-weighted average emissions of the various models sold within each class.) The California standards are relevant to the emission factors used in MOVES for two reasons. First, as discussed in more detail below, many motorcycles sold in all 50 states were voluntarily certified to the California standards to avoid the cost associated with distributing two different types of motorcycles. Second, even in cases where a manufacturer produces a California and ―49-state” version, the California-certified model is sometimes sold in other western states.

As shown in the first three rows of Table 3-3, EPA and CARB standards were identical for all 1978 and 1979 models. Class I vehicles were required to meet a 5 g/km (8.05 g/mi) HC standard and a 17 g/km (27.4 g/mi) CO standard. The HC standard for larger displacement models increased in proportion to engine displacement to a maximum of 14 g/km (22.5 g/mi). These could be considered transitional standards intended to initiate a phase-out of conventional 2-stroke engines.

For model years 1980 and 1981, a 5 g/km HC standard applied to all displacements, which eliminated all but a few 2-stroke models. The federal CO standard was reduced to 12 g/km (19.3 g/mi) for all displacements.

From 1980 through 2005, the federal standards remained unchanged; however, the California standards become more stringent starting with the 1982 model year when Class I and Class II vehicles become subject to a 1.0 g/km (1.61 g/mi) HC standard and Class III vehicles become subject to a 2.5 g/km (4.0 g/mi) HC standard. For 1986 and 1987, the HC standard for Class III California motorcycles is reduced to 1.4 g/km (2.25 g/mi).

Table 3-3
Motorcycle Exhaust Emission Standards (grams per kilometer, g/km)

Model Year	Engine Size (cc)	Federal Standards			California Standards		
		HC	CO	HC+NOx	HC	CO	HC+NOx
1978–1979	50–169	5.0	17	n.a.	5.0	17	n.a.
1978–1979	170–749	5–14[a]	17	n.a.	5–14[a]	17	n.a.
1978–1979	≥750	14	17	n.a.	14	17	n.a.
1980–1981	≥50	5.0	12	n.a.	5.0	17	n.a.
1982–1985	50–279	5.0	12	n.a.	1.0	12	n.a.
1982–1985[b]	≥280	5.0	12	n.a.	2.5	12	n.a.
1986–1987	50–279	5.0	12	n.a.	1.0	12	n.a.
1986–1987[c,d]	≥280	5.0	12	n.a.	1.4	12	n.a.
1988–2003	50–699	5.0	12	n.a.	1.0	12	n.a.
1988–2003	≥700	5.0	12	n.a.	1.4	12	n.a.
2004–2005[e]	50–279	5.0	12	n.a.	1.0	12	n.a.
2004–2005	≥280	5.0	12	n.a.	n.a.	12	1.4
2006–2007	0–279	1.0	12	n.a.	1.0	12	n.a.
2006–2007	≥280	n.a.	12	1.4	n.a.	12	1.4
2008–2009	0–279	1.0	12	n.a.	1.0	12	n.a.
2008–2009	≥280	n.a.	12	1.4	n.a.	12	0.8
≥2010	0–279	1.0	12	n.a.	1.0	12	n.a.
≥2010	≥280	n.a.	12	0.8	n.a.	12	0.8

[a] 5.0 + 0.0155 (D-170), where ―D" is engine displacement in cubic centimeters
[b] Note: California standards apply to vehicles produced prior to March 1, 1985
[c] Note: California standards apply to vehicles produced after February 28, 1985
[d] Compliance is based on corporate average after February 28, 1985 for California and 2006 federally.
[e] Note: Class I and II motorcycles subject to the 1.0 g/km HC standard, beginning in 2004 for California models and 2006 for federal models, may be optionally certified to a 1.4 g/km HC+NOx standard.

For 1988 to 2003, CARB extended the 1.0 g/km HC standard to all motorcycles up to 699 cc displacement. Motorcycles ≥700 cc remained subject to a 1.4 g/km HC standard.

Beginning with model year 2004, CARB revised its standards for Class III motorcycles to incorporate an HC+NOx standard and to delete the separate HC standard. Because uncontrolled NOx emissions are about 0.3 g/km, the new 1.4 g/km HC+NOx standard requires motorcycles ≥700 cc to have HC+NOx emissions about 18% lower than under the previous HC-only standard. In 2008, CARB's HC+NOx standard for Class III motorcycles is reduced from 1.4 g/km to 0.8 g/km (1.29 g/mi). Beginning in 2004, Class I and II motorcycles subject to the 1.0 g/km HC standard may optionally be certified to a 1.4 g/km HC+NOx standard.

The federal 2006 and 2010 model year standards were set to be equivalent to the 2004 and 2008 California standards. The federal and California exhaust emission standards are therefore identical for 2010 and subsequent model years.

By comparing the standards in Table 3-3 to the uncontrolled emission levels described above, it is apparent that nearly a 50% reduction in CO emissions was required for 4-stroke motorcycles beginning in model year 1978. Because there were no NOx standards, the most cost-effective way for manufacturers to meet the CO standards involved enleanment of the air-fuel ratio. This also reduced hydrocarbon emissions by an amount that was generally sufficient to comply with the CARB HC standard through model year 1985. As a result, 1978 through 1985 model 4-stroke motorcycles have similar emissions characteristics.

Regulated Pollutants – The available data on 1978–1985 models from SwRI and CARB are displayed in Figures 3-7, 3-8, and 3-9. As was the case with pre-1978 models, there is still a wide variation in test results from model to model. It is also apparent that there is little trend in emissions vs. mileage accumulation. The average of tests of 55

Figure 3-7
Exhaust Hydrocarbons vs. Odometer
1978–1985 4-Stroke Models

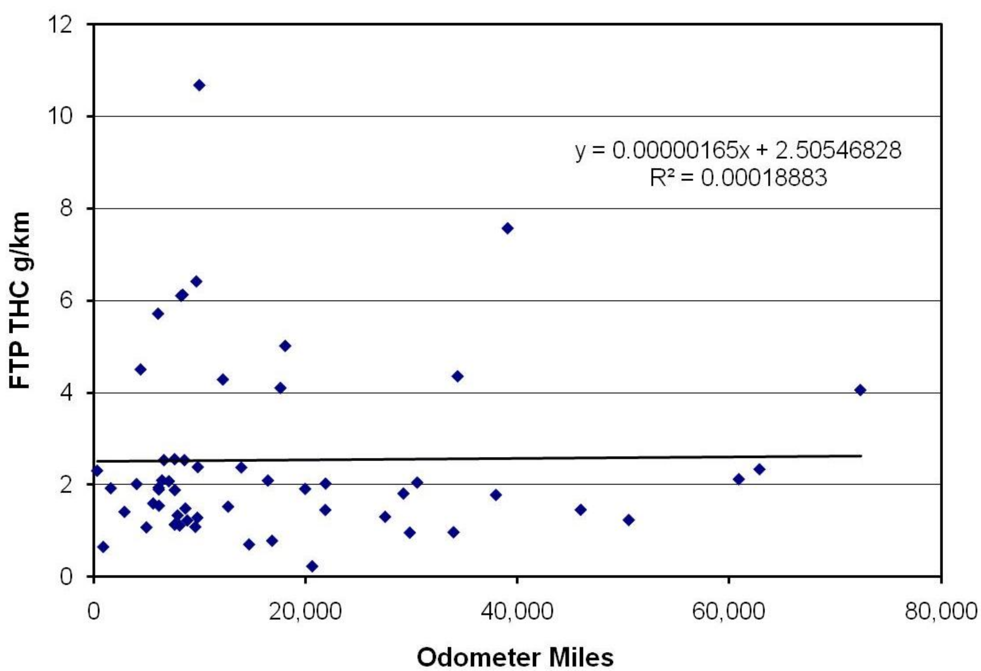


Figure 3-8
Exhaust Carbon Monoxide vs. Odometer
1978–1985 4-Stroke Models

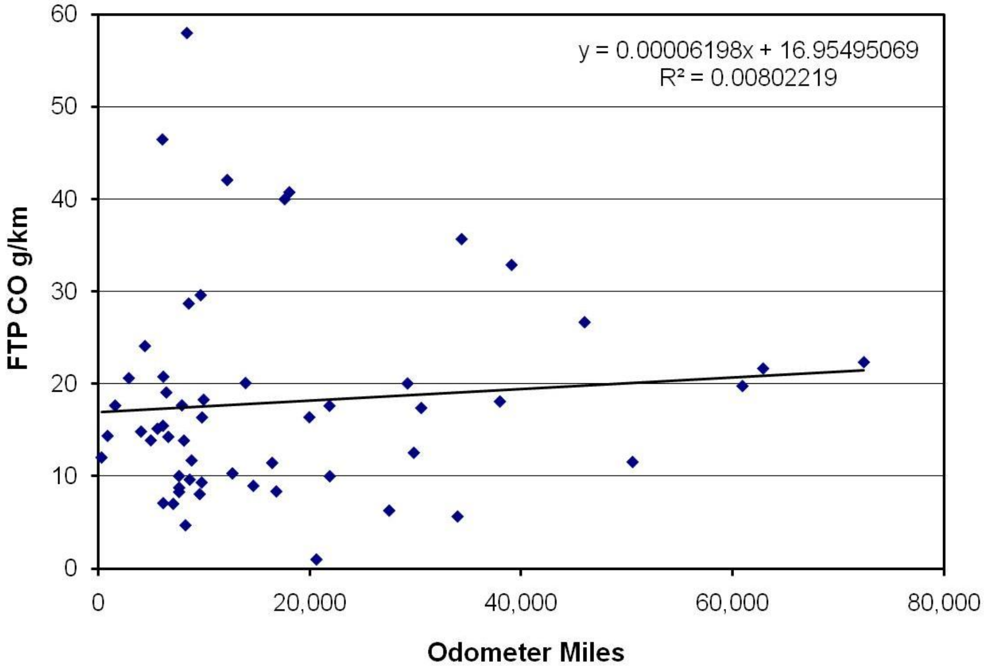
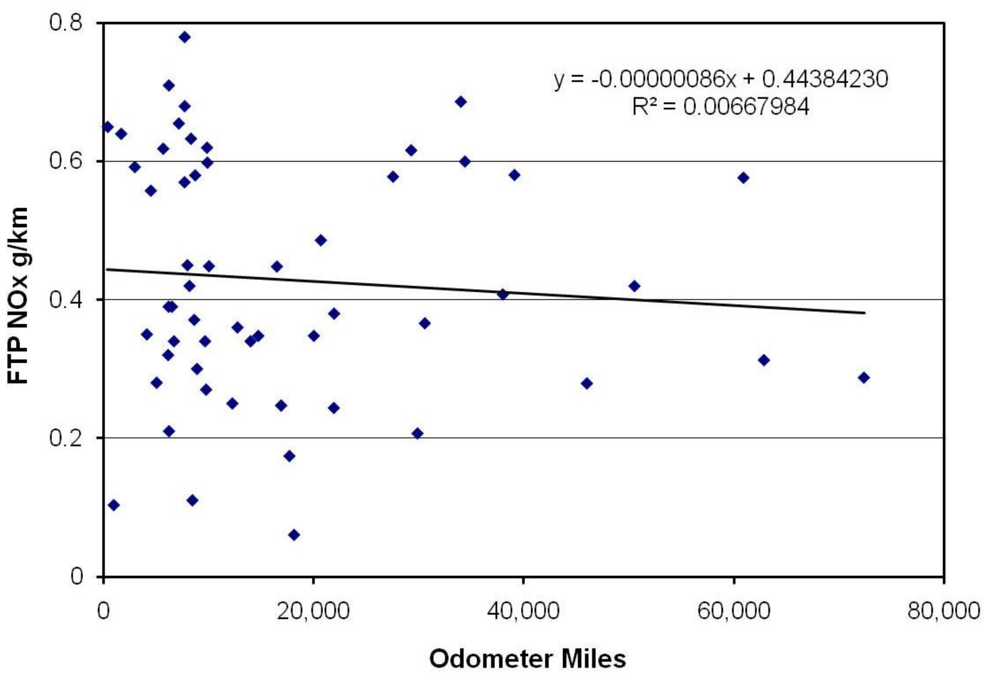


Figure 3-9
Exhaust Oxides of Nitrogen vs. Odometer
1978–1985 4-Stroke Models



individual 1978–1985 model year vehicles indicated FTP emissions of 2.534 g/km HC, 18.041 g/km CO, and 0.429 g/km NOx.

Figures 3-10, 3-11, and 3-12 present the available test results for 1986–1999 model year motorcycles from CARB's 1998 surveillance testing program. The California standards applicable to these model years ranged from 1.0 to 1.4 g/km HC depending on the displacement class.

As with earlier models, there is a wide variation in test results from model to model. Models with relative high emissions continue to be allowed because compliance with the California standards is based on corporate average emissions beginning with vehicles produced after February 1985. The average of tests of 59 individual 1986–1999 model year vehicles indicated FTP emissions of 1.34 g/km HC, 13.31 g/km CO, and 0.36 g/km NOx. Since only one Class I vehicle and one Class II vehicle were tested, there are insufficient data to distinguish between the three classes. The use of certification data to distinguish between the classes is frustrated by the lack of NOx data.

Although the federal exhaust emission standards remained at 5 g/km HC from 1986 through 2005, the majority of models certified for sale actually met the California exhaust emissions standards. Thus, the emission levels depicted in Figures 3-10 through 3-12 are representative of 49-state motorcycles.

Figure 3-10
Exhaust Hydrocarbons vs. Odometer
1986–1999 Models

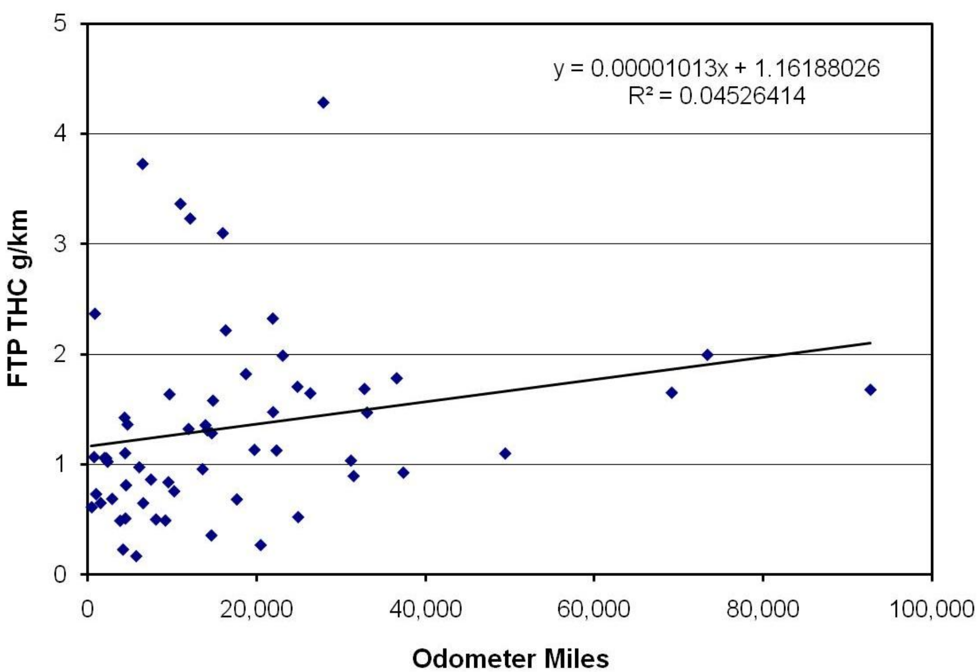


Figure 3-11
Exhaust Carbon Monoxide vs. Odometer
1986–1999 Models

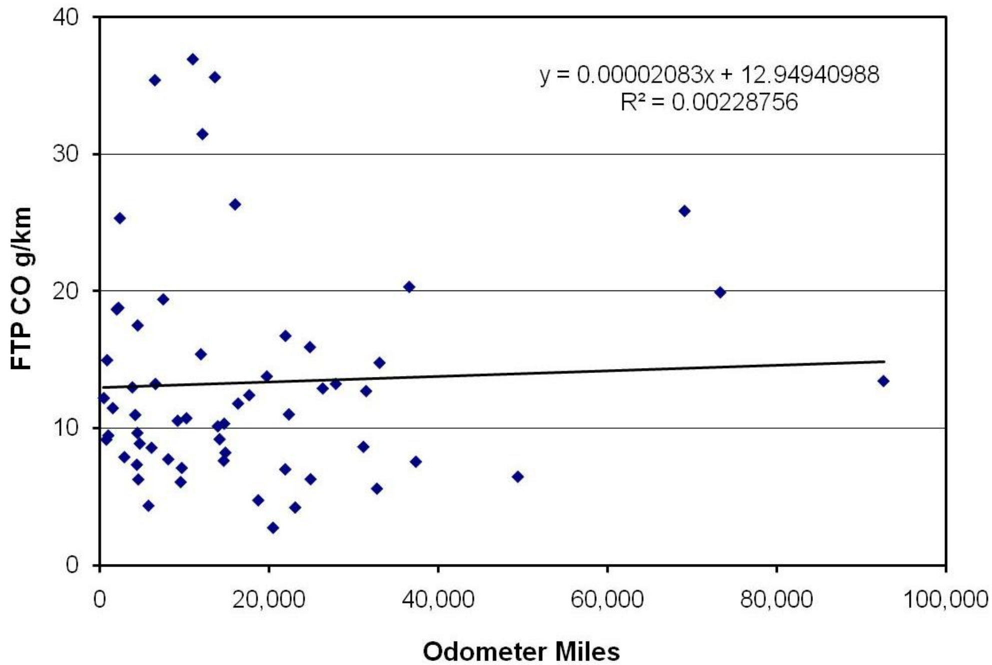
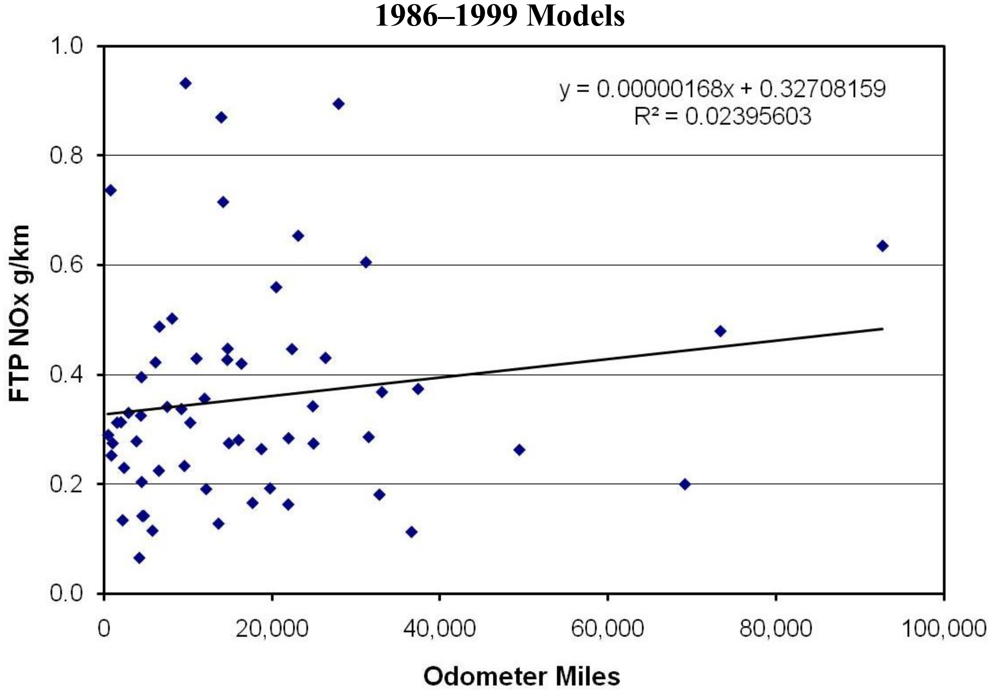


Figure 3-12
Exhaust Oxides of Nitrogen vs. Odometer
1986–1999 Models



There appears to be no significant trend in emissions vs. vehicle age for motorcycles of this vintage based on idle emissions data collected in the Arizona I/M program. Figures 3-13 and 3-14 illustrate the relationship between emissions and vehicle age using data from the late 1990s.[26]

Beginning with model year 2004 in California and 2006 federally, the HC-only standard is eliminated for Class III motorcycles and large-volume manufacturers are required to meet a 1.4 g/km HC+NOx standard. The CO standard remains unchanged at 12 g/km. Beginning with model year 2008 in California and 2010 federally, the HC+NOx standard for Class III motorcycles is tightened to 0.8 g/km (1.29 g/mi). Only very limited emissions data are available for motorcycles recruited from customer service that are subject to the HC+NOx standards. As a result, an alternative technique is required in order to estimate emissions in customer service.

Analysis of California certification data for model year 2009 Class III motorcycles indicates that the average HC+NOx emission rate reflects a 30% compliance margin for the applicable 0.8 g/km standard. Average HC+CO emissions for Class III models were 0.56 g/km. (This represents a 67% reduction from the average 1.70 g/km HC+NOx emissions of 1986–1999 models.) Average CO emissions were 4.0 g/km. Average emissions for the 84% of the 2009 Class III catalyst-equipped models were 0.45 g/km HC+NOx and 3.57 g/km CO. The non-catalyst models averaged 1.14 g/km HC+NOx and 6.16 g/km CO. Based on an analysis of 2008 model year certification data, HC exhaust emissions are about 60% of HC+NOx for both catalyst and non-catalyst models.

Figure 3-13
Idle HC Versus Motorcycle Age
Arizona I/M Data – July to September 1997

Idle HC Versus Motorcycle Age
Arizona I/M Data - July to September 1997

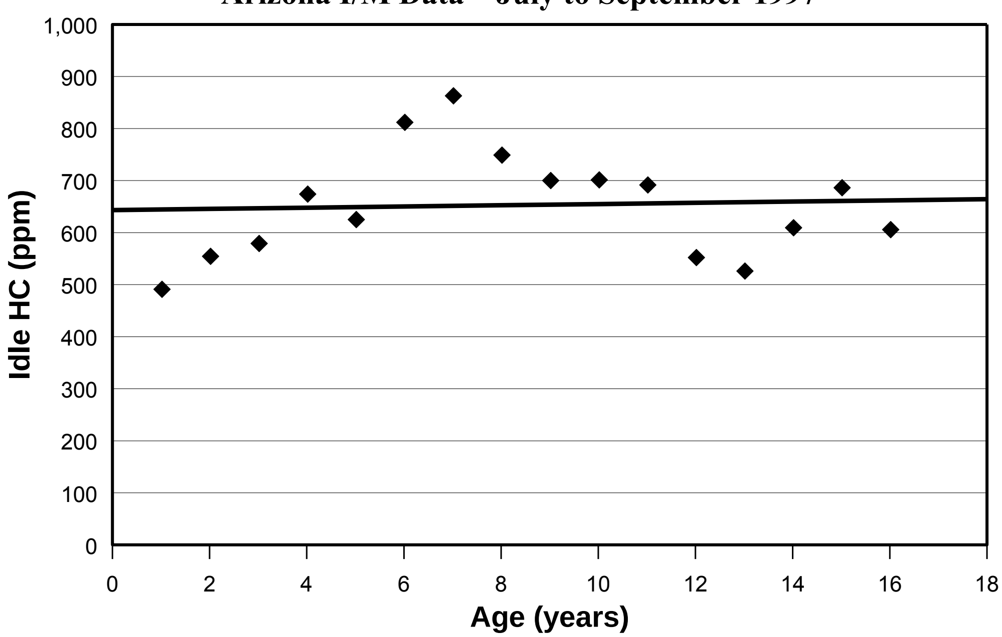
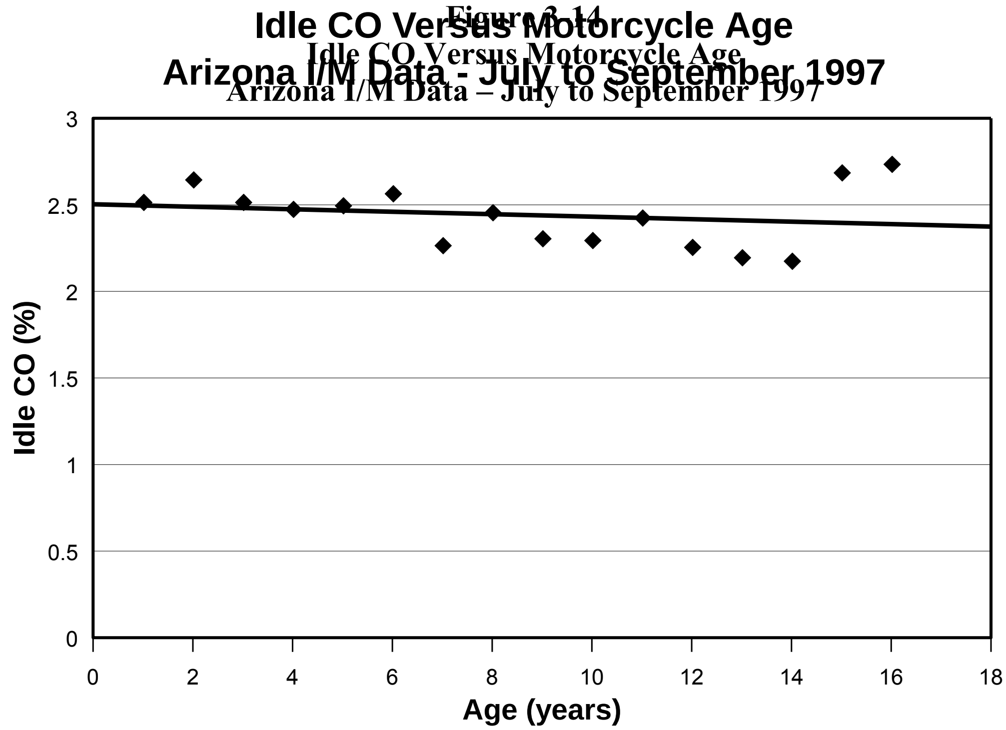


Figure 3-14
Idle CO Versus Motorcycle Age
Arizona I/M Data – July to September 1997



Because corporate averaging was allowed, compliance with the 1.4 g/km HC+NOx standard required for model years 2004–2007 in California was generally achieved by phasing in vehicles designed to meet the 0.8 g/km standard that became effective in 2008. As a result, model years subject to the 1.4 g/km "Tier 1" standard can be represented by a fleet with a smaller fraction of Tier 2 compliant vehicles. Only 25% of the Tier 2 vehicles are required to achieve the Tier 1 standard assuming the emissions of the non-catalyst vehicles are the same as 1986–1999 models. However, maintenance of a 30% compliance margin required about a 60/40 split of Tier 2 catalyst vehicles and vehicles with the average emissions of the 1986–1999 models. This yields a fleet average of 0.95 g/km HC+NOx and 7.5 g/km CO.

Based on analysis of 2008 model year certification test results, the average HC+NOx and CO exhaust emissions for Class I and Class II motorcycles are only slightly higher than the emissions from Class III models. NOx data were not available for all models (since compliance with the optional HC+NOx standard is voluntary); however, based on the available data, the HC+NOx emissions are 0.85 g/km for Class Ia, 0.91 g/km for Class Ib, and 0.95 g/km for Class II. CO emissions were 5.2 g/km for Class Ia, 6.5 g/km for Class Ib, and 7.1 g/km for Class II. Although catalytic converters are used on some Class I and Class II models, an insignificant catalyst removal rate is anticipated in customer service.

Unlike for non-catalyst motorcycles, catalyst-equipped motorcycles are not expected to maintain the same emissions in customer service that are demonstrated during certification testing. Survey data collected by the Motorcycle Industry Council indicate that replacement of OEM exhaust systems is a common occurrence on highway motorcycles. Although CARB has recently adopted regulations that provide for the certification of catalyst-equipped aftermarket exhaust systems, such systems will be more expensive than other aftermarket systems and generally quieter (because of the muffling effect of the catalyst). Given the current lack of any effective enforcement mechanism, it does not appear likely that the availability of catalyst-equipped aftermarket systems will have much effect on the emissions increase associated with the removal of OEM systems.

Surveys conducted over the last 10 years indicate an OEM replacement rate of 38%. Analysis of the 2008 model year CARB certification data indicates that catalysts are used on 84% of Class III motorcycles. Replacement of 38% of the OEM exhaust system will therefore eliminate the emission reduction accomplished by the catalyst on 32% of the vehicles.

To account for the effect of exhaust system replacement, the in-use emissions from vehicles certified to meet the 2008 California and 2010 federal standards can be estimated based on the following assumptions:

1. 52% of the vehicles will have emissions equivalent to the certification levels achieved by catalyst equipped motorcycles;

2. 32% of the vehicles will exhibit emissions similar to 1986–1999 models; and

3. 16% of the vehicles will have emissions equivalent to the certification levels achieved by non-catalyst motorcycles.

The assumption regarding emissions from motorcycles that have had their catalyst removed is consistent with data recently collected by CARB.* Based on these assumptions, fleet average emissions will be 0.96 g/km (1.54 g/mi) HC+NOx and 7.1 g/km (11.4 g/mi) CO.

After accounting for catalyst tampering, the estimated emissions for Tier 2 certified motorcycles are almost identical to the certification levels for Class I and Class II motorcycles. Since tampering is not expected to be significant for Class I and Class II models, the emission rates estimated for Tier 2 certified models can be applied to Class I and Class II models as well.

To estimate the effect of tampering on the fleet subject to Tier 1 standards, we have assumed that 37% of the vehicles emit at levels of catalyst-equipped Tier 2 vehicles

* Unpublished data provided by CARB from Project 2R0814. CARB tested four late-model motorcycles originally equipped with catalytic converters. With catalysts removed, the HC+NOx emissions averaged 1.59 g/km and CO emissions averaged 8.2 g/km.

(reflecting a 38% tampering rate on 60% of the vehicles) and the remainder emit like the average of the 1986–1999 models. This yields in-use emissions from vehicles certified to meet the 2004 California and 2006 federal standards of 1.24 g/km HC+NOx and 9.7 g/km CO.

Particulate Emissions – In the absence of data on U.S. specification motorcycles, the Ricardo estimates for 4-stroke motorcycles running on unleaded gasoline described above are assumed to be applicable to all controlled motorcycles.

Evaporative Emissions – California motorcycles have been subject to evaporative emissions standards since a phase-in that began in 1983 and was completed in 1984. The applicable test procedure is the one-hour SHED test that only partially captures resting loss emissions and does not require either real time or multiday diurnal tests. Federal standards require the use of low permeation fuel tanks and fuel hoses beginning in model year 2008. Table 3-4 summarizes our estimates of evaporative emissions from motorcycles with some form of evaporative controls.

Hot soak and diurnal emissions test results for six California-certified motorcycles equipped with evaporative emissions controls are shown in the first row of Table 3-4. Because a simple 1-hour SHED test was used, permeation and running loss emissions are not accounted for. As shown in the second row of the table, running loss emissions are assumed to be eliminated from a motorcycle equipped with a canister and purge system.[*]

Rows 3, 4, and 5 of the table repeat the resting and running loss estimates presented earlier in the discussion of uncontrolled evaporative emissions. These estimates apply to California-certified motorcycles prior to the requirement for low permeation fuel tanks and fuel hoses. The third row of Table 3-4 shows the resting loss calculation for a motorcycle with a plastic tank. The fourth row of the table shows the resting loss estimate for just the fuel hoses that was described previously. Row 5 of the table shows the resting loss estimate for a fleet of motorcycles with 10% plastic tanks.

Row 6 combines the estimates from rows 1, 2, and 5, and provides our estimates of each category of evaporative emissions from 1984–2007 model year California-certified motorcycles. Row 7 translates the evaporative emissions shown in row 6 into grams per mile based on a daily average VMT of 8.5 miles and 4 hot soaks per week. Diurnal emissions are estimated based on the assumption that 2 diurnal events per week produce emissions equal to the SHED test results and, on the other 5 days, diurnal emissions are estimated to be 32% of the uncontrolled diurnal emissions of a motorcycle parked outside.

[*] It is theoretically possible for a canister-equipped motorcycle to have sufficient vapor generation during operation to cause breakthrough, but such systems would have difficulty during the hot soak test because the canister would already be saturated.

Table 3-4
Controlled Highway Motorcycle Evaporative Emissions

		Hot Soak	Diurnal/ Heat Build	Resting Loss	Running Loss	TOTAL
1.	Tests of 6 CA-certified Vehicles	0.71 g	0.48 g	n.a.	n.a.	-
2.	Estimated Running Loss for CA-certified Vehicles	-	-	-	0 g/mi	-
3.	Pre-2008 Resting Loss Estimate For Vehicle with Plastic Tank	-	-	8.6 g	-	-
4.	Pre-2008 Resting Loss Estimate For Vehicle with Metal Tank	-	-	2.0 g	-	-
5.	Pre-2008 Resting Loss For 90% Metal Tanks	-	-	2.66	-	-
6.	Best Estimate of Controlled Emissions, 1984–2007 CA	0.71 g	0.48 g	2.66 g	0 g/mi	-
7.	Grams/mile, 1984–2007 CA, assuming 8.5 mi/day, 4 hot soaks/week, 71% of diurnals reduced by 68%	0.05	0.26	0.31	0	0.62
8.	As Above, Plus 15% Tampering	0.13	0.36	0.31	0.16	0.96
9.	Grams/mile, 2008 CA, assuming 8.5 mi/day, 4 hot soaks/week, 71% of diurnals reduced by 68%	0.05	0.26	0.03	0	0.34
10.	As Above, Plus 15% Tampering	0.13	0.36	0.03	0.16	0.68
11.	Grams/mile, 2008 federal, assuming 8.5 mi/day, 4 hot soaks/week, uncontrolled diurnals reduced by 14%	0.58	0.90	0.03	1.08	2.59

The diurnal emissions during the 5 days per week that the average California-certified motorcycle is not operating were calculated based on EPA's estimate from the earlier referenced Final Regulatory Impact Analysis that canisters reduce diurnal emissions by 60% when they are not purged between repeated diurnal cycles. The RIA summarizes the rationale for this estimate as follows:

> *…we have collected information showing that, during cooling periods, the canister is purged sufficiently enough so that it can be used effectively to reduce diurnal emissions. When the fuel in the tank cools, fresh air is drawn back through the canister into the fuel tank. This fresh air will partially purge the canister and return hydrocarbons back to the fuel tank. Therefore, the canister will have open sites available to collect vapor during the next heating event. Test data presented below show that a canister that starts empty is more than 90 percent effective at capturing hydrocarbons until it reaches saturation. Once the canister reaches saturation, it is still capable of achieving more than a 60 percent reduction in diurnal emissions due to passive purging. Passive purging occurs as a result of fresh air that is pulled through the canister during fuel tank cooling periods.*

As shown in the last column of row 7, the total evaporative emissions for a 1984–2007 model year California-certified motorcycle are estimated to be 0.62 g/mi, which represents a 78% reduction from the uncontrolled evaporative emission rate of 2.87 g/mi.

Row 8 of the table accounts for tampering with evaporative emission control systems on motorcycles in customer service. Sierra was unable to identify any existing survey data regarding evaporative system tampering, so a preliminary survey was conducted of the members of an Internet forum of motorcycle enthusiasts (www.ldriders.com).* A question was posed to members of the forum by one of the forum administrators who requested private responses and guaranteed that the respondents would remain anonymous. Owners of motorcycles that were originally equipped with evaporative canisters (i.e., 1984 and later models that were California or 50-state certified) were asked to report whether the canister was still in place. The make and model year of the motorcycle were also reported.†

Based on 78 responses to the above-described survey, canisters had been removed from 28% of the motorcycles owned by the forum members. The removal rate was higher for

* Unlike forums focused on a particular make and model of motorcycle, this forum includes members owning a broad range of makes and models. The focus of the forum is long distance riding and many of the forum topics address modifications to motorcycles to make them more suitable for long distance riding, such as auxiliary lighting, aftermarket saddles, GPS systems, and auxiliary fuel systems. The members are therefore frequently involved in modifying their motorcycles and are probably more likely to have tampered with evaporative emissions control system than the average owner.

† Responses usually were rejected if the owner did not know whether the motorcycle was originally equipped with a canister or did not know where the canister was located. The exception was in cases where the make and model was known to be 50-state certified and the original owners reported that, although they didn't know how to identify the canister, they had not removed any components.

the older models, many of which were near the end of their life. The removal rate for models up to five years old, the vehicles that have the highest annual average mileage accumulation, was approximately 19%. Based on this survey, 15% has been used as a conservative estimate of the canister removal rate for two reasons. First, motorcycle owners in the survey population are more likely to have tampered with their emissions control system than the average owner. Second, there is a likely reporting bias associated with the fact that owners who don't know whether their motorcycle was originally equipped with a canister would be unlikely to respond (and certainly wouldn't have removed the canister).

Row 8 of Table 3-4 shows the effects of the assumed 15% canister removal rate for 1984–2007 model year California-certified motorcycles. For hot soak, diurnal, and running loss, 15% of the fleet is assumed to have the uncontrolled evaporative emissions reported earlier in Table 1 and 85% of the fleet is assumed to have the controlled emissions estimates from row 8 of Table 3-4. The net effect is that total evaporative emissions are 0.96 g/mi, which is 67% below the uncontrolled estimate.

Row 9 of the table shows the effect of reducing resting losses by 90% to account for the use of gasoline tanks and fuel hoses meeting the permeation standards required by EPA regulations for 2008 and subsequent models. Ignoring the effect of tampering, the total evaporative emissions of motorcycles certified to meet the California evaporative emissions standards are reduced to 0.34 g/mi, which is 88% below uncontrolled levels.

Row 10 of the table shows the estimated evaporative emissions for 2008 and subsequent model year California-certified motorcycles when tampering is taken into account. The 0.68 g/mi emission rate is 76% below uncontrolled emissions.

The final row of Table 3-4 shows our estimate for the evaporative emissions of 2008 and subsequent model year federally certified motorcycles. The 2.59 g/mi composite emission rate is only 10% below uncontrolled emissions.

Summary of Controlled Emissions – Table 3-5 summarizes the analysis described above with all emissions translated into grams per mile. Due to the combined effects of crankcase, exhaust, and permeation standards, 2010 and later model federally certified motorcycles have 72% lower HC+NOx emissions than uncontrolled, pre-1978 models.

Due to the evaporative emissions standards, the HC+NOx emissions of California-certified models are 85% lower than uncontrolled. Both California and federal motorcycles have CO emissions that are 73% lower than uncontrolled.

Because of the relatively high fraction of models meeting California exhaust emissions standards that are sold in all 50 states, relatively little error is introduced by using the exhaust emissions estimates for 2004 and later California models for all 50 states. However, California evaporative emissions systems are not routinely used on models produced for sale outside of California.

Table 3-5 **Controlled vs. Uncontrolled Emissions (g/mi)** (FTP test conditions, 8.5 mi/day, 4 hot soaks per week, 2 regular diurnals per week, 5 multiday diurnals per week)								
	Exhaust							Total
Vehicle	HC	CO	NOx	PM	HC+NOx	Evap	Crankcase	HC+NOx
Pre-1978 Motorcycles	11.2	41.9	0.26	0.06	11.46	2.87	0.4	14.73
1978–1985 Motorcycle	4.07	29.0	0.69	0.01	4.76	2.87	0	7.63
1986–2003 Motorcycle	2.16	21.4	0.58	0.01	2.74	2.87	0	5.61
2004–2007 California	1.51	15.6	0.47	0.01	1.98	0.96	0	2.94
2006–2009 Federal	1.51	15.6	0.47	0.01	1.98	2.87	0	4.85
≥2008 California	1.09	11.4	0.45	0.01	1.54	0.68	0	2.22
≥2010 Federal	1.09	11.4	0.45	0.01	1.54	2.59	0	4.13

MOVES model year groups 70 (1960–1970) and 51 (1971–1977) can be used for pre-1978 models. Groups 6 and 7 can be used for 2011 and subsequent models. Most intermediate model years need to be in model year specific groups for greatest accuracy; however, Groups 61, 62, 63, 64, and 65 could also be used to minimize the number of groups. We recommend that California emission factors, except for evaporative emissions, be used for all 2004 and subsequent model years.

3.4 Inspection and Maintenance Effect

Arizona is the only state in the nation that includes motorcycles in its Inspection and Maintenance (I/M) program. Our review of the available documentation[27] indicates that no mass emissions data have ever been collected that can be used to provide a meaningful estimate of the benefits associated with subjecting motorcycles to I/M. The estimates of emission reductions made by the State of Arizona are based on the assumption that motorcycles will experience benefits proportional to those predicted by MOBILE6 for light-duty vehicles, with certain adjustments made to account for known differences in starts per day and VMT. In addition, an adjustment was made to account for the observed idle emissions test results for passing and failing vehicles in the I/M lanes. (The difference between the idle emissions of failing vehicles and the idle emissions standard was apparently assumed to be proportional to excess emissions.) Based on the information presented in the above-referenced report, the State of Arizona's 2004 calendar year estimate of the benefits of subjecting motorcycles to I/M was a 13.5% reduction in exhaust HC and a 20.1% reduction in exhaust CO.

Undoubtedly the Arizona I/M program required some motorcycles to have their idle air-fuel ratio adjusted in order to pass the test. However, the net effect on emissions in customer service is unclear for several reasons. First, there are no data correlating changes in the concentration of HC and CO emissions at idle to mass emissions changes in customer service. Second, there is no evidence that the air-fuel ratio adjustments required to pass the idle test were permanent. Third, the previously presented data showing the lack of correlation between failure rate and vehicle age raise questions about the appropriateness of the idle emissions standards being used.

The lack of correlation between the idle emissions failure rate and vehicle age described above is consistent with the lack of a significant trend between emissions and odometer in the surveillance testing data available from CARB. It therefore appears that the idle standards being used by Arizona were merely identifying that fraction of the motorcycle fleet at one end of a fairly broad distribution of idle emission levels. Under these circumstances, it does not appear reasonable to estimate I/M benefits based on a calculation that assumes excess emissions from failing vehicles are proportional to the extent to which their idle concentrations exceed the I/M standards.

The potential benefits of I/M may be fundamentally different for later model motorcycles originally equipped with catalytic converters. Unlike for non-catalyst motorcycles, there is fairly solid evidence of significant emissions deterioration in customer service associated with the replacement of OEM exhaust systems. However, there is great uncertainty regarding how effective I/M will be as a deterrent to catalyst removal. Unlike with light-duty vehicles, the exhaust systems on motorcycles can be changed rather quickly, typically in less than one hour. Re-installation of an OEM system for one day to pass an I/M test may be the approach used by many owners who prefer to use an aftermarket exhaust system on a routine basis.

In addition to the likelihood of repeat tampering, there are other practical problems associated with using a conventional I/M program as a deterrent to catalyst removal. There is no available analysis indicating that emission testing (dynamometer or idle) will be effective in identifying tampered vehicles. The existence of small-volume manufacturer standards and corporate averaging affects the feasibility of making an accurate pass/fail decision based on emissions test results. The HC+NOx standards that apply to recently certified motorcycle models range from 0.3 to 2.5 g/km HC + NOx. This is substantially greater than the difference in emissions associated with catalyst removal. It is also likely that visual inspections will be ineffective because OEM catalysts are often hidden. Checking for the presence of the EPA noise certification stamp may also be ineffective because the stamp is not placed on the catalyst itself; the stamp can remain when the catalyst has been removed.

For the reasons described above, the effective deterrence of catalyst tampering is likely to require something other than a conventional annual or biennial I/M program. There is greater potential for deterring tampering through more routine enforcement of noise standards. A substantial increase in noise level is typically associated with the use of aftermarket exhaust systems, especially when the system change involves removal of the OEM catalyst because catalysts are effective mufflers.

Until data are available demonstrating the actual effectiveness of a particular type of inspection program, we do not believe there is a reasonable basis for assigning a specific emissions benefit to the inclusion of motorcycles in a conventional I/M program.

3.5 Motorcycle Populations and Activity

Population – The population of highway motorcycles in customer service is difficult to accurately estimate and forecast for two reasons. First, registration data collected by individual states often fail to distinguish between highway motorcycles, off-highway motorcycles, and all-terrain vehicles. Second, the annual sales volume of new highway motorcycles is much more variable than annual sales of other highway vehicles because motorcycles are primarily used for recreational purposes and sales are extremely sensitive to the overall level of economic prosperity. During economic recessions, purchases of recreational vehicles decline much more than the purchase of other vehicles.

In model year 1980, the nationwide sales volume of highway motorcycles (including scooters and dual sport models) was 757,000 units. By 1990, the annual sales volume had declined by 70% to 226,000 units.[28] Sales stayed below 300,000 per year until 1998 and then started increasing rapidly, reaching 920,463 for model year 2008.[29] Projections for model year 2009 are that sales may decline by 40–50%.[30] How long this recent decline in sales will continue is impossible to accurately forecast.

In addition to the volatility in total highway motorcycle sales, several trends are apparent. The scooter population has expanded substantially in recent years. Just 10 years ago (in model year 1999), the sales of new scooters was 7,500 units per year, which was less than 2% of total highway motorcycle sales. Sales increased dramatically each year through model year 2008 when they reached 222,155 and accounted for 24% of total highway motorcycle sales. In addition to increasing sales, the annual average travel per scooter has increased by 38% in the last 10 years, to 1,331 miles per year.[31] The expanding use of scooters is correlated with the increased use of highway motorcycles by women. As recently as 1990, only 6% of motorcycle riders were female. In 2008, 12% of all motorcycle riders were female and 27% of scooter riders were female.[31]

Despite the increasing fraction of scooters, the average size of all highway motorcycles is increasing. In 1998, only 27% of highway motorcycles were ≥1100 cc. By 2008, the percentage of motorcycles ≥1100 cc had grown to 38%.[31] Average engine displacement increased from 690 cc to 833 cc during this same period.

In addition to becoming larger, highway motorcycles are lasting longer. The average age of motorcycles in customer service has gone down slightly in recent years, but this is due to the rapid increase in the sale of new motorcycles. When sales and registration data are jointly analyzed, it is apparent that the average life of each new motorcycle is increasing.

To develop the population data required by MOVES, Sierra performed a detailed analysis of the highway motorcycle population and scrappage rates using a combination of registration data and new vehicle sales data provided by MIC. Because the registration data were proprietary and confidential, Sierra agreed not to retain the data at the completion of the analysis.

The registration data were compiled by R.L. Polk for the 2008 calendar year. The data base included the total number of U.S. registrations for 9,156 unique combinations of make, model, and model year. Each entry was categorized as either ―On Highway," ―Off Highway," ―On/Off," ―Scooter," ―Moped," ―ATV," or ―Unknown." ―Segment," ―Body Style," ―Cylinder" count, ―Displacement" (in cubic centimeters), and ―Stroke" (2-stroke or 4-stroke) were also identified.

The level of detail in the registration data should have been sufficient to readily identify the total number of registered vehicles legal for highway use. Unfortunately, spot checking of the data uncovered numerous problems. Motorcycle models that were clearly legal for highway use were sometimes categorized as ―Off Highway." Motorcycles that were clearly illegal for highway use were sometimes categorized as ―On Highway" or ―On/Off." Some models labeled as ATVs were actually motorcycles. Sierra made hundreds of edits to correct errors in the registration data. The primary editing technique involved independently documenting the type of vehicle from the alpha-numeric model name.

Another problem with the Polk database is that only 36 specific manufacturers were identified. Other manufacturers were lumped together under the category ―Other Motorcycle" and no detail was available for models produced by ―Other" manufacturers with the exception of model year. While it might appear that detailed information regarding 36 specific manufacturers would be sufficient to cover over 99% of sales, that is not the case due to the relatively large volumes of scooters produced by a variety of Chinese manufacturers. Our analysis of the Polk data is based on the assumption that all of the models produced by ―Other" manufacturers are Class I scooters.

Table 3-6 summarizes our analysis of the retail sales and registration data after removing non-highway motorcycles from the registration data. All sales data in the table were provided by MIC. The last column of the table shows the ―survival fraction," which is calculated by dividing each model year's population estimate by the original sales for that model year. (The population for 2008 has been set equal to the sales estimate because the registration data for 2008 were incomplete.)

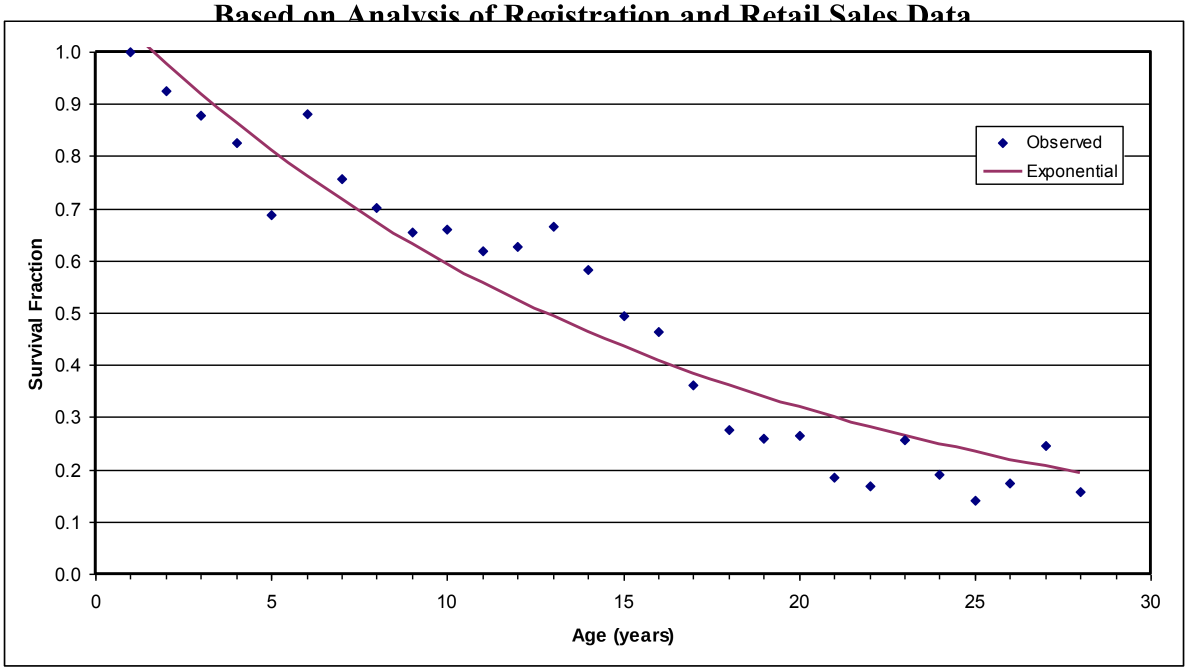
Table 3-6 On-Highway Motorcycle Population and Survival Estimated from Registration and Retail Sales Data					
				Survival Fraction	
Model Year	Age	Population	Original Sales	Raw	Smoothed
2008	1	920,463	920,463	1.00	1.00
2007	2	818,017	885,000	0.92	0.98
2006	3	782,641	892,000	0.88	0.92
2005	4	685,914	831,000	0.83	0.86
2004	5	516,665	750,000	0.69	0.81
2003	6	594,481	675,300	0.88	0.76
2002	7	484,488	640,000	0.76	0.72
2001	8	405,379	577,000	0.70	0.67
2000	9	320,950	490,000	0.66	0.63
1999	10	260,149	394,000	0.66	0.59
1998	11	192,851	311,000	0.62	0.56
1997	12	163,237	260,000	0.63	0.53
1996	13	161,308	242,000	0.67	0.49
1995	14	134,027	230,000	0.58	0.46
1994	15	112,809	228,000	0.49	0.44
1993	16	100,802	217,000	0.46	0.41
1992	17	73,690	203,000	0.36	0.38
1991	18	57,066	206,000	0.28	0.36
1990	19	58,631	226,000	0.26	0.34
1989	20	64,862	245,000	0.26	0.32
1988	21	61,991	335,000	0.19	0.30
1987	22	78,866	465,000	0.17	0.28
1986	23	121,352	470,000	0.26	0.26
1985	24	107,104	565,000	0.19	0.25
1984	25	84,732	605,000	0.14	0.23
1983	26	104,797	605,000	0.17	0.22
1982	27	141,210	575,000	0.25	0.21
1981	28	109,761	695,000	0.16	0.19
Pre-1981	n.a.	516,761	n.a.	n.a.	n.a.
TOTAL		**7,729,882**			

As shown in the next to last column of Table 3-6, the survival fraction does not smoothly and continuously decrease with age. The source of this unexpected result is not clear;

however, it should be noted that highway motorcycles are primarily recreational vehicles and it is common for owners to temporarily let the registration lapse on recreational vehicles after the first several years of use. The last column of the table shows the recommended survival fraction for use in MOVES.

Figure 3-15 shows the curve fit to the age vs. survival fraction data from Table 3-6 that was used to developed the smoothed estimate. The equation represented by the curve is Survival Fraction = $C_0 * e^{-(C1*A)}$, where C_0 is 1.1089 and C_1 is 0.0623. The coefficient of determination (r^2) is 0.92.

Figure 3-15
Motorcycle Survival Fraction vs. Age
Based on Analysis of Registration and Retail Sales Data



Due to the uncertainty associated with the category of vehicles produced by —Other" manufacturers in the Polk data, we are recommending the same survival curve for all classes of highway motorcycles, including scooters. Although the lifetimes indicated by the survival curve may seem excessive, this is due to the fact that many owners retain motorcycles that they are no longer riding.* This is supported by the discussion below regarding mileage accumulation rates as a function of age.

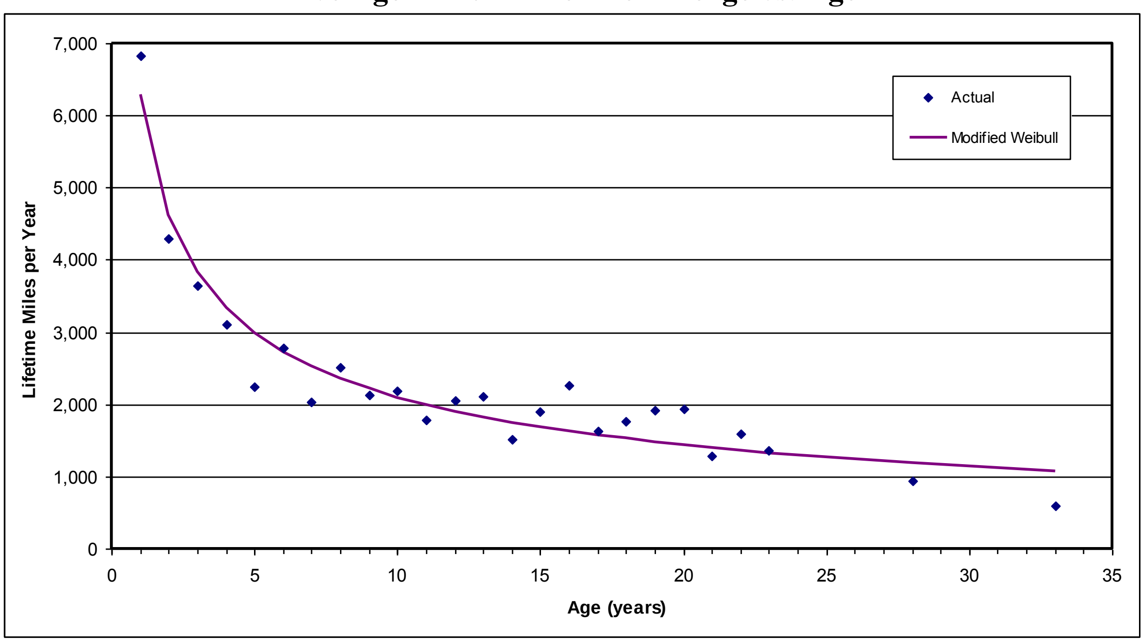
As noted previously, sales of highway motorcycles are down significantly for model year 2009. Our recommendation is that 2009 model sales be set at 50% of 2008 model year sales. For 2010 and 2011, we are recommending that sales be estimated at 67% and 83%

* Motorcycles are more easily stored for extended periods of time than passenger cars or light-duty trucks because of their relatively small size.

of 2008, respectively. For 2012 and later model years, we are recommending that sales be set at 100% of 2008 values.

Activity – Although MIC provided VMT as a function of age from its most recent survey, sample sizes for older vehicles were insufficient. In addition, the questions asked of survey respondents did not address total accumulated mileage. Based on the responses received, a question regarding mileage accumulated during the previous 12 months may have been misinterpreted by some respondents. Occasionally, responses from owners of vehicles more than 10 years old were representative of what would have been anticipated from the vehicle's odometer reading. Because of concerns with the MIC survey data, Sierra used odometer readings listed in advertisements for motorcycles offered for sale at www.cycletrader.com. Advertisements were sorted in order of their publication date for each of 25 different model years ranging from 1975 through 2007. Initial results indicated that the average of the odometer readings tended to stabilize at a sample size of approximately 60. Except for the oldest model years, where insufficient data were available, the most recent 60 ads with odometer values were recorded for each model year. To avoid a manufacturer-specific bias, ads for Harley-Davidson motorcycles were limited to one-third of the records for each model year. A total of approximately 1,500 ads were included in the sample. The results are presented in Figure 3-16.

Figure 3-16
Average Annual Lifetime Mileage vs. Age



A modified Weibull curve fit to the data produces a coefficient of determination (r^2) value of 0.92. The equation is of the following form:

$$\text{Miles/Year} = C_0 * C_1\text{^}(-((A/C_2)\text{^}C_3))$$

where: A = age
$C_0 = 872{,}845$
$C_1 = 202.79$
$C_2 = 2.3397$
$C_3 = 0.0874$

The modified Weibull curve-fitted average annual lifetime mileages were then translated into cumulative odometer levels with age by simply multiplying the age by the curve-fitted average miles per year. These curve-fit based cumulative odometer levels were then converted to annual mileage accumulation rates as a function of age by simply differentiating cumulative mileages at successive ages. The *MARCalcs* sheet in the ***MC_Activity_All.xls*** file on the accompanying delivery CD contains these translations.

While the modified Weibull curve fits the data well up to about 25 years of vehicle age, the available data indicate that the average annual lifetime mileage for older vehicles drops below the curve. Our review of the available advertisements for motorcycles more than 25 years of age indicates that most of them are collector's items that are infrequently, if ever, ridden.

In addition, we observed that the actual and Weibull curve-fitted VMT at Age 1 (model year 2008) was significantly higher than EPA assumed for Age 1 vehicles in MOBILE6 based on an earlier MIC survey. Actual annual VMT at Age 1 estimated from CycleTrader was over 6,800 miles, compared to Age 1 mileage from MOBILE6 of 4,786. We believe this higher recent Age 1 mileage, though real, is likely a short-term phenomenon that occurred in response to the run-up in retail gasoline prices during much of 2008, with the effect that motorcycles were driven more in households where drivers could choose between a motorcycle and a less fuel-efficient light-duty vehicle.

We therefore are recommending the annual VMT distribution shown in Table 3-7, which is based on a ―piecewise" fit using the modified Weibull curve through Age 23, and a power curve-based fit beyond Age 23 that matches the available data for the pre-1985 model year vehicles. To deal with the short-term effect of higher motorcycle VMT accumulation in 2008 likely resulting from high gasoline prices, we determined Age 1 mileage as the average of that predicted by the Weibull fit at Age 1 (6,296) and the MOBILE6 Age 1 mileage (4,786), or 5,541.

In conjunction with the scrappage curve described above, the VMT data in Table 3-7 produce a lifetime average total mileage accumulation value of 35,378 miles. For the first 13 years (at which point approximately half of the vehicles have been retired from

Table 3-7 Motorcycle Annual VMT vs. Age (years)			
Age	Annual VMT	Age	Annual VMT
1	5,541	26	485
2	2,958	27	452
3	2,237	28	418
4	1,852	29	392
5	1,604	30	366
6	1,426	31	339
7	1,292	32	313
8	1,185	33	287
9	1,097	34	260
10	1,024	35	234
11	962	36	208
12	909	37	182
13	862	38	155
14	820	39	129
15	783	40	103
16	750	41	76
17	720	42	50
18	692	43	24
19	667	44	0
20	644	45	0
21	623	46	0
22	603	47	0
23	585	48	0
24	551	49	0
25	518	50	0

service), the annual average VMT is approximately 1,700 miles. (The annual average VMT drops as age increases and some of the vehicles are periodically out of service.)

As would be expected, the available data indicate that the mileage accumulation rate for scooters and Class I motorcycles is about one-third of the average for the entire highway motorcycle fleet. The most recent MIC owner survey indicates an average of 3,195 miles per year for all motorcycles vs. 1,331 miles/year for scooters and 941 miles/year for all motorcycles and scooters under 125 cc displacement. (It should be noted that the annual average VMT from the MIC survey does not include motorcycles “not in running condition” at the time of the survey. The lower annual average VMT from our analysis is due in part to the fact that it accounts for vehicles being periodically not in running condition and accumulating 0 miles per year.) Since, as described previously, we are not differentiating between the emission levels of Class I, II, and III motorcycles, there is no need to incorporate class-specific VMT within MOVES.

Non-Uniformity of Activity – Most highway vehicles exhibit a relatively uniform pattern of activity and are used on almost a daily basis. In contrast, motorcycles are primarily recreational vehicles and are not practical for use in freezing temperatures. Data available from the MIC owner surveys and other sources indicate both seasonal and daily variations in use that are significant.

Table 3-8 presents data from the most recent MIC owners survey for the distribution of motorcycle use by season. Not surprisingly, owners in the Midwest region of the country report that only 1% of their annual operation of highway motorcycles occurs in the winter. This is not an unexpected result of the cold and snowy conditions associated with Midwestern winters. Perhaps more surprising is that owners in every region of the country use their motorcycles less in the winter. This is in part due to the fact that wind chill makes the use of motorcycles below 50°F uncomfortable without the use of electrically heated liners or heavily insulated riding suits.[*] Significant highway motorcycle activity occurs only when temperatures are above 50°F. The daily average VMT in the summer is approximately twice what would be expected from the annual average VMT. In the Spring and Summer months, daily average VMT is approximately the annual average divided by 365.

Table 3-8
Portion of Annual Operation by Season

Season	East	Midwest	South	West	U.S.
Spring	25%	22%	27%	26%	25%
Summer	53%	58%	41%	44%	48%
Fall	19%	19%	22%	22%	21%
Winter	3%	1%	10%	8%	6%

Available data make it clear that highway motorcycle operation is more frequent on weekends than on weekdays. According to a study by the U.S. Department of Transportation,[32] ―[t]here were 1.5 times as many two-vehicle motorcycle crashes involving passenger vehicles in 2005 during weekends than during weekdays." Assuming accidents are proportional to VMT, 60% of MC activity is on the two weekend days. Since weekend days are only 28.6% of all days, this indicates that VMT on the average weekend day is over twice as high as on the average week day.

[*] Electrically heated riding gear is available to extend the range of comfortable riding temperature to approximately freezing; however, very few motorcyclists own heated gear and many motorcycles lack the electrical system capacity necessary to operate such gear.

Data from the most recent MIC owner survey are consistent with the DOT accident data, indicating 56% weekend use.

The disproportionate use of motorcycles on weekends is consistent with owner responses to questions in the MIC owner survey regarding the “type of riding” done. “Casual Pleasure Riding” was reported to be the primary type of riding in all regions of the country.

Driving Patterns – In the absence of motorcycle-specific data, it is not unreasonable to assume that highway motorcycle driving patterns in customer service are similar to those for light-duty vehicles. Although motorcycles typically have higher performance than passenger cars and light trucks, previous surveys conducted by Sierra demonstrate that high-performance passenger cars have a similar driving pattern to other vehicles because they are constrained by traffic. Although lane sharing/splitting is allowed in California, motorcycles are similarly constrained by the flow of traffic in most areas.

Unlike the wealth of data that exists for light-duty vehicles, Sierra was not able to obtain detailed, second-by-second data for highway motorcycle operation in customer service. Efforts to obtain the data used to develop the World Motorcycle Test Cycle (WMTC) were unsuccessful. A representative of Harley-Davidson, the company that originally collected the U.S. data, reported that the data are no longer available at Harley.

Discussions with representatives of Harley-Davidson led us to the conclusion that the database from which the WMTC was developed was not demonstrated to be truly representative of highway motorcycle operation in the U.S. The selection of the road routes was somewhat arbitrary and only professional riders were used. It is not clear how these riders’ patterns of operation compare to other riders.

Notwithstanding the concerns about the data used to develop the WMTC, Figures 3-17 and 3-18 compare the Speed-Acceleration Frequency Distributions (SAFDs) and relevant driving statistics for the WMTC to Sierra’s best estimate of passenger car operation in customer service based on chase-car data collected in California subsequent to the elimination of the national 55 mph speed limit.

In Figure 3-17, the joint frequency distributions of vehicle speed (horizontal axis) and acceleration (vertical axis) for the WMTC are in the SAFD table for the WMTC. Below the SAFD table, a series of key statistics for the WMTC are shown, including MOVES VSP bin distributions.

Figure 3-18 presents similar distributions and key driving statistics for a driving cycle referred to as the “CalWtd” cycle. It was developed from light-duty vehicle driving data collected in California under a series of chase car-based driving studies[33,34] conducted in 2000 that were jointly sponsored by the California Department of Transportation (Caltrans) and the California Air Resources Board (CARB) encompassing four study areas:

Figure 3-17
World Motorcycle Test Driving Cycle SAFD (%)

World Motorcycle Test Driving Cycle SAFD (%)

ACCEL BIN (mph/s)	SPEED BIN (mph) 0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	TOTALS
-20																						
-19																						
-18																						
-17																						
-16																						
-15																						
-14																						
-13																						
-12																						
-11																						
-10																						
-9																						
-8																						
-7																						
-6																						
-5																						
-4		0.056	0.333	0.278	0.333	0.222	0.222	0.056														**1.500**
-3		0.444	0.389	0.333	0.222	0.222	0.389	0.444	0.222	0.278	0.056	0.056										**3.056**
-2		0.722	0.333	0.444	0.667	0.556	0.333	0.778	0.444	0.444	0.389	0.278	0.222	0.222	0.333	0.167						**6.333**
-1		0.778	0.167	1.222	1.556	0.889	0.778	1.444	1.000	0.556	0.667	0.222	0.278	0.333	0.389	0.556						**10.833**
0	8.889	0.056	0.556	3.667	4.500	2.278	3.000	3.833	2.500	2.944	3.222	2.444	2.556	0.667	7.278	6.778	0.667					**55.833**
1	0.444	0.500	0.611	1.500	1.222	1.056	0.833	2.167	1.556	1.056	1.000	0.722	0.556	0.722	0.444	0.278						**14.667**
2	0.111	0.333	0.333	0.333	0.444	0.500	0.889	0.500	0.278	0.222	0.278	0.111										**4.333**
3		0.611	0.167	0.278	0.333	0.444	0.056		0.056													**1.944**
4		0.167	0.056		0.222	0.056		0.056														**0.556**
5		0.222	0.167	0.222			0.056															**0.667**
6			0.111	0.056	0.056	0.056																**0.278**
7																						
8																						
9																						
10																						
11																						
12																						
13																						
14																						
15																						
16																						
17																						
18																						
19																						
20																						
Totals	**9.444**	**3.889**	**3.222**	**8.333**	**9.556**	**6.278**	**6.556**	**9.278**	**6.056**	**5.500**	**5.611**	**3.833**	**3.611**	**1.944**	**8.444**	**7.778**	**0.667**					**100.000**

Summary Statistics

Avg Speed (mph)	35.93	Time at Idle (%)	9.444	Avg Specific PKE (hp-sec/lb)	4.68
Min Speed (mph)	0.00	Time at Cruise (%)	68.444	Avg Total Specific Power (hp/lb)	0.0467
Max Speed (mph)	77.90	Time in Accel (%)	9.667	Avg Non-Zero Specific Power (hp/lb)	0.0977
Avg Non-Idle Speed (mph)	39.68	Time in Decel (%)	12.444	Max Specific Power (hp/lb)	0.6480
Avg Cruise Speed (mph)	41.95	Avg Trip Length (miles)	17.967	Spec Pwr Freq (%): 0 hp/lb	52.22
Avg Acceleration (mph/sec)	0.86	Avg Trip Time (min)	30.000	Spec Pwr Freq (%): >0-0.1 hp/lb	31.44
Max Acceleration (mph/sec)	6.03	# Stops per Mile	0.612	Spec Pwr Freq (%): >0.1-0.2 hp/lb	8.72
Avg Deceleration (mph/sec)	-1.10	# of 1-Sec Observations	1,800	Spec Pwr Freq (%): >0.2-0.3 hp/lb	5.28
Max Deceleration (mph/sec)	-4.47	# of Trips	1	Spec Pwr Freq (%): >0.3 hp/lb	2.33

EPA VSP (Vehicle Specific Power) Statistics

EPA Avg Veh Spec Pwr, VSP (kW/tonne)	4633.103
Bin 0 % (braking)	6122.715
Bin 1 % (idle)	8657.902

Bin 11 % (0-25 mph, <0 kw/tonne)	5883.523
Bin 12 % (0-25 mph, 0-3 kw/tonne)	8562.099
Bin 13 % (0-25 mph, 3-6 kw/tonne)	3778.853
Bin 14 % (0-25 mph, 6-9 kw/tonne)	861.000
Bin 15 % (0-25 mph, 9-12 kw/tonne)	861.000
Bin 16 % (0-25 mph, >=12 kw/tonne)	956.657

Bin 21 % (25-50 mph, <0 kw/tonne)	5166.000
Bin 22 % (25-50 mph, 0-3 kw/tonne)	3970.147
Bin 23 % (25-50 mph, 3-6 kw/tonne)	5835.704
Bin 24 % (25-50 mph, 6-9 kw/tonne)	3204.803
Bin 25 % (25-50 mph, 9-12 kw/tonne)	3396.136
----------------------------------	0.000
Bin 27 % (25-50 mph, 12-18 kw/tonne)	3300.482
Bin 28 % (25-50 mph, 18-24 kw/tonne)	861.000
Bin 29 % (25-50 mph, 24-30 kw/tonne)	191.335
Bin 30 % (25-50 mph, >=30 kw/tonne)	143.500

Bin 33 % (>50 mph, <6 kw/tonne)	3109.148
Bin 35 % (>50 mph, 6-12 kw/tonne)	4687.619
----------------------------------	0.000
Bin 37 % (>50 mph, 12-18 kw/tonne)	8131.599
Bin 38 % (>50 mph, 18-24 kw/tonne)	7079.294
Bin 39 % (>50 mph, 24-30 kw/tonne)	1195.846
Bin 40 % (>50 mph, >=30 kw/tonne)	143.500

Figure 3-18
California Urban & Rural Weighted (CalWtd) Driving Cycle SAFD (%)

California Urban & Rural Weighted (CalWtd) Driving Cycle SAFD (%)

ACCEL BIN (mph/s)	SPEED BIN (mph) 0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	TOTALS
-20																						
-19																						
-18																						
-17																						
-16																						
-15																						
-14																						
-13																						
-12																						
-11																						
-10																						
-9																0.100						**0.100**
-8																						
-7			0.100		0.100			0.015														**0.214**
-6			0.100	0.214	0.115	0.015	0.031	0.115	0.031													**0.621**
-5		0.015	0.214	0.146	0.146	0.146	0.031	0.031	0.100	0.031	0.015											**0.874**
-4		0.100	0.329	0.513	0.429	0.329	0.345	0.115	0.115	0.314	0.015											**2.604**
-3		0.398	0.429	0.314	0.597	0.314	0.214	0.245	0.046	0.130	0.115	0.015										**2.819**
-2		0.873	0.444	0.429	0.597	0.498	0.513	0.498	0.827	0.161	0.261	0.130	0.130	0.100	0.015	0.100						**5.575**
-1		1.324	0.115	0.398	0.398	0.697	0.796	1.141	0.842	0.698	0.790	0.622	0.936	0.331	0.744	0.254	0.108	0.015				**10.210**
0	9.180	1.616	0.329	0.612	1.455	2.167	2.711	2.971	2.995	2.636	2.731	3.187	4.169	4.633	4.381	2.288	0.493	0.154				**48.709**
1	0.245	1.172	0.299	0.697	1.011	1.324	1.470	1.731	1.379	1.005	0.814	0.837	0.936	0.598	0.897	0.223	0.062					**14.699**
2	0.100	0.758	0.758	0.812	0.842	1.103	0.804	0.720	0.422	0.276	0.376	0.146	0.130	0.130		0.015						**7.393**
3		0.559	0.758	0.751	0.590	0.376	0.230	0.261	0.214	0.115												**3.854**
4		0.413	0.314	0.214	0.230	0.115	0.214															**1.501**
5	0.100	0.299	0.214	0.115																		**0.727**
6		0.100																				**0.100**
7																						
8																						
9																						
10																						
11																						
12																						
13																						
14																						
15																						
16																						
17																						
18																						
19																						
20																						
Totals	**9.625**	**7.627**	**4.404**	**5.215**	**6.509**	**7.083**	**7.360**	**7.843**	**6.971**	**5.366**	**5.118**	**4.937**	**6.302**	**5.792**	**6.037**	**2.979**	**0.663**	**0.170**				**100.000**

Summary Statistics

Avg Speed (mph)	34.73	Time at Idle (%)	9.625	Avg Specific PKE (hp-sec/lb)	6.29
Min Speed (mph)	0.00	Time at Cruise (%)	59.088	Avg Total Specific Power (hp/lb)	0.0586
Max Speed (mph)	83.20	Time in Accel (%)	16.092	Avg Non-Zero Specific Power (hp/lb)	0.1319
Avg Non-Idle Speed (mph)	38.14	Time in Decel (%)	15.195	Max Specific Power (hp/lb)	0.6104
Avg Cruise Speed (mph)	42.06	Avg Trip Length (miles)	8.888	Spec Pwr Freq (%): 0 hp/lb	55.54
Avg Acceleration (mph/sec)	1.22	Avg Trip Time (min)	14.789	Spec Pwr Freq (%): >0-0.1 hp/lb	20.44
Max Acceleration (mph/sec)	5.81	# Stops per Mile	0.721	Spec Pwr Freq (%): >0.1-0.2 hp/lb	15.02
Avg Deceleration (mph/sec)	-1.50	# of 1-Sec Observations	2,003	Spec Pwr Freq (%): >0.2-0.3 hp/lb	5.87
Max Deceleration (mph/sec)	-9.05	# of Trips	2	Spec Pwr Freq (%): >0.3 hp/lb	3.14

EPA VSP (Vehicle Specific Power) Statistics

EPA Avg Veh Spec Pwr, VSP (kW/tonne) 4209.310

Bin 0 % (braking) 8072.835
Bin 1 % (idle) 8762.598

Bin 11 % (0-25 mph, <0 kw/tonne)	4475.686	Bin 21 % (25-50 mph, <0 kw/tonne)	5249.241		
Bin 12 % (0-25 mph, 0-3 kw/tonne)	4279.244	Bin 22 % (25-50 mph, 0-3 kw/tonne)	4570.025	Bin 33 % (>50 mph, <6 kw/tonne)	5471.770
Bin 13 % (0-25 mph, 3-6 kw/tonne)	3969.049	Bin 23 % (25-50 mph, 3-6 kw/tonne)	3521.147		
Bin 14 % (0-25 mph, 6-9 kw/tonne)	2406.305	Bin 24 % (25-50 mph, 6-9 kw/tonne)	4886.247	Bin 35 % (>50 mph, 6-12 kw/tonne)	5388.292
Bin 15 % (0-25 mph, 9-12 kw/tonne)	1556.606	Bin 25 % (25-50 mph, 9-12 kw/tonne)	3852.850		
Bin 16 % (0-25 mph, >=12 kw/tonne)	1273.095	----------------------------------	0.000	----------------------------------	0.000
		Bin 27 % (25-50 mph, 12-18 kw/tonne)	3115.659	Bin 37 % (>50 mph, 12-18 kw/tonne)	6726.784
		Bin 28 % (25-50 mph, 18-24 kw/tonne)	964.072	Bin 38 % (>50 mph, 18-24 kw/tonne)	4665.725
		Bin 29 % (25-50 mph, 24-30 kw/tonne)	494.750	Bin 39 % (>50 mph, 24-30 kw/tonne)	1704.819
		Bin 30 % (25-50 mph, >=30 kw/tonne)	112.219	Bin 40 % (>50 mph, >=30 kw/tonne)	581.568

1. Sacramento metropolitan area;
2. San Francisco Bay Area;
3. Stanislaus County (including the Modesto metropolitan area); and
4. South Coast (i.e., Los Angeles) combined metropolitan area.

These datasets contained driving in both urban and rural areas. In the post-processing that was performed under each of these studies, the type of roadway the vehicle was traveling on during each second was also recorded in the output dataset and categorized using the HPMS (Highway Performance Monitoring System) Functional Class scheme. These driving data were binned into urban and rural Functional Class groups and re-weighted using California VMT weightings by functional class obtained from HPMS.[*]

Driving cycles for urban and rural light-duty operation in California were then developed from the data in these re-weighted groups. The second-by-second speed traces for these individual urban and rural cycles, called Cal-Urban and Cal-Rural, were then weighted together using a VMT-based split of 81.8% urban vs. 18.8% rural operation for California from HPMS. Figure 3-18 presents the SAFD and key statistics for this combined urban/rural driving cycle called “CalWtd.”

The tabulations for WMTC and CalWtd cycles contained in Figures 3-17 and 3-18 show that they are fairly similar. Average speeds are 35.9 mph and 34.7 mph, respectively. Top speeds are 77.9 mph for the WMTC and 83.2 for the CalWtd. Acceleration and specific power statistics are also generally comparable between the two cycles. Average VSP (based on EPA’s VSP definition) is 5.38 kW/tonne for the WMTC and 4.89 kW/tonne for the CalWtd cycle. And the VSP distributions for both cycles are in relatively close agreement.

Despite the aforementioned concerns regarding the origins and methods used to develop the WMTC, the statistical comparisons reflected in Figures 3-17 and 3-18 indicate that the WMTC appears to closely resemble overall driving patterns of light-duty vehicles. Thus, until additional motorcycle-specific driving data are collected, we believe motorcycle driving patterns can be reasonably represented with those of light-duty vehicles.

3.6 Incorporation into MOVES Tables

The final element in the development of motorcycle emission and activity rates for MOVES consisted of translating the FTP-based exhaust and evaporative emission rates and activity data presented in the preceding sub-sections into the specific data tables used within the MySQL database underlying the MOVES model. These steps are described below, first for the emission rates, then the activity data.

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[*] *http://www.fhwa.dot.gov/policy/ohim/hs02/vm2.htm*

Motorcycle Emission Rate Tables – For the emission rate table, two key elements were performed to incorporate the basic exhaust and evaporative emission rates presented earlier in Table 3-5 into the specific tables and their data structures required by MOVES:

1. Translation of FTP-based exhaust rates into emission rates by operating mode bin; and

2. Conversion of –mode"-based evaporative emission rates into new process-based evaporative emission categories.

Translation of Running Exhaust Rates to Operating Mode Bins – A spreadsheet called ***MOVES_MC_EmissionRates_FT01.xls*** was developed to perform these detailed translations. (This spreadsheet was also provided to EPA as a deliverable on CD.)

First, FTP-based running exhaust emission rates by model year range for HC, CO and NOx were translated into emission rates by individual VSP/speed bin based on an analysis of modal, second-by-second emission tests collected under an in-use motorcycle emissions surveillance study[35] sponsored by CARB. Under that study, over 100 motorcycles were randomly procured and FTP and Unified Cycle (UC) bag and composite emissions were measured. Second-by-second FTP and UC cycle emission measurements were collected for a 15 vehicle subset, although modal data for one UC test were missing.

This modal emissions sample of 15 motorcycles ranged from model years 1966 through 1996. Only one of these motorcycles was catalyst-equipped. Thus, given the size of the sample and available resources, no effort was made to divide the test data by age or model year range to reflect their effects on emission distributions by VSP bin. In the supporting analysis spreadsheets, separate relationships for non-catalyst vs. catalyst groups were developed and examined, but the resulting catalyst group bin allocations contained anomalies caused by the fact that the data were based on a single motorcycle (run over both FTP and UC cycles). Thus, given the sample of available modal data for motorcycles, a single set of emission rates by operating mode bin was developed simply from averaging of the entire 15-vehicle sample.

Sierra performed fairly extensive data validation and cleaning on these modal emission test results prior to their use under this analysis. Second-by-second dilute concentration measurements were converted to a mass basis and properly time-aligned with the measured driving traces. This time alignment was carefully performed and applied on a test-by-test basis using comparisons of the second-by-second speed traces and dilute measurements.

The time-aligned second-by-second mass exhaust emissions were then binned into MOVES-based operating mode/VSP bins by calculating second-by-second VSP using the speed traces, dynamometer coast-down data and vehicle weights recorded for each test from the following equation:

$$VSP_t = \frac{Av_t + Bv_t^2 + Cv_t^3 + mv_t a_t}{m}$$

where

VSP_t is vehicle specific power (kW/tonne) at time t;
v_t is vehicle speed (m/sec) at time t;
a_t is vehicle acceleration (m/sec^2) at time t;
m is vehicle mass (tonne); and
A, B and C are track road load coefficients, representing rolling resistance, rotational resistance and aerodynamic drag, in units of kW-sec/m, kW-sec^2/m^2 and kW-sec^3/m^3, respectively.

(In the original modal motorcycle emissions testing study, track road load horsepower at 50 mph and mass was measured and recorded for each vehicle . The *A*, *B*, and *C* values were then calculated from these measurements using 0.35, 0.10 and 0.55 weightings, respectively.)

Note that the second-by-second VSP and mass emissions were binned only for the warmed-up portions (Bags 2 and 3) of the FTP and UC cycles. Modal measurements during Bag 1 were not used for this element of the analysis, which focused on development of stabilized/running exhaust emission allocations by VSP bin.

Binned VSP and exhaust emission measurements over the stabilized portions of the FTP and UC tests were assembled in a separate spreadsheet called ***MC_OpModeBinned.xls***. In the *OpBinEmis* sheet within this spreadsheet, a series of curve fits of HC, CO and NOx emissions vs. VSP were developed to address ―hole-filling" issues in bins where there were little or no data. From this 15-vehicle sample of modal FTP and UC cycle measurements, most of the operating mode bins contained at least 50 single-second observations. However, Bins 30, 39, and 40—which reflect high VSP ranges at the edge of, or beyond that, in the FTP or UC cycles—contained fewer observations. Upon examination, the 23 and 11 data points in Bins 30 and 39, respectively, were not found to substantially affect the resulting curve fits, so data in these bins were used. However, the few data points in Bin 40 were not included in the curve fitting process.

These curve fits were developed using the following exponential equation:

$$E_{i,j} = EXP[C_0 + C_1(VSP_j)]$$

where

E_i represents predicted emissions (g/hr) of pollutant *i* (either HC, CO or NOx) for operating mode bin *j*;
VSP_j is the measured mean VSP (kW/tonne) within each bin *j*; and
C_0 and C_1 are least-squares derived coefficients determined separate for each pollutant and operating mode bin range (i.e., Bins 11-16, 21-30 and 31-40 using EPA's numbering scheme as applied in MOVES).

Within the ***MC_OpModeBinned.xls*** analysis spreadsheet, the C_0 and C_1 coefficients were determined using Excel's built-in ―Solver" utility. As noted above, separate curve fits were generated for each pollutant and set of operating mode bins within a speed range. Emissions for Bins 0 (deceleration/braking) and 1 (idle) were not based on curve fits but simple means of measured values within each of those bins. As shown in detail in highlighted cells inRows 91-207 and Columns N, U, and AC of the *OpBinEmis* sheet in ***MC_OpModeBinned.xls***, these exponential curve fits generally produced correlations (expressed as R^2) to the actual binned measurements in excess of 0.9 for each of the bin groups and pollutants. However, correlations for the high speed (> 50 mph) group covering Bins 31-40 were generally lower than those for the other speed groups—for this speed range, the correlation for NOx was only R^2=0.30.

The resulting curve-fitted emission rates by operating mode bin (in grams/hr) reflect the emission levels of the 15-vehicle test sample upon which they were based, not the broader fleet of all on-highway motorcycles. Adjustments were made to translate the emission rates by bin from the test sample to hot-FTP ―allocation factors" that could be applied to the FTP-based fleet exhaust emission factors presented earlier in Table 3-5.

The first step involved calculating composite emissions (in grams) from hot FTP weighting of the curve-fitted emission rates (in g/hr) each bin. In the *OpBinEmis* sheet, these composite emission calculations are performed in Column AD and Rows 218-236 where the bin weightings are simply the number of seconds of observation in each bin over an FTP test.

The second and final step consisted of normalizing the curve-fitted bin emission rates from the measured study sample by their composite hot FTP emissions calculated above to yield operating mode bin emission rates in g/hr per gram of hot FTP emissions. This step is reflected in the table within the *OpBinEmis* sheet in Rows 259-271 and Columns E through AC.

These normalized bin rates could then be applied directly to the FTP-based fleet emission factors to generate running (hot) exhaust emission rates by operating mode bin for incorporation into MOVES.

The modal motorcycle emission measurement study only measured HC, CO, NOx and CO_2 exhaust emissions. PM exhaust measurements were not collected. Thus, the distribution of PM running exhaust by operating mode bin for motorcycles was assumed to be identical to that of gasoline-fueled passenger cars. Passenger car PM running exhaust emission rates were ―harvested" from the *EmissionRatebyAge* table in the Draft MOVES2009 database and loaded into the *PMRatesOC* and *PMRatesEC* sheets in the ***MC_OpModeBinned.xls*** file, for the organic carbon (OC) and elemental carbon (EC) components of exhaust PM, respectively. (Rates for both the OC and EC components were loaded from MOVES to confirm that the emission distributions by bin were the same for each, and they were.) A series of Excel pivot tables were generated in the *PMPvts* sheet to tabulate and aggregate these MOVES-based PM OC and EC rates across age and model year. These rates were then loaded into the *OpBinEmis* sheet and normalized to a gram/hour per gram of hot-FTP basis across the operating mode bins as was done for the HC, CO, and NOx data from the modal study.

The complete set of normalized running exhaust rates by operating mode bin for HC, CO, NOx, and PM (the latter separately as PM-OC and PM-EC) are presented below in Table 3-9.

Table 3-9
Normalized Motorcycle Running Exhaust Emission Rates (g/hr per gram Hot FTP) by Operating Mode Bin

	Poll	Running Exhaust Operating Mode Bin																						
Poll	ID	0	1	11	12	13	14	15	16	21	22	23	34	25	27	28	29	30	33	35	37	38	39	40
HC	1	1.7	1.5	2.4	2.8	3.1	3.4	3.8	4.5	2.7	3.1	3.4	3.7	4.1	4.6	5.5	6.6	7.9	3.8	4.3	4.7	5.1	5.6	6.5
CO	2	1.7	1.2	1.9	2.2	2.4	2.6	2.9	3.3	2.9	3.4	3.7	4.0	4.4	5.0	6.0	7.1	8.7	7.6	8.5	9.1	9.8	10.6	12.0
NOx	3	1.3	0.6	0.8	1.1	1.5	1.9	2.5	4.0	3.3	3.8	4.2	4.6	5.0	5.7	6.9	8.3	10.1	13.7	14.4	14.8	15.3	15.8	16.7
PM-OC	111	1.5	1.8	2.0	2.4	2.5	3.6	5.4	17.7	2.2	1.8	2.1	2.9	5.8	8.5	44.4	128	365	4.6	4.1	5.7	9.7	24.7	27.1
PM-EC	112	1.5	1.8	2.0	2.4	2.5	3.6	5.4	17.7	2.2	1.8	2.1	2.9	5.8	8.5	44.4	128	365	4.6	4.1	5.7	9.7	24.7	27.1

The normalized rates were then loaded from the ***MC_OpModeBinned.xls*** file into the ―main" spreadsheet used for translation to specific MOVES data tables and record structures, ***MOVES_MC_EmissionRates_FT01.xls***, into a sheet called *BinEmis*.

Within the main ***MOVES_MC_EmissionRates_FT01.xls*** spreadsheet, motorcycle running exhaust emission rates by pollutant, model year, age, and operating mode were then calculated and stored within the *MOVES_MC_EmissionRateByAge* sheet, which is similar in field structure to the *EmissionRateByAge* data table in the MOVES database. (This sheet also housed the calculations of motorcycle emission rates for the other evaporative and crankcase emission processes required by MOVES explained later in this section.) The FTP-based fleet emission rates by model year range presented earlier in Table 3-5 were loaded into a sheet called *FTPExh*. Within this sheet, FTP emission factors were translated into ―Hot FTP/LA4" and Cold Start Increment" components using FTP bag measurements from the 15-vehicle modal motorcycle study sample discussed above and contained in the neighboring *ColdHotFactors* sheet in the ***MOVES_MC_EmissionRates_FT01.xls*** workbook.

Beginning in Row 22 of the *FtpExh* sheet, the FTP-based emission factors, now separated into Running Exhaust and start Increment component, were asssigned to the specific set of model years or model year ranges mandated by EPA in MOVES for light-duty vehicles (and motorcycles). For the MOVES ModelYearIDGroup=19601980 (1980 and older models), this involved the development of separate allocation factors for the pre-1978 and 1978-1985 model year groups for which motorcycle FTP rates were developed and shown earlier in Table 3-5. These allocation factors are contained in a sheet called *MYGAlloc* within the workbook. The splits for the 1980 and older range were based on default motorcycle data in MOBILE6.

In Column V (labeled RevRun) of the *MOVES_MC_EmissionRateByAge* sheet, the FTP-based running exhaust emission factors by pollutant and MOVES model year group (in g/mi) from the FTPExh sheet were then combined with the normalized running exhaust operating mode emission rates discussed earlier using a series of table lookups. The calculation was performed as follows:

$$RunExh_{m,p,y}\ (g/hr) \ = \ HotFTP_{p,y}\ (g/mi) \times 7.5\ mi \times OpModeER_{m,p}\ (g/hr\ per\ g\ FTP)$$

where *HotFTP* is the Hot FTP (Bag 3 + Bag 2) emission rate; *OPModeER* is the normalized distribution of FTP-based running exhaust emissions by operating mode; and indices m = operating mode, p = pollutant, and y = model year group.

As explained earlier in Section 3.3, highway motorcycle in-use emissions deterioration is believed to largely result from tampering that occurs in the first few years of ownership. All of the assumed deterioration was modeled to occur in the first MOVES Age Group (0-3 years). Thus, Age Group was not incorporated in the above equation since motorcycle emissions were not assumed to vary by age after accounting for deterioration within this first 0-3 year old Age Group.

Translation of Starting Exhaust Rates to Operating Mode Bins – Translation of FTP-based starting exhaust rates into the MOVES-required structures was much simpler than running exhaust. MOVES uses eight discrete operating mode bins to represent the starting emissions reflecting different soak time intervals ranging from <6 minutes (OpModeID=101) to ≥ 12 hours (OpModeID=108). Unlike with running exhaust, there were no motorcycle-specific emission test data available from which to develop start increment vs. soak time relationships by MOVES operating mode bin.

In the absence of data, the distribution of starting exhaust emissions by MOVES operating mode bin for motorcycles was developed using starting exhaust rates extracted from MOVES for gasoline-fueled passenger cars. These extracted MOVES starting exhaust rates are contained in the *PCStartRates* sheet. A series of Excel Pivot tables were constructed from these passenger car starting exhaust rates in the *StartPvts* sheet, tabulating by model year group and operating mode bin for each pollutant. Separate tabulations were performed for two age groups (0-3 years) and (20+ years) at each end of the Age Group categories employed within MOVES to determine whether EPA has modeled age dependence into the distributions of starting exhaust rates, not their absolute levels, which are age dependent. It was confirmed that the normalized distributions (normalized to the >12 hour soak bin) are neither age nor model year dependent.

These normalized starting exhaust emission distributions for each pollutant were then loaded into Rows 38-42 of the *ColdHotFactors* sheet.

MOVES starting exhaust emission rates (in g/start) were then calculated in Column W (labeled RevStart) of the *MOVES_MC_EmissionRateByAge* sheet using lookup formulas for these normalized distributions and the FTP Cold Start Increment rates by model year group (reflecting a >12 hour soak) contained in the *FTPExh* sheet as follows:

$$StartExh_{m,p,y}\ (g/start) \ = \ ColdFTPIncr_{p,y}\ (g/start) \times OpModeES_{m,p}$$

Where *ColdFTPIncr* is the FTP cold start increment (Bag 1 – Bag 3); *OPModeES* is the normalized starting emission rate for a specific soak bin; and indices m = starting operating mode bin (soak bin), p = pollutant, and y = model year group.

<u>*Translation of Crankcase Rates*</u> – In the MOVES database, crankcase emissions are represented in a separate data table called *CrankcaseEmissionRatio*. Motorcycle crankcase emissions were thus entered into a separate sheet in the main workbook called *MOVES_MC_Crankcase* that resembled the field structure of the corresponding MOVES table. MOVES requires that the emission rates in this table be stored as ratios of crankcase-to-running exhaust emissions.

As discussed earlier in Sections 3.2 and 3.3, crankcase emissions on highway motorcycles were controlled starting in model year 1978 and no data were available to support an assumption of non-zero crankcase emissions from in-use deterioration for 1978 and later motorcycles. Thus, crankcase ratios for all 1978 and later models were set to zero in the *MOVES_MC_Crankcase* sheet.

As shown earlier in Table 3-5, crankcase emission rates for pre-1978 motorcycles were estimated to be 0.4 g/mi, reflecting an assumed 45%/55% split between two- and four-stroke engines for those models. (Two-stroke engines use a pressurized crankcase and do not have a crankcase vent; thus they have no crankcase emissions.) For pre-1978 models, the crankcase ratio for motorcycles was then simply calculated as:

$$\text{CC Ratio} \ = \ 0.4 \text{ g/mi} \div 10.6 \text{ g/mi (running exhaust FTP)} \ = 0.0363$$

and stored in the *MOVES_MC_Crankcase* sheet for HC and for these model years.

<u>*Evaporative Emission Rate Conversions*</u> – As described earlier, the evaporative emission data compiled under this study consisted of one-hour SHED (hot soak and diurnal) measurements from roughly 20 highway motorcycles, plus ―resting loss” (i.e., non-heat build portion) and running loss estimates developed from real-time 24-hour evaporative tests of two off-highway motorcycles. These older tests had to be translated to represent the three evaporative processes defined in MOVES:

1. *Permeation* – defined as the migration of hydrocarbons through elastomers in a vehicle’s fuel system;

2. *Tank Vapor Venting (TVV)* – expulsion of fuel vapor generated from fuel evaporative within the fuel system; and

3. *Liquid Leaks (LLs)* – fuel in liquid form leaking from the fuel tank or fuel system which ultimately evaporates into the atmosphere.

In addition, the ambient conditions and diurnal temperature changes reflected in the California evaporative test data had to be adjusted to reflect the reference conditions EPA established for these processes in MOVES: base permeation at 72°F and vapor venting based on a 72-96°F diurnal temperature change.

Two different database tables are used in MOVES to store evaporative emission rate data:

1. *EmissionRateByAge* – contains permeation, liquid leaker and “hot soak” TVV rates; and

2. *CumTVVCoeff* – contains “cold soak” TVV coefficients used during MOVES execution to dynamically generated cold soak TVV emissions from hourly ambient temperature and tank fuel temperature changes.

In the EmissionRateByAge table, MOVES uses a combination of the OpModeID and PolProcID fields to “map” and store process-specific evaporative rates as shown below in Table 3-10.

Table 3-10
MOVES Evaporative Processes by Pollutant/Process and OpMode

PolProcID	OpModeID		
	150 – Hot Soak	151 – Cold Soak	300 – All Running
111 – Permeation	-	-	Base Permeation
112 – TVV	Hot Soak TVV	-	Running Loss
113 - LL	-	Cold Soak LLs	-

The first step in translating the one-hour SHED test data and running loss estimates for motorcycles into this structure consisted of assembling basic rates for the old evaporative process definitions (hot soak, diurnal, resting and running losses) by model year range. For federally certified motorcycles, three model year ranges were employed: (1) pre-2004; (2) 2004-2007; and (3) 2008 and later. These rates, based on motorcycle evaporative estimates described in detail earlier in Sections 3.2 and 3.3, were loaded into the ***MOVES_MC_EmissionRates_FT01.xls*** workbook at the top of the *FTPEvap* sheet.

MOVES base permeation rates (in g/hr) were calculated from the resting loss (non-heat build) rates (in g/day) by dividing by 24 and adjusting these rates to reflect the difference between the ambient temperature during which these resting loss emissions were measured, best estimated to be 70.5°F, and the 72°F reference temperature used by EPA from the following equation:

$$P_{base} = \frac{P_{adj}}{e^{0.0385\,(Tadj - Tbase)}}$$

Base permeation rates were calculated to be 0.117 g/hr for pre-2008 models and 0.012 g/hr for 2008 and later models. As shown in Table 3-10, these base permeation emission rates were coded into the records in the *EmissionRateByAge* sheet for combinations of OpModeID=300 and PolProcID=111.

Running loss rates were converted from grams per mile to grams per hour. A value of 17.81 g/hr was applied to represent running loss emissions for federally certified motorcycles across all model year. Federal evaporative emissions standards for 2008 and later model years apply only to permeation; thus, running loss rates for all model years were estimated to be the same. In the *EmissionRateByAge* sheet, these running loss rates were applied for OpModeID=300 and PolProcID=112 records as noted in Table 3-10.

As described in EPA's MOVES Evaporative Emission Calculation Methodology,[36] the “remaining” evaporative emissions from the hot-soak and diurnal portions of SHED test measurements are accounted for under the Tank Vapor Venting process in MOVES.

First, hot soak TVV emission rates were calculated by subtracting out base effects from the hot soak SHED measurements using a five-step procedure detailed in Section 3.3.2 of the MOVES Evaporative Emission Calculation Methodology that accounts for tank temperature rise from the LA-4 cycle run prior to hot soak SHED measurement as well as temperature adjustments to the base permeation rates (at the 72°F reference temperature) to reflect the average temperature during the hot soak test. These calculations were performed in the *TankTempCalc* sheet and Rows 153 through 186 of the *FTPEvap* sheet in the ***MOVES_MC_EmissionRates_FT01.xls*** workbook. The resulting hot soak TVV rates by model year range were then loaded into the *EmissionRateByAge* sheet for records with OpModeID=150 and PolProcID=112 as indicated in Table 3-10.

Second, diurnal SHED measurements were translated into cold soak TVV emission rates following these steps contained in Section 3.3.1 of the MOVES Evaporative Emission Methodology. For cold soak TVV emissions, MOVES first finds the amount of tank vapor generated (TVG) as a function of fuel tank temperature and RVP during the temperature rise portion of a 24-hour diurnal temperature profile based on the Reddy Equation.[37]

To perform these calculations in a manner consistent with the MOVES approach, the 1-hour diurnal SHED measurements had to be translated to a real-time, 24-hour basis. These translations were based on regression equations developed from 1-hour and 24-hour testing performed by Automotive Testing Laboratories (ATL) for CARB in 1994 and cited in Section 5.3 of CARB's EMFAC emission factor model technical support documentation.* A linear regression of 1-hour to 24-hour diurnal emissions developed from 19 vehicles over a diurnal range of 60-84°F were used to convert the 1-hour diurnal measurements to an equivalent 24-hour basis as follows:

$$\textit{24-Hour Diurnal} = \textit{1-Hour Diurnal} \times 1.303 + 4.902 \qquad (R^2 = 0.46)$$

(The ATL testing also included measurements over a 65-105°F range. However, only the 60-84°F data were used since they more closely resembled the 68-86°F temperature cycle used in the actual 1-hour diurnal measurements from the CARB Motorcycle Surveillance Testing study.[19])

Once these 1-hour to 24-hour diurnal adjustments were made, hourly permeation rates were calculated over the 68-86°F temperature cycle upon which the diurnal measurements were based. These permeation rates were then summed over the entire 24-hour period and subtracted from the adjusted 24-hour diurnal emissions to calculate Total 24-Hour TVV emission rates by model year range.

Within Rows 33-149 of the *FTPEvap* sheet, hourly Tank Vapor Generation rates (in g/gal) were then calculated over this temperature cycle as a function of the hourly temperature and the fuel RVP based on the Reddy Equation. Once the hourly TVG rates were known and summed over the entire 24-hour period, cold-soak TVV rates were then calculated by apportioning Total TVV based on the hourly TVG rates.

In EPA's MOVES Evapororative Emissions Methodology documentation,[36] TVV rates for light-duty vehicles were determined based on polynomial curve fits of hourly measurements over a 24-hour diurnal test as a function of TVG using the following form:

$$\textit{Total TVV} = A_0 + A_1\,\textit{TVG} + A_2\,\textit{TVG}^2$$

For motorcycles, these curve fits were not necessary since real-time diurnal measurements were not available. Thus, the second-order A_2 coefficients described in this documentation were not applicable and were set to zero for the motorcycle cold-soak TVV rates.

In the *FTPEvap* sheet, the non-zero A_1 coefficient was then calculated simply as:

$$A_1 = \textit{Total TVV} \div \textit{Total TVG}$$

In addition, since MOVES is designed to perform the TVV emission rate calculation dynamically during execution based on a user-selected geographic modeling area and associated diurnal temperature profiles, these cold-soak TVV rates themselves were not stored in the MOVES database. Instead, the calculated coefficients† are stored within a

* *http://www.arb.ca.gov/msei/onroad/doctable_test.htm*

† In the MOVES Evaporative Emission Calculation documentation these coefficients are labeled A_1 and A_2. Within the MOVES database, these TVV coefficients are referred to as ―B and ―C." (The intercept coefficient A_0 or A is set to zero, based on EPA's constraint that the TVV curves pass through the origin.)

separate table in the database called CumTVVCoeff. A separate sheet named *MOVES_MC_CumTVVCoeff* within the ***MOVES_MC_EmissionRates_FT01.xls*** workbook was created based on the field structure of the corresponding MOVES database table and used to store the calculated cold-soak TVV coefficients.

Finally, Liquid Leak (LL) emission rates for motorcycles were assumed to be zero. This assumption was made because of the absence of liquid leak measurements specifically for motorcycles coupled with the inherent uncertainty in extrapolating LL rates from light-duty vehicles. This assumption also reflects the belief that, unlike cars and trucks, liquid fuel leaks from motorcycles are much more visible (i.e., puddles or drips are not hidden by the body/chassis) and that when detected, motorcycle owners would have their vehicles repaired in short order.

All of the MOVES evaporative process emission rates as a function of OpModeID, PolProcID, and ModelYearGroupID were then assembled into a table in Rows 193-270 of the *FTPEvap* sheet and used to populate the evaporative process-specific records within the *EmissionRateByAge* sheet in the ***MOVES_MC_EmissionRates_FT01.xls*** workbook.

Motorcycle Activity Data Tables – The updated motorcycle activity data described earlier in Section 3.5 were also converted into a series of Excel spreadsheets that conformed to the data structures of corresponding activity data tables in the MOVES database. The workbook ***MC_Activity_All.xls*** (provided on the delivery CD) was used to perform these conversions. Updated motorcycle activity data were provided for the six separate MOVES database tables listed below.

1. SourceTypeAge – normalized survival rates and mileage rates with age
2. SourceTypeAgeDistribution – normalized populations (registrations) with age
3. SourceTypeYear
4. HPMSVTypeYear
5. SampleVehicleDay
6. SampleVehicleTrip

First, the survival fractions and mileage accumulation rates presented earlier in Tables 3-6 and 3-7, respectively, are contained in the sheets *SurvivalCurve* and *MARCalcs* within the ***MC_Activity_All.xls*** workbook. The SourceTypeAge table of the MOVES database requires survival rates and annual mileage rates (normalized to a value of 1 at Age 0) for ages 0 through 30 years. The properly normalized survival rates and mileage rates with age were computed in the *SurvivalCurve* and *MARCalcs* sheets and loaded into a sheet within the ***MC_Activity_All.xls*** workbook called *MOVES_MC_SourceTypeAge* with the same field structure as the corresponding table in the MOVES database.

Second, normalized registration distributions with age were computed from the population data by model year presented in Table 3-6 within the PopnAge sheet. These normalized registration distributions were then loaded into the sheet named *MOVES_MC_SourceTypeAgeDistribut* in the ***MC_Activity_All.xls*** workbook.

Next, updated motorcycle sales growth and migration rates for calendar years 2000 through 2008 were calculated in the *GrowthCalcs* sheet and loaded into the *MOVES_MC_SourceTypeYear* sheet in the ***MC_Activity_All.xls*** workbook. It was necessary to calculate updated sales growth and migrates rates over this calendar year range (2000-2008) to account for differences between the default 2008 population projections contained in the MOVES database (projected from 1999 base year populations) and those obtained directly from MIC under this effort.

VMT growth rates between 2000 and 2008 were similarly updated based on calculations performed in the PopnAge sheet and loaded into the *MOVES_MC_HPMSVTypeYear* sheet. The updated VMT growth factors (expressed in MOVES as the change in VMT relative to the previous calendar year) between 2000 and 2008 were based on annual U.S. motorcycle VMT estimates by calendar year obtained from FHWA.[*]

Finally,the motorcycle-specific records in the SampleVehicleDay and SampleVehicleTrip database tables were updated using a FORTRAN program called **SynTables09** to incorporate constraints on weekday (WD) vs. weekend (WE) trip ratios and activity. As noted earlier in Section 3.5, U.S. DOT crash data[32] suggests the weekday/weekend activity split for motorcycles is about 40% weekdays and 60% weekends. (If motorcycle trip/activity rates were constant across all seven days, the weekend fraction would only be about 29%.)

SynTables09 is a modified version of an earlier program called **SynTables** developed by Sierra under a 2007 MOVES-related EPA study.[38] The earlier program was modified to ensure engine on-off trips by day of week matched this 40%/60% WD/WE split in the SampleVehicleDay and SampleVehicleTrip tables for motorcycles.

MySQL Table Loading –The sheets in the ***MOVES_MC_EmissionRates_FT01.xls*** and ***MC_Activity_All.xls*** Excel workbooks containing the emission rate and activity data in structure identical to their corresponding MOVES database tables were exported to a series of comma-delimited (CSV) files.

Two short MySQL batch scripts called ***Make_MOVESTable_MC_092809.txt*** and ***Load_MOVESTables_4-03_092809.txt*** were then written and executed to load the new emission rate data and updated activity data for motorcycles into the appropriate MOVES database tables in MySQL format.

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[*] FHWA Highway Statistics VM-1 Table VMT by Year

4. AIR TOXIC SPECIATION RATIOS

Draft MOVES2009 currently relies on algorithms carried over from MOBILE6.2 that are used to calculate air toxic emissions from on-road vehicles. These algorithms cover the following seven species: benzene, 1,3-butadiene, formaldehyde, acetaldehyde, acrolein, naphthalene, and ethanol. The final analytical task under this effort envisioned development of new speciation ratios for a broader list of Hazardous Air Pollutants (HAPs) included in EPA's National Mobile Inventory Model (NMIM) that were not included in Draft MOVES2009.

This section of the report describes the work performed under this air toxics task. It begins with an explanation of the form of air toxic emission rates defined and used in MOVES and identification of the list of additional HAPs contained in NMIM that EPA is seeking to integrate into MOVES. It then presents separate discussions on the data assembled and emission rates for individual air toxic species estimated for light-duty gasoline- and heavy-duty Diesel-fueled vehicles, respectively.[*]

4.1 MOVES Speciation Ratios

Table 4-1 lists the additional HAP species that EPA is integrating into MOVES. Along with the MOVES PollutantID and NEI pollutant codes that uniquely identify each compound, it also lists the PollutantDisplayGroupID for each species. This value is used internally within MOVES to group pollutants/compounds into logical groups for which specific calculations or processing options are performed within the model. For the HAPs listed in Table 4-1, values of –7,” –8,” and –9” refer to –Additional Air Toxics,” Dioxins/Furans,” and –Metallic Air Toxics,” respectively.

The rightmost column in Table 4-1 (and the row shading) identifies whether each compound was included in the speciation ratios developed from the data sources employed under this effort. Values of –G” and –D” refer to those species represented in the light-duty gasoline and heavy-duty Diesel study datasets, respectively. Species for which no data were available from the datasets examined under this effort are noted with

[*] EPA originally envisioned development of MOVES air toxic emission rates for other vehicle/fuel types including heavy-duty gasoline vehicles, heavy-duty Diesel using bioDiesel, light and heavy-duty CNG and LPG vehicles, as well as non-road engines. During the study, resources were re-prioritized into other tasks such that air toxic emissions for these other vehicle/fuel types were not considered. EPA plans to pursue development of MOVES air toxics rates for these vehicles under a separate study.

Table 4-1
List of New MOVES HAPs and Numerical Codes

PollutantName	MOVES PollutantID	NEIPollutant Code	Pollutant DisplayGroupID	Included in Study
2,2,4-Trimethylpentane	40	540841	7	G,D
Acenaphthene	41	83329	7[a]	D
Acenaphthylene	42	208968	7[a]	D
Anthracene	44	120127	7[a]	D
Benz(a)anthracene	45	56553	7[a]	D
Benzo(a)pyrene	46	50328	7[a]	D
Benzo(b)fluoranthene	47	205992	7[a]	D
Benzo(g,h,i)perylene	48	191242	7[a]	D
Benzo(k)fluoranthene	49	207089	7[a]	D
Chrysene	50	218019	7[a]	D
Dibenzo(a,h)anthracene	51	53703	7[a]	D
Ethyl Benzene	52	100414	7	G
Fluoranthene	53	206440	7[a]	D
Fluorene	54	86737	7[a]	D
Hexane	55	110543	7	G,D
Indeno(1,2,3,c,d)pyrene	56	193395	7[a]	D
Phenanthrene	57	85018	7[a]	D
Propionaldehyde	58	123386	7	G,D
Pyrene	59	129000	7[a]	D
Styrene	60	100425	7	G
Toluene	61	108883	7	G,D
Xylene	62	1330207	7	G
2,3,7,8-Tetrachlorodibenzo-p-Dioxin	301	1746016	8	-
1,2,3,7,8-Pentachlorodibenzo-p-Dioxin	302	40321764	8	-
1,2,3,4,7,8-Hexachlorodibenzo-p-Dioxin	303	39227286	8	-
1,2,3,6,7,8-Hexachlorodibenzo-p-Dioxin	304	57653857	8	-
1,2,3,7,8,9-Hexachlorodibenzo-p-Dioxin	305	19408743	8	-
1,2,3,4,6,7,8-Heptachlorodibenzo-p-Dioxin	306	35822469	8	D
Octachlorodibenzo-p-Dioxin	307	3268879	8	D
2,3,7,8-Tetrachlorodibenzofuran	308	51207319	8	D
1,2,3,4,6,7,8-Heptachlorodibenzofuran	309	67562394	8	-
1,2,3,4,7,8,9-Heptachlorodibenzofuran	310	55673897	8	D
1,2,3,4,7,8-Hexachlorodibenzofuran	311	70648269	8	-
1,2,3,6,7,8-Hexachlorodibenzofuran	312	57117449	8	-
1,2,3,7,8,9-Hexachlorodibenzofuran	313	72918219	8	-
1,2,3,7,8-Pentachlorodibenzofuran	314	57117416	8	D
2,3,4,6,7,8-Hexachlorodibenzofuran	315	60851345	8	D
2,3,4,7,8-Pentachtorodibenzofuran	316	57117314	8	-
Octachlorodibenzofuran	317	39001020	8	D

Table 4-1
List of New MOVES HAPs and Numerical Codes

PollutantName	MOVES PollutantID	NEIPollutant Code	Pollutant DisplayGroupID	Included in Study
Mercury (elemental gaseous)	201	200	9	-
Mercury (divalent gaseous)	202	201	9	-
Mercury (particulate)	203	202	9	D
Arsenic & compounds	204	93	9	D
Chromium (Cr3+)	205	16065831	9	-
Chromium (Cr6+)	206	18540299	9	-
Manganese	207	7439965	9	D
Nickel	208	7440020	9	D

[a] Pollutants within the 16-compund Polycyclic Aromatic Hydrocarbon (PAH) group (that also includes naphthalene) defined by EPA that occur in both gaseous and particle phases.

a dash (―-") symbol. As indicated in this column, measured test data were found for most, but not all, of the additional HAPs identified for inclusion in MOVES.

Within MOVES, air toxic emission rates are calculated based on toxic ―speciation ratios" that represent the mass emission fraction of an individual species relative to VOC (volatile organic compounds) or PM (particulate matter) of the following form:

Speciation Ratio = *Species Mass Emission Rate / VOC Mass Emission Rate*
or
= *Species Mass Emission Rate / PM Mass Emission Rate*

Speciation ratios for those compounds listed Table 4-1 with on-road measurement data were calculated by dividing the species emission rate by the VOC emission rate for the gaseous compounds (those with PollutantDisplayGroupID=7 or 8) or by the PM emission rate for metal-based compounds (PollutantDisplayGroupID=9). Within MOVES, these speciation ratios are multiplied by either VOC or PM emission rates as appropriate to produce air toxic emission rates (in grams per hour) by vehicle type, model year, etc. and generate composite rates for the vehicle fleet.

There was one exception to this basic approach. Polycyclic aromatic hydrocarbons (PAHs) identified as footnoted in the PollutantDisplayGroupID column in Table 4-1 are found in multiple phases: (1) gas phase, (2) particle phase, and (3) as semi-volatile organic compounds. As explained later in Section 5.3, multi-phase apportionment of PAH species measurements were performed based on factors from EPA's SPECIATE database.

Thus, the basic approach to this task consisted of reviewing literature and previous testing study datasets in which either individual air toxic emission rates were measured in conjunction with measurements of denominator pollutant emission rates or speciation ratios were developed from these measurements. EPA requested development of separate speciation ratios by vehicle type (i.e., SourceType), model year range or certification standards group (e.g., Tier 0, 1, 2), and fuel type where sufficient data were available.

Given this overall approach, the remaining two sub-sections provide further detail on the assembly of data and development of speciation ratios for light-duty gasoline and heavy-duty Diesel-fueled vehicles, respectively.

4.2 Light-Duty Gasoline-Fueled Ratios

Development of light-duty gasoline-fueled toxic speciation ratios was relatively straightforward. Of the nearly 50 additional toxic species listed earlier in Table 4-1, measurement data and ratios were available for seven species for light-duty gasoline vehicles.

Ratios for Tier 1 and earlier (model year 2003 and earlier) vehicles were assembled from SPECIATE model profiles[39] developed for EPA by ENVIRON. Separate speciation ratios were developed for exhaust and evaporative emission processes and the following fuels/blends: gasoline (i.e., E0), E10 (10% ethanol, by volume), and E85 (85% ethanol).

Table 4-2 presents these Tier 1 and earlier speciation ratios assembled from the ENVIRON study.

Table 4-2
Tier 1 and Earlier Light-Duty Gasoline Vehicle Speciation Ratios

Pollutant Name	Exhaust Emission Ratio			Evaporative Emission Ratio		
	Gasoline	E10	E85	Gasoline	E10	E85
2,2,4-Trimethylpentane	0.01823	0.01849	0.00898	0.01984	0.03354	0.01949
Ethyl Benzene	0.02147	0.01932	0.00222	0.02521	0.01721	0.00651
Hexane	0.01570	0.01593	0.00213	0.02217	0.02536	0.00606
Propionaldehyde	0.00086	0.00087	0.00019	n/a	n/a	n/a
Styrene	0.00108	0.00097	0.00022	0.00000	0.00000	0.00043
Toluene	0.09619	0.08657	0.00813	0.09643	0.14336	0.05193
Xylene [a]	0.07814	0.07032	0.00699	0.07999	0.06423	0.02205

n/a – not available
[a] Xylene is reported as the sum of O-xylene and M- and p-xylene.

Toxic speciation ratios for Tier 2 and later vehicles (model year 2004 and newer) were based on SPECIATE model profiles developed by EPA.[40] There were only exhaust emission data available for Gasoline and E10. No evaporative emission profiles or E85 profiles were available. Table 4-3 lists these available Tier 2 speciation ratios.

Table 4-3
Tier 2 Light-Duty Gasoline Vehicle Speciation Ratios

Pollutant Name	Exhaust Emission Ratio	
	Gasoline	E10
2,2,4-Trimethylpentane	0.0319	0.0123
Ethyl Benzene	0.0168	0.0166
Hexane	0.0028	0.0291
Propionaldehyde	0.0012	0.0005
Styrene	0.0009	0.0008
Toluene	0.0754	0.0744
Xylene[a]	0.0613	0.0605

[a] Xylene is reported as the sum of O-xylene and M- and p-xylene.

4.3 Heavy-Duty Diesel-Fueled Ratios

Diesel-fueled speciation ratios were calculated from emission measurements that were assembled into a comprehensive spreadsheet database that was assembled under the Coordinating Research Council (CRC) E-75 study.[41] This database organized speciated exhaust emission measurements from on-road medium- and heavy-duty Diesel vehicles from several earlier studies that are listed in Table 4-4.

The E-75 database is a large spreadsheet with information from the prior testing studies organized into individual sheets as summarized below.

- *Engine_Data* – Contains descriptive data of the vehicle/engine that was tested, such as make/manufacturer, vehicle type, engine application, model, model year, engine size, horsepower, etc.

- *Fuel_Data* – Lists basic name or type of fuel used for each test (e.g., conventional Diesel, bioDiesel, low-sulfur Diesel, etc.) and properties (cetane number, sulfur, oxygen, aromatic content, etc.) of that fuel.

Table 4-4 Study Data Represented in CRC-75 Speciation Database		
Study Name	Vehicles Tested	Model Years Covered
Southwest Research Institute (SwRI) School Bus Study	2 school buses	2001
SwRI study for the Ad Hoc Diesel Fuel Test Program	1 LDDV	N/A
New York City Clean Diesel Demonstration Program	2 Diesel transit buses	1999
California Institute of Technology	2 MHDDT, 2 HHDDT	1995 1987
BP Southern California ultra-low sulfur Diesel	3 HDDT	1996-1999
(ULSD)/DPF/CNG Heavy-duty study	1 transit bus 1 school bus	1998 1998
SwRI Fischer-Tropsch study	2 HDD engines	1999, 2000
CRC Mass vehicle tests	16 LDDVs	1977-1994
CRC AVFL-10a & 10b	4 LDDV/T, ~110 L/HDDV	2004 1978-2000
CE-CERT	14 HDDT, 28 LDDV/T	1996-2000 1983-1999
Gasoline-Diesel particulate matter (PM) Split Study	30 HDDT 2 buses	1982-2001 1982, 1992
CRC E55/59	1 MHDDT 8 HHDDT	1997 1985-2003
Desert Research Institute	4 LDDV 4 Diesel trucks	1991, 1998, 1999, 2000 N/A
Environment Canada	1 LDDT 2 urban buses	1998 1989, 1998

- *Pollutant_List* – Provides a cross-referenced list of nearly 1,000 individual pollutant species represented in the assembled test data that included primary and alternate pollutant names, Chemical Abstracts Service (CAS) numbers, and pollutant ID codes.

- *Test_Cycle* – Provides a description for each of the test cycle codes used in the database that identified the driving cycle over which emission measurements for each test were collected.

- *Emissions* – The emissions data were stored in several individual sheets broken into the following compound groups: regulated pollutants (e.g., THC, CO, NOx, PM, etc.), carbonyls, dioxins/furans, PAHs, speciated hydrocarbons, SVOCs and elements/inorganic compounds (i.e., metals).

The data records in each of the individual sheets in the E-75 database could be related or linked to one another using Project ID, Study ID, and Test ID fields contained in each sheet that uniquely identified data for a specific emission test.

Data Processing and Validation – Despite the organization of the E-75 spreadsheet, development of toxic speciation ratios for heavy-duty Diesel vehicles was much more involved than for the gasoline-fueled vehicles because a number of quality assurance checks, data linkage processes, and record culling steps had to be performed. A modified version of the original E-75 database called ***MOVES_AT_Speciations_Diesel_E-75.xls*** was created in which these steps were performed. (Both the original and modified E-75 spreadsheet databases are included on the delivery CD.) These processing steps are summarized below.

- *Removal of Invalid Data* – Data that had “bd,” “N/A,” “nd,” or “-99” entries in either the Emission or Emission Unit columns were excluded.

- *Assembly of Paired Measurements* – Paired measurements for the same vehicle and test that have both toxic emission measurements (numerator) and regulated emission measurements (denominator) were located in different sheets within the database. They were combined into a single sheet in the spreadsheet called *AllPollutants* by lookup formulas based on ProjectID, StudyID, and TestID fields in each individual sheet in order to calculate speciation ratios. In a number of cases, paired measurements of both the numerator and denominator measurements were not found using this lookup approach. Further investigation of these cases indicated that some of the mismatches occurred from incorrect entries (e.g., typos) in one of these three lookup fields (usually the TestID field) as originally stored in the database. Where it was obvious that this type of error had been made, corrective edits were made to values in the lookup fields to properly retrieve both the toxic species emission measurement and the paired “denominator” or base pollutant measurement for the same vehicle and test.

- *Unit Conversions* – In a number of instances, the emission units for the paired measurements were different. In these instances, the denominator emission unit was converted to a numerator emission unit to properly calculate the toxic speciation ratio. In some cases, incompatible emission units were observed—for example, if the numerator emission unit was “mg/mile” and the denominator unit was “g/mode.” (The testing studies included both transient cycles and steady-state modes.) In these cases where incompatible units were observed, the paired measurements were excluded.

- *Removal of Non-Conventional Fuel Tests* – The E-75 database included test measurements from a number of research studies for which a variety of Diesel blends and other alternative fuels were used. For this analysis, EPA directed Sierra to exclude all tests for fuels other than those that reflect conventional or low-sulfur Diesel blends currently or recently in-use within the U.S. As a result, tests for all other types of fuels contained in the E-75 database were excluded or removed from further analysis. These non-conventional blends included Fischer-Tropsch, bioDiesel, ethanol-Diesel blends, emulsified fuel, European blends, and other obvious research fuels.

- *MOVES Source Type Categorizations* – Based on vehicle description, engine application, make, and model entries in the Engine_Data sheet, classifications of vehicles into the MOVES SourceType scheme were performed when possible. In many cases, such for vehicles marked as ―Refuse Hauler" or ―School Bus," it was simple to assign the appropriate SourceType category. For others, internet searches performed based on manufacturer, model, and engine size clearly revealed the type of heavy-duty vehicle application (e.g., single- vs. combination-unit or delivery vehicle). In instances were there was ambiguity, a missing code was simply entered for the SourceTypeID field. The purpose behind these categorizations was to enable development of separate speciation ratios by SourceType for use in MOVES. However, once the categorizations were made and sample sizes were tabulated by SourceType, it became apparent that insufficient data were available for most of the SourceType categories containing Diesel-fueled vehicles. Given these small sample sizes, subsequent tabulations of Diesel speciation ratios under this effort were not SourceType-specific, but based on averages across all valid SourceTypes. (However, these SourceType categorizations were preserved for later use when these data are combined with other datasets for which MOVES SourceType categorizations are needed.)

- *Removal of Non Heavy-Duty Vehicle Tests* – When performing the SourceType categorizations, a small number of tests were found to have been included in the E-75 database for light-duty Diesel vehicles (e.g., Volkswagen Jetta and Toyota Corolla, Ford F-250). Because of the decision described above to simply calculate average speciation ratios across all valid vehicle types due to insufficient sample sizes), it was jointly agreed with EPA to remove these few light-duty vehicle tests from the validated E-75 sample. Thus, the resulting speciation ratios were solely representative of heavy-duty Diesel vehicles.

- *Outlier Treatment* – A simple screening threshold of 0.5 was used to filter and remove data with implausible speciation ratios. Ratios greater than or equal to 0.5 are considered as outliers and the data for these test records were removed from the final, validated sample contained in the *AllPollutants* sheet of the ***MOVES_AT_Speciations_Diesel_E-75.xls*** file.

<u>Treatment of Multi-Phase PAH Species</u> – In addition to the data processing and validation steps described above, additional processing was performed for the PAH compounds identified earlier in Table 4-1. This additional process was performed to account for the fact that PAHs occur in multiple phases: gas phase, particle phase, and as SVOCs.

Multi-phase allocation factors were developed for the 15 individual PAH species contained in Table 4-1 using estimates from EPA's SPECIATE4.2 database[42] where available. For species where allocations were not found in the SPECIATE database, emissions were estimated to occur either in the gas or particle phase based on each PAH compound’s physical properties. Those with lower molecular weights tend to be volatile, and were allocated to the gas phase; “heavy” higher weight compounds with higher molecular weights were allocated to the particle phase.

Table 4-5 summarizes the multi-phase allocation factors used to apportion emission rates for individual PAH compounds to the gas and particle phases. In the E-75 database, the speciation data were organized in a manner that identified whether the test measurement reflected the gas phase, particle phase, or both phases. If a test record was marked as “Gas Phase,” the speciation ratio calculated from the specie (numerator) and base (denominator) pollutant emission rates was adjusted by the Gas Phase fraction listed in Table 4-5. This adjustment was applied similarly for those records identified as “Particle Phase” tests. When the E-75 Phase field indicated the measurements were collected in both phases, no PAH allocation adjustments from Table 4-5 were used. PAH records for which no information was recorded in the Phase field were assumed to be collected in particle (PM) phase.

Table 4-5
Mult-Phase PAH Allocation Factors Used

PAH Species	Molecular Weight	Allocation Fraction		Reference
		PM Phase	Gaseous Phase	
Acenapthene	154	0	1	EPA/SPECIATE
Acenaphthylene	152	0	1	EPA/SPECIATE
Anthracene	178	0.466	0.534	EPA/SPECIATE
Benz(a)anthracene	228	0.723	0.277	EPA/SPECIATE
Benzo(a)pyrene	252	1	0	Sierra Research
Benzo(b)fluoranthene	252	1	0	Sierra Research
Benzo(g,h,i)perylene	276	0.773	0.227	EPA/SPECIATE
Benzo(k)fluoranthene	252	1	0	Sierra Research
Chrysene	228	0.823	0.177	EPA/SPECIATE
Dibenzo(a,h)anthracene	278	1	0	Sierra Research
Fluoranthene	202	0.516	0.484	EPA/SPECIATE
Fluorene	166	0.215	0.785	EPA/SPECIATE
Indeno(1,2,3-cd)pyrene	276	1	0	Sierra Research
Phenanthrene	178	0.335	0.665	EPA/SPECIATE
Pyrene	202	0.552	0.448	EPA/SPECIATE

Heavy-Duty Diesel Speciation Ratios – Once the processing, validation, and PAH allocations were completed, average speciation ratios for each available toxic pollutant were then calculated across all vehicle types and model years represented in the validated sample. Table 4-6 below shows these mean speciation ratios, along with the sample sizes (number of vehicle tests) and standard deviations (to provide a sense of the variation of the individual observations).

Table 4-6
Heavy-Duty Diesel Speciation Ratios and Basic Statistics

Pollutant Name	Pollutant Group	Count	Average	Std Dev
1,2,3,4,6,7,8-HpCDD	DioxinFuran	1	1.95E-10	n/a
1,2,3,4,7,8,9-HpCDF	DioxinFuran	1	2.49E-11	n/a
1,2,3,7,8-PeCDD	DioxinFuran	1	5.14E-12	n/a
2,2,4-trimethylpentane	TOG-VOC-NMOG	43	1.90E-03	5.19E-03
2,3,4,6,7,8-HxCDF	DioxinFuran	1	1.98E-11	n/a
2,3,7,8-TCDF	DioxinFuran	1	4.11E-11	n/a
Acenaphthene	PAH	105	2.46E-04	5.75E-04
Acenaphthylene	PAH	104	7.49E-04	1.63E-03
Anthracene	PAH	102	1.44E-03	6.70E-03
benz[a]anthracene	PAH	115	2.49E-04	9.87E-04
benzo[a]pyrene	PAH	101	9.44E-04	7.48E-03
benzo[b]fluoranthene	PAH	15	1.17E-05	1.07E-05
benzo[ghi]perylene	PAH	89	1.08E-05	3.97E-05
benzo[k]fluoranthene	PAH	13	6.52E-06	1.09E-05
Chrysene	PAH	115	7.87E-05	1.39E-04
dibenz[ah]anthracene	PAH	2	2.12E-06	1.80E-06
Fluoranthene	PAH	123	1.72E-03	7.85E-03
Fluorine	PAH	108	2.20E-03	7.21E-03
Hexane	TOG-VOC-NMOG	38	2.07E-03	7.21E-03
indeno[123-cd]pyrene	PAH	88	8.40E-06	2.47E-05
OCDD	DioxinFuran	1	7.71E-11	n/a
OCDF	DioxinFuran	1	6.94E-11	n/a
Phenanthrene	PAH	106	2.80E-03	9.31E-03
Propionaldehyde	carbonyl	60	4.91E-03	7.34E-03
Pyrene	PAH	123	1.95E-03	8.75E-03
Toluene	TOG-VOC-NMOG	49	4.54E-03	5.17E-03
As	Pm	95	1.67E-05	4.63E-05
Hg	Pm	98	4.87E-05	1.33E-04
Mn	Pm	98	3.57E-05	8.00E-05
Ni	Pm	97	2.65E-05	4.69E-05

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