
Investigation of MOBILE5a Emission Factors:

Evaluation of I/M and LEV Program Benefits

HEALTH AND ENVIRONMENTAL SCIENCES

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Health and Environmental Sciences Department

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ABSTRACT

The U.S. Environmental Protection Agency's (EPA's) on-road motor vehicle emission factors model, MOBILE5a, is being used increasingly as a regulatory and public policy tool. It is used to determine compliance with motor vehicle related control programs such as enhanced inspection and maintenance (I/M) and highway conformity determinations; its outputs were also used to develop EPA's Complex model for reformulated gasoline. Although MOBILE5a outputs are used for a broad array of purposes, the methods used to develop inputs to the model are largely undocumented. This report evaluates and documents many key MOBILE5a parameters, with particular emphasis on the way I/M programs and California low-emission vehicles are modeled. The evaluation included an analysis of the data used by EPA to develop I/M identification and repair effectiveness matrices for the MOBILE5a preprocessor model, Tech5; an assessment of the methodology used to estimate the benefits of evaporative system functional checks (i.e., "pressure/purge" testing); a comparison of real-world evaporative emissions test data to model output; a review of the data and methodology used to develop evaporative running loss estimates for MOBILE5a; and a review of the approach used by EPA to model the effects of low-emission and Tier I vehicles under standard and "maximum" I/M scenarios. The analysis indicated that a number of inputs to MOBILE5a were based on assumptions that likely result in an over-estimate of enhanced I/M program effectiveness for both exhaust and evaporative emissions. It also revealed that there is a severe shortage of data on which to base multi-day, high-temperature evaporative emissions estimates.

Investigation of MOBILE5a Emission Factors: Evaluation of I/M and LEV Program Benefits

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EXECUTIVE SUMMARY

The Clean Air Act Amendments (CAAA) of 1990 require the use of cleaner, "reformulated," gasoline in the nine worst ozone areas of the country beginning in 1995. In order for refiners to determine if particular fuel formulations meet the performance standards established for reformulated gasoline, a "Complex" model has been developed by the U.S. Environmental Protection Agency (EPA) that estimates reductions in volatile organic compounds (VOC), oxides of nitrogen (NO_x), and toxics as a function of various fuel parameters (e.g., oxygenate content, RVP, etc.). A critical component of the Complex model is EPA's onroad motor vehicle emission factor models, MOBILE4.1 and MOBILE5a*. Output from those models was used to derive the baseline exhaust and nonexhaust VOC emission rates for the Complex model, and it was also used to derive the correlation equations relating fuel RVP and nonexhaust emission rates. The MOBILE models were exercised under specific sets of inspection and maintenance (I/M) parameters to establish the Complex model baselines for both Phase I and Phase II of the program.

Because of EPA's reliance upon the MOBILE series of models, the American Petroleum Institute (API) contracted with Sierra Research, Inc. (Sierra) to perform an evaluation of the MOBILE models, with particular emphasis to be given to the manner in which the models account for I/M effects. This report documents that evaluation and summarizes the results that were presented in a number of technical memoranda submitted to API during the course of this effort.

While performing the analyses related to this project, it became apparent that very little documentation has been prepared by EPA to support many of the inputs to the model. This holds true for the MOBILE models as well as the "Tech" models, which are used to generate

* Some of the analyses performed by EPA during the development of the Complex model were based on the MOBILE5 version of the model. However, the final Phase II Complex model relations were based on MOBILE5a. In this report, "MOBILE5a" is used throughout to refer to both MOBILE5 and MOBILE5a.

several key inputs (e.g., base emission rates, I/M benefits) for MOBILE. Although EPA holds public workshops prior to the release of new versions of MOBILE, it is unclear how comments received at those workshops are addressed and incorporated into the final construct of the model. This raises serious concerns regarding the development of public policy based on a process that is essentially undocumented, yet requires industry to comply with the results of that process.

To collect information on the design of MOBILE, the contents of the MOBILE models, the Tech models, and handouts provided at public workshops were reviewed, and numerous telephone calls (over 30) were conducted with EPA staff responsible for relevant sections of the model. Although EPA was helpful in providing requested information, frequently answers to questions were unavailable and EPA staff had to review their work to determine what assumptions were made in developing inputs to the model. It is clear that much of the documentation presented in this report has not been done internally by EPA. As an example, the last written documentation of the Tech model was prepared in 1985 and was based on MOBILE3; a number of significant changes to the model structure have occurred since that time.

The summary below highlights the major findings from this study.

EXHAUST EMISSION ESTIMATES

The review of exhaust emission rates focused on an evaluation of MOBILE4.1 and MOBILE5a, as well as the emission factor and I/M benefits models, Tech4.1 and Tech5. That evaluation was directed at four main topics: 1) I/M identification rates developed for Tech5; 2) I/M after-repair emission rates developed for Tech5; 3) the distribution of VOC emissions between normal and high emitters; and 4) an assessment of onboard diagnostic systems. The results are summarized below.

Identification Rates

In terms of the impact on the Complex model formulation, the identification rates ascribed to a particular I/M program (i.e., the fraction of emissions identified by an I/M test) affect both the fleet-average g/mi exhaust emission rate and the contribution of normal and high emitters to this rate. This in turn impacts the ratio of exhaust to nonexhaust emissions and the relative effects of alternative fuel formulations. The analysis presented in this report focused on how EPA arrived at the identification rates for multipoint fuel-injected (MPFI) vehicles that are very high emitters because this technology/emitter group has the greatest impact on I/M benefits calculated for future-year MOBILE analyses.

The review of the identification rates generated for very high emitter MPFI vehicles indicated that EPA's analysis was based on very sparse data (16 vehicles), particularly given this category's contribution to the overall I/M benefits calculated for a year 2015 MOBILE run.* (2015 is the year upon which MOBILE runs were based for the Complex model.) In fact, one vehicle that passed the 0.8 g/mi cutpoint with an IM240 test result of 0.80 g/mi was the entire difference between a 100 percent identification rate for 0.8/15 IM240 HC/CO cutpoints and the 88.5 percent currently used in Tech5. For 0.8/20 HC/CO cutpoints (which were used to generate the baseline MOBILE output for the Complex model), this vehicle caused the identification rate to go from 99.3 percent to 87.9 percent (which is currently used in Tech5).**

* The total sample size for the development of identification rates was 274 vehicles. However, when the data were stratified by the 4 technology groups and 4 emitter categories specified in Tech5, the size of some other technology group/emitter category combinations was also relatively small. This is particularly true of the non-normal emitter categories, since normal emitters made up 59% of the identification rate sample.

** Note that the identification rate is not equivalent to the I/M credit. The generation of I/M credits relies on the fraction of emissions identified by an I/M test coupled with the before- and after-repair emission rates. As an example, if the before-repair emission rate is 5.0 g/mi, the after-repair emission rate is 1.0 g/mi, and the identification rate is 100%, then the average after-I/M emission rate is 1.0 g/mi and an I/M credit of 80% is observed (i.e., $(5.0 - 1.0)/5.0 = 80\%$). On the other hand, if the identification rate is 75%, then the average after-I/M emission rate is $0.75 \times 1.0 + (1 - 0.75) \times 5.0 = 2.0$ g/mi and an I/M credit of 60% is observed (i.e., $(5.0 - 2.0)/5.0 = 60\%$). Thus, a higher identification rate translates into a higher I/M credit and lower emissions predicted by MOBILE.

A bounding estimate was performed in which nine additional very high MPFI vehicles were included in the identification rate data base. (These vehicles were previously excluded from the data base for a variety of reasons.) The results of that analysis indicated a decrease in the HC identification rate for the 0.8/15 HC/CO IM240 cutpoints and an increase in the identification rate for 0.8/20 cutpoints relative to the values currently used by Tech5. Again, this points out how sensitive the identification rates are to changes in the underlying data and the overwhelming need for more data on this key technology and emitter group.

After-Repair Rates

The after-repair rates developed by EPA for use in Tech5 also influence the magnitude of the baseline exhaust VOC emission rate calculated by MOBILE5a, as well as the relative contribution of normals and highs to the exhaust emission rate. Lower after-repair emission rates directly impact the exhaust emission benefits associated with a particular I/M program and result in lower estimates of exhaust VOC emissions.

A review of the methodology used by EPA to develop after-repair emission rates as a function of before-repair rates indicates that the approach is reasonable and straightforward. In practice, however, the implementation is questionable. To increase the sample size available to develop the after-repair rates, EPA adjusted the observed after-repair FTP emission rates *downward* for cases in which the vehicle did not pass the I/M test after repair. The net result of this adjustment is a decrease in VOC exhaust emission rates predicted by MOBILE5a which is not supported by the test data.

It can be argued, however, that vehicles not passing the I/M test after repair (i.e., those data points that were adjusted in the MOBILE5a/Tech5 method) should be completely excluded from the analysis. (Presumably, vehicles failing the I/M test after repair should be accounted for in the waiver rate and compliance rate input to MOBILE.) If these "adjusted" data points are excluded, the net result is even *lower* after-repair emission rates. This, in turn, would lead to lower overall exhaust emission estimates from MOBILE5a.

It appears that one of two approaches should have been utilized by EPA in developing the I/M credits for MOBILE5a: (1) use the unadjusted FTP data to develop the after-repair rates, or (2) exclude vehicles that failed the IM240 test after repair to develop the after-repair emission rates and account for those failures with more reasonable estimates of waiver and noncompliance rates that match what the data show and not what EPA is predicting under its enhanced I/M guidelines.

Distribution of VOC Emissions Between Normal and High Emitters

Both the identification rates and after-repair rates as a function of I/M test type and cutpoints impact the fraction of vehicles remaining high emitters after repair, and, thus, the contribution of normal and high emitters to the exhaust VOC emission rate. This contribution is important, as the Complex model utilizes different equations for normal and high emitters to predict exhaust VOC emission changes as a function of fuel parameters. EPA has utilized a method that analyzes the IM240 data base directly to determine this fraction, and Sierra has developed an alternative methodology (based on predictions from the Tech5 model) that provides an upper-bound estimate of the fractional contribution of high emitters to the exhaust VOC emission rate.

EPA's method predicts that 55.6% of the exhaust HC emission rate calculated by MOBILE5a for the Complex model is from high-emitting vehicles, while Sierra's methodology (which was performed only for MPFI vehicles) predicts an upper-bound estimate of 61.1%. Because neither method accounts for vehicles that are waived or noncomplying, it can be argued that the fractional contribution from high emitters should be greater than that outlined above (i.e., vehicles receiving waivers or not complying with a required I/M check would be expected to have higher emissions, on average, than vehicles that pass the I/M test). Given the close agreement between the two approaches, the value computed by EPA is a fair representation of the split between high and normal emitting vehicles.

Onboard Diagnostics

Although the MOBILE runs performed for the development of the Complex model are based on 1990 vintage vehicles, during the time period for which the Phase II model is effective, there will be a considerable number of vehicles equipped with onboard diagnostic (OBD) systems. Because OBD will affect the in-use emissions performance of vehicles, API desired a review of how EPA estimates the benefits of the OBD regulation.

EPA's estimates of the emission benefits attributable to OBD were generated in a very simplistic fashion, which basically shifted the benefits of enhanced I/M to OBD after the year 2005 (i.e., EPA determined the benefits by running MOBILE5a with and without enhanced I/M and the difference was considered to be the OBD benefit). It can be argued, however, that OBD coupled with IM240 will result in an increased identification of high and very high emitters. Sierra performed an alternative benefits analysis that used more stringent IM240 standards for 1996 and subsequent model year vehicles to serve as a surrogate for OBD. That analysis indicated only a slight decrease in the exhaust VOC emission rate for the year 2005 (approximately 5 percent for LDGVs); thus, including the impact of OBD in the Complex model formulation would have a small effect on the overall results.

NONEXHAUST EMISSION ESTIMATES

The most important factors with respect to the evaporative emission estimates generated by MOBILE are the data and methodologies used by EPA in the development of the model. Under Task 1, the goal of this effort was to determine (1) if EPA's assumptions regarding the effectiveness of evaporative system functional tests are consistent with data collected at EPA's Hammond, Indiana, test lane and elsewhere; and (2) if MOBILE5a estimates of diurnal emissions are consistent with data obtained from real-time, high-temperature evaporative emissions testing. In addition to these items, further analysis was performed under Task 2 of this project. That included evaluating running loss emission rates more thoroughly, estimating the contribution of vehicles passing and failing the evaporative system functional test to the nonexhaust VOC emission rate calculated by MOBILE, analyzing apparent anomalies with the algorithms used to generate evaporative emission rates in

MOBILE, and reviewing how EPA models the impact of its new evaporative standards and test procedures.

Pressure/Purge Test Effectiveness

Because the MOBILE5a runs performed for the Phase II Complex model included the benefits of an annual evaporative system pressure/purge test, it is important to understand the assumptions made by EPA in developing those benefits. Nonexhaust VOC emissions are calculated in MOBILE5a by first segregating vehicles according to whether they pass or fail the pressure/purge test. The fraction of vehicles in each group (i.e., pass, fail pressure, fail purge) is then applied to emission rates that are specific to these groups, with higher emissions associated with the fail categories. The benefits of a pressure/purge check are determined by changing the fraction of vehicles in each group (i.e., a higher fraction of passing vehicles results from a pressure/purge check) and re-computing the composite emission rate.

Review of the data and methodologies used by EPA to develop baseline and after-repair pressure/purge failure rates revealed the following:

- EPA assumes a 95 percent effectiveness for its pressure/purge test for all vehicle categories. In conversations with EPA staff, it appears the 95 percent figure was determined by assuming that 5 percent of the vehicle fleet cannot be tested because of inaccessible canisters. If that assumption is made, then the 5 percent of the fleet that cannot be tested should experience a constantly increasing (with vehicle age) failure rate consistent with the baseline failure rate. However, EPA's analysis assumes that 95 percent of all failures get repaired each inspection cycle. This cannot be the case if a certain fraction of the fleet never gets inspected. An alternative analysis was performed that specifically separated non-testable vehicles. That analysis resulted in an increase in evaporative emissions relative to the Complex model baseline of 5% for LDGVs, 9% for LDGT1s, and 11% for LDGT2s.
- Alternative test programs have indicated a higher non-test rate than the 5% assumed by EPA. If the fraction of the vehicle fleet that cannot be tested is increased to 10%, evaporative emissions for LDGVs increase by

9% and by 15-20% for LDGT1 and LDGT2 vehicles. If the fraction of the fleet that cannot be tested is increased to 15% and the identification and repair effectiveness is assumed to be 95%, evaporative emission increases of 15%, 25%, and 32% are observed for LDGVs, LDGT1s, and LDGT2s, respectively.

- EPA assumes a 100% identification and repair effectiveness for those vehicles that can be tested, claiming that since a vehicle must eventually pass pressure/purge, it must get fixed. However, there are two flaws in that reasoning. First, that approach assumes baseline passing emission rates are equal to after-repair emission rates. Although there are no after-repair data for hot soak and diurnal emissions, running loss after-repair data do not support that assumption. Second, the 100% assumption implies that there are no waivers issued for evaporative system defects. Although evaporative system repairs have been estimated by EPA to be relatively inexpensive (\$56), there could be cases in which exhaust system repairs that are also needed drive the total cost of repair above the waiver limit.

Real-World Evaporative Emissions

Evaporative emissions estimates from MOBILE5a were compared to a very limited sample of test data that were collected under conditions that are more reflective of real-world conditions than the current certification test procedure. Three data sets were compared to predictions from MOBILE5a. The first data set contained high-temperature, multi-day diurnal and hot soak data that were collected in a cooperative test program conducted by the California Air Resources Board (ARB), General Motors (GM), and the Western States Petroleum Association (WSPA). Second, two papers published by GM report limited data for vehicles tested on 9.0 RVP fuel under 66-95°F or 72-96°F diurnals. Finally, high-temperature hot soak and extended (i.e., 3 - 6 hour) diurnal data collected by EPA and presented at the July 1992 MOBILE5a workshop were compared to model predictions. To the best of our knowledge, these are the only available data related to evaporative emissions testing at temperatures and time periods reflective of real-world conditions.

The results of the comparison revealed the following:

- Although the data are limited, it appears that MOBILE5a may underpredict high-temperature (65°-105°F), multi-day diurnals for throttle-body fuel-injected (TBI) vehicles with functional evaporative control systems (based on ARB/GM/WSPA data). For these data, the model underpredicted emissions by roughly 50%.
- A comparison of MOBILE5a results to the GM test data for a 72°-96°F diurnal (full and multi-day) indicated that MOBILE5a overpredicted diurnal emissions under these conditions. The magnitude of the overprediction ranged from 20% to 500%, depending on fuel delivery system and whether first-day or third-day results were being compared.
- For vehicles with evaporative system malfunctions, MOBILE5a appears to underpredict diurnal emissions under high temperature (65°-105°F) conditions (based on ARB/GM/WSPA data). The magnitude of the underprediction depends on the fuel RVP and model year being analyzed, but ranges from 20% - 60%.
- A comparison of MOBILE5a output to available data (ARB/GM/WSPA and EPA data) indicates that hot soak emission rates for MPFI vehicles at high temperatures are underpredicted by roughly 50%.
- A comparison of 3-6 hour diurnal EPA data (72°-96°F) for a limited sample of light-duty gasoline vehicles passing the pressure/purge functional test to MOBILE5a full day diurnal estimates indicated the following: for 9.0 RVP fuel, MOBILE5a appears to overpredict full-day diurnal episodes by 10 - 50%, while the model underpredicts full-day diurnal episodes (by 20% - 50%) for 7.0 RVP fuel.

Based on the limited number of vehicles tested, it is difficult to draw any firm conclusions when comparing the test data to MOBILE5a predictions. However, the trend in hot soak emission rates predicted by MOBILE5a for MPFI vehicles (i.e., only a very slight increase in emissions with increasing temperature) indicates a potential problem with the hot soak algorithm for this key technology group.

Running Loss Emission Estimates

An evaluation of data used in MOBILE5a for running loss emission estimates revealed the following:

- The data used to generate MOBILE5a running loss emission estimates for failing vehicles over-represents carbureted vehicles. When this bias is corrected, emissions from failing vehicles increase by 7%.
- Inspection of the "block data" in MOBILE5a used to estimate passing LDGT1 and LDGT2 running loss rates indicates an increase in emissions with a decrease in RVP. Clearly, this is an error.
- EPA's data indicate that after-repair running loss emission rates from vehicles initially failing pressure/purge are approximately 40% higher than vehicles initially passing the functional check.

Based on the above, it appears that consideration should be given to formatting the evaporative/running loss algorithm in MOBILE to separately account for after-repair emission rates.

Contribution of Passing and Failing Vehicles to the Fleet-Average Nonexhaust VOC Emission Rate

During the course of this study, API requested an analysis of the relative contribution of passing and failing vehicles to the fleet-average nonexhaust VOC emission rate. That analysis indicated that roughly 75 percent of nonexhaust VOC for LDGVs is attributable to vehicles passing the pressure/purge test. This fraction drops considerably for light-duty trucks because the passing vehicle running loss contribution is much lower for the LDGT1 and LDGT2 vehicle classes. It should be noted, however, that these results reflect the presence of an annual pressure/purge test as it is currently modeled by MOBILE5a. If no pressure/purge test were included in the modeling runs, or if more reasonable assumptions were made regarding pressure/purge test effectiveness, the contribution from failing vehicles would substantially increase.

Apparent Anomalies With the MOBILE5a Evaporative Emissions Algorithm

In performing the analyses of nonexhaust emission rates, it was necessary to carefully review the MOBILE5a FORTRAN source code. That review indicated several apparent anomalies in the evaporative emissions algorithm, which are highlighted below:

- Multiple-day diurnal emissions from vehicles passing the pressure/purge test are estimated by applying a correction factor to the full-day diurnal estimate. However, in cases where the calculated multi-day diurnal for passed vehicles is greater than a full-day diurnal from a failed purge vehicle, the pass vehicle is assigned the failed purge rate to represent a multi-day event. There are two points to be considered when making this assignment: (1) the correction factor developed to adjust the full-day diurnal to a multi-day estimate was based on ambient conditions similar to the conditions specified for the Complex model; and (2) a failed purge vehicle does not necessarily have a completely inoperable purge system. At a minimum, it seems that the maximum rate should be based on a failed *pressure* vehicle, which has higher emissions than a failed purge vehicle.
- It appears that there is an error in the MOBILE5a algorithm that is used to generate diurnal emission estimates for TBI vehicles. For example, under the temperature conditions specified for Class C areas in the Complex model (i.e., 71.6°-91.6°F), full-day diurnal estimates from TBI vehicles are zero at RVPs below 7.5. This clearly underpredicts nonexhaust VOC emissions at lower RVPs. (TBIs constitute 20 percent of the LDGV fleet and 40 percent of the LDGT1 and LDGT2 fleet for 1990 and subsequent model years.)

Both of the items above result in the model under-predicting nonexhaust emission rates, and a review of these issues should be conducted by EPA to determine if there are errors in the MOBILE code.

New Evaporative Test Procedure

The CAAA of 1990 directed EPA to promulgate new evaporative standards and test procedures to control running loss emissions and multi-day diurnal emissions under summertime, ozone conditions (i.e., elevated temperatures). The new procedures and standards will be effective with the 1996 model year and will be phased in over a four-year

period (i.e., 20 percent compliance in 1996, 40 percent compliance in 1997, 90 percent compliance in 1998, full compliance in 1999). Results from MOBILE5a indicate an approximate 60% fleet-average reduction in nonexhaust emissions (excluding refueling losses) when the regulations are fully implemented in an area with an annual pressure/purge test (i.e., a 2020 analysis year was specified in the MOBILE5a runs performed to make this comparison). However, since the emission reductions are diminished for vehicles failing the pressure/purge test, the fleet-average percent benefit is reduced if pressure/purge testing is not specified (i.e., if pressure/purge testing is not required, there are more failing vehicles in the fleet which have a smaller emission benefit from the new evaporative test procedures compared to passing vehicles).

LOW-EMISSION AND TIER I VEHICLES

API requested an evaluation of the method used by EPA to model the effects of California's Low-Emission Vehicle (LEV) program. In addition, API desired an assessment of how I/M benefits are applied to LEVs and Tier I vehicles under standard modeling conditions and under an "appropriate" (i.e., "maximum") I/M scenario. ("Maximum" I/M, which is different than an enhanced or basic program, assumes that all vehicles will meet their certification standards in customer service.) These points are summarized as follows.

Benefits of the California LEV program were modeled in MOBILE5a by developing separate base emission rate equations for each category of low-emission vehicle (i.e., transitional-low-emission vehicles [TLEVs], low-emission vehicles [LEVs], and ultra-low-emission vehicles [ULEVs]). These emission factors were developed using current model year (i.e., 1993) emission rates as the basis. Under a no-I/M or standard-I/M case, only the zero-mile component (i.e., intercept) of the current base emission rate equation was modified to reflect the implementation of new emission standards. In general, the zero-mile adjustments were made by applying the ratio of LEV-to-existing standards to the 1993 zero-mile level. In the case of hydrocarbons, several adjustments were also performed to account for the differences in how the standards are specified (i.e., total hydrocarbons versus non-methane organic gases) and the certification fuels. For carbon monoxide, the zero-mile levels were developed

based on EPA's assumption that electrically heated catalysts (EHCs) would be required for LEVs and ULEVs and that EHCs would reduce the existing CO zero-mile level by 75%.

The impact of I/M on LEVs and Tier I vehicles under a standard I/M scenario (e.g., basic or enhanced I/M) is estimated much the same as for conventional vehicles. I/M credits are applied as a function of model year and vehicle age, and emission rates are calculated to reflect the presence of an I/M program. (As explained in Section 4, a slight modification is made for LEVs to account for the differing zero-mile levels.) Under an "appropriate" or "maximum" I/M case, I/M credits are not utilized. Rather, the base emission rate equation deterioration rates are modified to reflect the assumption that these vehicles will meet their 50,000-mile certification standards in customer service. This results in significant emission reductions from in-use motor vehicles as illustrated in Figure ES-1 for Tier I light-duty gasoline vehicles.

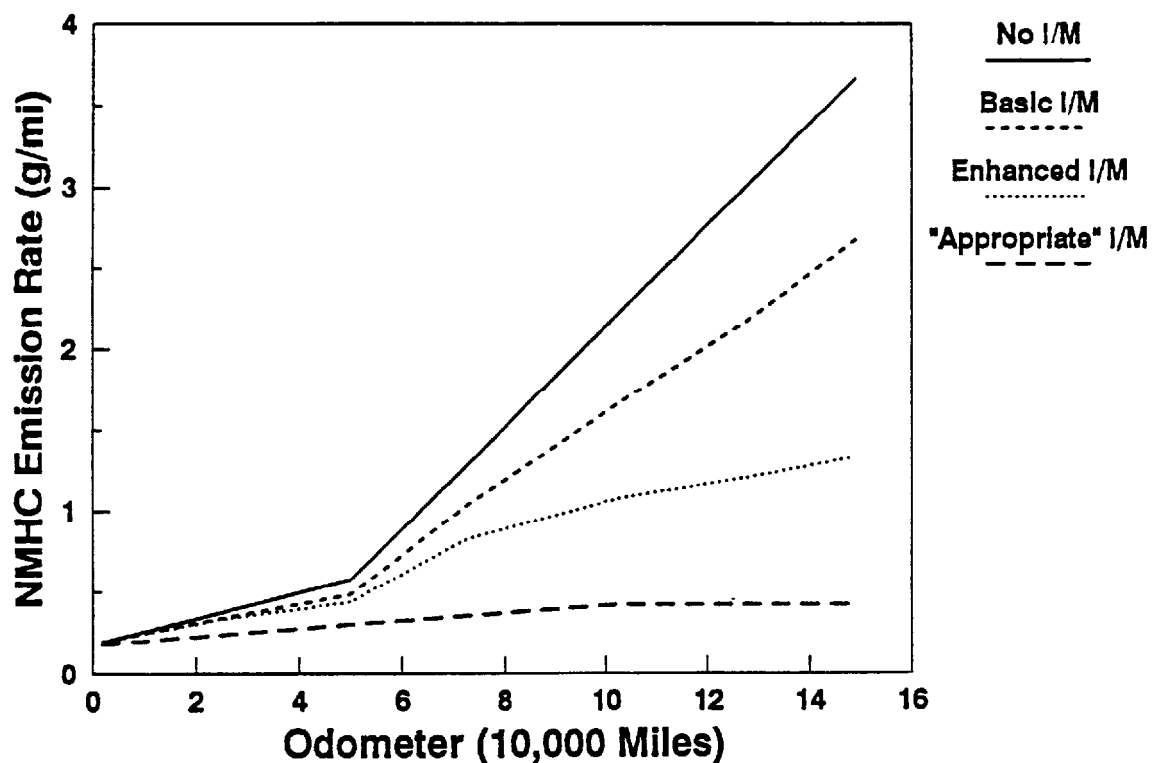


Figure ES-1. MOBILE5a Tier I NMHC Emission Factors as a Function of I/M Type

Section 1

INTRODUCTION

As part of the Clean Air Act Amendments (CAAA) of 1990, Congress directed EPA to establish regulations for cleaner gasoline and require its use in the nine worst ozone areas of the country. In developing the regulations for cleaner or "reformulated" gasoline (RFG), EPA entered into a regulatory negotiation ("reg-neg") with the affected industries. This effort resulted in the development of a "Complex" model that will be used by refiners to determine if particular fuel formulations comply with the RFG performance standards. EPA's onroad motor vehicle emission factors models, MOBILE4.1 and MOBILE5a, were critical to the development of the Complex model. Output from those models was used to derive the baseline exhaust and nonexhaust VOC emission rates for the Complex model. It was also used to derive the correlation equations relating fuel RVP and nonexhaust emission rates. The MOBILE models were exercised under specific sets of inspection and maintenance (I/M) parameters to establish the emissions baselines for both Phase I and Phase II of the RFG program. Because of EPA's reliance upon the MOBILE series of models, the American Petroleum Institute (API) contracted with Sierra Research, Inc. (Sierra) to perform an evaluation of the MOBILE models, with particular emphasis to be given to the manner in which the models account for I/M effects.

The initial purpose of this study was to evaluate how EPA constructed the emission factors produced by MOBILE that are used in the Complex model. The scope of the effort, however, evolved to a broader review of how data sources were utilized to develop inputs to the model as it became clear that the assumptions and methodologies used are largely undocumented. This is particularly troubling given the increased importance placed on MOBILE emissions estimates, which are now used to determine regulatory compliance with a number of CAAA directives such as enhanced I/M programs, conformity determinations, and reformulated gasoline. The MOBILE model has evolved as a critical component of regulatory development, but the process by which EPA updates the model has not followed that evolution. Many inputs to the model are not documented, and the development of those

inputs has not received the public comment and scrutiny normally afforded to regulatory items. This report (and its companion report, "Investigation of MOBILE5a Emission Factors - Evaluation of IM240-to-FTP Correlation and Base Emission Rate Equations") serves to document, and in a number of cases provide alternatives to, many of the key inputs developed by EPA for MOBILE5a.

BACKGROUND

The Complex model for RFG has relied upon output from the MOBILE models in two significant ways.* First, the MOBILE models were used to establish the baseline ratio of exhaust to nonexhaust VOC emissions. Clearly, this ratio has a significant impact on how beneficial control of certain fuel parameters (e.g., RVP) will be in meeting the performance specifications when certifying a fuel. Second, the MOBILE models (or the data and preprocessor programs that develop inputs for the MOBILE models) were used in establishing the relative contribution of normal and high emitters to the fleet-average VOC emission rate for the exhaust portion of the Complex model. This also can have an impact on how refiners blend reformulated gasoline to meet the performance standards (e.g., the draft Complex model indicates that increased oxygen content has a more pronounced effect on high emitters than normal emitters for technology group 1, i.e., multipoint fuel-injected vehicles with three-way catalysts, EGR, and no air injection). Thus, it is important to understand the MOBILE models and the manner in which differing assumptions related to I/M programs can change both the distribution between exhaust and nonexhaust emissions, as well as the fractional contribution of normal and high emitters to the exhaust VOC emission rate.

The MOBILE series of models has been developed by EPA to estimate in-use emissions of HC (exhaust and nonexhaust), CO, and NO_x from eight classes of onroad motor vehicles

* EPA used output from MOBILE4.1 with a basic I/M program in the Phase I Complex model development, while MOBILE5a with enhanced I/M (including an evaporative system functional test) was used for the Phase II Complex model.

(e.g., light-duty gasoline vehicles, light-duty gasoline trucks). The methodology used to calculate exhaust emissions consists of determining a base emission factor (in grams/mile) for each of the 25 model years assumed to make up the fleet of vehicles; applying corrections to account for speeds, temperatures, operating modes, etc., outside of standard conditions; weighting the corrected emission factor by the assumed travel fraction for the age of the vehicle; and summing over 25 model years. Nonexhaust HC emissions (i.e., hot soak, diurnal, running loss, resting loss, refueling loss, and crankcase emissions) are treated somewhat differently in the MOBILE models. Emission rates for hot soaks, diurnals, and running losses are first developed according to whether a vehicle would be expected to pass or fail EPA's functional evaporative system pressure/purge test. These results are weighted by an estimated pass/fail rate to generate a model year specific emission rate that includes pass and fail vehicles. (Emission rates for the remaining nonexhaust emission categories are not assumed to change based on whether the vehicle passes or fails the pressure/purge test.) The results of the above calculations are then weighted over 25 model years to arrive at an emission factor for each category of nonexhaust emissions and vehicle class.

For exhaust emissions, the impact of I/M programs is accounted for in MOBILE by making an adjustment to the model year specific base emission factor. The magnitude of this adjustment is a function of I/M test type (e.g., idle versus IM240), frequency of inspection (e.g., annual versus biennial), waiver rate, etc., and all of these parameters can influence the number of normal and high emitters in the fleet (which ultimately influences the Complex model formulation). Although the adjustment is performed within the MOBILE model, a preprocessor program (i.e., Tech4.1 for MOBILE4.1 and Tech5 for MOBILE5a) is utilized to develop the I/M credit matrices that are read by MOBILE. Thus, it is not possible to determine the fractional contribution of normal and high emitters by simply running the MOBILE models. A more detailed assessment of how Tech 4.1 and Tech5 calculate the I/M credits and an evaluation of the data that are input to the Tech4.1 and Tech5 models is needed to estimate that fraction.

The impact on nonexhaust emissions of EPA's pressure/purge evaporative system functional check in an I/M program is also modeled by MOBILE. The algorithm used to perform that calculation adjusts the anticipated fraction of passing to failing vehicles in the fleet by reducing the baseline failure rate according to an assumed identification and repair effectiveness (which was 100 percent in MOBILE4.1 and 95 percent in MOBILE5a). Assumptions made regarding the effectiveness of this test procedure have a direct bearing on the magnitude of nonexhaust emissions estimated by the MOBILE models and, therefore, the relative importance of nonexhaust versus exhaust emissions in the Complex model formulation. Thus, it is important to understand how EPA arrived at its estimates of pressure/purge test effectiveness.

ORGANIZATION OF THE REPORT

Immediately following this introduction, Section 2 provides a discussion of how MOBILE models the impact of I/M programs on exhaust emission estimates. That discussion includes a summary of the preprocessor programs, Tech4.1 and Tech5, and an evaluation of the data used by EPA to develop inputs to the Tech5/MOBILE5a models. Also included in Section 2 is an evaluation of how EPA has modeled the effects of onboard diagnostic systems on exhaust emission estimates. Section 3 focuses on nonexhaust emission rates calculated by MOBILE, which includes an assessment of the methodology used to account for the presence of an evaporative system functional check (i.e., pressure/purge) and a comparison of model output to available test data. Section 3 concludes with a description of how the new evaporative standards and test procedures are modeled by MOBILE5a. Finally, Section 4 contains a discussion of the California Low-Emission Vehicle (LEV) program and how that program is modeled by MOBILE5a, with particular emphasis on how I/M is modeled under standard and "appropriate" or "maximum" I/M scenarios. In addition, Section 4 summarizes the treatment of federal Tier I vehicles under a "maximum" I/M case.

Section 2

EXHAUST EMISSIONS

The Complex model utilized output from the MOBILE models to determine the baseline emission rates for exhaust and nonexhaust VOC. Further, the relative contribution of normal and high emitters to the fleet-average exhaust VOC emission rate impacts the formulation of the Complex model for exhaust emissions. As a result, it is important to understand how various I/M programs impact the exhaust emission estimates from MOBILE, and how these programs affect the contribution that normal and high emitters make to the fleet-average emission factor. This section discusses the methodologies and data used in MOBILE4.1 and MOBILE5a (as well as the preprocessor programs, Tech4.1 and Tech5) to model the effects of I/M programs on exhaust emission estimates. In addition, an assessment of how EPA modeled the impact of the onboard diagnostics (OBD) regulations is included.

BASIC MOBILE MODELING METHODOLOGY

The MOBILE models have been developed by EPA to estimate in-use emissions of HC (exhaust and nonexhaust), CO, and NO_x from eight separate classes of onroad motor vehicles (i.e., LDGV, LDGT1, LDGT2, HDGV, LDDV, LDDT, HDDV, and MC). Emissions are estimated by first determining the emission rate of each model year making up the vehicle class, weighting the model year specific emission rate by fractional usage (i.e., VMT fraction), and summing over all model years that comprise the vehicle class. In addition, a variety of corrections are applied to the base emission rates to account for conditions that are not included in the standard test procedures used to develop the base emission rates (e.g., exhaust emission rates may be corrected for nonstandard speeds, evaporative emissions may be corrected for differing fuel volatility and temperature).

In equational form, the calculation can be described by:

$$EF_{i,j,k} = \sum_{m=1}^n VMT_m * (BER_{j,k,m} * CF_{j,k,m...})$$

where $EF_{i,j,k}$ = fleet-average emission factor for calendar year i, pollutant j, and process k (e.g., exhaust, evap);

VMT_m = fractional VMT attributed to model year m (the sum of VMT_m over all model years n is unity);

$BER_{j,k,m}$ = base emission rate for pollutant j, process k, and model year m;

$CF_{j,k,m}$ = correction factor(s) (e.g., temperature, speed) for pollutant j, process k, model year m, etc;

and the sum is carried out over the n model years making up the vehicle class (e.g., 20 years for LDGV in MOBILE4, 25 years in MOBILE4.1 and MOBILE5a).

MODELING OF I/M BENEFITS BY MOBILE

When an I/M program option is invoked in a MOBILE run, the base emission rate ("BER" in the above equation) is adjusted to reflect the presence of I/M. This adjustment takes into account the features of the I/M program being modeled, such as:

- program type (centralized or decentralized),
- inspection frequency (annual or biennial),
- test type (idle, idle/2500, loaded idle, or IM240),
- emission cutpoints (for IM240 only),
- waiver rate, and

- compliance rate (i.e., the fraction of vehicles subject to the program that complete the process to the point of receiving a certificate of compliance or a waiver).

To perform the I/M adjustment on the BER, the following methodology is employed:

$$BER_{I/M} = BER_{Non-I/M} * (1 - [CRED_{I/M} * (1 - WVR)] * ADJ_{Compl})$$

where $CRED_{I/M}$ is the I/M credit for the test type, cutpoints, frequency, model year, and vehicle age being considered; WVR is the user-input waiver rate; and ADJ_{Compl} is an adjustment that accounts for the user-input compliance rate. The above calculation is valid for centralized program types; if a decentralized program is specified, the calculation includes an adjustment that reduces the overall effectiveness of the program by 50%.

As an example, consider a calendar year 2015 MOBILE5a run in which an annual, centralized IM240 program is specified and the effects of the 1990 Clean Air Act Amendments are turned off. Further, assume that the I/M compliance rate is 96% and the waiver rate is 3%. (These are the MOBILE5a parameters that EPA chose for the Phase II Complex model.) The non-I/M VOC base emission rate for a 2010 model-year LDGV is 1.021 g/mi, and the base emission rate including the effects of the above I/M program is:

$$BER_{I/M} = 1.021 * \{1 - [0.255 * (1 - 0.03)] * 0.92\}$$

$$BER_{I/M} = 1.021 * \{1 - 0.228\} = 0.788 \text{ g/mi.}$$

Several items are worth noting in the calculation above. First, the I/M credit is reduced from 25.5% to 22.8% when accounting for the effects of the waiver rate and the compliance rate. (The waiver rate represents those vehicles that cannot be repaired under the cost ceiling established for the program; the compliance rate reflects the fraction of vehicles subject to the program that complete the inspection process to the point of receiving a

certificate of compliance or a waiver.) Second, the adjustment performed to account for the compliance rate is nonlinear (i.e., although the compliance rate was 96% in the above example, the I/M benefits are reduced by 8% rather than 4%). This adjustment inherently assumes that the I/M failure rate of non-complying vehicles will be higher than that of the rest of the fleet.^{1*}

The I/M credits (i.e., $CRED_{I/M}$ in the above equation) are stored in data matrices that are read by MOBILE. For 1981 and later model years, these credits are developed by EPA's "Tech" models, and are a function of test type, inspection frequency, model year, and vehicle age. A description of how the Tech models develop these I/M credits is summarized below.

OVERVIEW OF THE "TECH" MODELS

The exhaust emission I/M program benefits are determined outside of the MOBILE models. The "Tech IV" model,² initially developed to determine I/M benefits for 1981 and later model year vehicles for MOBILE3, has been revised with each version of the MOBILE series. (The MOBILE4.1 version is termed Tech4.1, and the MOBILE5a version is known as Tech5.) These models estimate both the baseline emission factors (by model year) and the I/M program benefits associated with various program types.

The "Tech" series of models utilizes a "regime" approach in developing baseline emission factors and I/M benefits. After segregating emissions data by certification standard and technology (i.e., closed-loop multiport fuel-injection, closed-loop throttle-body injection, closed-loop carbureted, and open-loop), the data are stratified into four basic emitter groups (or regimes) which are defined as:

- Normal: $\leq 2 \times \text{HC Std.}$ and $\leq 3 \times \text{CO Std.}$
- High: $> 2 \times \text{HC Std.}$ or $> 3 \times \text{CO Std.}$

* Superscripts denote references provided at the end of this report.

- Very High: $> 4 \times \text{HC Std.}$ or $> 4 \times \text{CO Std.}$
- Super: $> 10 \text{ g/mi HC}$ or $> 150 \text{ g/mi CO}$

(The definition of these groups remained unchanged between MOBILE4.1 and MOBILE5a; however, the distribution of vehicles among the categories is significantly different, with MOBILE5a generally having a larger proportion of very high emitting vehicles at a given vehicle age.)

Once the technology and emitter categories are stratified as outlined above, the baseline emission rates (as a function of vehicle mileage or age) are determined by multiplying the emission rate of each emitter category by the fraction of each category making up the fleet at the mileage intervals corresponding to vehicle age. As an example, the incidence of emitter groups in the fleet is illustrated in Figure 2-1 for 1983 to 1993 model year multiport fuel-injected (MPFI) light-duty gasoline vehicles, and the exhaust HC emission rate of each group (as a function of vehicle age) is shown in Figure 2-2. (Note that this example is based on the Tech5 model.) Combining the data illustrated in Figures 2-1 and 2-2 results in the baseline HC emission rate shown in Figure 2-3.

The model then determines an "after-I/M" emission rate (for each emitter category and vehicle age) that is based on the identification rate and repair effectiveness of the specific I/M program type (e.g., IM240) and emission cutpoints being modeled. Mathematically, this calculation is represented by:

$$\text{Emission Rate}_{\text{IM}} = \{(1 - \text{ID}_{\text{RATE}}) * \text{EMIS}\} + \{\text{ID}_{\text{RATE}} * \text{EMIS} * (1 - \text{REF})\}$$

where ID_{RATE} is the identification rate specific to I/M test type, emitter category, and technology; EMIS is the baseline emission rate of the emitter group being analyzed; and REF is the repair effectiveness. (REF is calculated from the before- and after-repair emission rates according to $1 - (\text{after-repair})/(\text{before-repair})$; thus, $\text{EMIS} * (1 - \text{REF})$ is simply the after-repair emission rate.)

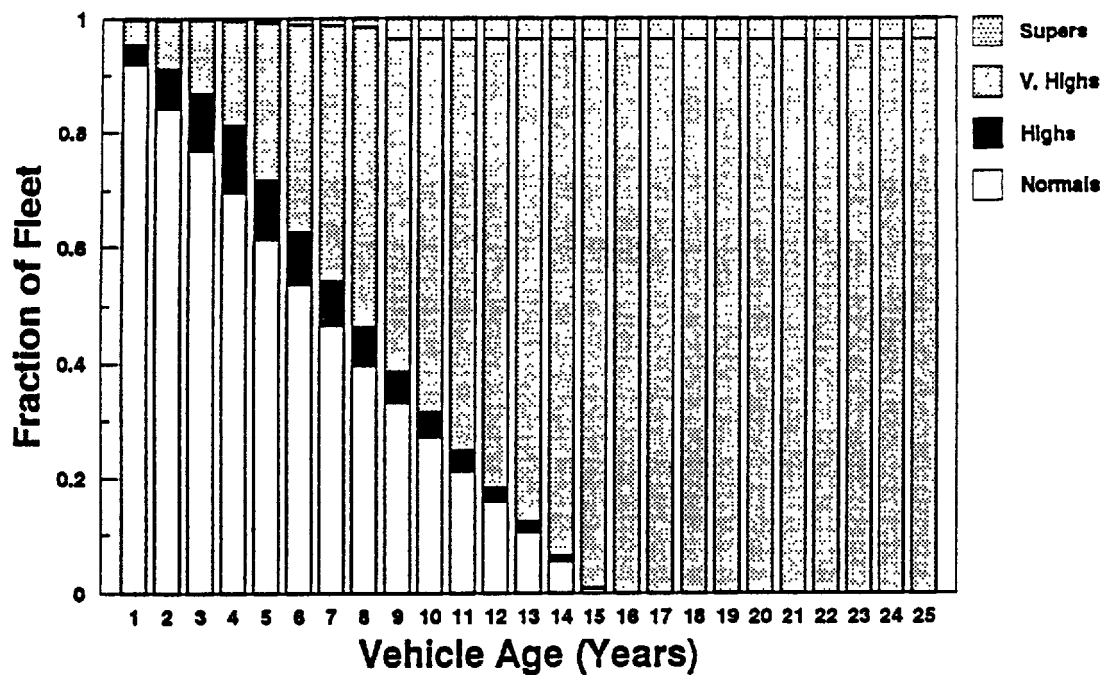


Figure 2-1. Incidence of Emitter Groups as a Function of Vehicle Age for 1983 to 1993 MPFI LDGV

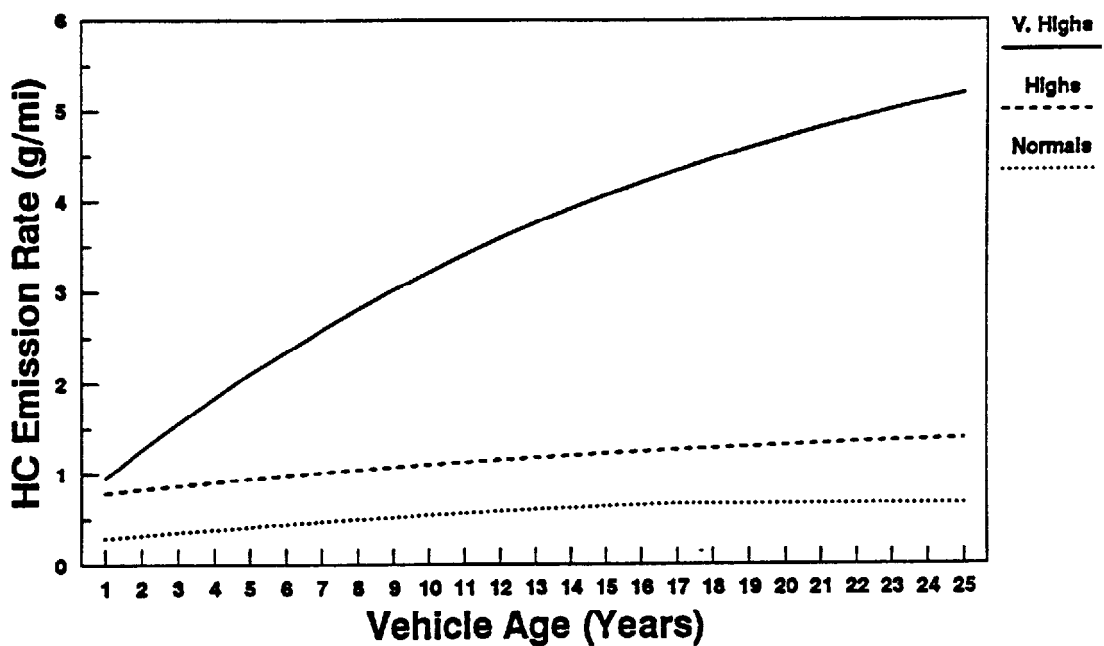


Figure 2-2. HC Exhaust Emission Rate by Emitter Category for 1983 to 1993 MPFI LDGV (The emission rate of super emitters is constant at 11.61 g/mi.)

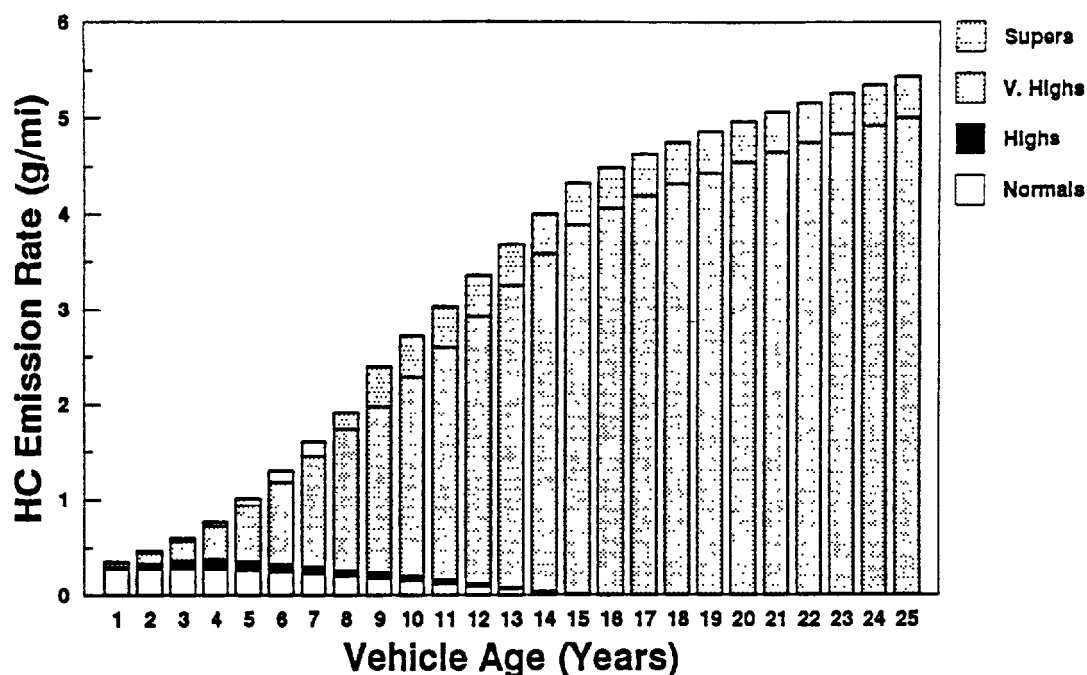


Figure 2-3. Contribution of Emitter Categories to Baseline HC Emission Rate for 1983 to 1993 MPFI LDGV

To illustrate, consider a six-year old MPFI vehicle in the very high emission category that is subject to an IM240 inspection with 0.8/20.0 HC/CO cutpoints. The Tech5 model indicates that its baseline emission rate is 2.356 g/mi HC, the ID_{RATE} for this emitter group and I/M test is 0.8786, and its after-repair emission rate is 0.868 g/mi. The I/M emission rate would then be:

$$\text{Emission Rate}_{IM} = \{(1-0.8786)*2.356\} + (0.8786*0.868) = 1.049 \text{ g/mi}$$

The way that EPA defines identification rate is an important concept in understanding how this rate impacts the number of high-emitting vehicles remaining in the fleet after an I/M test. EPA defines the identification rate as the fraction of emissions being identified by a particular test for a particular emitter group. This would not necessarily be expected to equal the number of failing vehicles in an emitter category. As an example, consider the case above in which the baseline very high category is emitting 2.4 g/mi and the

identification rate is 0.88. Assume that 20 percent of the vehicles within this category had an emission level of 4.5 g/mi, while the remaining 80 percent had an emission level of 1.875 g/mi (i.e., $(0.2 \times 4.5) + (0.8 \times 1.875) = 2.4$). If all of the 4.5 g/mi vehicles were identified by the I/M test, 80.8 percent of the 1.875 g/mi vehicles would have to be identified to arrive at the identification rate (as defined by EPA) of 0.88 (i.e., $(1 \times 0.2 \times 4.5) + (0.808 \times 0.8 \times 1.875) = (0.88 \times 2.4)$). Thus, the total fraction of vehicles identified by the test would be $(0.2 \times 1) + (0.8 \times 0.808) = 0.846$, which is 3.4 percentage points less than the emissions identified by the test.

The identification rates developed by EPA are a function of emitter category, I/M test type, and technology type, with the identification being close to 100 percent for the super and very high categories for most I/M tests and technologies. The after-repair emission rates are a function of before-repair emission rates, and are generally about 0.5 g/mi HC for normals, 0.8 g/mi HC for highs, 1.0 g/mi HC for very highs, and 0.9 g/mi HC for supers. Combining the identification rates with the before- and after-repair emission rates for MPFI vehicles results in the after-I/M emission rates shown in Figure 2-4. Comparing Figures 2-3 and 2-4 indicates that there is a significant reduction in emission level as a result of an I/M program, and most of the reduction is from the super and very high emitter categories.

The reduction in emissions as a result of I/M clearly changes the contribution of the high emitter categories (i.e., highs, very highs, and supers) to the overall fleet-average emission factor. However, because the Tech4.1 and Tech5 models define the identification rates in terms of emissions identified, not vehicles identified, it is difficult to determine the exact fraction of highs versus normals identified by an I/M test. This issue is further complicated by the fact that the after-repair emission rates are reported as mean values rather than a distribution, and a fraction of vehicles will remain high emitters after repair. This is illustrated in Figure 2-5, which compares after-repair FTP HC emission rates (for the IM240 test with 0.8/20.0 HC/CO cutpoints) to the normal-high cutpoint of 0.82 g/mi. The mean after-repair values shown in this figure are above the normal emitter cutpoint at before-repair emission rates greater than 1.8 g/mi. However, this is not to say that all of these vehicles

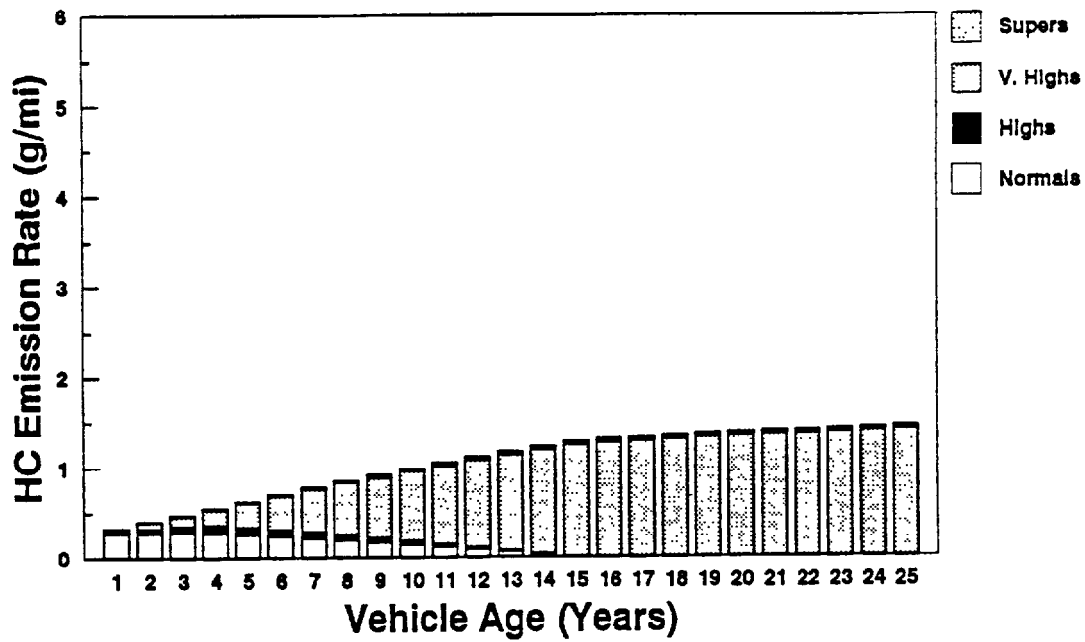


Figure 2-4. Contribution of Emitter Categories to After-I/M HC Emission Rate for 1983 to 1993 MPFI LDGV (Based on 0.8/20.0 HC/CO Cutpoints)

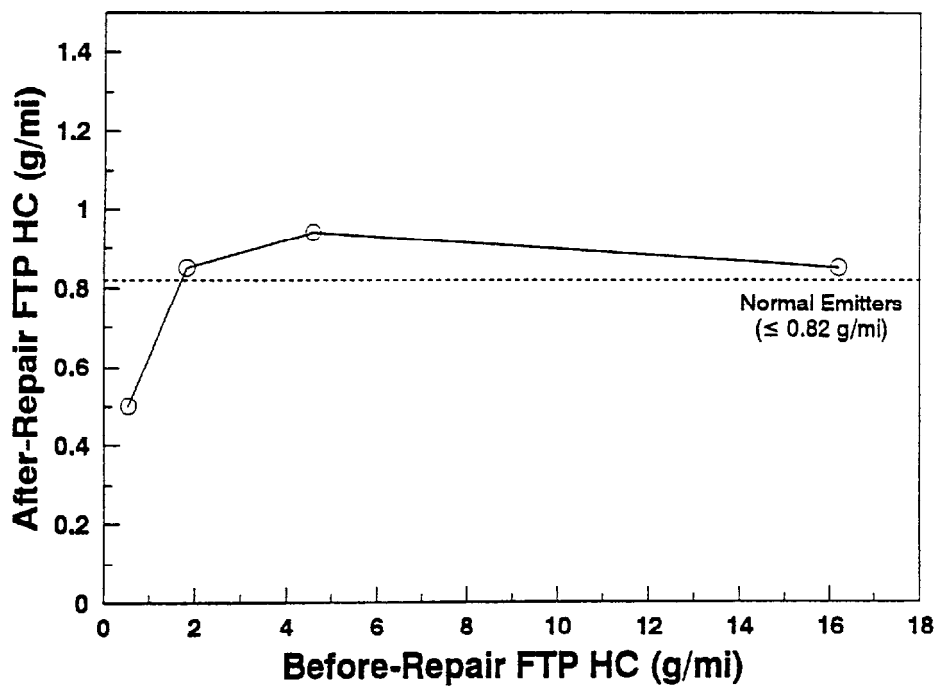


Figure 2-5. After-Repair FTP HC Emission Rates Based on IM240 Testing with 0.8/20.0 HC/CO Cutpoints

remain high emitters after repair. The after-repair values represent a varied distribution, with some vehicles being normal emitters after repair and others being high emitters after repair.

Given the above, estimating the proportion of highs to normals in a fleet of vehicles subject to I/M requires knowledge of the proportion of highs not identified by the test as well as the fraction of highs remaining in the repaired fleet. These estimates are not made by the Tech4.1 and Tech5 models, and it does not appear that EPA determines these values independently. To thoroughly address this issue, analysis of the data upon which the identification rates and repair effectiveness matrices were based is needed. This is discussed in a later section of this report.

I/M PARAMETERS FOR THE COMPLEX MODEL

EPA defined specific MOBILE input parameters that were used in the development of exhaust emission rates for the Complex model. These parameters varied according to which phase of the program is being considered (e.g., MOBILE4.1 with basic I/M was used for Phase I; MOBILE5a with enhanced I/M was used for Phase II). Set forth below is a summary and comparison of the I/M program parameters used in developing the Complex model for each phase of the program.

MOBILE4.1

The Draft Regulatory Impact Analysis (DRIA)³ prepared for the reformulated gasoline regulations specified that the baseline emission rates for the Phase I Complex model were based on output from MOBILE4.1 with an idle/2500 rpm I/M test. As outlined above, the emission rates calculated with an I/M program in place are a function of assumed identification rates and repair effectiveness. For MOBILE4.1, the HC identification rates for the idle/2500 rpm tests were based on historical emission factor data and are shown in Figure 2-6. As seen, the identification rates are a function of technology and emitter category. The after-repair emission rates as a function of before-repair rates are given in

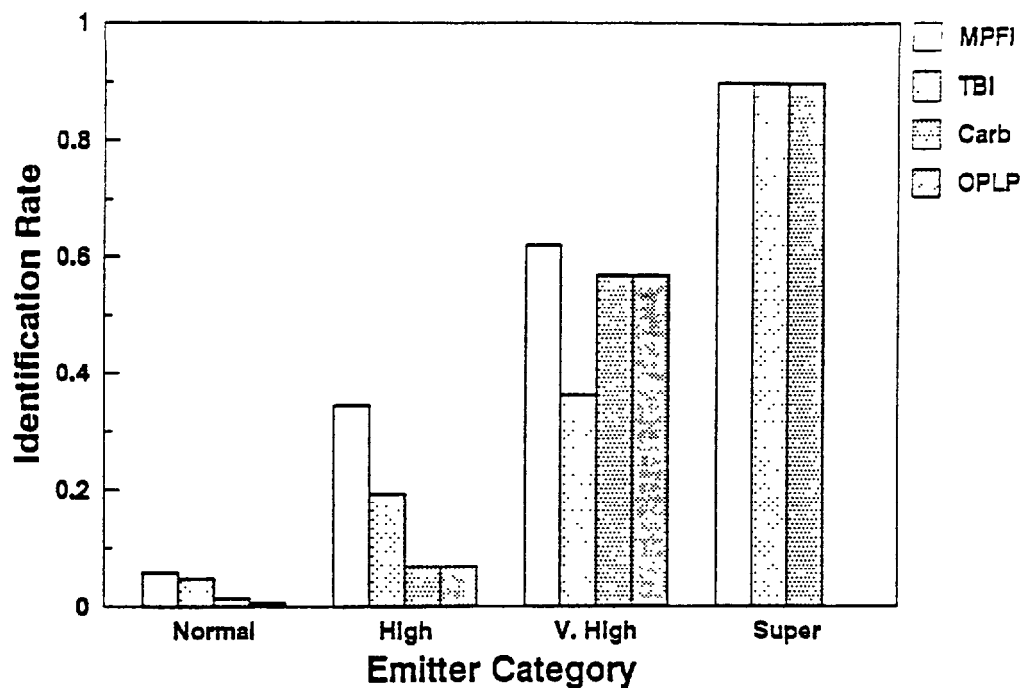


Figure 2-6. Tech4.1 HC Identification Rates Based on Idle/2500 rpm Testing

Figure 2-7. These rates are dependent upon technology type and I/M test type; MOBILE4.1 predicted slightly lower after-repair emission levels from the idle/2500 rpm test compared to an idle-only test, and fuel-injected vehicles were predicted to have relatively lower after-repair emission rates than carbureted vehicles.

Although the DRIA does not specify an enhanced I/M program for MOBILE4.1 analyses, it is interesting to compare how EPA modeled enhanced programs with MOBILE4.1 versus MOBILE5a. The technical support document prepared for EPA's I/M rulemaking⁴ presented estimates of IM240 identification rates that can be used in conjunction with the Tech4.1 model to calculate benefits from an IM240 test. These rates are shown in Figure 2-8. At the time the technical support document was prepared, little data existed on the after-repair effectiveness of IM240 tests. Thus, EPA utilized the after-repair rates developed for the idle/2500 test (shown in Figure 2-6). Although the after-repair emission rates are the same for the idle/2500 and the IM240, the identification rates are generally higher for the IM240 test, resulting in higher benefits being estimated for the transient test.