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Determination of NOx and HC Basic Emission Rates, OBD and I/M Effects for Tier 1 and later LDVs and LDTs

Final Report M6.EXH.007

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1 Introduction

This report presents the updated MOBILE6 methodology for NOx and exhaust HC basic emission rates (BERs) for Tier 1 and later light-duty vehicles (LDVs) and light-duty trucks (LDTs), and the effects of On-Board Diagnostic (OBD) systems and Inspection/Maintenance (I/M) on these vehicles. This report supercedes the draft version of the report (EPA-420-P-99-009) published in March 1999, and reflects several updates based on stakeholder comments,[1] new data and updated methodologies. These updates are summarized as follows:

1) NOx emission rates have been revised based on the analysis of a substantially larger database of vehicle and trucks certified to a 0.4 gram/mile 50,000 mile NOx certification standard.
2) The upward adjustment of NOx high-emitter frequencies to account for test program recruitment bias has been reduced based on reanalysis of Tier 0 and Tier 1 high emitter data.
3) The upward adjustment to NOx high-emitter frequencies to account for the presence of an I/M program in the test sample has been eliminated.
4) HC emission rates have been reduced in response to the correction of an error in the high-emitter frequencies presented in the draft report.
5) The emission level after repair of an OBD-detected malfunction has been revised to assume repair to the normal emitter average emission level at a given milage, capped at 1.5 times the 50,000 mile certification standard.
6) The response/repair rate for vehicles flagged as malfunctioning by OBD systems in areas with OBD/IM programs has been increased from 90 to 99 percent, to allow for treatment of cost waivers and program noncompliance in a manner consistent with exhaust-based I/M programs..

The updated NOx emission rates, encompassing issues (1) through (3), have a lower intercept (zero-mile level) but higher deterioration rate than those presented in the draft report. Total emissions over the life of an average vehicle are reduced slightly with the updated rates. The HC emission rates are more significantly lower than originally proposed, and the change in OBD repair level results in a slight increase in the benefit of OBD repair.[2]

In additional to stakeholder review, the draft final version of this report (published in December 1999) underwent paid peer review by an external expert. The results of this peer review are contained in Appendix E. This report has been updated to reflect key

[1]Comments were received on the draft report from the State of Colorado and Applied Analysis, Inc. via the MOBILE6 comment process; General Motors and the Alliance of Automobile Manufacturers (AAM) also submitted substantive comments via the comment process for the Tier 2 /Sulfur proposed rulemaking. Detailed responses to the GM and AAM comments are contained in the Tier 2 Summary and Analysis of Comments. All of the comments are available in the Tier 2 Docket.

[2]A comparison between the draft and updated emission rates as well as ARB's EMFAC7G emission rates is contained in "Comparison of EPA, ARB and AIR Emission Rates", Memorandum from John Koupal to the Tier 2 Docket (A-97-10)

recommendations from this review.

2 Overview

The methodology discussed in this paper will be applied to generate BERs across all vehicle classes (LDV and LDT1 through 4) for all Tier 1 and later standards, including the TLEV, LEV, and ULEV standards under the California LEV I and Federal NLEV program, Federal Tier 2 standards, and LEV II standards recently adopted by California. For brevity, however, the results presented here focus on the Tier 1, LEV and ULEV standards for each vehicle class. Per peer review comments, emission rates for the primary Tier 2 standards have been added in Appendix B.

Sufficient in-use data from LDVs or LDTs complying with Tier 1 or later standards on which to base these emission rates are not available. Thus, the methodology used in the development of Tier 1 and later BERs is based on the differences in certification standards across standard level and vehicle class. For NOx, Tier 1 and later BERs were based on a sample of 1,122 LDVs and 62 LDT1s certified to a 50,000 mile 0.4 gram/mile NOx standard (the Federal Tier 1 standard). For HC, Tier 1 and later emission rates were based on BERs developed for 1988 through 1993 Ported Fuel Injection (PFI) LDVs. Using certification standard as the base for Tier 1 and later BERs has two implicit ramifications. First, the BERs reflect the fuel which a vehicle is certified on the meet the standard: Indolene for Tier 1 standards, and California Phase II RFG for LEV and later standards. Second, the HC BERs are expressed as non-methane hydrocarbon (NMHC) for Tier 1 LDV/LDTs, and non-methane organic gas (NMOG) for LEV and later LDVs/LDTs.

On-Board Diagnostics systems were required on all LDVs and LDTs sold outside California beginning in 1996. Tier 1 vehicles began entering the fleet in 1994, and for two years (1994 and 1995) were not equipped with OBD. For MOBILE6, it will be assumed that all 1996 and later LDVs and LDTs are equipped with OBD systems, which are designed to detect emission system malfunctions resulting in emissions at or above 1.5 times the applicable emission standard.[3] If this criteria is met, a light on the vehicle's dashboard (the malfunction indicator light, or MIL) is illuminated to alert the driver that an emissions system repair is required. Thus, the rate of emission deterioration for Tier 1 and later vehicles must take into account the impact OBD systems will have overall in-use emissions, including a) the effectiveness of these systems in detecting emission malfunctions, b) the owner response rate to illuminated MILs, and c) the effectiveness of repair in addressing the detected problem.

Beginning in 2001, all Inspection/Maintenance programs will require an OBD system

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[3]The "1.5 times the standard" criteria was initially required by ARB, while EPA adopted a different malfunction threshold approach. However, manufacturers were allowed to meet the federal program through compliance with ARB's requirement, and most chose this option. EPA's requirement has recently been amended to harmonize with ARB by requiring the "1.5 times the standard" criteria for vehicle sold federally. For MOBILE6, it will be assumed that all vehicle equipped with OBD since 1996 comply with the "1.5 times" malfunction criteria.

check for OBD-equipped vehicles. In I/M areas, this will greatly increase the rate at which illuminated MILs are addressed, hence further improving the average rate of in-use deterioration for Tier 1 and later vehicles.

Most Tier 1 and later vehicles will be equipped with an OBD system and, if in an I/M area, subject to OBD-based I/M rather than traditional exhaust I/M. However, some Tier 1 vehicles will not be equipped with OBD (model years 1994 and 1995). To model emissions under these scenarios, a methodology for generating basic emission rates was developed for the following cases:

No OBD/No IM (Base) applies to pre-OBD Tier 1 vehicles (1994 and 1995 model years). It is also used as a basis for the computation of BERs under the OBD-only and OBD/IM cases.

OBD-Only (OBD/ No IM) applies to 1996 and later OBD-equipped vehicles where an I/M program is not present.

OBD/IM applies to 1996 and later OBD-equipped vehicles where an I/M program which conducts OBD checks is present. An exhaust test may or may not be performed; it is not differentiated from an I/M program with both OBD checks and exhaust testing, since additional I/M reductions are not given for exhaust testing if OBD checks are performed.

Exhaust I/M represents a situation in which only an exhaust test is conducted in an I/M program (an IM240, ASM, or idle test). This will apply to 1994 and 1995 model year Tier 1 vehicles in all calender years. The details on the derivation of emission benefits from these programs are contained in a separate document, M6.IM.001.

This report gives an overview of the basic approach for generating BERs, then describes the specific details of BER development for NOx and exhaust HC for each case. It is important to reinforce that the analyses performed for Tier 1 and later emission rates as well as OBD benefits are based largely on engineering judgement. Aside from Tier 1 light-duty vehicles, adequate in-use data upon which to base emissions over the life of vehicle and trucks certified to recently promulgated standards are not available. With regard to the benefits of OBD, the lack of adequate data to assess performance of and owner response to the OBD system over the life of a vehicle necessitates that technical judgement be employed.

3 Basic Emission Rate Derivation Concept

The basic concept underlying the generation of Tier 1 and later BERs is similar to the approach used to develop the I/M credits for 1981 through 1993 vehicles.[4] For the No OBD/No IM case, this concept segregates in-use vehicles into “normal” and “high” emitters. High

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[4]Glover, E., and Brzezinksi, D., “MOBILE6 Inspection/Maintenance Benefits Methodology for 1981 through 1993 Model Year Light Vehicles”, Draft MOBILE6 Report No. M6.IM.001, March 1999. Hereafter referred to as “Tier 0 I/M Report”

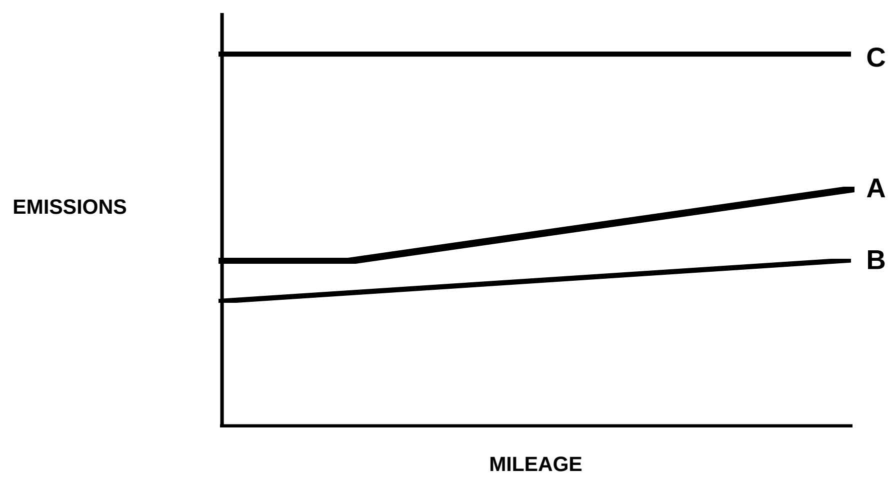
emitters are vehicles that have emission control systems which are malfunctioning in some way, and are producing average emission levels which are considerably higher than the overall mean emission levels. The threshold for defining a high emitter for NOx and HC is 2.0 times the intermediate life (50,000 mile) certification emission standard. The remainder of the fleet are considered "normal" emitters, defined as vehicles with emissions below 2.0 times the intermediate life certification standard. It is important to note that both pollutants are considered independently when determining whether a vehicle is a high emitter. Thus, a vehicle could be a high NOx emitter, but a normal HC emitter.

Although the segregation of vehicles into the "normal" and "high" categories (and their thresholds) is a somewhat arbitrary modeling method, the concept that average in-use emissions are driven by a group of vehicles emitting well above the applicable standard is supported by data from many years of EPA vehicle test and repair programs. This phenomena is contributed to by the "go/no go" nature of emission control technology components such as EGR valves and air pumps, and the high sensitivity of emissions to degradations in performance of other critical components such as the catalyst, oxygen sensor(s) and fuel injectors. Two important assumptions in the development of BERs for Tier 1 and later vehicles are a) the rate at which vehicles malfunction and become high emitters is independent of the certification standard level, and b) the average emission levels for high emitters becomes higher *relative to the standard* as the certification standard becomes lower.

Under this methodology, average in-use emissions are computed as a weighted average of high and normal emitters. Figure 1 is a general graphical view of the concept with the y-axis representing emissions in grams per mile, (grams for start emissions) and the x-axis representing mileage.[5] The three lines presented in Figure 1 reflect a) the average or basic emission rate, b) the normal emitter emission rate, and c) the high emitter emission level.

[5]MOBILE6 uses vehicle mileage as a surrogate for vehicle age. Age and mileage are used interchangeably throughout this document.

Figure 1
GENERAL EMISSION FACTOR SCHEMATIC



The basic emission rate is shown as Line A. This line represents the average emissions of the fleet as a function of both normal emitters and high emitters.

Line B represents the average emissions of normal-emitting vehicles. These are the vehicles which have emission control systems which are generally performing as designed. The line is shown as a linear function of mileage to reflect the gradual deterioration that normal vehicles experience, primarily due to catalyst degradation over the life of the vehicle. Normal emitter emissions are generally expressed by a least squares linear regression of emissions versus mileage.

Line C represents the average emissions of high-emitting vehicles. This line is a flat horizontal line because emissions from these vehicles do not appear to be a strong function of mileage, based on previous analysis of Tier 0 data[6] and born out by analyses of Tier 1 NOx data presented in the following section. The underlying phenomena expressed here is that emission control malfunction will drive high emissions regardless of vehicle mileage; as discussed in subsequent sections, what changes as the vehicle ages is the *probability* of malfunction, rather than the emission levels resulting from a malfunction.

Line A represents the weighted average of lines B and C, based on appropriate weighting factors for normal and high emitters. On a fleet-wide basis, this weighting factor represents the fraction of high emitters in the fleet, as a function of vehicle age; on a per-vehicle basis, this weighting factor can be considered to be the probability the vehicle will be a high emitter at a given age. This weighting factor can be derived at any given vehicle age ***A*** (represented by vehicle mileage) by transforming Equations 1 and 2 into Equations 3 and 4 below.

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[6] Tier 0 I/M report

$$\text{Highs} + \text{Normals} = 1 \qquad \text{Eqn 1}$$

and

$$\text{AVE} = \text{High\_ave} * \text{Highs} + \text{Norm\_ave} * \text{Normals} \qquad \text{Eqn 2}$$

Solving for the variables Highs and Normals produces:

$$\text{Highs} = (\text{AVE} - \text{Norm\_ave}) / (\text{High\_ave} - \text{Norm\_ave}) \qquad \text{Eqn 3}$$

$$\text{Normals} = 1 - \text{Highs} \qquad \text{Eqn 4}$$

Where:

Highs = fraction of High emitters, age = ***A***
Normals = fraction of Normal emitters, age = ***A***
AVE is the average emission rate, age = ***A***
High_ave is the high emitter emission average (independent of age)
Norm_ave is the normal emitter emission average, age = ***A***

4 NOx BERs and Emitter Fractions: No IM/No OBD Case

4.1 Tier 1 LDVs

The No IM / No OBD case was developed first because it did not require accounting for high emitters which underwent repair due to OBD MIL-on; hence, the methodology closely followed the basic emission rate derivation concept outlined in the previous section. Tier 1 LDVs served as the basis for developing BERs across vehicle class (LDT1 through 4) and standard level (LEV, ULEV). Thus, the derivation of these BERs is the first step in the generation of all BERs for all OBD/IM cases, vehicles classes and standards. For this analysis, Tier 1 and later BERs were first generated in FTP space and subsequently split into running and start components, as discussed in Section 7; this deviates from the approach used 1981 through 1993 vehicles, for which start and running BERs were developed independently. The start and running BERs will be used by MOBILE6 as the basis for estimating emissions from Tier 1 and later LDVs and LDTs.

The database used to generate No OBD/No IM BERs for Tier 1 LDVs has been greatly expanded since the draft report, which relied on 186 LDVs and LDTs tested by the California Air Resources Board (ARB) as part of Surveillance Programs 12 through 14. The dataset used for the updated analysis included these vehicles plus 40 additional vehicles tested by ARB, 884 vehicles tested by the auto industry, and 74 vehicles tested by EPA.[7] In total, 1,122 LDVs and 62

[7] 15 EPA vehicles had repeat tests.

LDTs were used for the analysis. All were model year 1988 and later certified to a 50,000 mile intermediate useful life NOx standard of 0.4 g/mi; 1,041 under California's Tier 0 standards, and 143 under the Federal Tier 1 standard.[8]

The first step in assessing the updated dataset was to establish whether it was appropriate to consider all of the vehicles together, or disaggregate the analysis by vehicle class (LDV or LDT). This issue was raised by Applied Analysis, GM and AAM who all suggested that LDVs and LDTs behave differently in-use, and should be modeled separately. We assessed this issue by performing a multiple regression analysis on NOx emissions for the entire LDV/LDT1 normal emitter sample using a model with vehicle class (LDV or LDT) as a factorial and mileage and the cross product of mileage and class as continuous variables. The purpose of this test was to determine whether there is a statistically significant difference between either the intercept or deterioration rate for LDVs and LDTs certified to the same standard. The results are shown in the table below:

Parameter	**P-Value**	**Significant?**
Intercept	<0.0005*	Yes
Mileage	<0.0005*	Yes
Vehicle Class (Factorial)	0.254	No
Vehicle Class * Mileage	0.447	No

* P-Value equals zero to three significant digits

The lack of significance for vehicle class and class/mileage cross product indicates that there is no statistically significant difference in the intercept or deterioration rate for in-use LDVs and LDTs certified to the 0.4 g/mi standard. We therefore concluded that it was appropriate to aggregate the LDV and LDT data points at the 0.4 g/mi standard level.

The next step was to establish whether it was appropriate to disaggregate the analysis by certification standard class (Tier 0 and Tier 1). This issue has been raised by AAM, who suggested that the advent of Tier 1 standards and OBD would inherently reduce deterioration rates from Tier 0 vehicles, even if certified to the same standard. We assessed this issue by performing a multiple regression analysis on NOx emissions for the entire LDV/LDT1 normal emitter sample using a model with standard class (Tier 0 or Tier 1) as a factorial and mileage and the cross product of mileage and standard class as continuous variables. The purpose of this test was to determine whether there is a statistically significant difference between either the intercept or deterioration rate for Tier 0 and Tier 1 vehicles certified to the same standard. The results are shown in the table below:

[8]The raw datasets are contained in the Microsoft Excel files ARB.XLS, AUTO.XLS and EPA.XLS, located in the Tier 2 Docket.

Parameter	P-Value	Significant?
Intercept	<0.0005*	Yes
Mileage	<0.0005*	Yes
Standard Class (Factorial)	0.166	No
Standard Class * Mileage	0.504	No

* P-Value equals zero to three significant digits

The lack of significance for standard class and class/mileage cross product indicates that there is no statistically significant difference in the intercept or deterioration rate for Tier 0 and Tier 1 vehicles certified to the 0.4 g/mi standard. We therefore concluded that it was appropriate to include the Tier 0 0.4 g/mi vehicles in the analysis of Tier 1 emission rates.

4.1.1 Normal and High Emitter Emission Level

The average FTP normal emitter emission level was obtained by separating the normal emitters from the high emitters in the EPA/Auto/ARB sample according to the “2.0 times the standard” criteria (i.e. all vehicles in the sample above 0.8 g/mi were defined as high emitters). Using this cutpoint, 31 vehicles were defined as high emitters, and the remainder (1,153) were defined as normal emitters.[9] Figure 2 presents NOx emissions for the normal emitters versus mileage, broken down by the three data sources.

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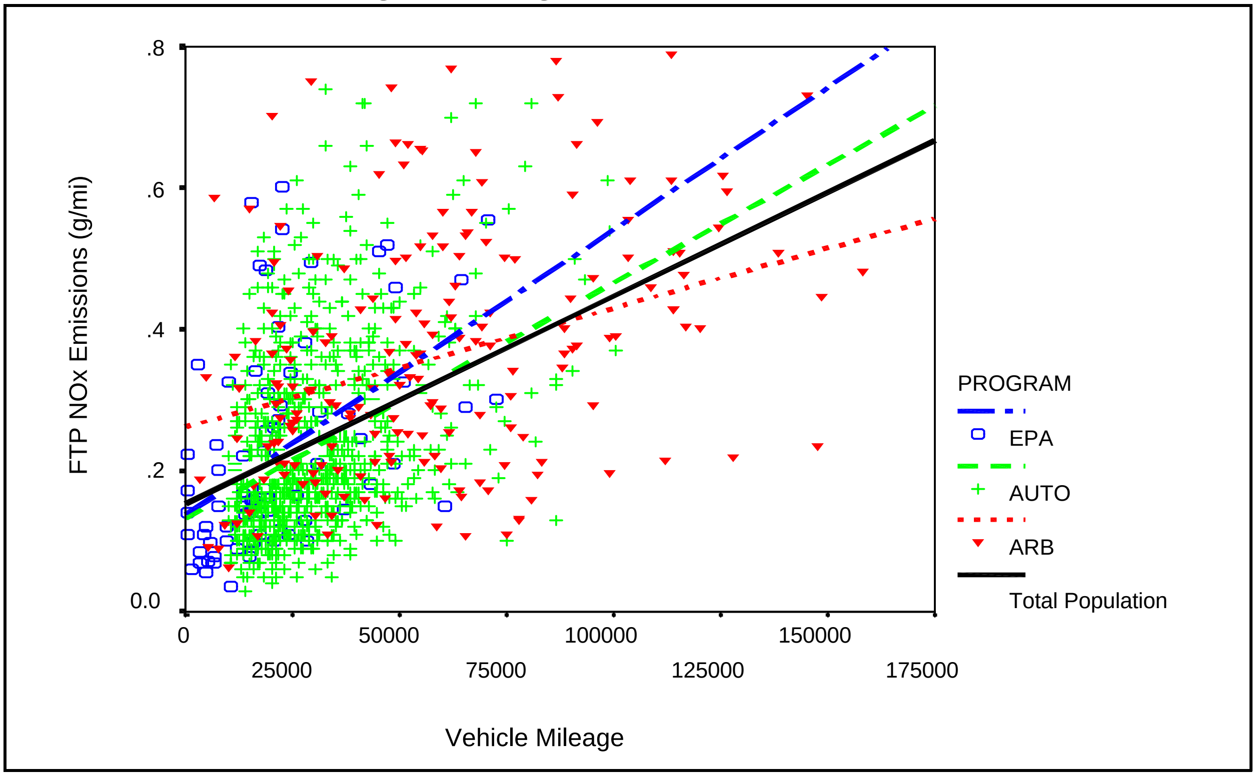
[9] One EPA vehicle with repeat tests had NOx results on either side of the high emitter threshold - one at 0.21 g/mi, and one at 1.31 g/mi. This vehicle was classified as a high emitter.

Figure 3 - 0.4 g/mi NOx Normal Emitters



The EPA and Auto data were generated on relatively new vehicles (generally under four years old); this is reflected by the scarcity of vehicles from either dataset above 75,000 miles. The ARB dataset, on the other hand, contains a broader range of vehicle ages and mileages, with several vehicles exceeding 75,000 miles. Despite the differences in sample makeup, we believe the combined dataset is appropriate for determining normal emitter emissions. Our basis for this is the fact that although the intercept of the EPA and Auto samples are much lower relative to the ARB sample, the deterioration rates are much higher; because of this, we expect that total emissions over the life of an average normal emitting vehicle would be comparable between the three samples. Given that we cannot assess which program is "more representative", and because the results from all of the samples appear reasonably consistent, the most straightforward approach for generating the NOx BER for normal-emitting Tier 1 LDVs and LDTs is to fit a linear regression of FTP emissions versus mileage through the entire sample, as represented by the "Total Population" line in Figure 2. The result of this regression is shown in Equation 5 (the variable 'odom' is in units of ten thousand miles).

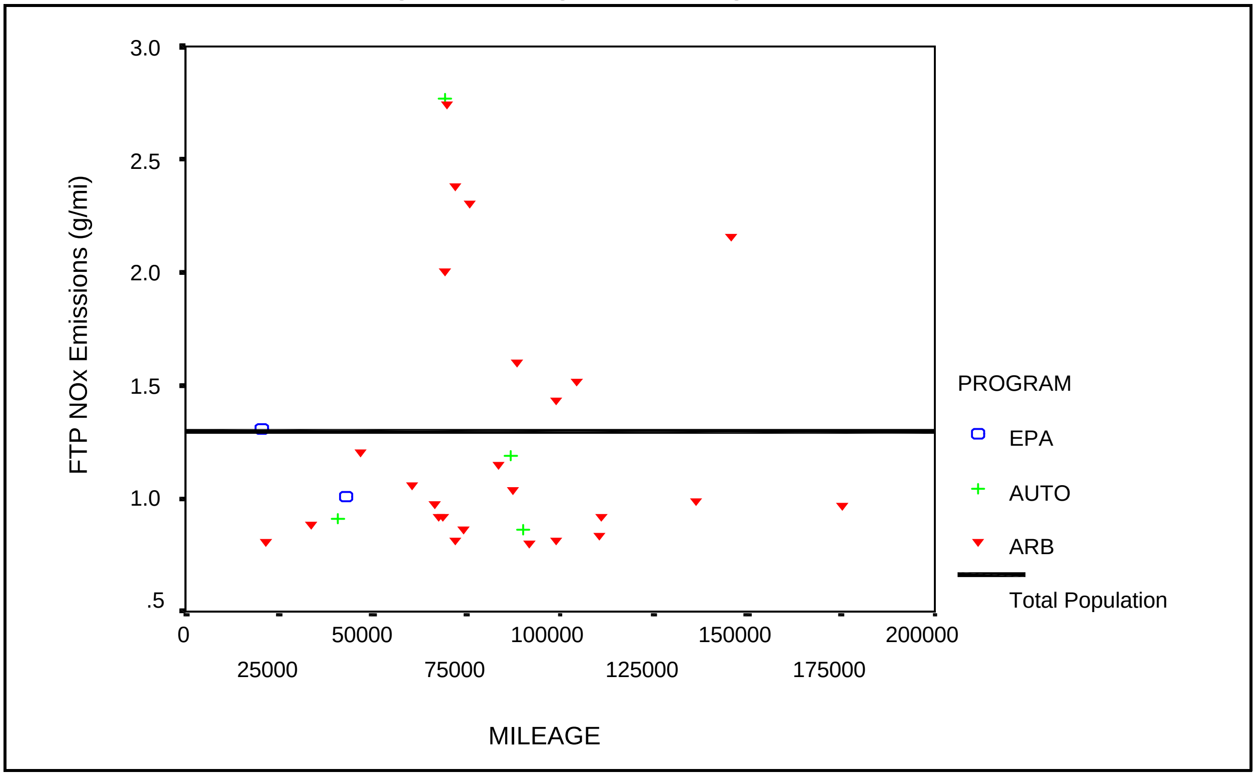
Norm_Ave(g/mi)[10] = 0.153 + 0.02941 * odom   Eqn 5

We used a similar approach for determining the NOx BER for high-emitting

[10]Complete results for the regression equations and averages presented in equation form are contained in Appendix C.

Tier 1 LDVs and LDTs. Figure 3 shows NOx emissions for the high emitters versus mileage, broken down by the three data sources.

Figure 4 - 0.4 g/mi NOx High Emitters



We generating the BER for high-emitting Tier 1 LDVs and LDTs by simply averaging the sample of 31 high emitters presented above. Based on comments from Colorado and Applied Analysis , we assessed whether this BER should include a deterioration term by performing a linear regression of these data; the slope (mileage) term was not statistically significant (p-value equal to 0.868). We therefore concluded that a straight average is still the most appropriate model for these vehicles. The resulting BER is as follows:

$$High\_Ave(g/mi) = 1.294 \qquad \text{Eqn 6}$$

4.1.2 High Emitter Fractions

As discussed in Section 3, high emitter fractions allow the computation of average in-use emissions based on normal and high emitting BERs. These fractions increase with vehicle age, and for OBD-equipped vehicles will be used as the basis for computing OBD and/or I/M benefits. It is at this stage of the NOx BER computation that key assumptions regarding the representativeness of recruitment-based[11] in-use emission testing program become relevant. Our analysis of in-use emission rates for Tier 0 LDVs and LDTs for MOBILE6 found a clear difference between average emissions of vehicles tested in voluntary recruitment-based FTP emission testing programs, and of vehicles tested in I/M programs (in which participation is mandatory).[12] This offset has been attributed to so-called "recruitment bias," in which owners of higher-emitting vehicles are less likely to respond to solicitations for participation in voluntary programs. For Tier 0 emission rates in MOBILE6, this offset was translated to a "high emitter adjustment factor". The NOx emission rates for Tier 1 and later vehicles developed above are based solely on data from voluntary recruitment-based FTP test programs. However, a direct comparison between data from these test programs and I/M data on Tier 1 vehicles (as was done for Tier 0 vehicles) cannot be performed; because of the relatively recent implementation of Tier 1 and standards and the tendency for new vehicles to be waived from I/M participation early in their life, sufficient IM data are not available on Tier 1 vehicles to derive a high emitter adjustment in a manner similar to that for Tier 0 vehicles. Because the FTP data used to generate the Tier 0 and Tier 1 NOx emission rates were collected within the same test programs, we believe it is necessary to apply a high emitter adjustment factor to the Tier 1 FTP data sample to account for the lack of representation of high emitters, as was done with the Tier 0 FTP data. As discussed below, the magnitude of this adjustment has been decreased from the level presented in the draft report.

Our draft methodology also included a second adjustment to "remove" the impact of California's I/M program, which the vehicles included in the ARB sample were subjected to. GM and AAM questioned the methodology used for generating this adjustment. While this issue is still of concern, we are not including such an adjustment in our final methodology. This adjustment was in fact very minor, as it was based on MOBILE5 I/M credits for an idle I/M program, which provides little benefit for NOx. Because we do not believe that MOBILE5 can be used to appropriately correct for such a bias we have eliminated the separate "I/M" adjustment.

The high-emitter adjustment is relevant at this stage of the calculation because they only affect the weighting of high and normal emitters - in other words, they were used to increase only the *number* of high emitters estimated in the fleet. As discussed in Section 3 (and shown in Equations (1) through(4)), the high/normal weighting factor is a function of normal and high emitter emission levels and their combined average in-use emission level. Emissions for normal and high emitters as computed in Equations (5) and (6) were not affected by this adjustment. The high-emitter adjustment was applied directly to the in-use average emission levels; based on normal and high emitter emissions computed from Equations (5) and (6), the high emitter fractions were then back-calculated using Equations (1) through (4). This methodology is

[11]"Recruitment-based" in-use emission testing programs are defined here as programs in which vehicles are procured for testing from the general population in exchange for money and/or other incentives. Participants are initially contacted through mail or phone solicitation based on registration mailing lists, and participation is strictly voluntary.

[12]Enns, et al, "Determination of Running Emissions as a Function of Mileage for 1981-1993 Model Year Light-Duty Cars and Trucks", EPA Draft MOBILE6 Report No. M6.EXH.001, March 1999

detailed in the following steps:

(1) The unadjusted average in-use NOx emission level as a function of mileage was computed from the combined EPA/Auto/ARB dataset. This FTP NOx emission average was obtained by linear regression of the raw data versus mileage. The resulting regression equation is shown below:

NOx FTP (g/mi) = 0.117 + 0.04617 * Odom   Eqn 7

(2) The second step was to generate an additive high emitter correction factor to account for the potential effects of recruitment bias on the EPA/AAM/ARB sample. While none of the stakeholder comments disgreed entirely with the application of this adjustment, opinions as to the appropriate level of this adjustment were varied. Colorado and Applied Analysis contended that this adjustment should be higher than proposed, because of concerns with the representativeness of the Dayton I/M data on which the adjustment was based; GM and AAM simply labeled our original methodology as arbitrary. In light of these comments, we have reevaluated how this NOx high emitter adjustment for Tier 1 and later vehicles should be derived. We still consider it appropriate to base the Tier 1 adjustment on the Tier 0 high emitter adjustment in the absence of sufficient I/M data on Tier 1 vehicles. To assess whether the Tier 0 adjustment should be reduced for Tier 1, we compared average FTP emission results for Tier 0 and Tier 1 high emitters,. The Tier 1 high-emitter BER calculated in Equation (6) (1.294 g/mi) is 56 percent lower than average high-emitter emissions for 1988-1993 ported fuel injection (PFI) Tier 0 LDVs planned for MOBILE6 (2.96 g/mi).[13,14] Thus, the high emitter adjustment applied in the derivation of Tier 1 and later emission rates was calculated by reducing the high emitter adjustment for 1988-1993 PFI Tier 0 LDVs by 56 percent, versus 25 percent used in draft report. This is reflected in Equation (8).

HECF = 0.00466 * Odom   Eqn 8

Where:

HECF is the high emitter correction factor.
Odom is the mileage, in ten thousands

(3) The corrected in-use average NOx FTP results (C_NOXFTP) were obtained by applying the high emitter adjustment factor from Equation 8 to the raw NOx FTP value from

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[13]Enns, et al, "Determination of Running Emissions as a Function of Mileage for 1981-1993 Model Year Light-Duty Cars and Trucks", EPA Draft MOBILE6 Report No. M6.EXH.001, March 1999; Glover and Carey, "Determination of Start Emissions as a Function of Mileage and Soak Time for 1981-1993 Model Year Light-Duty Vehicles", EPA Draft MOBILE6 Report No. M6.STE.003, March 1999

[14]Calculated values for 1988-1993 Tier 0 PFI NOx high emitters vary slightly by mileage; this represents the value at 68,000 miles, the average in-use mileage for LDVs based on MOBILE6 travel fraction.

Equation 7, as shown in Equation 9.

C_NOXFTP = (NOx FTP + HECF) Eqn 9

(4) The fraction of high emitters in the fleet under NO I/M and NO OBD conditions (labeled $High_{BASE}$) is calculated by inserting the value of C_NOXFTP, Norm_ave, and High_ave (from Equations (5) and (6)) into Equation (3). Mathematically, this is shown in Equation 10.

$High_{BASE}$ = (C_NOXFTP - Norm_ave) / (High_ave - Norm_ave) Eqn 10

The resulting high emitter fractions for the No OBD/No IM case for ages one through 25 are shown in Appendix A, Table A-1 (mileage levels as a function of age are shown in Appendix A, Table A-3). Because the intercept from Equation (7) is less than the intercept from Equation (5), Equation (10) resulted in a negative high-emitter fraction for vehicle ages less than two. For these years the high-emitter fraction was set to zero, in effect estimating that vehicles won't become high emitters until at least the third year of their life.

The average in-use FTP-based NOx emission level for Tier 1 LDVs without OBD or I/M can be calculated at any vehicle age using Equation (2), based on the terms "High_ave" (Equation 6), "Norm_ave" (Equation 5), and "Highs" (Equation 10). According to Equation (4), "Normals" is simply 1 - Highs.

4.2 All Other Standard Levels and Vehicle Classes

NOx BERs for No OBD / No IM conditions are required for LDVs under post-Tier 1 standards, and all Tier 1 and later LDTs (LDT1 through 4). At the time of this analysis, EPA was not aware of any dataset which provided an adequate sample of in-use data for these combinations of vehicles class and standard level. BERs for these classes were derived from the Tier 1 LDV BERs developed above, using a set of specific assumptions about how average emissions for normal and high emitters, and high emitter fraction, would apply across standard level and class.

4.2.1 Normal Emitters

It was assumed that for post-Tier 1 LDVs and Tier and later LDTs, normal emitter NOx emissions will on average maintain the same performance relative to the applicable 50,000 mile standard as Tier 1 LDVs. Thus, normal emitter BERs for all post-Tier 1 LDVs and Tier 1 and later LDTs were developed by calculating the ratio of the applicable standard level ("std") to the Tier 1 LDV standard, and applying this ratio to the Tier 1 BER (zero-mile level and deterioration rate), as follows:

Norm_ave ZML(std) = Norm_ave ZML(tier1ldv) * (Cert Std(std) / Cert Std(tier1 ldv)) Eqn 11a

Norm_ave DR(std) = Norm_ave DR(tier1 ldv) * (Cert Std(std) / Cert Std(tier1 ldv)) Eqn 11b

For example, normal-emitting LDV LEV BERs were generated by multiplying the normal-emitting Tier 1 ZML and DR from Equation (5) by 0.5 (0.2 g/mi divided by 0.4 g/mi, the 50,000 miles standards).

The rationale behind this approach is that basic emission levels for properly operating vehicles should receive the full benefit of reduced standards, including lower deterioration rates for lower standard levels. This approach presumes that normal emitters for all standards and vehicle classes will on average achieve the same compliance margin ("headroom") with the 50,000 mile certification standard as the normal emitters observed in the EPA/Auto/ARB 0.4 NOx data.

With regards to trucks, this approach acknowledges that LDT emission performance relative to the standard is expected to be similar to LDVs because of increased similarities in a) emission control technology, b) manufacturer design practices, and c) driving and usage patterns. In general, sufficient in-use data do not exist to empirically establish emission rates for Tier 1 and later LDTs; some level of judgement about how these vehicles will perform in-use is therefore required. Stakeholder comments varied on how LDTs should be treated relative to LDVs. Applied Analysis suggesting that LDTs have higher emissions than LDVs; however, their analysis was based on a comparison of I/M data on LDVs and LDTs which doesn't appear to consider higher certification standards for trucks. Our emission rates do project higher emissions for LDTs certified to higher standards, but not at the same certification standard. GM and AAM suggested that our emission rates for LDTs were too high, based on certification data and in-use Tier 0 data; their analysis has several flaws, however, as discussed in Section 27.4.(J) of the Tier 2 Response to Comments.

To assess this issue, we performed two analyses: first comparing Tier 1 LDVs and LDTs certified to the same standard, then LDVs and heavier LDTs certified to their respective Tier 1 standards. A univariate regression analysis was performed on NOx emissions for the entire LDV/LDT1 normal emitter sample using a model with vehicle class (LDV or LDT) as a factorial and mileage and the cross product of mileage and class as continuous variables. The purpose of this test was to determine whether there is a statistically significant difference between either the intercept or deterioration rate for LDVs and LDTs certified to the same standard. The results are shown in the table below:

Parameter	**P-Value**	**Significant?**
Intercept	<0.0005*	Yes
Mileage	<0.0005*	Yes
Vehicle Class (Factorial)	0.254	No
Vehicle Class * Mileage	0.447	No

* P-Value equals zero to three significant digits

The lack of significance for vehicle class and class/mileage cross product indicates that there is no statistically significant difference in the intercept or deterioration rate for in-use LDVs and LDTs certified to the same Tier 1 standard.

To assess this issue for heavier trucks, an analysis of in-use emissions from heavier LDTs was performed on a sample of 50 discrete tests of 38 late-model Tier 1 LDT2s and LDT3s tested by EPA (37) and ARB (1). The majority of these vehicles were under 3 years old when tested and had an average mileage below 30,000 miles (the maximum mileage was 93,000). The emission levels of this sample reflected its newness; all tests complied with the 50,000 mile NOx standard of 0.7 grams per mile. Overall, we do not consider this sample adequate for generating in-use emission rates directly; but, it is useful for comparing emission performance relative to the standard and early in a vehicle's life with a sample of comparable Tier 1 LDVs. To determine whether the emission performance of the LDTs relative to the 0.7 g/mi standard was different from the performance of comparable Tier 1 LDVs relative to the 0.4 g/mi standard, we performed a multiple regression analysis on a sample consisting of the LDT2/3s and a subset of Tier 1 LDVs which complied with the 0.4 gram/mile standard. The dependent variable for this analysis was "headroom", calculated by dividing each emission test by the standard (to normalize across the two standard levels). Vehicle class (LDV or LDT) was a factorial and mileage and the cross product of mileage and class were continuous variables. The results are shown below:

Parameter	**P-Value**	**Significant?**
Intercept	<0.0005*	Yes
Mileage	<0.0005*	Yes
Vehicle Class (Factorial)	0.813	No
Vehicle Class * Mileage	0.912	No

* P-Value equals zero to three significant digits

The lack of significance for vehicle class and class/mileage cross product indicates that there is no statistically significant difference in the intercept or deterioration rate relative to the standard for a sample of comparable Tier 1 LDVs and LDT2/3s, despite a higher emission standard for the LDT2/3s.

Based on these analyses, we believe it is appropriate to treat LDVs and LDTs the same with regard to generating Tier 1 and later emission rates.

4.2.2 High Emitters

High Emitter BERs are meant to estimate emissions from vehicles that significantly exceed their certification standards due to malfunctioning emission control systems. A key assumption in the development of high-emitter BERs is that, as emission standards are lowered (or “raised” for truck BERs), emission levels for high emitters will not be changed in proportion to the standard change. This approach is based on our judgement that post-Tier 1 vehicles are increasingly reliant on catalyst conversion efficiency to maintain compliance with the standard, so that tailpipe emissions are increasingly sensitive to degradation of catalyst conversion efficiency. Comments from Applied Analysis supported this reasoning, in fact contending that increased dependence on catalyst conversion may mean that high emitter emissions should not be reduced with decreases in certification standard. Conversely, GM and AAM supported a reduction in high emitter emissions fully proportional to the decrease in certification standards.

To assess this issue, we analyzed available engine-out emission data for Tier 1 vehicles tested as part of the Supplemental Federal Test Procedure (SFTP) review project, and a combined sample of LEV/ULEVs tested as part of the auto industry’s sulfur test program. This analysis shows that LEV/ULEV high emitters would actually have better catalyst conversion efficiency than Tier 1 high emitters, although their emission levels would be higher relative to the 50,000 mile standard than Tier 1 high emitters. This is illustrated in the following table:

NOx	Engine-Out FTP NOx Emissions	Projected catalyst efficiency at 50K standard	Projected catalyst efficiency at high emitter emission rate
Tier 1	2.33 g/mi[15]	83%	45%
LEV/ULEV	2.59 g/mi[16]	92%	63%
HC	Engine-Out NMHC Emissions	Projected catalyst efficiency at 50K standard	Projected catalyst efficiency at high emitter emission rate
Tier 1	1.90 g/mi[4]	87%	12%
LEV/ULEV	1.50 g/mi[5]	95%	18%

As shown, the reductions necessary to meet the tighter LEV standards come primarily from improvements in the catalyst. This means that similar drops in catalyst conversion efficiency will more adversely affect the emissions of LEVs, and result in higher emissions relative to the 50,000 mile certification standard than for Tier 1 vehicles. This analysis shows that degradation in NOx catalyst efficiency between normal and high emitters would actually be less for LEVs than for Tier 1 vehicles under our assumption that LEV high-emitter emissions would only be reduced by ½ of the reduction in the 50,000 mile certification standards.

[15] Source: “Supplemental FTP Emissions Database”, CD distributed by AAMA/AIAM, January 1997 (21 vehicles)

[16] Source: AAMA Sulfur Test Program (9 vehicles). Higher NOx engine-out results for LEVs are considered a function of manufacturer’s attempts to improve HC performance and catalyst light-off through engine calibration strategies, such as a leaner fuel mixture at startup (as indicated by reductions in engine-out HC).

A second approach to assessing our estimates of high emitter emissions is to analyze trends in available Tier 0 and Tier 1 data (this analysis was performed only for NOx, since available Tier 1 data for HC is from relatively new vehicles and does not include any high emitters). Although the combined EPA/AAM/ARB dataset does not include any post-Tier 1 vehicles, the trend towards less-than-proportional decreases in high emitter emissions as certification standards are lowered does bear out based on a very limited sample of catalyst-equipped (1988 and later) LDV/LDT1 high emitters:

1 NOx Standard	**2** Percent reduction in certification standard	**3** High emitter sample size	**4** Average emissions (g/mi)	**5** Percent reduction in average high emitter emissions from previous standard level	**6** Percent proportional (Column 5 / Column 2)
1.0 (Tier 0)	-	8	2.46	-	
0.7 (Cal Tier 0	30% (from 1.0 standard)	3	1.85	25%	83%
0.4 (Tier 1)	43% (from 0.7 standard)	31	1.29	30%	70%

Column 2 in the table above shows the percent reduction in certification standard level, from Tier 0 through Tier 1; Column 5 shows the percent reduction in high-emitter emissions at these standard levels. The fact that the values in Column 5 are lower than in Column 2 means that emission levels for high emitter are not reduced in proportion to the certification standard, which supports the underlying assumption for our development of post-Tier 1 high-emitter emission rates. Column 6 shows the decrease in high emitter emissions relative to the decrease in certification standards (comparable to our estimate of 50 percent proportional for post-Tier 1 high emitters). This value decreases as the standard level drops from 1.0 g/mi to 0.7 g/mi, and 0.7 g/mi to 0.4 g/mi; in other words, decreases in high emitter emissions become less and less proportional to decreases in the standard, for lower standards. We expect this trend to continue for post-Tier 1 standards, based on our analysis of engine-out emissions for post-Tier 1 vehicle presented above; extrapolating these results, we believe it is reasonable to assume only a 50 percent proportional drop in high emitter emissions as standards are reduced beyond Tier 1 levels.

BERs for high emitters were thus developed for post-Tier 1 LDVs and Tier 1 and later LDTs by taking the average of the Tier 1 LDV high emitter NOx BER (1.278 g/mi) and the BER that would result if the ratio of 50,000 mile standards were applied to the Tier 1 BER, according to Equation 12:

$$High\_ave(std) = average[High\_ave(tier1ldv) * (Cert\ Std(std) / Cert\ Std(tier1\ ldv)),\ High\_ave(tier1ldv)] \qquad \text{Eqn 12}$$

The result of this average is a high emitter BER which is 50 percent proportional to the change in standard, reflecting that malfunctioning vehicles will derive some benefit on average from lower emission standards, but not the full benefit as afforded to normal emitters. High emitter emissions are therefore tied closely to the Tier 1 LDV high emitter level, and the change in high emitter emissions is “muted” relative to changes in standard.

Normal and high emitter BERs for LDVs and LDTs complying with Tier 1, LEV and ULEV standards are presented in Appendix B.

4.2.3 High Emitter Fractions

The rate at which vehicles become high emitters under the No OBD / No IM scenario was assumed constant for all vehicles and standard classes. Thus, the age-based high emitter fractions developed in Equation 10 and presented in Appendix A were applied to Tier 1 and later BERs for all classes. The rate of emission control technology malfunction was assumed the same between LDVs and LDTs, given that their emission technology and usage patterns are increasingly similar. Reduced certification standards are also not expected to influence the rate at which emission control technology malfunctions, because a) manufacturer’s design and durability practices are not expected to differ between Tier 1 and later standards, and b) many cases of emission control degradation and/or malfunction are owner-induced, and hence outside the manufacturer’s liability for in-use emission performance. It should be noted that the high-emitter fractions in Appendix A are shown to vary by class, due to differences in accumulated mileage at a given age. At the same mileage, the high emitter fractions are the same across all classes.

The No OBD / NO I/M average in-use NOx emission rate for *vehicle/standard = (V,S)* can be calculated at any vehicle age using Equation (2), based on a) the Tier 1 LDV “High_ave” and “Norm_ave” terms from Equations (5) and (6) adjusted as described above based on the *(V,S)* standard level, and b) the base (No OBD / No IM) high emitter fractions from Appendix A, Table A-1.

5 NMHC/NMOG BERs and Emitter Fractions: No IM/No OBD Case

The development of NMHC/NMOG BERs shared many of the methodological assumptions outlined for NOx in Section 3. As with NOx, NMHC BERs for Tier 1 and NMOG

BERs for LEV and later LDVs and LDTs were developed off of “base” LDV BERs; the primary difference between the methodologies for the two pollutants was the source of the base data. At the time of this analysis, sufficient in-use data on vehicles complying with EPA’s Tier 1 NMHC standards (for any vehicle class) were not available. The EPA/Auto/ARB dataset used for the NOx analysis included 143 LDVs/LDT1s and 38 LDT2/3's certified to the Federal Tier 1 standard. However, these vehicles were generally less than four years old at the time of testing. As such, these data were judged to be inadequate for assessing overall in-use emission deterioration of Tier 1 LDVs. As discussed below, however, we did use these data to validate the zero-mile level of the predicted Tier 1 normal emitter emission rate, and to verify the appropriateness of basing emission rates for heavier LDTs on LDV emission rates.

Tier 1 and later HC BERs were based on proposed MOBILE6 BERs for model year 1988 through 1993 Tier 0 LDVs with ported fuel injection (PFI). These BERs were developed based on several thousand vehicles tested by auto manufacturers, EPA, and through I/M programs. The Tier 0 emission rates were considered a good starting point for developing Tier 1 and later BERs because emission control technology used on later Tier 0 vehicles (e.g., 3-way catalysts and ported fuel injection) are generally similar to those used on Tier 1 and later vehicles. A comprehensive treatment of Tier 0 BERs and the datasets used to derive them are contained in other MOBILE6 reports, and thus are not presented here. For this analysis a simplifying step was performed to generate a linear form of Tier 0 normal-emitter BERs, since as proposed for MOBILE6 these are expressed as nonlinear functions.[17] The resulting normal and high emitting Tier 0 BERs (expressed as Total Hydrocarbon, or THC) used as a basis for Tier 1 and later BERs are shown in Equations (13) and (14).

$$\text{Norm\_Ave(g/mi)} = 0.16 + 0.0186 * \text{odom} \qquad \text{Eqn 13}$$

$$\text{High\_Ave(g/mi)} = 2.076 \qquad \text{Eqn 14}$$

“odom” represents mileage in units of ten thousand miles.

Using the values presented in Equations (13) and (14) as a starting point, normal and high emitter NMHC/NMOG BERs for all Tier 1 and later LDVs and LDTs were developed using the identical methodology as for NOx (described in Sections 3.2.1 and 3.2.2) based on the ratio of the applicable 50,000 mile standard level to the Tier 0 level of 0.41 g/mi. Since Tier 1 standards are expressed as NMHC and LEV and later standards are expressed as NMOG, the shift from THC to these pollutants is accounted for in the standard ratios.

We assessed the validity of the predicted Tier 1 zero-mile level (intercept) by comparing this level with emission from nine Tier 1 LDVs/LDT1s (13 tests) within the EPA/Auto/ARB

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[17] Equations 13 and 14 were derived by first combining the running and start emission rates for normal-emitting 1988-1993 PFI LDVs according to FTP weightings. The raw running and start emission rates can be found in MOBILE6 report M6.IM.001, “MOBILE6 Inspection/Maintenance Benefits Methodology for 1981 through 1993 Model Year Light Vehicles”. At a given mileage, FTP emissions were derived from start and running emission rates according to Equation 26. For normal emitters, the combined non-linear FTP emission rates were then regressed by mileage to create a simple linear model, resulting in Equation 13.

dataset with odometer readings below 5,000 miles. This comparison is shown in the following table:

	Average FTP NMHC Emissions	95% CI Lower Bound	95% CI Upper Bound
Predicted Tier 1 LDV/T1 Zero-Mile Level	0.098 g/mi	-	-
Actual Tier 1 LDV/T1 below 5,000 miles	0.091 g/mi	0.083 g/mi	0.122 g/mi

As shown, the difference between our predicted value and the actual emission results is not statistically significant, since the predicted average falls within the 95 percent confidence band of the 5,000 mile data.

In their comments, Applied Analysis provided a summary of I/M data which showed higher emissions for LDTs relative to LDVs over the 1994-1995 model years, and suggested that LDTs should be modeled separately from LDVs. Again, this analysis doesn't appear to consider higher certification standards for trucks; their results are consistent with our approach to generating emission rates for LDTs with higher certification standards.

To assess the appropriateness of basing emission rates for heavier LDTs on the LDV emission rates, we compared a sample of Tier 1 LDVs/LDT1s with the sample of Tier 1 LDT2/3s discussed under Section 4.2.1. As mentioned, we do not consider either sample adequate for generating in-use emission rates directly; but, it is useful for comparing emission performance relative to the standard. To determine whether the emission performance of the LDTs relative to the 0.32 g/mi standard was different from the performance of comparable Tier 1 LDVs relative to the 0.25 g/mi standard, we performed a multiple regression analysis on a sample consisting of normal-emitting LDT2/3s (all were below the standard except for one vehicle well above the high-emitter cutoff, and one at 1.5 times the standard; we excluded the high-emitting vehicle) and a subset of Tier 1 LDVs below 1.5 times the 0.25 gram/mile standard. The dependent variable for this analysis was "headroom", calculated by dividing each emission test by the standard (to normalize across the two standard levels). Vehicle class (LDV or LDT) was a factorial and mileage and the cross product of mileage and class were continuous variables. The results are shown below:

Parameter	P-Value	Significant?
Intercept	<0.0005*	Yes
Mileage	<0.0005*	Yes
Vehicle Class (Factorial)	0.218	No
Vehicle Class * Mileage	0.608	No

* P-Value equals zero to three significant digits

The lack of significance for vehicle class and class/mileage cross product indicates that there is no statistically significant difference in the intercept or deterioration rate relative to the standard for a sample of comparable Tier 1 LDVs and LDT2/3s, despite a higher emission standard for the LDT2/3s.

The high emitter fractions developed for 1988 through 1993 Tier 0 PFI LDVs were used as the No OBD/No IM emitter fractions for all Tier 1 and later vehicles, because of the expected similarity in vehicle malfunction rates across standard level and vehicle class as discussed in Section 3.2.3. Subsequent to publication of the draft report, we found an error in these rates; The corrected rates show a lower fraction of high emitters than originally reported. These corrected rates are shown in Appendix A, Table A-2.

The No OBD / No IM average in-use NMHC/NMOG emission rate for *vehicle/standard = (V,S)* can be calculated at any vehicle age using Equation (2), based on a) the Tier 0 "High_ave" and "Norm_ave" terms from Equations (13) and (14) adjusted based on the *(V,S)* standard level, and b) the base (No OBD / No IM) high emitter fractions from Appendix A, Table A-2.

6 Effects of OBD and OBD-based I/M for NOx and HC

Separate BERs were developed for all standard and vehicle classes to account for the effects of OBD and OBD-based I/M programs. The methodology used to account for these programs were identical for NOx and HC, based on reducing the fraction of high emitters in the fleet from the No OBD/No IM case. Thus, emission levels for normal and high emitters were not changed under these programs, only the fraction of highs in the fleet. This methodology introduces a new category of vehicle into the fleet: "Repaired" emitters. These vehicles are high emitters that are flagged by an OBD system and undergo successful repair. For the OBD-only and OBD/IM cases, these vehicles are treated distinctly from normal and high emitters (although our revision of OBD after-repair levels means that normal emitters and repaired emitters have the same emission level for most of a vehicle's life).

6.1 OBD Effectiveness

OBD effectiveness is defined by three parameters: a) the probability the OBD system will detect a failure (MIL-on Rate), b) the probability an owner will respond to a MIL-on (Response

Rate), and c) the average after-repair emission level for responding vehicles (Repair Level). In general sufficient in-use data are not available to determine in-use patterns for these parameters, although limited data has recently been published which allows some assessment of our estimates for MIL-on rate and post-repair emissions.[18] Our estimates for the projected likelihood of malfunction detection, owner response and repair level are presented in Sections 5.1.1 through 5.1.3 for both the OBD-only and OBD/IM cases.

6.1.1 MIL-on Rate

For all vehicle classes and standards, we are maintaining our original proposal that OBD systems will detect (i.e., set an appropriate code and illuminate the MIL) 85 percent of high emitters. Because high emitters are defined independently for HC and NOx, this response rate is assumed to apply equally to both pollutants. The remaining 15 percent of fleet will not be identified, and thus will remain in the fleet as high emitters. No deterioration in the ability of the OBD system to correctly identify high emitters is assumed. Because this parameter is solely dependent on the vehicle's OBD system, it is the same for I/M and non-I/M areas.

Stakeholder comments were mixed on this issue; Colorado supported our proposal, while AAM contended that the MIL-on rate should be increased to as high as 100 percent. Sufficient data are not available to empirically estimate the effectiveness of and response to OBD systems in the field over the life of a vehicle, and the stakeholder comments did not provide any quantitative data on which to base a change. AAM contends that our assumptions should reflect how OBD systems are required to perform in-use; using this logic, it could also be argued that our estimates of in-use emission rates should assume that vehicles only comply with the FTP emission standard, since this is the requirement manufacturers are held to in-use. However, in-use emission test programs repeatedly verify that vehicles do exceed their FTP emission standard, particularly beyond the useful life mileage point on which the standards are based. Accordingly, it is reasonable to assume that not all OBD systems will perform as intended by the manufacturer, particularly beyond the mileage level for which they are held liable for its performance.

Two potential limitations of current OBD systems must be taken into account when predicting the real-world performance of these systems. First, current OBD systems are required to identify problems with individual components of the emission control system which can cause a vehicle to exceed its emission standards by a factor of 1.5. It is possible in-use, however, for a combination of minor problems to cause a similar level of emission increase. Current OBD systems will most likely not detect such a situation, as long as any individual problem is minor. Second, catalyst performance monitoring is still limited by available technology. The HC conversion efficiency of a catalyst is usually inferred from the oxygen storage capacity of the catalyst; the assumption being that if a catalyst experiences sufficiently high temperatures to significantly reduce its HC conversion efficiency, the same high temperatures will have significantly reduced its oxygen storage capability. This is supported by lab-based correlations,

[18] Gardetto. E., and Trimble, T., "Evaluation of On Board Diagnostics for Use In Detecting Malfunctioning and High Emitting Vehicles", EPA Report EPA420-R-00-013, August 2000

but may not be as accurate a predictor in-use. Adequacy of the CO and NOx conversion efficiencies of the catalyst are not even indirectly measured, but are assumed to be the same as the HC conversion efficiency.

EPA's recently published results for the assessment of OBD performance on high-emitting vehicles echoes some of these themes. This study reports that of 21 vehicles over 2.0 times the applicable certification standard, the OBD system caught 19 (a 90 percent success rate). Of 31 vehicles over 1.5 times the applicable certification standard, the OBD system caught 27 (an 87 percent success rate). The study confirms the concern about the catalyst monitor discussed above; some of the "missed" vehicles were cases in which the CO and/or NOx emissions had high emissions, but were not flagged because the HC emissions were not above the OBD threshold. It is also important to note that, as OBD technology is relatively new, these vehicles were all under four years old when tested. As a result, these vehicles are less likely to exhibit the synergistic effects of multiple minor problems discussed above. Our estimate of OBD failure detection rate must take into account the average performance of the OBD system under all conditions, over the entire life of a vehicle. Given the uncertainty in how these systems will perform in-use (particularly at higher mileages, where the highest concentration of emission malfunction will occur), and the technical considerations detailed above, our estimate that on average 85 percent of emission failures will be detected by the OBD system is not unreasonable. It goes without saying, however, that this issue will need to be revisited as OBD information becomes available on older vehicles.

6.1.2 Response/Repair Rate

In order to obtain emission reductions from a vehicle equipped with an OBD system, not only must the system correctly identify the vehicle, but the motorist must also respond to the MIL and take corrective action in a timely manner (response rate) and the vehicle must be fixed correctly (repair rate). MOBILE6 uses separate estimates for these rates depending on whether an OBD-based I/M program is being modeled, with different connotations depending on which case in invoked. For OBD I/M programs, response rate is handled in MOBILE6 through the estimates of noncompliance and cost waivers applied to the I/M program inputs. Hence, for the OBD I/M case the value discussed here reflects only the rate of repair for MIL-on vehicles which show up to the I/M station and do not qualify for a cost waiver. This repair rate for OBD/IM areas is assumed to be 99 percent over the entire life of the vehicle; it was not made 100 percent simply to reflect the slight possibility that a vehicle with OBD failure is not detected as such in an I/M lane. The original proposal was for a combined response/repair rate of 90 percent, which accounted for the combination of cost waivers and noncompliance. This change has been made to allow cost waivers and noncompliance to be handled consistently with exhaust-based I/M benefit calculations discussed in M6.IM.001; to not make this change would results in double-counting of cost waiver and noncompliance effects.

For non-IM areas, this value reflects a combined response/repair rate for vehicles in which the MIL is illuminated. This repair/response rate is assumed to be a function of vehicle warranty. It is assumed that an owner is much more likely to respond to a MIL-on when repairs will be paid for by the manufacturer. Three mileage bins were therefore developed: 1) 0 through

36,000, the standard bumper-to-bumper warranty period; 2) 36,001 to 80,000, for which federal law mandates that catalysts and electronic control modules (ECMs) remain under warranty; and 3) above 80,000, for which no warranty is in effect (extended warranties are not accounted for in this methodology).

Under 36,000 miles, it is assumed that 90 percent of MIL-on vehicles will be repaired. This is based on the judgment that for new vehicles still under warranty, owners will have little hesitation in addressing a MIL-on. The 10 percent loss accounts for a small percentage of owners who will not respond to a MIL-on even with the warranty incentive.

Between 36,000 miles and 80,000 miles, it is assumed that 10 percent of MIL-on vehicles will be repaired. This response rate is greatly reduced from the pre-36,000 mile level to account for the discontinuation of warranty coverage on several emission-related components (e.g. secondary air, EGR, oxygen sensors, fuel injectors), and reduced willingness of owners to make emission-related repairs on an aging vehicle in the absence of an I/M program.

Above 80,000 miles, it is assumed that no MIL-on vehicles will be repaired. This assumption reflects the end of warranties, the lower economic value of the vehicle, and the (further) reduced willingness of owners to make emission-related repairs in the absence of an I/M program.

Stakeholder comment on these estimates was mixed. Colorado supported these estimates, citing results from their I/M program which show that many newer vehicles are failing their I/M program due to MIL lights, which "seems to point to general disregard to MIL indications". AAM and GM contend that response rates during the warranty period should be higher (up to 100 percent), and that post-warranty response rates in non-I/M areas should decrease more gradually, mirroring the gradual depreciating value of the vehicle. GM also contends that our response/repair rate in I/M areas assumes that owners will receive repair almost immediately upon MIL illumination. The issue of owner response, particularly in non-I/M areas, is at this time strictly a matter of judgement. Recommendations made by AAM and GM reflect their own judgement, with no data provided to substantiate their claims. With regard to the duration prior to repair, MOBILE6 is structured to estimate emissions based on a "snapshot" of the fleet once per year, meaning that in essence the distribution between "normal", "high" and "repaired" vehicles is assessed once per year. Implicit within this structure is the assumption that vehicles have up to one year (or six months on average) to become a high emitter and receive repair. This presumes an annual I/M program; MOBILE6 will allow the flexibility for other program intervals.

6.1.3 Repair Level

We have revised our estimates regarding the level to which vehicles will be repaired through response to an OBD system failure. Our proposal estimated that vehicles on average would be repaired to 1.5 times the 50,000 mile standard, where it would remain constant (not deteriorate) for the remainder of its life. This emission level is the maximum allowed before the OBD light should come on. Colorado supported this approach, while AAM and GM commented that it is overly conservative, and recommended that the after-repair level be 1.0 times the FTP standard, without deterioration.

Based on our analysis of after-repair data from IM240 programs, we believe that after-repair emission levels will be lower than our original estimate, but that emissions from these vehicles will deteriorate in a manner more consistent with normal emitters. Our revised approach to modeling after-repair emissions is to therefore assume that upon repairs, high emitters are returned to the normal emitter emission level at the appropriate mileage point. On average this approach actually presumes lower after-repair emissions than for dynamometer-based exhaust I/M programs; we consider this to be appropriate given that OBD systems will likely improve diagnosis of emission malfunctions, a conclusion reinforced by EPA's recently published OBD study.

The after-repair emission levels are capped at 1.5 times the standard, the threshold for OBD failure detection. This occurs at approximately 150,000 miles for NOx, and nearly 240,000 miles for HC (the levels at which the normal emitter equations presented in Equations (5) and (13) equal 1.5 times the applicable standard - 0.6 and 0.615 g/mi, respectively). After these mileage points a third emitter category is required - "repaired" emitters. Repaired emitters are assumed to have constant emissions at the after-repaired emission level, although a subset of these vehicles "migrate" back to the high emitter category. The emission level after an OBD-induced repair above these mileage thresholds is assumed to be 1.5 times the applicable 50,000 mile certification standard. The repaired emitter "BER caps" are presented across standard and vehicle class in Appendix B.

6.2 High Emitter Fractions for OBD and OBD-based I/M

Equations 15 through 17 were used to calculate the high emitter growth rate under the OBD and OBD-based I/M scenarios ($High_{OBD}$). Overall, the high emitter fraction in a given year is a function of a) the number of high emitters in the previous year, b) the base high emitter "growth rate" in the absence of OBD or I/M, and c) the OBD effectiveness assumptions outlined in Section 5.1. The subscript 'i' is the vehicle age. High(0) is assumed to be zero. MOBILE6 will assign a value of 'odom' for each age 'i'.

$$Nonhigh(i) = 1.0 - High_{BASE}(i) \quad \text{Eqn 15}$$

$$Delta\_High(i) = High_{BASE}(i) - High_{BASE}(i-1) \quad \text{Eqn 16}$$

$$Growth\_High(i) = Delta\_High / Nonhigh(i-1) \quad \text{Eqn 17}$$

$$High_{OBD}(i) = High_{OBD}(i-1) + [(1-OBD)*MIL*Growth\_High(i)*(1-High_{OBD}(i-1))] + [(1-MIL)*Growth\_High(i)*(1-High_{OBD}(i-1)] \quad \text{Eqn 18}$$

Where:

$High_{OBD}(0)$	=	0.0
MIL	=	0.85
Nonhigh	=	the fraction of normal and repaired vehicles
Growth_High	=	the growth rate of high emitters (or, the rate at which “nonhighs” migrate into the high emitter category)

‘OBD’ is the OBD response rate; 0.90 for OBD-based I/M, and 0.90/0.10/0.0 for mileage bins (0 - 36K), (36K - 80K), and (80K+).

An elaboration on Equations 15 through 18 is as follows: for a given vehicle age, the fraction of high emitters is a) the number of highs from the year before, plus b) the number of MIL-on highs added in that year due to OBD nonresponse (a function of “nonresponse” rate, MIL-on rate, and the high emitter growth rate applied to the available pool of normal and repaired vehicles), plus c) the number of highs added in that year that the OBD system did not detect (a function of MIL-“off” rate and the high emitter growth rate applied to the available pool of “non-highs”). The high emitter growth rate for a given year is the absolute increase in high emitters under the No OBD / No IM case from the previous year divided by the fraction on nonhighs - i.e., the available pool of vehicles which can become high emitters.

Once the high emitter fraction is calculated for the OBD or OBD/IM cases, the fraction of repaired emitters can be calculated as the difference between the fraction of high emitters that would occur without OBD or I/M ($High_{BASE}$, from Equation (10)) and the fraction of high emitters with OBD and/or I/M from Equation 18. In equation form,

$$Repaired(i) = High_{BASE}(i) - High_{OBD}(i) \qquad \text{Eqn 19}$$

The rate of normal emitters remains constant between the No OBD / No I/M, OBD-only and OBD/IM case; only the number of high emitters decrease, directly replaced by repaired emitters. The emitter fractions for normal, high and repaired emitters for the OBD Only and OBD/IM cases are shown in Appendix A (Tables A-1 and A-2) for NOx and HC, by vehicle class.

6.3 BER Calculation for OBD and OBD-based I/M

Calculation of average in-use FTP-based NOx and NMHC emission rates at a given vehicle age for the OBD-Only and OBD/IM cases are similar to the methodology for No OBD / No I/M vehicles (Equation (2)); the primary differences are a) use of $High_{OBD}$ rather than $High_{BASE}$ emitter fractions, and b) addition of a term to account for repaired emitters. As mentioned, the normal and high emissions rates are unchanged from the No OBD / No I/M case. This computation is as follows:

$$AVE = High_{OBD} * High\_ave + Normal*Norm\_ave + Repaired * Rep\_ave \qquad \text{Eqn 20}$$

Reflecting the change in our after-repair assumptions, Rep_ave is equal to Norm_ave below 150,000 miles for NOx and 240,000 miles for HC; above these thresholds, Rep_ave is equal to

1.5 times the applicable 50,000 mile certification standard.

7 NOx and HC BERs for Exhaust-Only I/M

Since an OBD check is currently an unproven concept in an I/M program, some I/M credit scenario must be developed for those areas that use traditional exhaust I/M test procedures. This scenario will be likely used frequently until calendar year 2001. By that time, it is assumed that I/M test procedures utilizing OBD checks on vehicles equipped with OBD will be in place.

7.1 No OBD with Exhaust I/M

The "No OBD / Exhaust I/M" emission levels for this scenario are calculated using the methodology described in draft MOBILE6 document M6.IM.001 ("MOBILE6 Inspection / Maintenance Benefits Methodology for 1981 through 1993 Model Year Light Vehicles"). This methodology utilizes I/M exhaust test identification rates and after repair effectiveness levels based on data collected from the Arizona I/M program. The "No I/M" and the "With Exhaust I/M" emission rates are used to calculate the I/M emission level and I/M credits for situations where exhaust-only I/M tests are being performed on Tier 1 vehicles without OBD. The only vehicles which will fall in this category are the 1994 and 1995 model years certified to Tier1 standards. In this case, the structure of the I/M credits is identical to the Tier 0 I/M credits with the exception that the Norm_ave, High_ave, and fraction of highs in the fleet ($High_{BASE}$) are different from analogous Tier 0 parameters. Equation 21 defines this case mathematically.

$$AVE = Norm\_ave*(1-High_{BASE}) + High\_ave*High_{BASE}*(1-IDR) + High_{BASE}*IDR*W*High\_ave*RW + Norm\_ave*R*High_{BASE}*IDR*FIX + High\_ave*High_{BASE}*IDR*NC \quad \text{Eqn 21}$$

<u>IDR</u> is the identification rate of high emitters using an exhaust emission test.
<u>R</u> is the after repair emission level of vehicles repaired to pass an exhaust I/M test.
<u>Fix</u> is the fraction of vehicles which are repaired.
<u>NC</u> is the fraction of vehicles which are in non-compliance following their I/M test
<u>W</u> is the fraction of vehicles which receive a cost or other type of waiver.
<u>RW</u> is the after repair level of the vehicles which get waived. It is shown as a fraction of the high emitter level.

(see report M6.IM.001 for a full explanation of these terms).

7.2 OBD and Exhaust I/M

In this scenario, the vehicles in the fleet are OBD compliant, but the state continues to conduct an exhaust I/M test; this is most likely scenario prior to calendar year 2001. For this scenario, the same I/M equations and assumptions used to model the 1981-93 Tier 0 vehicles are used. The primary difference is the fraction of high emitters is reduced somewhat due to the effects of OBD program (i.e., $High_{OBD}$ is substituted for a higher rate of high emitters used in Tier0.

$$AVE = Norm\_ave*(1-High_{BASE}) + Rep\_ave*(Repaired) + High\_ave*High_{OBD}*(1-IDR) + High_{OBD}*IDR*W*High\_ave*RW + Norm\_ave*R*High_{OBD}*IDR*FIX + High\_ave*High_{OBD}*IDR*NC \quad \text{Eqn 22}$$

8 Derivation of Running and Start BERs for NOx and HC

MOBILE6 will not use FTP-based BERs, but rather separate BERs for start and running operation which are recombined according to estimates of in-use activity data. This requires that the Tier 1 and later BERs developed on an FTP-basis, factors are required to derive running and start BERs from FTP-based BERs. For HC, this report contains significant modification to the approach published previously. Our original estimates were based on an independent analysis of a small number of Tier 1 and LEV vehicles. Subsequent validation showed that the resulting start and running emission rates for Tier 1 and later vehicles were not internally consistent with start and running emission rates for pre-Tier 1 vehicles; hence, we have revised our factors for deriving start and running BERs to be consistent the start/running split for Tier 0 vehicles. For NOx, the running adjustment factors were derived from 1988-1993 PFI Tier 0 LDV emission rates at 100,000 miles. A single adjustment was chosen for NOx since the ratio of running emissions to FTP emissions was relatively stable over mileage. For HC, however, the ratio of running emissions to FTP emissions varied significantly over mileage (Appendix D). As a result we developed a running correction factor (RCF) from the 1988-1993 PFI Tier 0 LDV emission rates as a function of mileage, as shown in Equation 24. Equations 23 and 25 will be used to generate running BERs for Tier 1 and later standards for all vehicle classes:

Running NOx BER (g/mi) = 0.9 * FTP NOx BER Eqn 23

Running NMHC/NMOG RCF = $(6E\text{-}05x^3 - 0.0032x^2 + 0.0656x + 0.2536)$ Eqn 24
x=mileage

Running NMHC/NMOG BER (g/mi)= RCF* FTP NMHC BER Eqn 25

Start BERs (in grams per start) are related to FTP and Running BERs as shown in Equation (26):[19]

FTP BER = (Running BER*7.5 +Start BER*0.43+Start BER*0.57*HS) / 7.5 Eqn 26

Where:

Running BERs	=	the results of Equations (23) and (25)
7.5	=	total miles of the LA4
0.43/0.57	=	Bag 1/Bag 3 weighting across total FTP
HS	=	the ratio of Bag 3 emissions to Bag 1 emissions, based on 1988-1993 Tier 0 LDV PFI BERs proposed for MOBILE6 (0.16 for HC, 0.204 for NOx)

Using this equation and the running and FTP BERs developed above, start factors were derived for NOx according to Equation (27):

Start NOx BERs (grams) = 1.37 * FTP BER Eqn 27

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[19] Glover, E., and Carey, P., "Determination of Start Emissions as a Function of Mileage and Soak Time for 1981-1993 Model Year Light-Duty Vehicles", MOBILE6 report number M6.STE.003

For HC, since the running BERs are a function of mileage, a start correction factor (SCF) were also derived as a function of mileage as shown in Equation (28). Using this equation and the running and FTP BERs developed above, start factors were derived for HC according to Equation (29):

Start NMHC/NMOG SCF	=	$(-0.0008x3 + 0.0474x2 - 0.9518x + 10.752)$ *x=mileage*	Eqn 28
Start NMHC/NMOG BER (grams)	=	SCF * FTP BER	Eqn 29

These factors were applied equally to each emitter class: normal, high and repaired. The resulting BERs for Tier 1, LEV and ULEV across all classes are shown in Appendix B.

APPENDIX A:
a) Emitter Fractions: No OBD/No IM, OBD Only, OBD/IM Cases
b) Vehicle Mileage As A Function of Age

Table A-1: NOx Emitter Fractions

Age (Years)	LDV						LDT1/2						LDT3/4					
	All	Base	OBD Only		OBD/IM		All	Base	OBD Only		OBD/IM		All	Base	OBD Only		OBD/IM	
	Normal	High	High	Repair	High	Repair	Normal	High	High	Repair	High	Repair	Normal	High	High	Repair	High	Repair
0	1.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000
1	1.000	0.000	0.000	0.000	0.000	0.000	0.995	0.005	0.001	0.004	0.001	0.004	0.991	0.009	0.002	0.007	0.001	0.008
2	0.975	0.025	0.006	0.019	0.004	0.021	0.956	0.044	0.037	0.007	0.007	0.037	0.949	0.051	0.041	0.010	0.008	0.043
3	0.946	0.054	0.033	0.021	0.009	0.046	0.916	0.084	0.074	0.010	0.014	0.070	0.905	0.095	0.082	0.013	0.015	0.080
4	0.916	0.084	0.061	0.023	0.014	0.071	0.874	0.126	0.112	0.013	0.021	0.105	0.859	0.141	0.124	0.017	0.023	0.117
5	0.885	0.115	0.090	0.025	0.019	0.096	0.831	0.169	0.156	0.013	0.028	0.141	0.812	0.188	0.172	0.016	0.032	0.156
6	0.853	0.147	0.120	0.027	0.025	0.122	0.786	0.214	0.202	0.012	0.037	0.177	0.763	0.237	0.222	0.015	0.041	0.196
7	0.821	0.179	0.154	0.026	0.030	0.149	0.740	0.260	0.248	0.011	0.046	0.214	0.713	0.287	0.274	0.014	0.051	0.236
8	0.788	0.212	0.188	0.025	0.037	0.176	0.693	0.307	0.296	0.011	0.055	0.252	0.661	0.339	0.327	0.013	0.062	0.277
9	0.754	0.246	0.222	0.024	0.043	0.203	0.645	0.355	0.345	0.010	0.066	0.289	0.607	0.393	0.381	0.012	0.074	0.319
10	0.720	0.280	0.258	0.023	0.050	0.230	0.596	0.404	0.394	0.009	0.077	0.327	0.552	0.448	0.437	0.011	0.087	0.360
11	0.685	0.315	0.294	0.021	0.057	0.258	0.547	0.453	0.444	0.008	0.089	0.364	0.496	0.504	0.494	0.010	0.102	0.402
12	0.649	0.351	0.331	0.020	0.065	0.286	0.498	0.502	0.495	0.008	0.102	0.400	0.439	0.561	0.552	0.009	0.118	0.443
13	0.613	0.387	0.368	0.019	0.073	0.314	0.448	0.552	0.545	0.007	0.116	0.436	0.381	0.619	0.612	0.007	0.137	0.482
14	0.576	0.424	0.406	0.018	0.082	0.342	0.399	0.601	0.594	0.006	0.131	0.469	0.321	0.679	0.672	0.006	0.158	0.520
15	0.539	0.461	0.444	0.017	0.092	0.370	0.351	0.649	0.643	0.005	0.148	0.501	0.261	0.739	0.734	0.005	0.183	0.555
16	0.501	0.499	0.483	0.016	0.102	0.397	0.304	0.696	0.691	0.005	0.166	0.530	0.200	0.800	0.796	0.004	0.213	0.586
17	0.463	0.537	0.523	0.015	0.113	0.425	0.258	0.742	0.738	0.004	0.186	0.556	0.139	0.861	0.858	0.003	0.252	0.609
18	0.424	0.576	0.562	0.013	0.124	0.451	0.214	0.786	0.782	0.003	0.208	0.578	0.077	0.923	0.921	0.002	0.304	0.618
19	0.386	0.614	0.602	0.012	0.137	0.477	0.172	0.828	0.825	0.003	0.233	0.595	0.015	0.985	0.984	0.000	0.392	0.592
20	0.346	0.654	0.643	0.011	0.151	0.503	0.132	0.868	0.866	0.002	0.261	0.607	0.000	1.000	1.000	0.000	0.489	0.511
21	0.307	0.693	0.683	0.010	0.166	0.527	0.094	0.906	0.904	0.001	0.294	0.611	0.000	1.000	1.000	0.000	0.489	0.511
22	0.268	0.732	0.724	0.008	0.183	0.549	0.059	0.941	0.940	0.001	0.336	0.605	0.000	1.000	1.000	0.000	0.489	0.511
23	0.228	0.772	0.765	0.007	0.202	0.570	0.026	0.974	0.973	0.000	0.394	0.579	0.000	1.000	1.000	0.000	0.489	0.511
24	0.188	0.812	0.806	0.006	0.224	0.588	0.000	1.000	1.000	0.000	0.490	0.510	0.000	1.000	1.000	0.000	0.489	0.511
25	0.148	0.852	0.847	0.005	0.251	0.601	0.000	1.000	1.000	0.000	0.490	0.510	0.000	1.000	1.000	0.000	0.489	0.511

Table A-2: NMHC/NMOG Emitter Fractions																		
Age (Years)	LDV						LDT1/2						LDT3/4					
	All	Base	OBD Only		OBD/IM		All	Base	OBD Only		OBD/IM		All	Base	OBD Only		OBD/IM	
	Normal	High	High	Repair	High	Repair	Normal	High	High	Repair	High	Repair	Normal	High	High	Repair	High	Repair
0	0.983	0.017	0.004	0.013	0.003	0.015	0.983	0.017	0.004	0.013	0.003	0.015	0.983	0.017	0.004	0.013	0.003	0.015
1	0.981	0.019	0.004	0.014	0.003	0.016	0.978	0.022	0.005	0.017	0.003	0.019	0.977	0.023	0.006	0.018	0.004	0.020
2	0.971	0.029	0.007	0.022	0.005	0.024	0.959	0.041	0.023	0.018	0.007	0.034	0.955	0.045	0.026	0.019	0.007	0.038
3	0.953	0.047	0.024	0.023	0.008	0.040	0.935	0.065	0.045	0.020	0.010	0.054	0.929	0.071	0.050	0.021	0.012	0.060
4	0.935	0.065	0.041	0.024	0.011	0.055	0.912	0.088	0.067	0.021	0.014	0.074	0.904	0.096	0.073	0.023	0.016	0.080
5	0.918	0.082	0.057	0.026	0.013	0.069	0.890	0.110	0.089	0.021	0.018	0.092	0.880	0.120	0.098	0.022	0.020	0.100
6	0.901	0.099	0.072	0.027	0.016	0.083	0.868	0.132	0.111	0.020	0.022	0.110	0.858	0.142	0.121	0.021	0.024	0.118
7	0.885	0.115	0.089	0.026	0.019	0.096	0.848	0.152	0.132	0.020	0.026	0.127	0.836	0.164	0.143	0.021	0.028	0.136
8	0.869	0.131	0.105	0.026	0.022	0.109	0.828	0.172	0.152	0.019	0.029	0.143	0.815	0.185	0.164	0.020	0.031	0.153
9	0.854	0.146	0.121	0.025	0.025	0.122	0.810	0.190	0.171	0.019	0.033	0.158	0.796	0.204	0.184	0.020	0.035	0.169
10	0.839	0.161	0.136	0.025	0.027	0.134	0.792	0.208	0.190	0.018	0.036	0.172	0.777	0.223	0.203	0.019	0.039	0.184
11	0.825	0.175	0.151	0.024	0.030	0.145	0.775	0.225	0.207	0.018	0.039	0.185	0.759	0.241	0.222	0.019	0.042	0.198
12	0.811	0.189	0.165	0.024	0.032	0.157	0.760	0.240	0.223	0.018	0.042	0.198	0.742	0.258	0.239	0.019	0.046	0.212
13	0.798	0.202	0.179	0.023	0.035	0.167	0.745	0.255	0.238	0.017	0.045	0.210	0.726	0.274	0.255	0.018	0.049	0.225
14	0.785	0.215	0.192	0.023	0.037	0.178	0.731	0.269	0.251	0.017	0.048	0.221	0.711	0.289	0.271	0.018	0.052	0.237
15	0.773	0.227	0.205	0.023	0.040	0.188	0.719	0.281	0.264	0.017	0.051	0.231	0.697	0.303	0.286	0.017	0.055	0.248
16	0.761	0.239	0.217	0.022	0.042	0.197	0.707	0.293	0.276	0.016	0.053	0.240	0.683	0.317	0.299	0.017	0.058	0.259
17	0.749	0.251	0.229	0.022	0.044	0.206	0.696	0.304	0.287	0.016	0.055	0.248	0.671	0.329	0.313	0.017	0.061	0.269
18	0.738	0.262	0.240	0.022	0.047	0.215	0.686	0.314	0.298	0.016	0.057	0.256	0.659	0.341	0.325	0.017	0.063	0.278
19	0.728	0.272	0.251	0.021	0.049	0.223	0.677	0.323	0.307	0.016	0.059	0.263	0.647	0.353	0.337	0.016	0.066	0.287
20	0.718	0.282	0.261	0.021	0.051	0.232	0.669	0.331	0.315	0.016	0.061	0.270	0.596	0.404	0.389	0.015	0.078	0.326
21	0.708	0.292	0.271	0.021	0.053	0.239	0.662	0.338	0.323	0.015	0.063	0.275	0.498	0.502	0.490	0.012	0.102	0.400
22	0.698	0.302	0.281	0.021	0.055	0.247	0.655	0.345	0.330	0.015	0.064	0.281	0.485	0.515	0.503	0.012	0.105	0.409
23	0.689	0.311	0.290	0.020	0.057	0.254	0.649	0.351	0.336	0.015	0.066	0.285	0.473	0.527	0.515	0.012	0.109	0.418
24	0.681	0.319	0.299	0.020	0.059	0.261	0.644	0.356	0.341	0.015	0.067	0.289	0.462	0.538	0.526	0.012	0.112	0.426
25	0.672	0.328	0.308	0.020	0.061	0.267	0.627	0.373	0.359	0.015	0.071	0.302	0.452	0.548	0.537	0.011	0.115	0.433

Table A-3: Draft MOBILE6 Cumulative Mileages (10,000 miles)							
Age (Years)	**LDV**	**LDT1/2**	**LDT3/4**	**Age (Years)**	**LDV**	**LDT1/2**	**LDT3/4**
1	1.491	1.950	2.133	14	15.338	18.453	19.583
2	2.908	3.788	4.120	15	16.072	19.165	20.371
3	4.256	5.519	5.970	16	16.770	19.815	21.104
4	5.537	7.146	7.692	17	17.434	20.406	21.786
5	6.755	8.672	9.297	18	18.064	20.941	22.422
6	7.912	10.100	10.791	19	18.664	21.425	23.014
7	9.013	11.436	12.183	20	19.234	21.861	23.566
8	10.059	12.681	13.478	21	19.776	22.252	24.079
9	11.054	13.839	14.685	22	20.291	22.602	24.557
10	12.000	14.914	15.809	23	20.781	22.914	25.003
11	12.899	15.910	16.856	24	21.247	23.191	25.418
12	13.753	16.829	17.830	25	21.690	23.438	25.804
13	14.566	17.676	18.738				

APPENDIX B:
TIER 1, LEV/ULEV I and Tier 2 BERs By Emitter Category

Table B-1: Tier 1 & LEV/ULEV I NOx Basic Emission Rates							
Vehicle Class	Standard Class	50K Standard (g/mi)	Mode	"Normal" BER (g/mi)		"High" BER (g/mi)	"Repaired" BER Cap (g/mi)
				ZML	DR		
LDV/T1	Tier 1	0.4	FTP	0.153	0.0294	1.29	0.600
			Running	0.138	0.0265	1.16	0.540
			Start (grams)	0.210	0.0403	1.77	0.822
	LEV/ULEV	0.2	FTP	0.077	0.0147	0.97	0.300
			Running	0.069	0.0132	0.87	0.270
			Start (grams)	0.105	0.0201	1.33	0.411
LDT2/3	Tier 1	0.7	FTP	0.268	0.0517	1.78	1.050
			Running	0.241	0.0465	1.60	0.945
			Start (grams)	0.367	0.0708	2.44	1.439
	LEV/ULEV	0.4	SAME AS LDV/T1 TIER 1				
LDT4	Tier 1	1.1	FTP	0.421	0.0809	2.43	1.650
			Running	0.379	0.0728	2.19	1.485
			Start (grams)	0.577	0.1108	3.33	2.261
	LEV/ULEV	0.6	FTP	0.230	0.0441	1.62	0.900
			Running	0.207	0.0397	1.46	0.810
			Start (grams)	0.315	0.0604	2.219	1.233

Table B-2: Tier 2 NOx Basic Emission Rates

Vehicle Class	Standard Class	50/120K Standard (g/mi)	Mode	"Normal" BER (g/mi)		"High" BER (g/mi)	"Repaired" BER Cap (g/mi)
				ZML	DR		
LDV/T1	Tier 2	0.05/0.07	FTP	0.019	0.004	0.73	0.075
			Running	0.017	0.003	0.65	0.068
			Start (grams)	0.026	0.005	1.00	0.103
LDT2	Interim	0.2/0.3	SAME AS LDV/T1 LEV (M6.EXH.007)				
	Tier 2	0.05/0.07	SAME AS LDV/T1 TIER 2				
LDT3	Interim A	0.4/0.6	SAME AS LDV/T1 TIER 1 (M6.EXH.007)				
	Interim B	0.14/0.20	FTP	0.054	0.010	0.87	0.210
			Running	0.048	0.009	0.78	0.189
			Start (grams)	0.073	0.014	1.19	0.288
	Tier 2	0.05/0.07	SAME AS LDV/T1 TIER 2				
LDT4	Interim A	0.4/0.6	SAME AS LDV/T1 TIER 1 (M6.EXH.007)				
	Interim B	0.14/0.20	SAME AS LDT3 INTERIM B				
	Tier 2	0.05/0.07	SAME AS LDV/T1 TIER 2				

50,000 mile standard levels used to derive Tier 2 BERs for all bin categories according to the methodology presented in this report (g/mi):

Bin	LDV	LDT1	LDT2	LDT3	LDT4
1[a]	0	0	0	0	0
2[a]	0.014	0.014	0.014	0.014	0.014
3[a]	0.021	0.021	0.021	0.021	0.021
4[a]	0.029	0.029	0.029	0.029	0.029
5	0.05	0.05	0.05	0.05	0.05
6	0.08	0.08	0.08	0.08	0.08
7	0.11	0.11	0.11	0.11	0.11
8	0.14	0.14	0.14	0.14	0.14
9[b]	0.2	0.2	0.2	0.2	0.2
10[b]	0.4	0.4	0.4	0.4	0.4

[a] 50,000 miles certification "standards" estimated by multiplying full useful life standard by ratio of Bin 5 intermediate life / full useful life standards (0.05 / 0.07 = 0.71)

[a] Interim standard bins

Table B-3: Tier 1 & LEV/ULEV I NMHC/NMOG Basic Emission Rates

Vehicle Class	Standard Class	50K Standard (g/mi)	Mode	"Normal" BER (g/mi) ZML	"Normal" BER (g/mi) DR	"High" BER (g/mi)	"Repaired" BER (g/mi)
LDV/T1	Tier 1 (NMHC)	0.25	FTP	0.098	0.0113	1.67	0.375
			Running	FTP*RCF (See Section 8)			
			Start (grams)	FTP*SCF (See Section 8)			
	LEV	0.075	FTP	0.029	0.0034	1.23	0.113
			Running	FTP*RCF (See Section 8)			
			Start (grams)	FTP*SCF (See Section 8)			
	ULEV	0.04	FTP	0.016	0.0018	1.14	0.060
			Running	FTP*RCF (See Section 8)			
			Start (grams)	FTP*SCF (See Section 8)			
LDT2	Tier 1 (NMHC)	0.32	FTP	0.125	0.0145	1.85	0.480
			Running	FTP*RCF (See Section 8)			
			Start (grams)	FTP*SCF (See Section 8)			
	LEV	0.10	FTP	0.039	0.0045	1.29	0.150
			Running	FTP*RCF (See Section 8)			
			Start (grams)	FTP*SCF (See Section 8)			
	ULEV	0.05	FTP	0.020	0.0023	1.17	0.075
			Running	FTP*RCF (See Section 8)			
			Start (grams)	FTP*SCF (See Section 8)			
LDT3	Tier 1 (NMHC)	0.32	FTP	0.125	0.0145	1.85	0.480
			Running	FTP*RCF (See Section 8)			
			Start (grams)	FTP*SCF (See Section 8)			
	LEV	0.16	FTP	0.063	0.0073	1.44	0.240
			Running	FTP*RCF (See Section 8)			
			Start (grams)	FTP*SCF (See Section 8)			
	ULEV	0.10	SAME AS LDT2 LEV				
LDT4	Tier 1 (NMHC)	0.39	FTP	0.152	0.0177	2.03	0.585
			Running	FTP*RCF (See Section 8)			
			Start (grams)	FTP*SCF (See Section 8)			
	LEV	0.195	FTP	0.076	0.0088	1.53	0.293
			Running	FTP*RCF (See Section 8)			
			Start (grams)	FTP*SCF (See Section 8)			
	ULEV	0.117	FTP	0.046	0.0053	1.33	0.176
			Running	FTP*RCF (See Section 8)			
			Start (grams)	FTP*SCF (See Section 8)			

<table>
<tr><th colspan="8">Table B-4 - Tier 2 NMOG Basic Emission Rates</th></tr>
<tr><th rowspan="2">Vehicle Class</th><th rowspan="2">Standard Class</th><th rowspan="2">50/120K Standard (g/mi)</th><th rowspan="2">Mode</th><th colspan="2">“Normal” BER (g/mi)</th><th rowspan="2">“High” BER (g/mi)</th><th rowspan="2">“Repaired” BER Cap (g/mi)</th></tr>
<tr><th>ZML</th><th>DR</th></tr>
<tr><td>LDV/T1</td><td>Tier 2</td><td>0.075/0.09</td><td colspan="5">SAME AS LDV/T1 LEVI</td></tr>
<tr><td>LDT2</td><td>Interim/Tier 2</td><td>0.2/0.3</td><td colspan="5">SAME AS LDV/T1 LEV I</td></tr>
<tr><td rowspan="5">LDT3</td><td>Interim A</td><td>0.16/0.23</td><td colspan="5">SAME AS LDT3 LEV I</td></tr>
<tr><td rowspan="3">Interim B</td><td rowspan="3">0.125/0.156</td><td>FTP</td><td>0.049</td><td>0.057</td><td>1.35</td><td>0.188</td></tr>
<tr><td>Running</td><td colspan="4">FTP*RCF (See Section 8)</td></tr>
<tr><td>Start</td><td colspan="4">FTP*SCF (See Section 8)</td></tr>
<tr><td>Tier 2</td><td>0.05/0.07</td><td colspan="5">SAME AS LDV/T1 LEV I</td></tr>
<tr><td rowspan="3">LDT4</td><td>Interim A</td><td>0.16/0.23</td><td colspan="5">SAME AS LDT3 LEV I</td></tr>
<tr><td>Interim B</td><td>0.125/0.156</td><td colspan="5">SAME AS LDT3 INTERIM B</td></tr>
<tr><td>Tier 2</td><td>0.075/0.09</td><td colspan="5">SAME AS LDV/T1 LEV I</td></tr>
</table>

50,000 mile standard levels used to derive Tier 2 BERs for all bin categories according to the methodology presented in this report (g/mi):

Bin	LDV	LDT1	LDT2	LDT3	LDT4
1[a]	0	0	0	0	0
2[a]	0.007	0.007	0.007	0.007	0.007
3[a]	0.04	0.04	0.04	0.04	0.04
4[a]	0.051	0.051	0.051	0.051	0.051
5	0.075	0.075	0.075	0.075	0.075
6	0.075	0.075	0.075	0.075	0.075
7	0.075	0.075	0.075	0.075	0.075
8[b]	0.1	0.1	0.1	0.125	0.125
8[c]	n/a	n/a	n/a	0.1	0.1
9[d]	0.075	0.075	0.1	0.14	0.14
10[e]	0.125	0.125	0.125	0.16	0.195

[a] 50,000 miles certification “standards” estimated by multiplying full useful life standard by ratio of ULEV intermediate life / full useful life standards under LEV program (0.04 / 0.055 = 0.73)

[b] temporary standards for LDT3/4

[c] final standards for LDT3/4

[d] interim standard bin with optional LDT2 standard

[e] interim standard bin with optional LDT4 standard

APPENDIX C:
Detailed Results for NOx Regression Model

Equations 5, 6 and 7 are the only “new” regression model results presented in this paper for basic emission rates used directly in MOBILE6. The detailed regression results for these equations are presented below. Other equations used to derive the basic emission rates presented in this paper are based on analyses documented in other MOBILE reports. Information pertaining to the source of these equations are also included, but not the detailed results.

Equation 5 - NOx Normal Emitter Model

Descriptive Statistics

	Mean	Std. Deviation	N
NOX	.2523	.1410	1167
MILEAGE	33923.55	22759.61	1167

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.475	.225	.225	.1241

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	5.225	1	5.225	339.173	.000
	Residual	17.947	1165	1.541E-02		
	Total	23.172	1166			

Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	.153	.007		23.382	.000	.140	.165
	MILEAGE	2.941E-06	.000	.475	18.417	.000	.000	.000

Equation 6: Analysis of significance for mileage term in high emitter model

Descriptive Statistics

	Mean	Std. Deviation	N
NOX	1.2942	.5977	31
MILEAGE	79987.19	33999.56	31

Correlations

		NOX	MILEAGE
Pearson Correlation	**NOX**	1.000	.031
	MILEAGE	.031	1.000
Sig. (1-tailed)	**NOX**	.	.434
	MILEAGE	.434	.
N	**NOX**	31	31
	MILEAGE	31	31

Variables Entered/Removed

Model	Variables Entered	Variables Removed	Method
1	MILEAGE	.	Enter

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.031	.001	-.033	.6076

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1.038E-02	1	1.038E-02	.028	.868
	Residual	10.705	29	.369		
	Total	10.716	30			

Coefficients

		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
Model		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	1.250	.283		4.421	.000	.672	1.829
	MILEAGE	5.472E-07	.000	.031	.168	.868	.000	.000

Equation 6: NOx High Emitter Average

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
NOX	31	.80	2.77	1.2942	.5977
Valid N (listwise)	31				

Equation 7: NOx All LDV/LDT (0.4 g/mi Standard) Model

Descriptive Statistics

	Mean	Std. Deviation	N
NOX	.2793	.2360	1198
MILEAGE	35115.51	24229.87	1198

Correlations

		NOX	MILEAGE
Pearson Correlation	NOX	1.000	.474
	MILEAGE	.474	1.000
Sig. (1-tailed)	NOX	.	.000
	MILEAGE	.000	.
N	NOX	1198	1198
	MILEAGE	1198	1198

Variables Entered/Removed

Model	Variables Entered	Variables Removed	Method
1	MILEAGE	.	Enter

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.474	.225	.224	.2079

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	14.982	1	14.982	346.669	.000
	Residual	51.687	1196	4.322E-02		
	Total	66.668	1197			

Coefficients

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.	95% Confidence Interval for B Lower Bound	95% Confidence Interval for B Upper Bound
1	(Constant)	.117	.011		11.072	.000	.096	.138
	MILEAGE	4.617E-06	.000	.474	18.619	.000	.000	.000

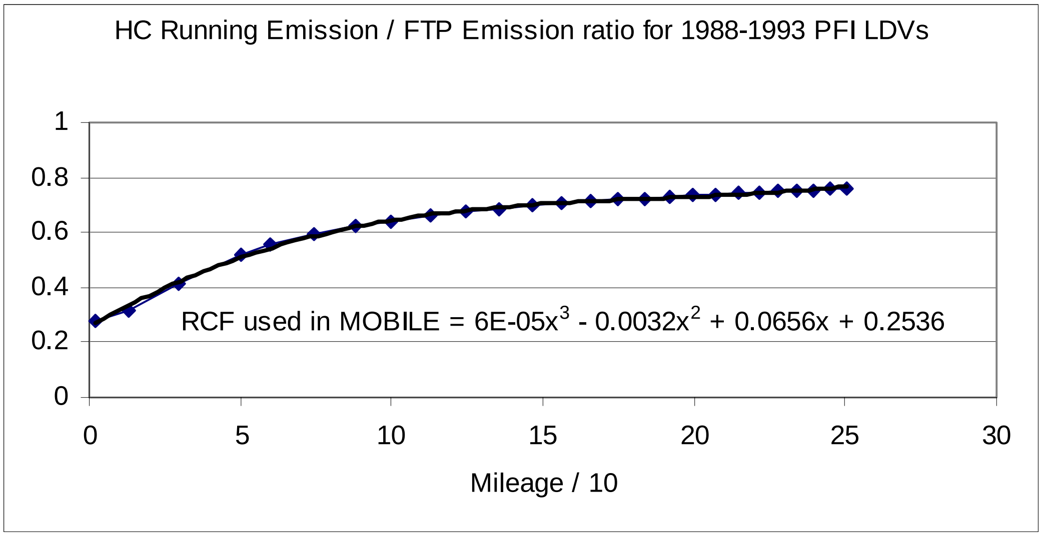
Information pertaining to other equations

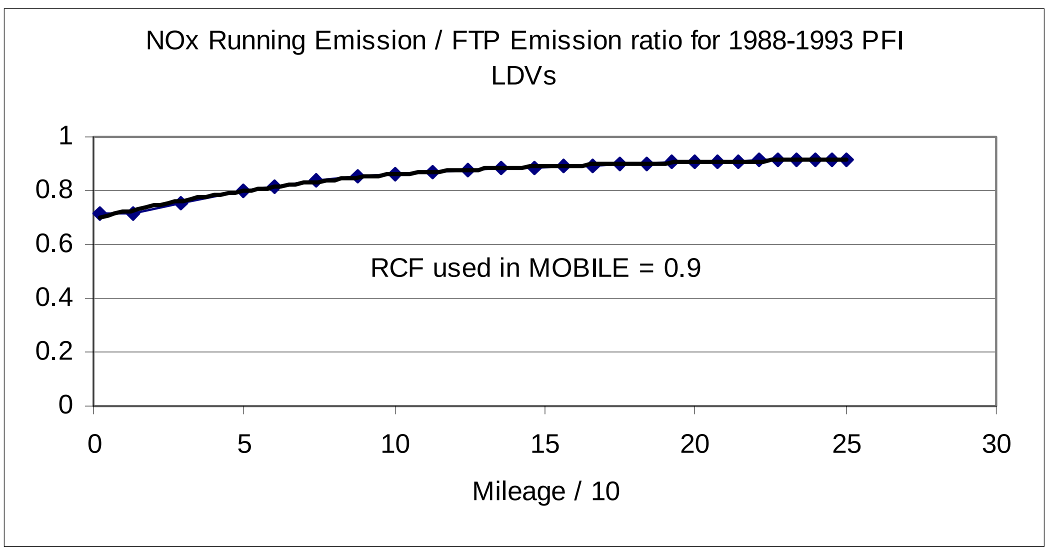
- Equation 8: The high emitter correction factor is derived from an analysis presented in MOBILE6 report M6.EXH.001, "Determination of Running Emissions as a Function of Mileage for 1981-1993 Model Year Light-Duty Cars and Trucks", Enns et. al.

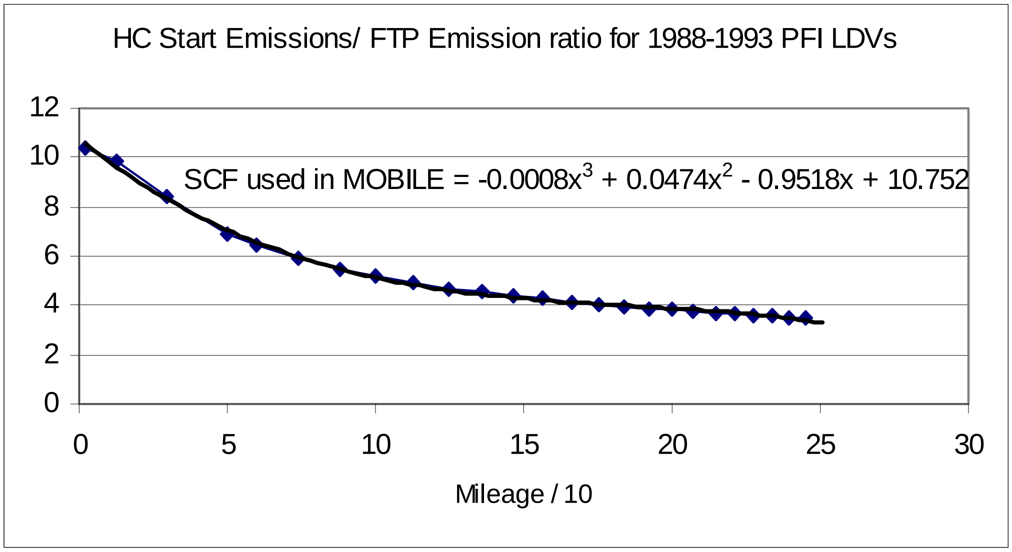
- Equations 13 and 14 were derived by first combining the running and start emission rates for normal-emitting 1988-1993 PFI LDVs according to FTP weightings. The raw running and start emission rates can be found in MOBILE6 report M6.IM.001, "MOBILE6 Inspection/Maintenance Benefits Methodology for 1981 through 1993 Model Year Light Vehicles". At a given mileage, FTP emissions were derived from start and running emission rates according to Equation 26. For normal emitters, the combined multi-linear FTP emission rates were then regressed by mileage to create a simple linear model, resulting in Equation 13.

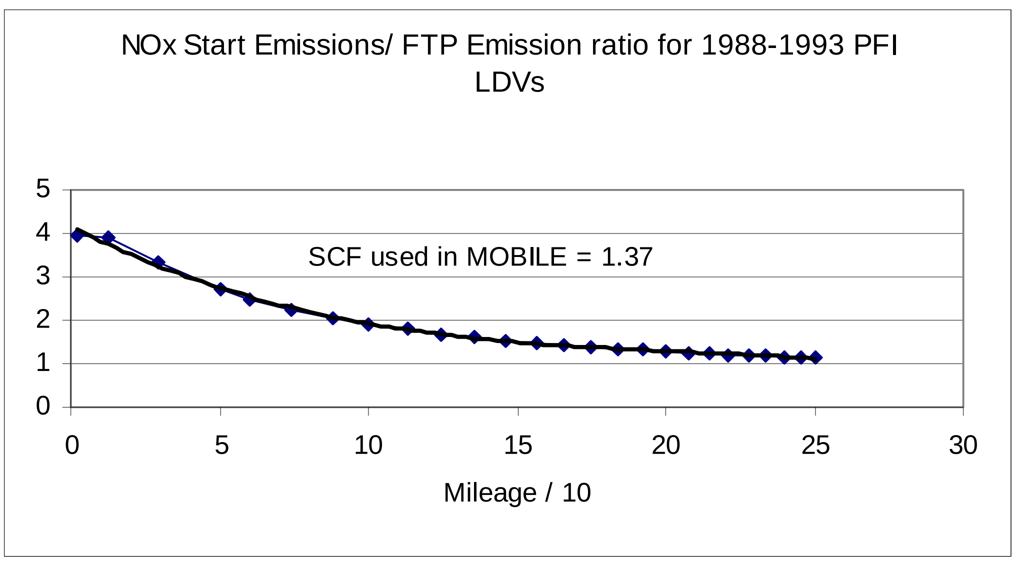
- Equations 24 and 28 were developed to create a simple fit to multi-linear modeled data.

APPENDIX D:
Running and Start Correction Factors Used In Developing Running and Start BERs from FTP-Based BERs


HC Running Emission / FTP Emission ratio for 1988-1993 PFI LDVs
1
0.8
0.6
0.4
0.2
0
RCF used in MOBILE = 6E-05x3 - 0.0032x2 + 0.0656x + 0.2536
0
5
10
15
20
25
30
Mileage / 10


NOx Running Emission / FTP Emission ratio for 1988-1993 PFI LDVs
1
0.8
0.6
0.4
0.2
0
RCF used in MOBILE = 0.9
0
5
10
15
20
25
30
Mileage / 10


HC Start Emissions/ FTP Emission ratio for 1988-1993 PFI LDVs
SCF used in MOBILE = -0.0008x3 + 0.0474x2 - 0.9518x + 10.752
12
10
8
6
4
2
0
0
5
10
15
20
25
30
Mileage / 10


NOx Start Emissions/ FTP Emission ratio for 1988-1993 PFI LDVs
SCF used in MOBILE = 1.37
5
4
3
2
1
0
0
5
10
15
20
25
30
Mileage / 10

APPENDIX E:
Peer Review Comments

REPORT REVIEW

M6.EXH.007 — TIER 1 AND LATER HC AND NOX EXHAUST EMISSIONS EQUATIONS IN MOBILE6

Prepared for U. S. Environmental Protection Agency
Under Order Number 0A-0249-NATX

March 21, 2000

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Table of Contents

Introduction

The U. S. Environmental Protection Agency (EPA) requested an independent peer review of the report entitled “Determination of NOx and HC Basic Emission Rates, OBD and I/M Effects for Tier 1 and later LDVs and LDTs.” This report, numbered M6.EXH.007, is one part of the work being done to provide an updated version of EPA’s mobile source inventory model, MOBILE6. It proposes equations to compute HC and NOx emissions for light-duty vehicles (LDV) and light-duty trucks (LDT), with and without onboard diagnostics (OBD) or inspection maintenance (I/M) programs. These are late-model year and future vehicles certified to a 0.4 g/mi NOx standard (Tier 1), low-emission vehicles (LEV), and ultra-low-emission vehicles (ULEV).

EPA provided a copy of the report and overall directions for this review. EPA also provided copies of comments that stakeholders had made on a previous draft of the M6.EXH.007 report and copies of data files used in their NOx analysis. The directions for this review asked for the following areas to be addressed:

1. report clarity
2. overall methodology
3. appropriateness of the data sets selected
4. the data analyses conducted, including the statistical approaches used and models selected
5. appropriateness of the conclusions with specific attention to and comments on:
   - the ratio approach for basic emissions
   - the effects of OBD and I/M on the basic emission rates.
6. recommendations for any alternate data sets or analyses.

The overall directions for review also asked for a separation of recommendations for improvements that could be made in the short term versus longer-term improvements.

The body of this review is in the next section, subdivided into the six topics listed above. That is followed by a conclusions section that identifies the short-term and long-term recommendations.

Body of the Review

Overall clarity

The report assumes that the reader is familiar with mobile source emissions and the procedures for calculating such emissions. For this reader, the report is presented in a reasonably clear fashion. Some editorial comments are listed below.

All data shown in the report should be rounded to match the values used in MOBILE6. For example, the NOx emission level for high-emitting Tier 1 vehicles is listed as 1.294 g/mi on page 9, and is rounded to 1.29 g/mi in Table B-1. A check of the fractions of high and normal NOx emitters for Tier 1 LDVs, given in Table A-1, shows agreement when the high emitter value of 1.294 g/mi is used. When the value of 1.29 g/mi is used, some values of this fraction are off by 0.001 from the values reported in Table A-1. This discrepancy indicates that the values in Table B-1 have been rounded and are not the numbers used in the actual MOBILE6 calculations. The numbers in the report should be revised to match those used in MOBILE6, with the same number of significant figures.

The analysis on pages 14 and 15 compares emissions from Tier 1 light-duty trucks in different weight classes (LDT1/2 *vs.* LDT3/4). This analysis could be rearranged to introduce and reenforce the concept that the regression analysis is done in terms of "headroom," which is defined as the ratio of the actual emissions to the emissions standard. Although the discussion defines this at one point and concludes that there are no differences "relative to the standard," it takes careful reading to understand this section. To clarify, the discussion (starting in the middle of page 14) could be reworded to read as follows:

> To assess this issue for heavier trucks, an analysis of in-use emissions from heavier LDTs was performed in terms of the ratio of the emissions to the emission standard. This variable, called the "headroom," allows a test of the hypothesis that there are no significant differences between the different truck classes when the emissions are adjusted by dividing the data for light-duty vehicles by the appropriate emission standards.

The summary of regression coefficients for basic emission rates in Table B-1 could be augmented by stating the formula and data used for the emission calculations. For example:

The fleet emission rate, E, is computed from the emissions of high-emitting vehicles, E_H, normal-emitting vehicles, E_N, and the high-emitter fraction, f, as follows:

$$E = f E_H + (1 - f) E_N$$

The high emissions fraction for NOx is found in terms of the odometer reading, odo (in units of 10,000 miles), from the following equation.

$$f = \frac{-0.036 + 0.2142\, odo}{1.141 - 0.02941\, odo}$$

A similar paragraph, with the appropriate equation for NMHC or NMOG, could be included on the same page as Table B-2.

Consider using the same vertical scale for all the charts in Appendices C and D. Alternatively, use the same scale for all NOx charts in Appendix C, which could be different from the scale used for the NMHC and NMOG charts in Appendix D. The similar scale would allow a ready visual comparison among charts of the differences in emission rates for the different technology classes. For example, the benefit of OBD and I/M appears much larger for LDV/LDT1 ULEV NMOG than it does for LDT2/LDT3 Tier 1 NMHC; it is actually less (in grams per mile or total lifetime grams). In this same example the *relative* effect of OBD and I/M is greater for LDV/LDT1 ULEV NMOG than it is for LDT2/LDT3 Tier 1 NMHC. If the goal is to display the *relative* differences visually, the different vertical scales could be retained. If the vertical scale is not changed, the format for the vertical axis should be changed on some charts so that numbers are not repeated. Either use two significant figures in the axis labels or change the value used for the increment.

The discussion of the method used for the analysis of OBD (pages 24 and 25) is not very clear, and it has two errors. The first error is the definition (in the fourth line after equation 18) of "Nonhigh" as the fraction of normal and repaired vehicles. Equation 15 correctly defines Nonhigh(i) as 1.0 - $High_{BASE}$(i). This is different from the fraction of repaired plus normals, which is 1.0 - $High_{OBD}$(i). The second error is in equation 17. It should read Growth_High(i) = Delta_High(i)/Nonhigh(i-1). These subscripts maintain consistency for the entire set of equations. A simpler alternative would combine equations 15 to 17 into a single equation:

$$Growth\_High(i) = \frac{High_{BASE}(i) - High_{BASE}(i-1)}{1 - High_{BASE}(i-1)}$$

With the equation written as shown above, the fundamental assumption about the method used for calculating the high fraction under OBD can be illustrated by the following equation.

$$\frac{High_{OBD}(i) - High_{OBD}(i-1)}{1 - High_{OBD}(i-1)} = Growth\_High(i) = \frac{High_{BASE}(i) - High_{BASE}(i-1)}{1 - High_{BASE}(i-1)}$$

This equation emphasizes that the relative growth rate of high emitters used for OBD calculations is assumed to be the same as the relative growth rate found without OBD.

Combining equations 15 to 17 into one equation eliminates the “Nonhigh” term and the need to define it. The current definition of “Growth_High” refers to nonhighs and would have to be changed. The entire discussion of the material between equations 15 and 19 could be improved by integrating the equations with the text.

In the discussion of running emissions and start emissions on page 28, it may be appropriate to remind the reader that “start” emissions are defined as cold-start emissions that are subsequently adjusted for soak time. This makes it easier to understand equation 25. Also, the ratio 0.43/0.57 is defined as the “Bag 3/Bag 1 weighting across total FTP.” It may be clearer to define this as the ratio of cold-start trips to hot-start trips used to derive the bag weightings in the FTP.

Minor editorial comments

Page 6, footnote 7 states that 15 of the 74 vehicles tested by EPA had duplicate tests, but it does not say how these duplicate tests were treated in the data set. Were 74 or 89 data points from EPA vehicles used in the regression analysis?

Page 9, first line under Figure 3: “generating” should be “generated.”

Page 11, first sentence: “adjustment is” should be “adjustments are.”

Page 15: the first line is the footnote from the table on the previous page.

Page 16: the last two rows of the table contain references to footnotes 4 and 5 as data sources for engine-out NMHC emissions; these references do not seem correct.

Page 22, fourth line from the bottom: “will smaller” should be “will be smaller.”

Page 25, equation 18, second line: The closing “]” should be a “)]”. Presumably this equation has not been simplified to the form shown below in this report to better illustrate the two components of the growth: MILs that do not illuminate and owners who do not respond.

$$High_{OBD}(i-1) + (1 - OBD*MIL)Growth\_High(i)*(1-High_{OBD}(i))$$

Overall methodology

This report confronts a significant problem of mobile source emission models. Such models are required to make estimates of emissions in future years, but the data to do so are not available. Thus, approximations and engineering judgements must be used to estimate these future emissions.

The overall approach for Tier 1 vehicles is a modification of the exhaust emission method used for 1981-1993 vehicles where a substantial database was available. For those model years, the original analyses were used to determine running and start emissions separately. In this report, the FTP emissions are used as the basis for the analysis and the equations derived for FTP emissions are then modified to determine running and start emissions.

The analysis continues the division of the fleet into normal and high emitters, used in previous analyses. At the top of page 11, the report notes that this adjustment affects only the proportions of normal and high emitters and not the emissions of these two regimes. As noted in a previous review,[*] this is a fundamental assumption of the method used to compute the high-emitter fraction. Errors in this assumption would lead to errors in the computed high-emitter fraction. EPA staff should continue their efforts to obtain data that would justify this assumption, as they proposed doing in the M6.IM.001 report.

In general, the emissions of future vehicles are computed from the ratio of the future emission standard to the emission standard for the existing vehicles in the database. This is a reasonable approach to take in the absence of data. Details of this approach are discussed further below under the “Appropriateness of Conclusions” heading.

[*] L. S. Caretto, “Report Review. Inspection and Maintenance Analyses for 1981-1993 Light Vehicles in MOBILE6,” Review of the M6.IM.001 report for U. S. Environmental Protection Agency under order number 9A-0738-NATX, September 20, 1999.

The determination of future emissions must be based on extrapolation of existing data. The methods used for such extrapolations can be readily questioned, but they cannot be easily justified. There may be more than one reasonable choice to make in these extrapolations and the ones used in this report represent reasonable choices using the best judgement of the authors.

Appropriateness of the data sets selected

The report uses three vehicle data sets for modeling NOx emissions. These data sets are from tests by EPA, the California Air Resources Board (ARB), and the automobile industry. EPA used the data for passenger cars certified to the Tier 1 NOx standard of 0.4 g/mi. The three data sets contained results from 1,122 passenger cars and 62 light-duty trucks. The overall sample size is sufficient for computing the regression equation for normal emitters. The scatter in the data, which is shown in Figure 1, is typical for emissions data. Based on this figure, the ARB and EPA data sets appear to have more scatter than the results obtained from the automobile industry.

Because of a lack of sufficient data, particularly at high mileages, NMHC emission equations for Tier 1 vehicles were obtained by adjusting the similar equations for 1988-1993 vehicles with emission control technology similar to that used on Tier 1 vehicles.

The series of reports describing the development of MOBILE6 have generally not provided details of how data were used in the various databases. The general descriptions provided in the reports allow the reader to understand the approach used. However, an interested user may not be able to reproduce the actual results. The footnote on page eight of the report, which notes that one vehicle with NOx readings of 0.21 g/mi and 1.31 g/mi was treated as a high emitter, is an example of the kind of information required for another reader to check the original calculations.*

A preliminary examination of the data for NOx high emitters, in 1988-and-later vehicles certified to 0.4 g/mi NOx, was not able to match the data in the report. The data supplied by EPA in three spreadsheets had 27 high emitters with an average value of 1.298 g/mi. The average value is only slightly different from the value of 1.294 g/mi found in the report. However, the table on page 17 lists the number of high-emitting vehicles as 31 instead of 27. The high emitters found in this review were compared with the data in Figure 3, which shows the emissions of individual high emitters as a

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*Although this footnote explains how the data are treated, it does not say why the vehicle was considered a high emitter. At the average value of 0.76 g/mi, this vehicle would be a normal emitter. A comparison of the original data set and Figure 3 shows that only the 1.31 g/mi value was used for this vehicle rather than the average.

function of mileage. The two vehicles from the EPA data and the four vehicles from the auto industry data match the data in the figure. However, not all the ARB data match the points in the figure.

Some formal record should be kept of the actual databases used in each analysis and the reasons for including or eliminating any particular data points. Such information should be recorded, either in the M6 series of reports or separately, for any special treatment of data.

Several comments on the draft report have suggested the consideration of alternative databases (on past emissions performance) which would lead to different extrapolation assumptions. However, there are no other databases that would provide additional information on the actual emissions performance of the vehicles modeled here.

Data analyses, including statistical approaches and models

Regression analysis is the main tool used in this report. Refined techniques for more detailed analyses used in other MOBILE6 analyses were not used here, *e.g.*, the multilinear regressions used for 1981-1993 model year light-duty cars and trucks in the M6.EXH.001 report. Such tools were presumably not used here because the authors thought that they were not justified, given the approximations required to provide forecasts of future vehicle emissions.

The authors use some analysis of the regression statistics to determine the appropriateness of model choices. However, no statistical results such as confidence intervals or standard errors are provided for the data presented here. Such statistical results should be reported. The uncertainty for the emission predictions for future vehicles that results from the assumptions made to predict those emissions will be greater than any statistical uncertainty. However, estimates of this kind of "assumption uncertainty" could be provided. The comparison, on page 19, of Tier 1 NMHC data for low mileage to the model equations for Tier 1 NMHC derived from 1988-1993 vehicles is an example of such an estimate. A similar estimate of the uncertainty in this approach could be done for higher mileages by comparing the NOx emission rates found from data on Tier 1 vehicles with NOx emission rates for such vehicles derived from 1988-1993 vehicles.

With the data sets selected, the statistical analyses that have been done are appropriate. Commenters have suggested that the emission rates should be different for cars and trucks and that the changes in the normal emissions regressions are not proportional to the standards ratio as proposed in the report. However, once the choice of a data set was made, the regression analysis of the entire truck-plus-car data set was not able to determine that the different vehicle types had a statistically significant difference in regressions. This conclusion is likely due to the limited amount of data available on trucks certified to 0.4 g/mi.

Appropriateness of conclusions

There is no explicit conclusion section in three of the reports. There is an implied conclusion that the data analyses were effectively done to provide an appropriate estimate of Tier 1 and later light-duty car and truck NOx and NMOG/NMHC exhaust emissions for MOBILE6. Because this report deals with vehicles for which there is not a sufficient database to determine the emissions, the conclusions need to be more tentative than in other reports. Perhaps the report should contain an explicit acknowledgment that its results are based in part on data analysis and in larger part on engineering judgement.

The report title speaks of “Tier 1 and later” vehicles, but the report only discusses Tier 1 vehicles, LEVs and ULEVs. There is a brief mention of, but no quantitative data for, transitional low-emission vehicles (TLEV). The results of this report will also apply to Tier 2 vehicles. There should be some mention of, if not complete emissions equations for, Tier 2 vehicles in this report.

Ratio approach for basic emissions

The ratio approach is an appropriate technique for predicting future emissions in the absence of data. For normal emitters, this method could be justified more strongly by comparing data on previous changes in standards and seeing if the ratio method works. This is done in the analysis on page 19 for low-mileage, Tier 1, NMHC emissions.

In addition, the “headroom” analysis of the heaviest light-duty trucks (LDT4) NOx emissions on pages 14 and 15 can be considered a test of the ratio approach. This analysis basically uses a regression of different data sets, with different emission standards. However, the regressed data is expressed in terms of the ratio of the emissions to the emissions standard. The results of the analysis show that there is no difference in the regression between the LDT4 and other light-duty trucks, when the data are expressed as the ratio of emissions to the emissions standard. Other data sets could be compared, however the two results cited here show that the ratio approach appears to work for normal emitters when the emissions control technology is similar.

One problem with this approach is that it assumes that there will be no improvements or degradation in the ability of the emission control system to maintain lifetime emissions. Harley's remote sensing data from Phoenix has shown that later model year vehicles have much better CO emissions durability than early model-year vehicles, even though both model-year vehicles were certified to the same standard. It is also possible that the future changes requiring new emission control technologies will need some time to become stable as compared to the vehicles considered in Harley's study. Thus, the emissions deterioration (slope) could increase or decrease in future model years.

Comments by AIR using the auto database noted that the ratio method was not applicable to cars and trucks certified to NOx standards between 0.4 and 1.7 g/mi. Observations on this data set could be used to develop an alternative extrapolation procedure to the ratio method. Such a procedure would have to analyze how close the normal emission level would come to the actual standard for past and future vehicles. Since there will be technology changes with the new standards, it is not clear that an extrapolation procedure developed by this approach would be any better than the ratio method. Without any definitive data, the ratio method is the simplest approach to use for normal emitters.

An additional question about the ratio approach arises in the treatment of high emitters. As noted in the report, high emitters represent failed emission control systems. The emissions from two average vehicles with failed control systems may not be in direct proportion to their certification standards. Thus a weighting factor, w, is used to predict the high emissions from a future vehicle, H_F, in terms of the high emissions from an existing vehicle with data, H_D, and the emission standards for the future and data vehicles, S_F, and S_D, respectively. This weighting factor is applied to the existing high-emitter level, with and without the application of the standards ratio, according to the following equation:

$$H_F = w\, H_D \frac{S_F}{S_D} + (1 - w)\, H_D \qquad [1]$$

In the absence of data there are two possible arguments that can bound w. The first argument is that the high emitters would have the same proportional emission reduction implied by the standard and assumed for normal emitters. This argument leads to a value of w = 1. The second argument assumes that a failed vehicle would have the same emissions regardless of its emission control system. This leads to a value of w = 0. In both this report and in the previous draft, EPA has used a value of 0.5 for w, which is the midpoint of this range. EPA conducted two analyses to support this choice of w = 0.5. These are discussed below.

The first analysis examined data on engine-out emissions and calculated the difference in catalyst efficiency between two exhaust emission points: (1) the efficiency required to achieve the emission standard at 50,000 miles, (2) the efficiency for the average high emitter, assuming the value of w = 0.5 was used to compute the high emitter value for LEV and ULEV vehicles.* This analysis shows that the decrease in catalyst efficiency required to produce a high emitter is consistent with the assumption that w = 0.5. However, this analysis requires the questionable assumption that the only cause of a high emitter is a change in catalyst efficiency; the engine-out emissions are assumed to remain the same.

The second analysis, on page 17 of this report, compares limited data on high emitters to infer a value for w. That analysis uses equation [1], after rearrangement to solve for w. The result, after some algebra, is shown below.

$$w = \frac{1 - \frac{H_F}{H_D}}{1 - \frac{S_F}{S_D}} \qquad [2]$$

In the table on page 17, the numerator of equation [2] is in column five, the denominator is in column two, and the value of w is in column six. The data in that table compare federal Tier 0 vehicles, with a NOx standard of 1.0 g/mi; California Tier 0 vehicles, with a NOx standard of 0.7 g/mi; and Tier 1 vehicles with a NOx standard of 0.4 g/mi. The first comparison – NOx standards of 1.0 and 0.7 g/mi – gives a value of w = 0.83. The second comparison – NOx standards of 0.7 and 0.4 g/mi – gives a value of w = 0.70. The authors then argue that these two values of w and their associated emission levels suggest the following trend:

Lower NOx standard from 1.0 to 0.7 g/mi	w = 0.83
Lower NOx standard from 0.7 to 0.4 g/mi	w = 0.70
Lower NOx standard below 0.4 g/mi	w = 0.50

This implied trend is used to support the choice of w = 0.5 for emission reductions below a NOx standard of 0.4 g/mi.

No statistical evaluation of the data used in the analysis on page 17 is presented; such an analysis is likely to show that the difference between the two mean emission levels is not statistically significant. Since there are not sufficient data in the report to

*The LEV and ULEV classes are combined in both the NOx analysis and the NMOG analysis. The LEV and the ULEV classes have the same NOx standard, however their NMOG standard is different. The NMOG analysis uses the high emitter value for LEVs. There is no indication of the different proportions of LEVs and ULEVs in the data set analyzed.

determine this, an analysis to determine the likelihood that the differences would or would not be significant was carried out. In this analysis, shown below, the value of the standard deviation required for the differences to be statistically not significant was computed.

The confidence interval for the difference between the true or population means, denoted as μ_b and μ_a, can be expressed in terms of the sample means, denoted as $\bar{x}_b$ and $\bar{x}_a$, by the following equation.

$$\mu_b - \mu_a = \bar{x}_b - \bar{x}_a \pm t_{\alpha/2,\, n_b+n_a-2}\, s \sqrt{\frac{1}{n_b} + \frac{1}{n_a}} \qquad [3]$$

In this equation, α is the significance level, n_b and n_a represent the number in each sample and $t_{\alpha/2,nb+na-2}$ is the value of the t-distribution for the given significance level and sample sizes. The standard deviation, s, is the pooled estimate from both samples. It is computed from the individual standard deviations, s_b and s_a, by the following equation.*

$$s = \sqrt{\frac{(n_b - 1)\, s_b^2 + (n_a - 1)\, s_a^2}{n_b + n_a - 2}} \qquad [4]$$

The value of s that would show no difference between the two population means (at the extreme end of the confidence interval) can be found by setting $\mu_b = \mu_a$ in equation [3] and solving for s. This gives the following result.

$$s = \frac{\left| \bar{x}_b - \bar{x}_a \right|}{t_{\alpha/2,\, n_b+n_a-2} \sqrt{\frac{1}{n_b} + \frac{1}{n_a}}} \qquad [5]$$

Using the data for federal and California Tier 0 vehicles, in the table on page 17 of the report, gives $\bar{x}_b$ =2.46, $\bar{x}_a$ = 1.85, n_b = 8, and n_a = 3. The value of the t statistic for a significance level of 0.05 and $n_b + n_a - 2 = 9$ is 2.201. With these data the confidence interval for $\mu_b - \mu_a$ contains zero if the pooled estimate of the standard deviation is 0.41

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*This equation assumes that both samples have the same variance, σ^2. The pooled estimate of the variance, s, is the estimate of this common variance.

or greater. Similarly, when the California Tier 0 vehicles are compared with the Tier 1 vehicles ($\bar{x}_b$ =1.29, $\bar{x}_a$ = 1.85, n_b = 31, and n_a = 3), the value of s required to have zero in the confidence interval for the difference between the true means is 0.42.

It is likely that the standard deviation for high-emitter data will be greater than the values of 0.41 and 0.42, computed above.* If s is greater than 0.42, the differences in the means used to imply a slope in the discussion on page 17 are not statistically different. The actual standard deviations should be used to compute the significance of the differences between the mean values compared in this analysis.

Based on this review, neither of the arguments used to justify the value of w = 0.5 is very convincing. They should be retained, however, to illustrate the possible kinds of analyses that could be used to establish a value for w. In the absence of any convincing data to the contrary, there is no apparent reason to change this value from the initial choice of w = 0.5 assumed in the draft report.

Effects of OBD and I/M

The basic approach used to model the effects of OBD is to assume that the fraction of normal vehicles, as a function of vehicle age or mileage, remains the same as with no OBD. In addition, the relative growth in the fraction of high emitters is assumed to be the same with and without OBD. This assumption is illustrated by the equation below.

$$\frac{High_{OBD}(i) - High_{OBD}(i-1)}{1 - High_{OBD}(i-1)} = \frac{High_{BASE}(i) - High_{BASE}(i-1)}{1 - High_{BASE}(i-1)} \quad [6]$$

The fraction on the right-hand side is calculated from data on the base case – no OBD and no I/M. The fraction is then applied, in the OBD case, to the number of normal plus repaired vehicles. This allows both normal vehicles, which have never been repaired, and vehicles that have previously been repaired, to migrate into high emitters.

Once the migration into the high-emitter group is calculated, the OBD and I/M effects are used to calculate the fraction of those new high emitters repaired. The repair

*The preliminary examination of data for 1988-and-later NOx high emitters certified to 0.4 g/mi NOx, discussed on page 6, found 27 vehicles (instead of the 31 vehicles listed in the table on page 17) with an average NOx emission rate of 1.298 g/mi instead of 1.294 g/mi. The standard deviation was 0.590 g/mi and the coefficient of variation (COV) was 0.590/1.298 = 45.4%. If all the data in the table on page 17 had this same COV, the pooled estimate of the standard deviation would be large enough to make the comparisons of the means statistically insignificant.

calculation is based on three parameters: (1) the illumination rate for the malfunction indicator light (MIL), (2) the response rate – the rate at which owners will have their vehicles repaired when their MIL is illuminated, and (3) the emission level of repaired vehicles. In the absence of data, EPA has assumed the following values for these parameters:

- The MIL will illuminate in 85% of the high emitters.
- The motorist response to an illuminated MIL will be 90% in an area with I/M, regardless of the vehicle age.
- In an area with no I/M program, the motorist response will be 90% during the warranty period from 0 to 36,000 miles; it will then drop to 10% between 36,000 and 80,000 miles when the emission warranty is in effect. Beyond 80,000 miles the response rate, in a non-I/M area, is zero.
- The after-repair emission level is the lesser of (1) the normal emission level at the given mileage or (2) 1.5 times the emission standard for 50,000 miles.

The report notes that different stakeholder comments either support or recommend changes in the values used for the MIL illumination rate or the OBD response rate. These values were not changed in the final report because the commenters did not provide any data to support recommended changes. Qualitatively, the report makes three assumptions: (1) that the MIL will illuminate most of the time in a high emitter; (2) that vehicle owners will respond (*i.e.*, have their vehicle repaired) most of the time the MIL is illuminated only if there is an I/M program in place or if the vehicle is under full warranty; (3) the response rate becomes very small for high-mileage vehicles. These qualitative assumptions seem correct. However, it is not possible to make any definitive recommendations to support or to change the values used in the report in the absence of data.

The authors state that the after-repair emission level was an assumption, based on an analysis of data from IM240 programs. No details or quantitative results of that analysis are mentioned. The assumption that the after-repair emissions are the same as those of normal vehicles is consistent with the results in the I/M report, M6.IM.001 (July 22, 1999 revision). That report contains regression equations for the ratio of after-repair emission level to normal emission level. For the most stringent cut points used (HC = 0.4 g/mi, CO = 10 g/mi, NOx = 1 g/mi), the average value for the ratio of after-repair emissions to normal emissions for vehicles fifteen years old[*] and less is 1.00 for HC, 1.27 for CO and 0.68 for NOx. For the phase-in cut points (HC = 1.2 g/mi, CO = 15 g/mi, NOx = 3 g/mi), the same average ratios are 1.66 for HC, 1.43 for CO and 1.43 for NOx.

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[*]The value of fifteen years was used in this average because the regression equations in MOBILE6 are not used outside this range. The after-repair-to-normal emissions ratio for fifteen-year-old vehicles is used for all vehicle ages greater than fifteen years.

Other issues

The report notes that an initial draft had a correction factor to account for the effects of I/M on the ARB data used in the report. This factor was dropped in the final report reviewed here. This was a good decision because of the anomalous results presented by this correction factor. According to the original correction factor equation, the California idle I/M program increases NOx emissions for Tier I vehicles. In that equation, the effects of I/M on NOx emissions are highest at zero miles and are absent for odometer readings of 150,000 and greater. An I/M program that uses only HC and CO exhaust measurements (with no visual or functional check that may catch NOx defects) can increase NOx emissions, but there should be no effect at zero miles. The correction factor should be 1 at an odometer reading of zero and then should increase as vehicles went through their biannual I/M tests. A multiplicative correction factor (CF) regression of the form $CF = 1 + a(odo) + b(odo)^2$ would have no correction at zero mileage. Such a regression could possibly show an increase in the correction factor with odometer reading and a subsequent decrease back to 1, as was found in the original correction factor equation. The decision to drop the I/M correction factor equation is justified not only by the small size of the correction factor, but also because the effect of the correction factor did not represent the expected behavior of an I/M program.

Conclusions and Recommendations for Further Studies

Short-term improvements

The comments in the previous section deal mainly with editorial changes and recommendations for inclusion of more statistical information about existing results. No short-term recommendations call for changes in the MOBILE6 model itself. In particular, the following recommendations can be done in the next revision of the report:

- Make the revisions recommended in the Overall Clarity subsection.
- Include statistical information (standard error, sample size, confidence limits, p-values, etc.) for the regressions and average values presented in the report.
- Include results for Tier 2 vehicles.
- Provide an explicit conclusion that the results rely, to a large degree, on engineering judgement.

Long-term improvements

That more data should be obtained on new-technology vehicles is so obvious that it does not need to be stated. Besides the usual data on the long-term emission performance of the vehicles discussed here, it will also be necessary to obtain data on the parameters for OBD-based I/M programs. This is especially true for the MIL illumination rate and the motorist response rate. Plans to gather future I/M data should ensure that data fields to collect information from the OBD system are included for all vehicles. This needs to be done for both I/M programs and for future inventory-related data-gathering studies.

The calculation of the high-emitter fraction in this report and in other parts of MOBILE6 assumes that the average emission level of high emitters in the correction data is the same as that in the base fleet. On page 16 of the M6.IM.001 report EPA noted that it was investigating IM240 data from Wisconsin and Colorado to confirm this assumption. This work should be completed to determine if there is any significant error in the assumption used for the high-emitter fraction calculation.

The I/M correction factor that was not included in the final analysis of the ARB data set suggests a potential problem for future versions of MOBILE. The typical emissions analysis is based on starting with data on vehicles that have not been through an I/M program. With the widespread introduction of OBD and I/M programs, it will be difficult to get a large data set that has not been subject to an I/M program. It is not too early to think about how future data collection efforts and exhaust emission models will be done to account for this.

EPA should collect a formal record of the data used in the construction of MOBILE6, including a list of the choices made (and their rationale) for including or excluding groups of data and individual data points.