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Final Facility Specific Speed Correction Factors

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ABSTRACT

In MOBILE5, adjustments were made to the basic exhaust emission estimates to account for the effects of area wide average trip speeds using speed correction factors developed from a number of driving cycles with varying average speeds. For MOBILE6 EPA has adjusted for differences in driving behavior versus roadway (facility) type and aggressive driving effects as well as average speed. EPA has developed new facility-specific inventory driving cycles, based on “real world” representative driving studies, and tested vehicles using these cycles to address these purposes. This report describes the analysis of the new driving cycle data and presents the resulting speed correction factors used in MOBILE6 for the gasoline passenger car and light duty gasoline truck classes.

1.0 Summary

Although the adjustments described in this document are called “speed” correction factors, the adjustments include all of the effects on emissions caused by differences in driving behavior, of which average speed is the most obvious and easiest to measure. The speed correction factors described in this document are used in MOBILE6 to replace the speed correction factors now used in MOBILE5 for all light duty passenger cars and light duty trucks of all model years and technologies for average speeds above 7.1 mph. Low speed adjustments, below 7.1 mph, will still use the MOBILE5 estimates. The speed correction factors for heavy duty vehicles, diesel fueled vehicles and motorcycles from MOBILE5 would be retained for use in MOBILE6. This document also describes the method for applying the new speed correction factors to future technology vehicles for which no data is yet available.

The new MOBILE6 speed correction factors specifically account for aggressive driving behavior not represented in older driving cycles. The effect of aggressive driving behavior is accounted for separately using an emission offset to allow for future control strategies, such as the Supplemental Federal Test Procedure for vehicle certification, to be explicitly modeled. The new speed correction factors also allow for evaluation of vehicle emissions by roadway type (facility) and by roadway segments (links). There are four roadway types modeled in MOBILE6:

- Freeways
- Arterial/Collectors
- Freeway Ramps
- Local Roadways

EPA recognizes that many factors, such as the number of lanes and other roadway geometry, are not explicitly accounted for in the development of the four roadway types. However, each driving cycle used includes a representative amount of the driving behavior on a variety of roadways of that roadway type. EPA is confident that these four roadway types will be sufficient to allow for better modeling of the wide variety of roadways found in urban areas than previous models.

The speed correction factors for freeways and arterial/collectors depend on both speed and basic emission levels of the vehicles. The correction factors for freeway ramps and local roadways depend only on emission level and cannot be adjusted for average speeds different than the national average. All speed corrections are based on new driving cycles designed to reflect “real world” representative driving behavior, including the effects of aggressive driving not found in the standard vehicle FTP certification driving cycle (Urban Dynamometer Driving Cycle) and most older driving cycles used in emission testing.

Since the data for this analysis were collected using the new, representative driving cycles, an emission impact of aggressive driving is included in the effect of the new speed correction factors on emissions. The introduction of the new Supplemental FTP (SFTP)[1] into

vehicle emission certification will require the reduction of the emission effects from aggressive driving for future vehicle certification.

Table 16 contains the MOBILE6 speed correction factors for freeways. Table 17 contains the MOBILE6 speed correction factors for arterial/collector roadways. For MOBILE6, the correction factor for Local Roadways and Freeway Ramps assume a national average speed and will not have an adjustment for local average speeds. The speed correction factors for freeways and arterial/collectors converge below 7.1 mph and at higher speeds, depending on the pollutant and emission level. At those points the freeway and arterial/collector speed correction factors become identical. The speed correction factors for speeds below 7.1 mph will remain the same as in MOBILE5, but are adjusted to account for the difference between the old and new speed correction factors at 7.1 mph.

MOBILE5 did not model average speeds above 65 miles per hour. The new driving cycles also do not address average speeds above 65 miles per hour. EPA will consider whether sufficient information is available to model average speeds above 65 miles per hour in MOBILE6 and will present any proposals for these higher speeds in a separate document. As in MOBILE5, MOBILE6 will not explicitly address average speeds less than 2.5 miles per hour. Idle emissions will be assumed to be the same as the grams per hour emitted at an average speed of 2.5 miles per hour. This “idle” emission rate will be available as an output from MOBILE6.

Table 13 shows the coefficients used to calculate the freeway ramp and local roadway emissions from the basic emission rate. Table 14 and 15 show the additive offsets used to calculate the adjusted basic emission rate which is adjusted by the speed correction factors. Appendix B has an example calculation of the application of speed correction factors to the base emissions calculated by MOBILE6.

Figures 4a through 4c show the effect of emission level in the sample of light duty gasoline vehicles as a function of speed for freeways, estimated using the new MOBILE6 speed correction factors. Figures 5a through 5d show the MOBILE6 speed correction factors for freeways for the three emission levels. Figures 6a through 7i compare the new MOBILE6 speed correction factors with selected MOBILE5 speed correction factors. Care should be taken in interpreting these figures, since there are many differences in how these factors are applied in MOBILE6 as compared to MOBILE5. These figures are discussed in more detail in Section 9.

This report is organized into sections which address various aspects of the analysis.

Section 2 gives a brief background of the need for new, facility based, speed correction factors.

Section 3 discusses the development of the facility cycles and the emission testing sample used in the development of the speed correction factors.

Section 4 discusses the statistical analysis of the data sample.

Section 5 describes the approach developed to summarize the emissions data.

Section 6 uses the emission levels developed in Section 5 to develop the speed correction factors and off-cycle effects used for MOBILE6.

Section 7 discusses how the new Supplemental Federal Test Procedure (SFTP) will affect the estimate for off-cycle emissions and speed correction factors.

Section 8 describes how the new speed correction factors will be used in MOBILE6 and how MOBILE6 will estimate the speed correction for other vehicle classes.

Section 9 compares the speed correction factors developed in Section 6 to the existing speed correction factors in MOBILE5.

2.0 BACKGROUND

EPA's highway vehicle emission factor model, MOBILE, is used for inventory modeling. MOBILE has historically been based on emission testing using the Federal Test Procedure (FTP) used to certify all light duty vehicles sold in the United States. The FTP uses a driving cycle (the Urban Dynamometer Driving Cycle, commonly referred to as the LA4[2]) which simulates urban driving on a laboratory dynamometer. Correction factors for various conditions (e.g., average speed, temperature, fuels) are applied to emissions measured at the FTP "standard" conditions. The speed correction factors were based on test results for vehicles tested on both the LA4 (Urban Dynamometer Driving Cycle) and several other cycles, each having a different average speed. MOBILE6 will address two areas not adequately addressed in previous versions of the model. These are "real world" representative driving behavior and the expanded use of transportation models in determination of area-wide inventories.

"Real-World Driving"

The FTP has been used for emissions certification of all light duty vehicles sold in the United States. The Clean Air Act Amendments of 1990 mandated a closer look at "real-world driving" - that is, driving modes that are not covered by the FTP (and the Urban Dynamometer Driving Cycle) and representative of actual observed driving behavior. EPA organized the Federal Test Procedure Review Project to address this mandate. A new Supplemental FTP (SFTP) rule was finalized in October 1996.[3] This rule specifies the addition of a new certification cycle with more aggressive driving and associated vehicle emission standards.

MOBILE6 must address both the emission impacts of more aggressive driving than is covered in the driving cycles that were used to develop MOBILE5 and the effects of the new

SFTP standards on future model year vehicles. A special EPA emission testing project was initiated to address these concerns. The results of that testing are the basis for the analysis in this document.

Transportation Models

The current and older versions of the MOBILE model were developed to estimate area-wide emission inventories using trip-based emission estimates with trip-based adjustments for average speed. Vehicle trips are defined as all driving from key-on to key-off. These vehicle trips may include a variety of roadways and speeds.

Local officials have begun to integrate transportation models into their regional air quality planning processes. Most transportation models represent the roadway system as a network of "nodes," which are usually intersections, connected by "links." Each link represents a particular type of roadway or "facility." Transportation models generate link-specific estimates of speed and traffic volume. Transportation planners have begun using MOBILE to generate link-specific emissions estimates for planning purposes.

Recent data from instrumented vehicles and chase car studies show that some types of facility-specific driving contain more frequent and more extreme acceleration and deceleration than others.[4] Different facilities may have similar average speeds, but may differ significantly in the amount of steady cruise. These differences suggest that there is a need to quantify the emission differences (if any) between facilities in order to evaluate facility-specific speed related traffic control measures in inventory modeling.

For example, at an average speed of 25 mph, travel over surface streets is likely to have a relatively low level of traffic congestion, but will include many stops for traffic signals. Travel on a freeway at 25 mph may indicate a high congestion level, but may include fewer stops. MOBILE5's trip based emission estimates do not differentiate between roadway types. If MOBILE5 is used to model roadways separately, it cannot account for any differences in emissions at similar average speeds resulting from these differences in driving behavior. This particularly affects the planning process, where plans that affect different roadways cannot be modeled adequately.

Other Approaches

California is also updating it’s highway emission factor model.[5] However, California has taken a different approach to modeling the effects of changes in vehicle speeds. Rather than attempt to discern what the driving behavior is for various facilities at various average speeds, they divide all observed driving into speed bins. Each bin contains “microtrips” with similar average speeds, regardless of the roadway type where the driving was observed. By weighting the results of the various speed bins, any area-wide average speed can be modeled. Changes in driving behavior can be modeled by varying the distribution of speeds.

This approach requires areas to evaluate their fleet activity as "trips", where individual vehicles travel over a variety of roadway types at varying speeds to reach a destination. These trips are then used to develop a distribution of average trip speeds. Transportation models generally do not produce trip statistics and transportation planners would need to adjust their models to generate these distributions. Any changes in the roadway system resulting in changes in average speeds on specific roadways will require a change in the full area-wide distribution of trip speeds. Evaluation of the emission impact of changes in the specific roadways will require new estimates of the area-wide emission levels.

One important advantage of California's approach is the need for fewer driving cycles. Given limited testing budgets, this allows more vehicles to be tested over each cycle, thus increasing the statistical confidence in the emission test results. Development of the driving cycles themselves requires fewer assumptions such as decisions about where and under what conditions the observed driving occurred. The resulting trip-based California driving cycles are also similar in concept to the trip-based Unified Driving Cycle (or LA92),[6] which is used by California as the basis for the highway vehicle emission factors. The approach for MOBILE6 requires more driving cycles with more detailed information about driving conditions and location.

The most important disadvantage of California's approach is the dependence on vehicle trip information. Since vehicle trips occur over a variety of roadways at a variety of average speeds, evaluation of trips is most relevant for only area-wide (i.e., county-wide) emission estimates, where all trips can be assumed to begin and end within the area. The confidence in the estimate of emissions will decrease as the size of the area to be modeled is decreased or if only specific roadways or links are to be modeled. In addition, many transportation planners do not currently generate trip speed distributions and other trip information from their models. This will mean that changes will need to be made in the transportation models in many cases in order to effectively use the California emission factors. In comparison, the MOBILE6 approach is more compatible with analysis by roadway type and link. Since most transportation models already estimate speeds and miles traveled by link, MOBILE6 will not normally require major changes in the output from existing transportation models. Using MOBILE6, the area-wide emissions are still able to be estimated by compiling the results from the four roadway types.

A more detailed description of the California approach or a comparison of the two approaches is beyond the scope of this document. Readers are encouraged to obtain information directly from California[7] for comparison with the results documented in this report.

3.0 VEHICLE TESTING

3.1 New Driving Cycles

The basis for the analysis found in this report is a set of light-duty, gasoline fueled vehicles recruited and tested in 1997. The testing included new driving cycles specifically designed to address the effects of in-use driving behavior on emissions. Table 1 gives a brief description of the new cycles that were used in the testing. Collectively, these new driving schedules will be referred to in this document as "facility" cycles. The driving behavior in each driving schedule is selected from data collected from a particular roadway type during periods of various congestion levels. These congestion levels have been roughly grouped into "levels of service" (LOS) using letters A through G, similar to congestion category designations used in transportation models. Briefly, LOS "A" refers to "free flow" (uncongested) situations and the subsequent letters indicate increasing levels of congestion. The data used and the definition of these categories is discussed in more detail in a separate EPA report describing the development of the new facility driving cycles.[8] Although the new cycles are labeled using a letter system similar to that used by transportation agencies, there will be additional uncertainty in matching conditions in the field with these new cycles due to the mismatch between LOS defined by air agencies and transportation agencies. This can be alleviated somewhat by careful selection of the average speeds and roadway types used in MOBILE6 to be those that best represent the driving behavior observed in the field.

Table 2 compares the new cycles' statistics to the target population statistics for each cycle. The statistics for each driving cycle will differ somewhat from the observed speed and acceleration statistics which the cycle is designed to simulate (or "target population"). For example, the highest *average* speed of the new arterial/collector cycles is 24.8 mph. Driving on specific arterial/collector roadways can have average speeds higher than that. The *maximum* speed of the arterial/collector cycles is only 58.9 mph, while the maximum speed observed in the target population is 74.9 mph. This is a result of the cycle development process which chooses the best combination of microtrips to match the target population. It is likely that the particular microtrip which contained the maximum observed speed in the targeted population over-represent certain aspects of driving behavior and was, therefore, not able to be used within the confines of a single driving cycle of limited duration.

Each cycle was designed to result in emission levels representative of the emissions that are expected from the driving behavior observed in the target population. Characteristics which were deemed important to the match were specific power, speed, and amount of acceleration, deceleration and idle. The factor which most affects emissions, shown from previous experience in development of the Supplemental FTP, is the power distribution. The average speed or maximum speed of the resulting cycles may not exactly match the target population. More importantly, however, the cycles approximate the power distribution of the target population. EPA feels that the emissions generated from the new cycles are a good representation of the expected emissions from the driving behavior that was observed in the target population from which the cycle was generated. The development of these cycles is discussed in much more detail in a separate document.[9]

It must be pointed out that however well the resulting driving cycles match the targeted population data, the use of fixed driving cycles, by it's nature, cannot precisely match a particular roadway modeling situation. Any difference between the targeted population data and the specific modeling scenario will add an additional uncertainty to the modeling results. This uncertainty will be reduced the more the specific modeling scenario resembles the targeted population data used in development of the driving cycles. This will be the case in larger, area wide analysis, where average driving behavior will likely better match the population data that was used.

In addition to the new cycles described in Table 1, each vehicle was also tested using the following cycles:

- Federal Test Procedure (FTP), with an additional hot running 505 seconds of the LA4 (Urban Dynamometer Driving Cycle).
- California Air Resources Boards (CARB) area-wide Unified Cycle (LA92).
- New York City Cycle (NYCC), a low speed cycle which has previously been used for speed correction factors in the MOBILE model.
- ST01, a cycle based on instrumented vehicle data representing the beginning of trips which is the first 258 seconds of the vehicle certification air conditioning cycle (SC03).

Table 3 shows more information on these additional cycles.

Although the New York City cycle (NYCC) was not developed specifically for MOBILE6, it had been developed specifically to address the effects of "real world" representative driving behavior at low average speeds. Although it has a low average speed (7.1 mph), it has maximum accelerations that are twice those found in the LA4 cycle. It was included in the set of results used to generate the speed corrections factors to provide a data point below 11.6 mph (Arterial/Collector LOS E-F) in the analysis and provides a data point common to earlier emission testing samples for comparison.

3.2 Sample Selection

The vehicle sample for this analysis came from EPA Emission Factor testing performed at both the Automotive Testing Laboratories, Inc. (ATL), in Ohio and EPA's National Vehicle and Fuels Emission Laboratory (NVFEL), in Ann Arbor, Michigan, in the spring of 1997. All of the vehicles at ATL were recruited at Inspection and Maintenance lanes run by the State of Ohio, and were tested in an as-received condition (without repairs). At the time of this analysis, a total of 62 1983 through 1996 model year vehicles had been recruited and had completed testing in Ohio, and 23 1990 through 1996 model year vehicles recruited and tested in Ann Arbor. The sample of 85 vehicles includes 22 light-duty trucks. Most of the 85 vehicles were fuel injection, with 3 carbureted passenger cars and 4 carbureted light duty trucks. Only 12 of the vehicles tested were certified to the Tier 1 exhaust emission standards.[10] The rest are certified to the earlier Tier 0 emission standards.

The vehicles tested at the EPA laboratory were recruited randomly. The vehicles tested at ATL were selected as a stratified random sample, with strata corresponding to IM240 pass or fail outcome determined at state run IM240 inspection stations in Ohio. ATL used the final phase-in cutpoints recommended by EPA for use in I/M programs using the IM240 test procedure to identify vehicles in need of maintenance. Twenty of the vehicles in the ATL sample failed the IM240 test. Proper analysis of the ATL data requires careful weighting of the passing and failing vehicles if emitter status is not considered as a factor in the analysis.

Table 4 shows the mix of EPA vehicle emission certification standards and fuel delivery technology in the sample used in this analysis. Table 5 lists all of the vehicles individually, showing vehicle make and model, odometer mileage, engine size and whether the vehicle passed or failed an IM240 test procedure using final phase-in cutpoints. Table 6 shows the mix of model years and vehicle class (car or truck) in the sample.

3.3 Vehicle Testing

All vehicles were tested using the driving cycles described in Section 3.1 above in the as-received condition using vehicle certification test fuel. Testing of vehicles was done on the cycles in random order to reduce any order bias. Vehicles were tested at FTP ambient conditions (i.e., temperature and humidity). Emission results were measured both as composite "bags" and in grams second by second. Only the bag results were used in this analysis.

4.0 STATISTICAL ANALYSES

The purpose of the testing using the new facility cycles was to determine the effects of "real world" representative driving behavior on basic (LA4) emissions. Separate cycles were developed for freeway and arterial/collector roadways to allow comparison of those two roadway types. The testing program also "over sampled" high emitting vehicles in order to provide a sufficient sample size to allow separate analysis of high emitting vehicles. Although vehicle mileage (or vehicle age) is considered important for estimating emissions, it is not thought that vehicle mileage is a factor in the effect of average speed on emissions. Together, the following testing and vehicle parameters were considered as potentially important in determining the effect of average speed on emissions:

1. Emitter status.
2. Roadway type.
3. Vehicle class.
4. Exhaust Emission Standard.

These parameters subsume a host of other potentially important parameters, such as technology differences. The statistics of each list item will reflect the variability in emissions from a larger set of parameters that are subsumed within the list item.

The data from the vehicles tested using the new facility cycles were evaluated to determine if the effect of the average speed on emissions differed significantly by these parameters. The sections below (Sections 4.1 through 4.4) discuss the statistical results for each parameter evaluated. Section 4.5 discusses the statistical support for the convergence of the freeway and arterial/collector estimates. Section 4.6 summarizes the conclusions derived from the statistical analysis. Section 5 describes the final methodology.

Although the vehicle pool contains a large range of model years (1983 through 1996 model years), the total sample size (85 vehicles) was not sufficient for analysis explicitly by model year or age. For this analysis, any model year dependency is assumed to be captured by through the emission standards.

Table 7(a-c) shows sample means and standard deviations for the combined dataset for each cycle, stratified into high and normal emitter levels. A vehicle may be a Normal emitter for one pollutant, but considered a High emitter for another. In some cases the sample sizes (Normal and High) do not sum to 85 vehicles. This is because some test results on some vehicles were voided due to errors in the testing or sampling and could not be used. No valid emission test results were eliminated from the analysis.

Figure 1(a-c) graphically shows the effects of average speed on emissions. Each point is the ratio of the mean for the emissions of each of the 14 facility cycles versus mean emissions for the LA4 (Urban Dynamometer Driving Cycle) for the same vehicles. The data show that the high emitting vehicles do not exhibit as much sensitivity to speed, resulting in smaller ratios.

It was expected that as the average speed increases the difference between emissions from cycles representing arterial/collector roadways and emissions from cycles representing freeways would decrease. An analysis was done to confirm the observed convergence of freeway and arterial/collector roadway emissions versus average speed. This analysis is discussed in Section 4.5 below.

The method of analysis of variance was used to judge the effect of the above parameters on the relation between average speed and emissions. The dependent variables in these analyses were chosen to be the logarithm of grams-per-hour emissions. The grams-per-hour measure is more stable than grams-per-mile, particularly at lower speeds, where very little distance is traveled over a long time. The log transformation yields values that better satisfy the ANOVA test requirements of normally distributed constant-variance errors. In the actual fitting of speed correction factor equations, described in Section 5, gram-per-hour units were used for analysis at average speeds less than 30 mph. However, at high speeds (average speeds above 30 mph), using a linear fit and grams per hour units, when converted back to grams per mile, forces a curve shape (tailing downward) which does not match the data trends (tailing upward). For speeds above 30 mph, gram per mile units were used. The resulting equation has the following form:

$$Emissions_{AverageSpeed} = Exp(A + B * AverageSpeed)$$

Where Emissions are reported in units of grams-per-hour for segments covering speeds below 30 mph and Emissions are reported in units of grams-per-mile for segments at speeds above 30 mph. The coefficients A and B are determined from the linear regression of the log transformed speed cycle results and the average speed of the speed cycles.

Table 8 reports the ANOVA results in terms of p-values associated with tests of the various factors described above. The p-value gives a concise way of judging statistical significance. The p-value of a test is the smallest level of significance at which the null hypothesis can be rejected. In these models, the null hypothesis states that the levels of a given factor, e.g., roadway type, have equal effect on emissions. The level of significance for this test is the probability of rejecting the null hypothesis when it is true. That is, of falsely concluding that a difference exists. This will be referred to as a Type I error. By convention, the level of significance is chosen to be arbitrarily small, typically 0.05, in order to limit the occurrence of Type I error. If p is smaller than the chosen level of significance, the null hypothesis is rejected in favor of the claim that a difference exists.

For example, in comparing the normal and high emitter classes of total hydrocarbons, Table 8 reveals a p-value of 0.000 for the main effect of the emitter class. In graphical terms, the main effect captures the intercept of a line relating (the logarithm of the) emissions to speed. Thus, the small p-value provides support for the rather obvious hypothesis that high emitters have different average emissions than normal emitters. However, for the interaction of emitter class with speed, the p-value is 0.1411, implying that the difference in the slopes (the relationship between emissions versus average speed) of the normal and high emitter lines (regressions) is not statistically significant.

Further, more detailed ANOVA results are shown in Appendix A at the end of this report. Below are the statistical results for the individual factors.

4.1 Emitter Status

The sample was separated into “emitter status groups” based on their Hot Running LA4 exhaust emissions. Hot Running LA4 are emissions that would result from an FTP test which does not include any engine starts. These emissions are intended to be the basic unit of exhaust emissions for use in MOBILE6.[11] The emitter status groups were defined by the following pass/fail cutpoints:

- 0.8 g/mi Total Hydrocarbons (THC)
- 15 g/mi Carbon Monoxide (CO)

- 2.0 g/mi Oxides of Nitrogen (NOx)

These are the final phase-in cutpoints recommended by EPA for use in I/M programs using the IM240 test procedure to identify vehicles in need of maintenance. A vehicle is considered a Normal emitter if its emissions are less than or equal to the cutpoint level for that pollutant. It is considered a High emitter if its emissions exceed the cutpoint level for that pollutant. Once a vehicle is identified by emitter status for a pollutant using the Hot Running LA4 emission results, it is always categorized that way in this analysis, regardless of its emission results on another driving cycle. The cutpoints were not used in combination. A vehicle could be considered as a Normal emitter for the CO analysis even if it were designated as a High emitter for NOx or THC.

Table 8 confirms that the average emissions differ statistically by emitter class. The speed variable also is significant, i.e., emissions vary with average speed. However, except for CO, the emitter class-speed interaction is statistically non-significant.

While it is not always the case that the other factors available for analysis in the data sample - roadway type, vehicle type, and emissions standard - interact statistically with emitter class, engineering judgement warrant modeling these factors separately for normal and high emitters. Statistical conclusions for these factors are presented next.

4.2 Roadway Type

For modeling in MOBILE6, four roadway types are considered: arterial/collectors, freeways, freeway ramps and local roads. With arterial/collectors and freeways, the range of average speeds in the facility cycles overlaps at speeds below 30 mph. At higher speeds, only freeway cycles are available. The interaction between roadway type and vehicle type and between roadway type and emission standard was examined.

Figure 2 (a-c) shows the effects of average speed on emissions in terms of the ratio of the means for the emissions versus emissions for the LA4 (Urban Dynamometer Driving Cycle) for normal emitting vehicles. The cycles representing freeway driving and arterial/collector driving are connected with lines to show the difference in these road types versus average speed. The Unified Cycle (LA92), the Area-wide Non-Freeway cycle, Local Roadway cycle and Freeway Ramp cycle results are also shown in the figures. The same vehicles were tested on all cycles, so differences between freeways and arterial/collectors are controlled for the vehicle effect.

The emissions data were compared statistically to determine if there is reason to model arterial/collectors and freeways separately. The ANOVA results appear in Table 8. For all pollutants in the normal emitter class, the main effects are statistically significant. The speed interaction effects also are significant, albeit marginally so for hydrocarbons. Among high emitter vehicles, only NOx exhibits a significant difference between the arterial/collector and freeway road types.

Since only freeway cycles are represented at speeds over 30 mph, no comparisons of roadway type are required. Local roadways and freeway ramps are represented by only a single cycle each and therefore cannot be analyzed for the effect of average speed.

4.3 Vehicle Class

Of the 85 vehicles in the facility cycle sample, 22 are light duty trucks. The high emitters among the trucks number three for NOx, six for CO and 10 for THC/NMHC. In the freeway and arterial/collector roadway categories, for the normal emitters, the ANOVA results for passenger cars versus light duty trucks in Table 8 show significant main effects. However, the interaction with speed effects all are non-significant. For the high emitters, none of the vehicle type comparisons is statistically significant at the 0.05 level.

For the local and freeway ramp driving cycles, the results are mixed for normal emitter vehicles. NOx emissions differ at the 0.05 level on both cycles and CO is significant for the ramp cycle. Among high emitters, vehicle type is not significant for any of the pollutants on either cycle.

4.4 Emission Standard

It was expected that vehicles certified to the new Tier 1 exhaust emission standards would exhibit a different response to average speed than the Tier 0 vehicles. Since the facility cycle sample contains only 12 Tier 1 vehicles, a method was developed for increasing the sample size by reclassifying a portion of the Tier 0 vehicles in the sample. Vehicles were defined as "Clean" Tier 0 vehicles if their emissions were less than 70% of both the NMHC and NOx Tier 1 certification standard as measured on the standard FTP test. The Tier 1 standards are:

o NMHC standard: 0.25 g/mi (< 50,000 miles), 0.31 g/mi (>50,000 miles).
o NOx standard: 0.4 g/mi (< 50,000 miles), 0.6 g/mi (>50,000 miles).

A total of eight clean Tier 0 vehicles were identified by this criterion. One Tier 0 vehicle (number 5016) had low FTP Bag 1 and Bag 3 emissions and technically qualified for reassignment. However, because it had large Bag 2 and IM240 emissions, it was not considered representative of Tier 1 emission behavior and thus retained Tier 0 status under the new definition. The clean Tier 0 vehicles were used both in the analysis of both Tier 0 and Tier 1 emission levels. Table 9 shows the subset of 20 vehicles used to represent Tier 1 emission behavior. Tables 11 (a-d) show the average emissions for each driving cycle in the sample of normal emitting Tier 0 vehicles, high emitting Tier 0 vehicles and the expanded sample of vehicles considered normal emitting Tier 1 vehicles. Figure 3 (a-c) compares the Tier 0 and the expanded Tier 1 sample of vehicles for the difference in the effects of average speed on emissions. Emissions are shown in terms of the ratio of the means for the emissions versus emissions for the LA4 (Urban Dynamometer Driving Cycle).

The ANOVA results in Table 8 compare emissions of the Tier 0 and Tier 1 vehicles for the reallocated sample. On the arterial/collector and freeway cycles, for normal emitters the emissions standard main effect is highly significant for all pollutants, and the interaction with speed is significant for hydrocarbons. (The results are similar for the official emission standard classification.) For the local and freeway ramp facility cycles, all main effects are also significant.

There were no high emitter Tier 1 vehicles for any of the pollutants, so no test of the standard factor can be made for that emitter class.

4.5 Convergence of Freeways and Arterial/Collectors

The data show a statistical difference between the freeway and arterial/collector cycles below 30 mph, where the data overlaps. However, there are no arterial/collector cycles above 24.8 mph and there are no freeway cycles below 13.1 mph. If the speed correction factors for both of these roadway types are to cover the entire spectrum of average speeds available in the MOBILE6 model (0 to 65 mph), then some assumptions about the effect of average speed on emissions will need to be made for the speeds outside the typical range for these roadways.

Based on the facility cycle emission testing results, it appears that as average speed increases there is a decrease in the difference between emission results for arterial/collector cycles and freeway cycles at the same average speed. This suggests, that above a certain average speed, the same relationship between average speed and emissions can be used for both freeways and arterial/collector roadways.

Support for the hypothesis that mean gram-per-hour emissions of arterial and highway driving converge in the neighborhood of 30 mph can be found in the data from tests on the cycles that represent these two forms of driving. Consider the following model of emissions:

$$Y = b_0 + b_1X + b_2*D + b_3X*D$$

where Y is emissions (in grams/hour) of a given pollutant; X is average speed of the cycle tested; and D is a dummy variable representing road type (D = 0 for arterial, D = 1 for highway). This equation effectively models two lines. When D = 0, the function estimates emissions versus speed for arterials, with slope b_1 and intercept b_0. When D = 1, the line represents highway emissions with slope $(b_1 + b_3)$ and intercept $(b_0 + b_2)$.

This model is useful for examining differences between arterial and freeway emissions. The basic question of whether the linear functions differ is answered by testing the coefficients of terms involving variable D. If both these coefficients (b_2 and b_3) are zero, then the road types are judged to be the same. For the 85 car sample, tests of this hypothesis are rejected for all categories of emission standard and emission level.

Given that arterial and highway speed-emissions lines are significantly different, we now ask if they differ at a chosen speed, e.g., 30 miles per hour. This is answered by constructing an appropriate function of the linear model described above. When X = 30, the function becomes:

$$Y = b_0 + b_1*30 \quad \text{for arterials}$$

$$Y = b_0 + b_1*30 + b_2*1 + b_3*1*30$$

$$= (b_0 + b_2) + (b_1 + b_3)*30 \quad \text{for highways}$$

The two functions are identical when the linear combination $b_2 + b_3*30$ equals zero. This hypothesis can be tested using the ESTIMATE feature of the SAS GLM procedure.

Table 10 presents results of these tests for Tier 0 normal and high emitters, and for Tier 1 normal emitters. At the five percent level, a significant difference is found in only in one case, for Tier 0 normal CO emissions. This gives strong support for the claim that arterial/collector roadway and freeway emissions are similar at speeds around 30 mph, even though their relationship at average speeds below 30 mph is different. Based on this convergence, EPA has concluded that the relationship between average speed and emissions for arterial/collector roadways and freeways should be the same at average speeds above about 30 mph.

4.6 Summary

The statistical analysis of the important parameters resulted in the following decisions about how the data would be grouped for the MOBILE6 analysis:

Roadway Type

There will be different equations for the two roadway types (freeways and arterial/collectors) for CO and NOx emission at both High and Normal emitter groups. There will be different equations for the two roadway types for THC and NMHC emissions only for normal emitting vehicles. Since the equations converge, there will be only one equation for all roadway types and pollutants at average speeds above about 30 mph. The exact average speed where the equations converge varies. For high emitting Tier 0 vehicles there will be no difference between the two roadway types for THC and NMHC emissions at any average speed.

Vehicle Class

There will not be different equations for vehicle class (car versus truck). The equations used will depend on emission level (below), which will adequately cover any emission standard differences between cars and trucks. Splitting the data by both emission standard (below) and vehicle class would make sample sizes much too small for any meaningful results.

Emission Standard

There will be separate equations for Tier 0 and Tier 1 emission standard vehicles for normal emission levels. There are no high emitting Tier 1 vehicles in the sample.

Emission Levels

The Tier 0 emission standard data will be further separated by emitter status (Normal and High) for all pollutants with separate speed equations for each. For the purpose of analysis, this effectively results in three samples of vehicles representing three distinct emission levels:

- Level 1 : Tier 1 (Normal emitter)
- Level 2 : Tier 0 (Normal emitter)
- Level 3 : Tier 0 (High emitter)

5.0 EMISSION LEVEL CALCULATION

Once the appropriate aggregations for the existing data were determined as described in the previous section, least square linear regressions were fit to the emission results versus average speed. This was done in a "multi-linear" fashion (piece-wise linear function, continuous), rather than using a single line or using another non-linear curve shape. Attempts to fit non-linear curves to the total data sample resulted in unacceptably high error coefficients. A linear fit of smaller groupings of the data provided a closer fit to the data. A separate linear regression was done for different groupings of cycles based on ranges of average speeds. Together, these lines will define the change in emissions of the sample over the entire range of average speeds.

5.1 Freeway Versus Arterial/Collector Effects

As discussed in the previous section, the data show a statistical difference between the freeway and arterial/collector cycles below 30 mph, where the data overlap. However, there are no arterial/collector cycles above 24.8 mph and there are no freeway cycles below 13.1 mph. If the speed correction factors for both of these roadway types are to cover the entire spectrum of average speeds available in the MOBILE6 model (0 to 65 mph), then some assumptions about the effect of average speed on emissions will need to be made for the speeds outside the data range.

Logically, both curves will converge at idle (zero mph). Idling emissions should not depend on roadway type. Also, it is logical to assume that driving which has a high average speed must consist almost entirely of cruise with little stopping or idle, regardless of roadway type. This suggests a model where freeways and arterial/collector roadways have different emissions at normal arterial/collector average speeds, but have the same emissions at extremely low speeds (and idle) and at higher speeds. Based on this model, EPA has defined the following speed/facility segments:

- o High Speeds (above about 30 mph) for both freeways and arterial/collectors.
- o Intermediate Speed Freeways (from 13.1 to about 30 mph) for freeways.
- o Low Speed Freeways (from 7.1 to 13.1 mph) for freeways.
- o Arterial/Collectors (from 7.1 to about 30 mph) for arterial/collectors.
- o Extremely Low Speed and Idle (less than 7.1 mph) for both freeways and arterial/collectors.

MOBILE6 will use a combined emission estimate for both arterial/collector and freeway facilities for THC and NMHC at the highest emission level. This will mean that, at high emitting THC and NMHC emission levels, that there will be no emission difference between the two facility types. There are still separate freeway and arterial/collector estimates for CO and NOx emissions at high emitting levels.

5.1.1 High Speeds

A regression was done of emissions versus average speed for the three emission standard/emitter groups described above for the four freeway cycles with an average speed above 30 mph (Freeway at 30.5 mph, Freeway at 52.9 mph, Freeway at 59.7 mph and Freeway at 63.2 mph) in grams per mile for each pollutant. Tables 12a, 12b, 12c and 12d show the results of those regressions. All of the slope coefficients of the regressions are statistically significant, meaning that, with high probability, the increase or decrease in emissions versus average speed is different than zero. These regressions will be used to estimate the emissions of vehicles on both freeway and arterial/collector roadways at average speeds above the point where the equations converge.

5.1.2 Intermediate Speed Freeways

A linear regression was done of emissions versus average speed for each of the emission standard/emitter groups described above for the four freeway cycles representing freeway driving in the most congested conditions (Freeway at 13.1 mph, Freeway at 18.6 mph and Freeway at 30.5 mph) in grams per hour for each pollutant. Tables 12a, 12b, 12c and 12d show the results of those regressions. These regressions will be used to estimate the emissions of vehicles on freeways between average speeds of 13.1 mph and about 30 mph. Note that the freeway cycle at 30.5 mph was included in both the intermediate speed freeway and high speed estimates. It is expected that the two regressions should converge at about this average speed.

5.1.3 Low Speed Freeways

None of the existing facility cycles for freeway driving have an average speed below 13.1 mph. It will be assumed that at speeds lower than 7.1 mph (the average speed of the New York

City Cycle) the effect of average speed on emissions will be the same for freeways and arterial/collector roadways. The emissions of freeway driving for average speeds between 13.1 mph and 7.1 mph will be calculated by linear interpolation between these emission levels in grams per hour. Tables 12a, 12b, 12c and 12d show the resulting equations representing this interpolation. Most freeway travel will occur at average speeds well above this range.

5.1.4 Arterial/Collectors

The freeway cycle at 30.5 mph (already included in the freeway estimate) was included in the arterial/collector roadway estimates as well. It was shown that the two regressions should converge at about this average speed. The New York City Cycle was also included in the arterial/collector roadway estimates. The New York City Cycle was not derived from the same chase car or instrumented data used to develop the other facility cycles. However, the New York City Cycle was originally developed as a speed correction cycle and, as shown in Table 3, does contain acceleration rates higher than those contained in the LA4 (Urban Dynamometer Driving Schedule). It was deemed that the New York City Cycle was representative of "real world" representative driving and could be included in the analysis as another facility cycle.

A linear regression was done of emissions versus average speed for each of the emission standard/emitter groups described above for the arterial/collector cycles (Arterial/Collector at 11.6 mph, Arterial/Collector at 19.2 mph, Arterial/Collector at 24.8 mph) in grams per hour for each pollutant. Included in that regression was data from the New York City Cycle (with and average speed of 7.1 mph) and the Freeway at 30.5 mph cycle for the same vehicles.

Tables 12a, 12b, 12c and 12d show the results of those regressions. These regressions will be used to estimate the emissions of vehicles on arterial/collector roadways in this range of average speeds.

5.1.5 Extremely Low Speeds and Idle

No data was collected for the vehicles in the sample at speeds lower than 7.1 mph (the average speed of the New York City Cycle). In this range the model will assume that the effect of average speed on emissions will be the same for freeways and arterial/collector roadways. Since the MOBILE5 model already has estimates for the effect of average speed on vehicles at speeds from 2.5 to 7.1 mph, and since there is no need to differentiate this effect by facility type, the existing speed correction factors in MOBILE5 will be used for this range of average speeds for both freeways and arterial/collectors.

The MOBILE5 speed correction factors do not match the new speed correction factors at 7.1 mph. This discontinuity will be resolved by adding the difference in the two estimates to values calculated using the old MOBILE5 speed correction factors. As in MOBILE5, emissions at idle will be assumed to be the same (in grams per hour) as the emissions at 2.5 mph (the lowest average speed modeled).

5.2 Local Roadways and Freeway Ramps

There is only one cycle each to represent driving on local roadways and freeway ramps. As a result, these cycles are not included in the analysis of emissions versus average speed. However, the data from these cycles were separated using the same sample splits by emission standard (Tier 0 versus Tier 1) and emitter status (Normal versus High) as are used for the freeway and arterial/collectors. The average emission levels were analyzed as a quadratic function of the base emission rate (hot running LA4 emissions). The local roadway regressions do not include a constant (gram per hour) value, since it is assumed that driving on these roadways does not include offcycle driving behavior. These regressions will be used to estimate the emission levels for these roadway types as a function of the base emission rate calculated in MOBILE6. The coefficients for these regressions are shown in Table 13.

5.3 Special Cases

Ideally, the equations above would define a rational, smooth relationship for emissions versus average speed for the range of 0 to 65 mph for each pollutant based on the available data. However due to vagaries of using observed driver behavior data and the use of a multi-linear modeling approach, some of the equations resulting from the general approach will cause small discontinuities in the overall relationship. For example, the intermediate speed freeway emission level for NOx (computed in gram per hour) does not intersect with the high speed freeway emission level estimate (computed in grams per mile) at any speed. These discontinuities will require special handling to be coded mathematically. For MOBILE6, some basic “rules” will be used to assure that there are no abrupt or counter-intuitive changes in emissions versus average speed.

1) If at 30.5 mph, the emission estimate for the intermediate speed freeway equation is still higher than the emissions for freeways calculated using the high speed equation, then the emission value calculated for 30.5 mph using the intermediate speed freeway equation will be used for speeds greater than 30.5 mph until the value for the high speed equation for that speed exceeds the intermediate speed freeway value. This rule keeps the intermediate speed freeway value from increasing beyond the emission level calculated at 30.5 mph, which is the highest average speed data point used in the regression (no extrapolations).

2) When calculating the emissions of an arterial/collector roadway, the arterial/collector estimate for emissions will be used unless the estimate for freeways at that same speed are higher than the arterial/collector estimate. This rule defines at what average speed the arterial/collector and freeway emission estimates will converge. Above that speed the arterial/collector and freeway emission estimates will be assumed to be the same. All of the MOBILE6 arterial/collector equations intersect with the freeway estimate between 24 and 34 mph.

6.0 SPEED AND OFF-CYCLE CORRECTION FACTORS

Using the methods in the previous section, the emission data can be described as a series of continuous, smooth functions for the two roadway types (freeways and arterial/collectors) by emission levels for all pollutants over the entire range of average speeds in MOBILE6 (2.5 to 65 mph). This generalized relationship between emissions and average speed for any emission level is referred to in the model as speed correction factors. For the freeway and arterial facility types, these speed correction factors are the values which will be stored and used in MOBILE6 to adjust exhaust emission estimates to account for average speed. As discussed in the following section, an additional correction factor is applied for the freeway and arterial facility types to account for "off-cycle" emissions, separately from average speed.

6.1 Basic Modeling Approach

The basic exhaust emission rate generated by MOBILE6 will be based on a hot running LA4 emission estimate with an average speed of 19.6 mph. In MOBILE6, freeway ramp and local roadway emissions do not depend on speed and can be determined directly from the basic exhaust emission rate. For freeways and arterial/collector roadways, the adjustment to account for the average speed and facility type is supplemented by an additional adjustment to account for "off-cycle" emissions. The off-cycle adjustment is meant to capture the change in emissions resulting from higher power operation not reflected in changes in average speed. The speed correction factor (SCF) represents the change in emissions which results from a redistribution of vehicle operating modes which occurs an different levels of roadway congestion. The segregation of off-cycle and average speed effects was made in MOBILE6 primarily to assess the benefit of the Supplemental Federal Test Procedure (SFTP) requirement, as discussed later in Section 7.

In MOBILE6, the running basic emission rate is adjusted using the following general method to account for off-cycle and average speed effects:

Local Roadways and Freeway Ramps:

$$\text{Adjusted BER} = \text{BER} * \text{CF}$$

Where:
BER = Basic Emission Rate (running emissions for the LA4 cycle).
CF = Multiplicative correction factor

Freeways and Arterials:

$$\text{Adjusted BER} = (\text{BER} + \text{OC}) * \text{SCF}$$

Where:

BER = Basic Emission Rate (running emissions for the LA4 cycle).
OC = Off-Cycle Emissions Offset (a function of BER emissions)
SCF = Multiplicative Speed Correction Factor (a function of speed and emissions)

The calculation of the correction factor for freeway ramps and local roadways in discussed in Section 5. The remainder of this section addressed the development of off-cycle emissions adjustment and freeway/arterial speed correction factors.

Using the above equation, with a BER identical to the average hot running LA4 emissions of each sample of vehicles in each of the three emission level groupings described in Section 4.6, the estimate of emissions at any speed for each facility will match the average emission level predicted by the regression equations from the facility cycle data from that vehicle sample. For cases where the BER is not identical to the average hot running LA4 emissions of any of the facility cycle sample emission level groupings, the off-cycle adjustment OC will still be calculated as a function of the BER, however the SCF will be interpolated using the three emission level sample estimates. The interpolation would be determined by the emission level of the sum of the BER and the OC. There are three cases, which cover the generation of SCFs for any base emission level:

- If the emissions were equal to one the three predetermined emission level thresholds, the SCF from that level would be used.

- If the emissions are between levels, the SCF would be interpolated between the values for those levels.

- If the emissions were below the Level 1 level or the above the Level 3 level, Level 1 and Level 3 SCF would be used, respectively.

It is important to note that the latter case results in the Level 1 SCFs being applied for most vehicles and trucks under the NLEV and Tier 2 emission standards. As discussed in Section 7, the effects of the SFTP rule will reduce the overall adjusted emissions for vehicles under these programs, but the relative magnitude of the SCF (i.e. the shape of the SCF curve) will remain unchanged from Level 1.

6.2 Off-Cycle Adjustment

It has been long recognized that the FTP does not reflect vehicle operation at higher speeds and accelerations, which contribute significantly to overall emissions. The maximum speed of the FTP is 57 miles per hour (mph), and the maximum acceleration (determined by limitations in chassis dynamometer technology in early 1970's) is 3.3 mph per second. A more direct measure of cycle stringency is power, a combined measure of speed and acceleration which has been found to correlate well with emissions. One metric for power is “specific power”, calculated according to the following equation:

$$\text{specific power} = V_f^2 - V_i^2,\ V_f > V_i$$

Where V_i and V_f are the initial and final velocity, respective to a one-second interval.[12] Using this metric, the average and maximum specific power for the FTP is 192 mph^2/sec. In contrast, data from Baltimore gathered in the early 1990's as part of the FTP review project’s in-use driving surveys found a maximum specific power level of 558 mph^2/sec. More importantly, the distribution of specific power for Baltimore showed a higher proportion of higher specific power events than the FTP; for example, 2.6 percent of operation on the FTP is at specific power over 100 mph^2/sec, while 6.4 percent of Baltimore events were above this threshold.[13] This emissions implications of this are significant given the contribution of these events to overall emissions.

In MOBILE6, an off-cycle correction factor was developed separately from the speed correction factor in an attempt to isolate the effects of high power operation. An alternate approach would have been to create a single correction factor which accounted for both “off-cycle” and speed effects; this approach was suggested by Guensler in an independent peer review of the off-cycle methodology, contained in Appendix E. We are maintaining these effects as separate adjustments, however, because emissions resulting from aggressive driving behavior and emissions resulting from changes in average cycle speed reflect two different processes which should be accounted for separately in assessing the benefit of the off-cycle provision of the SFTP requirement.

The off-cycle adjustment reflects the emissions change resulting from average power levels higher than those on the FTP, independent of average cycle speed. In order to isolate the high power effects separate from changes in average cycle speed, the off-cycle adjustment was derived by comparing running LA4 emissions to an emission test cycle of comparable average speed used in the development of the freeway speed correction factor, the Freeway Level Of Service (LOS) F cycle. The average speed of this cycle is 18.6 mph, but the maximum acceleration rate is 6.9 mph/s, as opposed to 3.3 mph/s over the LA4. The average specific power of the Freeway F cycle is 44 mph^2/s, 15 percent higher than the 38 mph^2/s of the LA4. It was thus assumed that significant emissions differences between this cycle could be attributed to the difference in cycle stringency, or off-cycle emissions. The off-cycle correction factor is a function of base running emissions, relating the difference in emissions between the freeway LOS F cycle and the LA4 to base running (LA4) emissions, as shown in the following equation:

$$\text{Off-Cycle (g/mi)} = \text{Freeway F(g/mi)} - \text{LA4(g/mi)}$$

The data underlying the off-cycle emission effects is from EPA testing of 85 cars and trucks with model years 1983 through 1996 (the same sample used for generating the SCFs). The sample consisted of 63 cars and 22 light trucks that received emissions tests on both the LA4 and Freeway F cycles. The additive approach of the equation above was used for all three pollutants. The overall model hypothesis was that ultimately only a vehicle's base LA4 emissions was significant in determining the off-cycle emissions. Other variables potentially significant to emissions generation such as vehicle type, model year, and fuel delivery system were accounted for in the base emission rates, and were eliminated from the model through stepwise regression because of insufficient statistical significance.

6.2.1 CO Off-Cycle Emission Effects

Prior to the analysis of the CO emission off-cycle effects, the data was examined in a graphical form, and found to contain considerable scatter for vehicles with high CO emissions. 12 data points were between 10 and 100 grams/mile, in general an order of magnitude higher than the remaining 73 data points. As a result of the scatter and the potential for these high emission vehicles to have an unrepresentatively large influence on the final model, it was decided to separate the sample into high and normal emitters based on a given vehicle's overall FTP emission level. The threshold emission level dividing the 'normal' and 'high' emitters that was chosen was 10.2 g/mi over the FTP, or three times certification standard. This level was chosen to maintain consistency in the definition of 'high' emitter throughout MOBILE6.

Least squares regression was performed separately on both the normal and high emitter samples. The CO Off-Cycle emissions as defined in Equation 4 were least squares regressed versus LA4 CO emissions, LA4 CO emissions squared, fuel delivery type, vehicle type (car or truck), and model year. For the 'normal' emitters, stepwise regression with a 5 percent significance requirement (p-value < 0.05) eliminated all of the variables except the LA4 CO emissions and LA4 CO emission squared terms. For the 'high' emitters, stepwise regression eliminated all of the variables. A subsequent regular regression showed that none of the variables were close to being statistically significant. All of the statistical results are shown in Appendix A.

The fit which was chosen to represent the CO off-cycle emissions in normal emitters in MOBILE6 was a quadratic linear fit of the CO off-cycle offset versus running LA4 CO emissions. This regression fit was force through zero because it is believed that off-cycle emissions will be zero on zero emitting LA4 vehicles. The regression equation proposed for use in MOBILE6 for normal emitters is shown the the following equation

$$OC_{CO} = 0.984 * LA4CO \;-\; 0.07638 * (LA4CO)^2$$

Where:

OC_{CO} is the CO emission increase due to off-cycle operation in g/mi.
LA4CO is the base CO emission level over the LA4.

A regression analysis of the high emitting vehicles resulted in no significant predictors of the off-cycle offset, including LA4 CO emissions. The average results was also not significantly different from zero. Thus, we are establishing the off-cycle offset for CO high emitters at zero. A likely explanation for this is that high emitting CO vehicles are likely already experiencing excess enrichment over the LA4, which the increase in cycle stringency is not exacerbating.

The CO Off-Cycle effect as a function of LA4 CO emissions is shown in Figure 8a. The line annotated with circles is CO off-cycle effect for the 'Normal' emitters. The zero line is the CO off-cycle effect for 'High' emitters.

6.2.3 HC Off-Cycle Emission Effects

In the case of hydrocarbon emissions, the base LA4HC emission level and the squared value of the LA4HC were found to be the only statistically significant variable using as stepwise regression process. Segregation of the data into low and high emitters was not found to be necessary in the case of HC offset. The full regression statistics are shown in Appendix A.

The equation predicting the NMHC off-cycle offset in units of g/mi is shown in the following equation. The equation and the underlying data are also shown in graphical form in Figure 8b.

$$OC_{HC} = 0.305 * LA4HC \; - \; 0.02492 * (LA4HC)^2$$

Where:

OC_{HC} is the HC emission increase due to off-cycle operation in g/mi.
LA4HC is the base HC emission level over the LA4.

Since the THC off-cycle emission fit is a quadratic in form, it produces a peak offset which declines and eventually goes negative. The maximum THC off-cycle offset is 0.933 g/mi and occurs when the base LA4 THC emission level equals 6.12 g/mi (See Figure 2). It was decided that the value of the THC offset would be fixed at 0.933 g/mi for all LA4 emission levels exceeding 6.12 g/mi rather than let it decline. The rationale for this assumption is that it is counter-intuitive to expect that the lightly loaded LA4 cycle would produce HC emission levels which are less than or even declining relative to the Freeway F emission cycle. The HC offset function's maximum occurs at a LA4 emission level which is virtually out of the range of the running LA4 HC emission levels in the model. Only very high emitting older model year light vehicles will approach a value of 6.12 g/mi running LA4. Thus, the assumption of a maximum offset value of 0.933 g/mi THC will rarely be invoked.

6.2.3 NOx Off-Cycle Emission Effects

Similar to HC, for NOx only the base LA4 emission level, its squared value, and an intercept forced through zero were found to be statistically significant. Segregation of the data into low and high emitters was also not found to be necessary in the case of NOx offset. The full regression statistics are shown in Appendix A. The equation predicting the NOx off-cycle offset in units of g/mi is shown in Equation 8.

Since the NOx off-cycle emission fit is a quadratic form, it produces a peak offset which declines and eventually goes negative. The maximum NOx off-cycle offset is 0.58 g/mi and occurs when the base LA4 NOx emission level equals 3.50 g/mi (See Figure 3). At higher NOx levels, the downward trend is dictated by limited data, and as a result we have decided to impose an artificial cap of 0.58 g/mi for all LA4 NOx emission levels exceeding 3.50 g/mi rather than let it decline. On late model light vehicles, only the very high emitter levels will approach a value of 3.50 g/mi running LA4 (for comparison the current FTP certification standard is 0.40 g/mi NOx). Thus, the assumption of a maximum NOx off-cycle offset value of 0.581 g/mi will rarely be invoked.

$$OC_{NOX} = 0.332 * LA4NOx - 0.04745 * (LA4NOx)^2$$

Constraint: LA4NOx <= 3.50 g/mi

$$OC_{NOX} = 0.58 \text{ g/mi}$$

Constraint: LA4NOx > 3.50 g/mi

Where:

OC_{NOX} is the NOx emission increase due to off-cycle operation in g/mi.
LA4NOx is the NOx emission level over the LA4.

6.3 Calculating Speed Correction Factors

As discussed in Section 6.2, MOBILE6 adjusts the basic exhaust emission rates (BER) by first adding an emission value which accounts for off-cycle emissions (OC). From this point, SCFs are generated to account for changes in facility type and average speed. For freeway and arterial roadways, the SCF is applied as a multiplicative adjustment directly to the sum of the BER and the off-cycle adjustment.

The SCF is defined as the ratio of the predicted emissions at any average speed to the predicted emissions at 19.6 mph for freeways for the same vehicle. Using the emission level equations described in Section 5, a set of SCFs will be determined for each speed in increments of 5 mph beginning at 5 mph through 65 mph and at 2.5 mph for each of the three emission levels within MOBILE6. These increments correspond to the increments of average speed for the VMT average speed distribution for freeways and arterial/collector roadways in MOBILE6. MOBILE6 calculates these speed correction factors directly from the emission levels, rather than store the resultant speed correction factors themselves. Table 16 shows the freeway SCF sets for the three emission levels. These SCF sets are shown graphically in Figures 5a, 5b, 5c and 5d. Table 16 shows the freeway emissions at 19.6 mph for each emission level. Table 17 shows the arterial/collector SCF sets for the three emission levels.

The vehicle miles traveled (VMT) average speed distribution for freeways and arterial/collector roadways in MOBILE6 represent the distribution of speeds for the area to be modeled. Each average speed bin is the fraction of all miles traveled which occurs within a given speed range. For example, the 30 mph bin will include the miles traveled on links where the average speed is between 27.5 mph and 32.5 mph. The sum of the distribution fractions must always be one. If only a single roadway is to be modeled, the average speed can be entered as two adjacent bin values whose average speed matches the average speed for the roadway. In this case, all other speed bin values would be zero. MOBILE6 is intended to model average roadway speeds and cannot model the emissions of vehicles at an instantaneous (cruising) speed.

6.4 Test for Model Stability

Guensler's peer review comments (Appendix E) suggested a method to test for the stability of the overall off-cycle and speed modeling methodology. This method was to develop an alternative model in which the off-cycle adjustment was generated using a facility cycle other than FWYF (LOS B or C was specifically suggested), and comparing the results of this alternate model to that used in MOBILE6 on other LOS cycles, or an independent data set. Guensler suggested that if the alternate model was shown to predict the same results as the MOBILE6 approach over the range of LOS cycles, the model estimation approach would be shown to be stable.

Overall, we expect that the suggested approach would yield similar results no matter what cycle was used as the basis for the off-cycle adjustment and SCFs. This is because the off-cycle adjustment is simply the expression of the emission increase between the LA4 and a single cycle (FWYF in this analysis), and the SCFs are in turn the expression of the emission increase from any average speed relative to that same cycle. Changing the base cycle will not change this overall relationship; if the relationship between the LA4 and base cycle were changed, the SCFs would change accordingly, resulting in similar predictions of overall emissions.

In demonstrate this, we formulated an alternate model for off-cycle adjustments and SCFs which relied on emission results from the Freeway AC cycle, one of the highest average speed cycles tested for this analysis (average speed of 59.7 mph). We focused on the 22 vehicles used to derive the "Level 1" SCFs discussed in Section 5. We then used this alternate model to predict arterial emissions at 11.6 mph (average speed of the Arterial E cycle), representing the lowest end of the speed range and relatively high SCFs. The hypothesis was that if stability were shown at the low end of the speed range where SCFs are the highest, it could be inferred on the remainder of the speed curve.

The base and alternative models are shown in Table 6-1, along with the prediction of mean emissions for arterials at 11.6 MPH. The means show less than 3 percent difference between the two models, and 95 percent confidence intervals confirm this difference is not significant. This analysis suggests that the modeling approach used to estimate off-cycle emissions and SCFs would result in stable emissions predictions regardless of which cycle is used as the base cycle.

Table 6-1: Test For Model Stability for Arterial at 11.6 mph

Pollutant	Model Approach	Model Formulation (LA4 + Off-Cycle Adjustment)*SCF	Predicted Level 1 emissions (g/mi) ± 95% CI
NOx	MOBILE6	$[LA4NOx+(0.332*LA4NOx-0.04745*LA4NOx^2)]*(1.71)$	0.43 ± 0.13
	Alternate	$[LA4NOx+(2.05*LA4NOx-4.42*LA4NOx^2)]*(1.71/1.42)$	0.42 ± 0.09
HC	MOBILE6	$[LA4HC+(0.305*LA4HC-0.02492*LA4HC^2)]*(1.86)$	0.093 ± 0.023
	Alternate	[LA4HC+(0.775*LA4HC)]*(1.86/1.24)	0.095 ± 0.023
CO	MOBILE6	$[LA4CO+(0.984*LA4CO-0.07638*LA4CO^2)]*(1.34)$	2.23 ± 0.91
	Alternate	$[LA4CO+(3.417*LA4CO-0.823*LA4CO^2)]*(1.34/1.59)$	2.26 ± 0.7

7.0 BENEFITS OF THE SFTP REQUIREMENT

7.1 Methodology used to calculate SFTP benefit

Increasing attention to the importance of off-cycle emissions led to the development of a new compliance procedure, known as the Supplemental Federal Test Procedure (SFTP). In addition to “off-cycle” emissions, the SFTP addresses emissions which are generated with the air conditioning on, which were also inadequately represented by the FTP. The SFTP requirements grew out of the 1990 Clean Air Act Amendments, which instructed EPA to review the existing procedures and revise them in whatever ways were necessary to make them more representative of actual in-use conditions. Developed in conjunction with the California Air Resources Board (ARB) and auto manufacturers, the SFTP requirement adds two additional certification cycles, and tailpipe standards associated with those cycles, to impose control of off-cycle (US06 cycle) and air conditioning emissions (SC03 cycle). The US06 is run with the vehicle in the hot stabilized condition; that is, with the vehicle fully warmed up to insure that the engine and catalytic converter have reached typical operating temperatures. The SC03 follows a 10-minute soak and is run with vehicle air conditioning (A/C) in operation or with an appropriate simulation of air-conditioning operation.

The assigned benefits of the SFTP rule will depend on whether a vehicle is a Tier 1 vehicle or a LEV. EPA and ARB promulgated separate requirements applying to these standard levels, and hence the benefits resulting from the rule must take into account the relative stringency of the EPA and ARB rules. Under NLEV, the Tier 1 rule will only apply to LDTs above 6000 pounds (LDT3s and LDT4s), which phase in to the SFTP requirement at 40 percent in 2002, 80 percent in 2003, and 100 percent in 2004.[14] These trucks will be allowed to certify to the Tier 1 SFTP standards until they begin phasing into the Tier 2 final standards in 2008, at which point they will be required to comply with the SFTP provisions under the Tier 2 rule discussed below.

For Tier 1 and interim Tier 2 LDT3s and LDT4s, the benefits derived in EPA's SFTP final rulemaking shown in Table 7-1 will be used directly in MOBILE6 (Post-SFTP CO air conditioning emissions are a special case, as discussed below). The percent reductions shown for the SFTP rule will be applied directly to the off-cycle adjustment to generate final off-cycle adjustments for SFTP-compliant vehicles.

TABLE 7-1
TIER 1 SFTP BENEFITS FROM
OFF-CYCLE OPERATION and AIR CONDITIONING

POLLUTANT	OFF-CYCLE	AIR CONDITIONING
HC	88%	100%
CO	72%	Fuel Consumption Increase
NOx	78%	50%

*EPA rule estimated benefits of Tier 1 SFTP standards, in terms of percent reduction of uncontrolled "excess" emissions.

A detailed derivation of these benefits are contained in the SFTP final rulemaking.[15] They were derived by comparing the emission results over off-cycle driving from a sample of light-duty vehicles and trucks tested in an uncontrolled condition (pre-SFTP), and with emission control software modifications made by vehicle manufacturers to reduce off-cycle emissions (e.g. eliminating commanded enrichment). This approach is consistent with that suggested by the Guensler comments, which suggests "comparing the percentage reduction in emissions that will occur for current vehicles as they move from their current emissions levels on the composite SFTP to the compliance emission rates...". Because vehicles complying with the SFTP are just starting to enter the market, an assessment of SFTP benefit on the in-use fleet is not yet possible. We therefore consider the approach used in the EPA SFTP rule to be the best available.

Under NLEV, the ARB rule will apply to LEV LDVs and LDTs under 6,000 pounds (LDT1/2). The ARB rule contains NOx and HC certification standards which differ from EPA's both in terms of the relative stringency over the US06 and SC03 cycles, and the mileage at which a vehicle is required to show compliance. The percent reductions derived for EPA's Tier 1 ruletherefore cannot be applied directly to vehicles complying with the ARB standards.

A sample of vehicles with emissions below the Tier 1 SFTP standards, based on compliance strategies developed by the auto manufacturers, were available to develop the benefits of EPA's Tier 1 rule. A comparable sample was not available in which to derive benefits from the ARB standards under NLEV. For the purpose of MOBILE6, we therefore developed a methodology which estimated the percent reductions for the ARB standards on LEVs based on the EPA Tier 1 benefits presented in Table 1. This methodology required an assessment of the relative stringency of the EPA and ARB SFTP standards compared to their respective FTP standard. Several factors added complication to this analysis: first, the ARB standards are applicable at 4,000 miles whereas the EPA standards are applicable at 50,000 miles and full useful life (100/120K miles); second, the SFTP standards are expressed at NMHC+NOx, while MOBILE treats these pollutants separately. Third, the SFTP standards are based on operation when the vehicle is warmed-up, necessitating that the warmed-up component of the FTP be extracted in order to performing comparisons with the SFTP standards. An analytical step was required to address each of these factors.

Reductions in off-cycle emissions due to ARB's LEV SFTP standards for NOx and HC were estimated through a determination of the stringency of the ARB and EPA US06 standards. The stringency of the ARB and EPA standards is characterized by how well they control off-cycle emissions for LEVs and Tier 1 vehicles, respectively; this stringency is thus best determined through a comparison. A direct comparison between these standards This comparison was made in relation to emissions over the FTP   The basis for this determination was a comparison between the US06/SC03 standards and an estimation of "running certification levels" (i.e. the running component of FTP certification levels) calculated for Tier 1 vehicles and LEVs, according to the following steps, shown in Tables 7-2 and 7-3:

1) Average certification emissions for model year 1999 LDVs and LDTs were generated from EPA's CFEIS database at 4,000 miles for LEVs and 50,000 miles for Tier 1 (Row 1).   The certification database used to generate these averages are provided with this report.

2) "Running certification levels" were estimated for Tier 1 and LEV by multiplying the certification levels from Step 2 by the appropriate running BER fractions discussed in Draft Final MOBILE6 Report M6.EXH.007 (December 1999); 0.90 for NOx and 0.23 for HC. The FTP certification levels and the derived "running certification levels" are shown in Row 2.

3) NMHC+NOx US06 and SC03 standards were split into separate NMHC and NOx standards by applying a split of 0.14/0.86 for NMHC/NOx, derived from the development of EPA's Tier 1 standards, and discussed in EPA's final SFTP rule (Rows 3 and 4).

4) A ratio of the resulting 50,000 mile SFTP NMHC and NOx "standards" from Step 3 and the running certification levels from Step 2 were calculated for both the Tier 1 (EPA) and LEV(ARB) requirements for US06 (Row 5). The ratio (R) represents the magnitude of increase allowed between the FTP and US06 cycles, and hence represents the stringency of the SFTP standard relative to the FTP standards.

5) The stringency of the ARB standards relative to the EPA standards were estimated by comparing the value of R calculated in Step 4, according to the following equation (Row 6):

$$\text{Additional Stringency of ARB Standards (\%)} = [(R_{EPA} - 1) - (R_{ARB}-1)] / (R_{EPA} - 1)$$

The additional stringency represents the additional off-cycle emissions which would be eliminated above and beyond the reductions under the Tier 1 standards.

6) Benefits under the ARB rule were then derived by adjusting the Tier 1 benefits (Row 7) from Table 7-1 according to the additional stringency contained in Step 5, according to the following equation (Row 8):

$$\text{ARB Benefit (\%)} = \text{EPA Benefit} + (\text{Step 5}) * (1 - \text{EPA Benefit})$$

These steps are illustrated in Tables 7-2 and 7-3.

Table 7-2: Worksheet for Developing LEV NOx Benefits

	Tier 1 (50K Miles)				LEV (4K Miles)			
	LDV/ T1	LDT2	LDT3	LDT4	LDV/ T1	LDT2	LDT3	LDT 4
(1) Average FTP Certification Level	0.17	0.19	0.24	0.30	0.07	0.11	0.13	0.16
(2) Estimated "Running" Certification Level	0.15	0.17	0.21	0.27	0.06	0.10	0.11	0.14
(3) Estimated NOx 4K Standard (ARB)					0.12	0.22	0.34	0.52
(4) Estimated NOx 50K Standard (EPA)	0.50	0.78	0.78	1.15				
(5) US06 Standard / Running Certification Level	3.26	4.57	3.69	4.19	1.87	2.15	3.03	3.68
(6) Additional Stringency of ARB Standard					62%	68%	25%	16%
(7) EPA SFTP Benefit (%)	78	78	78	78				
(8) ARB Benefit (%)					**92%**	**93%**	**83%**	**81%**

Table 7-3: Worksheet for Developing LEV HC Benefits

	Tier 1 (50K Miles)				LEV (4K Miles)			
	LDV/ T1	LDT2	LDT3	LDT4	LDV/ T1	LDT2	LDT3	LDT4
(1) Average FTP Certification Level	0.10	0.10	0.10	0.13	0.03	0.05	0.05	0.07
(2) Estimated "Running" Certification Level	0.02	0.02	0.02	0.03	0.01	0.01	0.01	0.02
(3) Estimated NOx 4K Standard (ARB)					0.02	0.04	0.06	0.08
(4) Estimated NOx 50K Standard (EPA)	0.08	0.13	0.13	0.19				
(5) US06 Standard / Running Certification Level	3.62	5.34	5.50	6.40	2.44	3.17	4.69	5.40
(6) Additional Stringency of ARB Standard:					45%	50%	18%	19%
(7) EPA SFTP Benefit (%)	88	88	88	88				
(8) ARB Benefit (%)					**93%**	**94%**	**90%**	**90%**

We consider the ARB CO standards over the US06 to be functionally equivalent to the EPA standards. We expect that these standards (9.0 g/mi for Tier 1, 8.0 g/mi for LEV) will serve as more of a cap on excess CO emissions, unlike the NOx and HC standards. As such, we are proposing to apply the Tier 1 benefit (78 percent) to LEVs as well.

The resulting SFTP benefits for LEVs are presented in Tables 7-4.

TABLE 7-4
LEV SFTP BENEFITS OVER OFF-CYCLE OPERATION

	LDV/T1	LDT2	LDT3	LDT4
HC	93%	94%	90%	90%
CO	78%	78%	78%	78%
NOx	92%	93%	83%	81%

7.2 Applying the SFTP Benefit in MOBILE6

The effect of the SFTP rule will be modeled in MOBILE6 by applying the percent reductions derived in Section 7.1 to the off-cycle adjustment (OC) for freeways and arterial roadways, and to the correction factor (CF) for freeway ramps. In equation form, this is represented as follows:

Freeway Ramps: Adjusted BER w/ SFTP = BER * CF * (1-SFTP)_

Where:
BER = Basic Emission Rate (running emissions for the LA4 cycle).
CF = Multiplicative correction factor
SFTP = SFTP benefit from Section 7.1

Freeways and Arterials: Adjusted BER w/ SFTP = (BER + (OC*(1-SFTP)) * SCF

Where:
BER = Basic Emission Rate (running emissions for the LA4 cycle).
OC = Off-Cycle Emissions Offset (a function of BER emissions)
SCF = Multiplicative Speed Correction Factor (a function of speed and emissions)
SFTP = SFTP benefit from Section 7.1

This approach was generated based on the following assumptions about how "excess" emissions are generated, defined as emissions higher than the running LA4 in terms of grams/mile:

- "excess" emissions over the local roadway cycle are due solely to reduced travel efficiency (e.g. less distance traveled per unit of engine work), rather than off-cycle driving, and hence emissions will not be reduced from the SFTP.

- "excess" emissions over the freeway ramp cycle are due solely to off-cycle driving, and hence "excess" emissions will be reduced in direct proportion to the SFTP benefits;

- "excess" emissions over the freeway and arterial cycles are due to both off-cycle emissions and reduced driving efficiency, and hence emissions will be reduced only over the off-cycle driving events on these cycles, in proportion to the SFTP benefits.

This latter situation for freeways and arterial is the primary reason why two separate adjustments (Off-Cycle and SCFs) have been developed to address the overall issue of driving behavior. Peer review comments from Guensler suggested that two separate adjustments were unneccessary, instead recommending that a single adjustment be developed which encompassed both corrections. However, the specific contribution of off-cycle emissions must be estimated in order to account for the benefit of the SFTP. A single adjustment factor would combine "excess" emissions due to both off-cycle emissions and reduced travel efficiency, making it difficult to estimate the benefits of off-cycle control from SFTP.

Guensler's peer review comments infer that applying SFTP reductions only to the off-cycle adjustment translates to emission reductions not being applied on all freeway and arterial driving due to the SFTP. This is not the case; as indicated in the Freeway and Arterial equation above, reductions in the off-cycle adjustment will result in reductions over the entire speed range for freeway and arterial roadways. What will vary, however, is the relative magnitude of these reductions. The SFTP benefits reported in Section 7.1 will only be realized in full over the FWYF cycle, because the "excess" emissions over this cycle are assumed to be due exclusively to off-cycle emissions. For cycles with average speeds lower than 19.6 mph, it is not appropriate to treat all of the "excess" emissions as off-cycle emissions, since reduced travel efficiency contributes to these emissions as well. For cycles with average speeds higher than 20 mph, it is more reasonable to assume that excess emissions are caused predominately by off-cycle emissions, and hence the assumption that the SFTP rule will reduce the calculated off-cycle increment is likely conservative.

7.3 Applicability of SCFs to SFTP-compliant vehicles

The SCFs were developed on a sample of vehicles which were not certified to comply with the SFTP. Given the advent of the SFTP rule, we felt it important to assess whether the SCFs could reasonably be applied for vehicles which would comply with the off-cycle requirements. We analyzed emissions results across EPA facility-specific test cycles for a subset of test vehicles with low off-cycle emissions; our criteria for choosing these vehicles was emission performance on the "Freeway Ramp" cycle, a short cycle which is meant to mimic driving performance while entering a freeway. As such, this cycle as high acceleration rates, comparable to those found on the US06 cycle. If a vehicle performs well on the Ramp cycle, we presume it would likewise perform well on the US06; in particular, it is likely that such a vehicle would have adequate catalyst volume so as to not experience severe catalyst "breakthrough", an important contributor to high off-cycle emissions.

Our criteria for choosing "clean" SFTP vehicles was whether the vehicle's emissions over the ramp cycle were at or below EPA's implied NMHC+NOx US06 standard at 50,000 miles (0.58 grams/mile). 20 vehicles met this criteria, and are listed in Table 7-5 along with g/mi emissions over the Ramp cycle. CO emissions are also listed; the US06 standard for CO is 9 g/mi, which all of the vehicles meet, most by over 50 percent.

Table 7-5: "Clean SFTP" Vehicles

Vehicle	Ramp NMHC+NOx/CO (g/mi)	Vehicle	Ramp NMHC+NOx/CO (g/mi)
5021	0.13/4.6	5213	0.33/0.47
5217	0.13/2.17	5013	0.36/2.91
5240	0.14/0.28	5062	0.37/0.86
5007	0.16/1.11	5060	0.38/2.52
5229	0.20/6.5	5038	0.38/0.08
5061	0.22/0.69	5234	0.43/1.35
5063	0.23/0.86	5231	0.47/5.2
5017	0.26/3.4	5059	0.53/7.8
5018	0.30/3.4	5223	0.55/0.03
5010	0.31/0.7	5221	0.58/2.53

It is likely that most of these vehicles were included in the sample used to develop the "Level 1" (low emission) MOBILE6 speed correction factors. Hence, the comparison is not of two completely independent data sources. The main purpose of this exercise is to assess whether the SCFs which were developed with pre-SFTP vehicles in mind can reasonably be applied to the subset of vehicles we project would comply with the SFTP requirement. It is important to note that, because of the SFTP benefits discussed in Section 4, speed-corrected emissions will be lower for SFTP-compliance vehicles than for pre-SFTP vehicles, even if the same SCFs are applied. At issue is whether the relative increase in emissions observed for pre-SFTP vehicles across the speed range applies to post-SFTP vehicles as well.

We computed average emissions from this sample for the freeway, arterial, and local facility-specific test cycles used to develop the SCFs presented earlier in this paper. We then divided these emissions by that of the Freeway F cycle, which is approximately the basis for generating the MOBILE6 SCFs. In this way, we could develop SCFs specifically for the clean SFTP vehicles, and compare them to the "Level 1" SCFs proposed for MOBILE6.

The results of this comparison are shown in Figures 9a-9c for NOx, HC and CO. As shown by these charts, the SCFs for vehicles with low off-cycle emissions are consistent with the MOBILE6 SCFs. From this we conclude that it is reasonable to apply the MOBILE6 SCFs to vehicles which comply with the SFTP.

8.0 Application in MOBILE6

The speed corrections described in this document are applied to gasoline fueled, light-duty vehicles (cars and light trucks) of all model years and technologies. The speed correction factor would be applied to the basic exhaust hot running emission rates, adjusted to freeway emission levels at 19.6 mph. Additional adjustment would be made to the freeway emission estimate between 7.1 and about 30 mph to account for arterial/collector roadways. MOBILE6 would continue to use the existing speed correction factors and methodology found in MOBILE5 for diesel vehicles, gasoline fueled heavy-duty vehicles and motorcycles. Heavy-duty diesel vehicles will also be adjusted for NOx excess emissions separately from the MOBILE6 speed correction factors.

In MOBILE6, the daily average emission rate will be calculated by VMT weighting an emission estimate for each hour of the day. Within each hour of the day, there will be a distribution of speeds (either a default national average or a user supplied distribution) for freeways and arterial/collectors. The speed correction would be applied to the estimate of Normal and High emitters within each model year separately. Older (pre-1981) model year gasoline fueled, light-duty vehicles will have only composite (combined Normal and High) basic exhaust emission rates. In these cases the speed correction will be applied to the composite basic exhaust emission rates (including both Normal and High emitters). Speed correction factors will not be applied to the effects of engine start on emissions estimated by MOBILE6.

The speed distribution in MOBILE6 will consist of average speed "bins" from 5 to 65 mph in 5 mph increments and for 2.5 mph (14 speed bins) representing the distribution of average speeds within each hour.[16] Each hour of the day will have an estimate of the distribution of vehicle miles traveled (VMT) on freeways, ramps, local and arterial/collector roadways. These distributions will be used to weight together the emission estimates in each speed bin to give an hourly emission estimate. Freeway Ramps and Local Roadways will have hourly emission estimates and VMT estimates, but will not have speed distributions. The hourly emission estimates will be weighted by the hourly VMT distribution separately for each facility. Finally, the VMT distribution between facilities will be used to combine the results into an area-wide running exhaust emission estimate. Emissions due to engine start within each hour will be calculated separately.

In summary, MOBILE6 will:

- o Determine the basic running exhaust emission rate (BER).
- o For each hour, correct the BER for temperature and fuel effects.
- o Using the corrected BER, calculate the emissions for Freeway Ramps, Local Roadways and for the 14 speed bins for freeways and arterial/collectors using the appropriate emission offsets and speed correction factors described in this document.
- o Using the speed distributions, weight the freeways, ramps, local and arterial/collector speed bin results to get hourly emissions.
- o Using the hourly VMT distributions, weight together the hourly facility results to get daily emissions by facility.
- o Using the facility VMT distribution, weight the daily facility emissions to get the area-wide running exhaust emission estimate.
- o Combine the running exhaust emission estimate with the engine start emissions to get the composite exhaust emission rate.

Appendix B shows an example speed correction calculation.

The national average default factors used in MOBILE6 for VMT weighting the speed-corrected, facility-type emissions into a single area-wide running emissions rate is described in a report prepared for EPA by Systems Applications International.[17] This report also contains the default distributions of average speeds on each facility over the day. All of these default values can be overridden by the user with local information using methods described in a separate guidance document.[18]

The operating mode inputs used in MOBILE5 will not be needed for MOBILE6. Instead, MOBILE6 uses values for the number of engine starts, the distribution of soak times between engine starts, the mileage accumulation rates and the distribution of these factors over the day.[19] These values are used to determine the weighting of the running exhaust emissions with the effects of engine starts to calculate a composite exhaust emission factor. Although MOBILE6 contains default values, these default values will normally be overridden by user supplied local information.

Similarly, once the composite running and engine start emissions are calculated, the composite exhaust HC emissions can be combined with the calculated non-exhaust HC emissions. The reader should refer to the reports regarding the non-exhaust emission estimates and their associated activity for more details on how these values are calculated.[20]

8.1 Light Duty Diesel Vehicles

The speed correction factors (SCFs) for LDDV and LDDT in MOBILE5 were derived from the SCFs calculated for HDDV. However, in MOBILE5, an adjustment was added for LDDV and LDDT to account for user supplied changes to the operating modes, which are cold start versus hot start VMT fractions applied to FTP bag emission rates, to account for the different average speeds between the FTP bags. These fractions did not affect HDDV, since the emissions from HDDV are not calculated from individual FTP bag emission results.

In MOBILE6, there will not be user inputs for operating modes. The emission estimates for LDDV and LDDT in MOBILE6 have been split into the portion that occurs as a result of engine starts separately from the hot running emissions. The intention of the operating mode adjustment to the SCFs for LDDV and LDDT in MOBILE5 was to account for user supplied changes in the mix of FTP bag results in the basic exhaust emission rates. However, the basic exhaust emission rate for LDDV and LDDT in MOBILE6 is not affected by user inputs and is based solely on the LA4 driving cycle, which is the basis for the full FTP. As a result, the operating mode adjustment to the SCFs for LDDV and LDDT in MOBILE6 will be set to a constant based on the standard FTP operating mode mix. The adjustment to account for changes in speed that were caused by the operating mode will no longer be necessary in MOBILE6.

The MOBILE5 speed correction factor coefficients for LDDV and LDDT from MOBILE5[21] are shown in Table 18. These factors will be used in MOBILE6 as well, but with the SADJ value fixed at 19.6 mph, which is the speed of the basic emission rate cycle, the LA4.

8.2 Heavy Duty Vehicles

The speed correction factors for heavy duty vehicles are not changed from those used in MOBILE5.[22] The coefficients used in MOBILE6 are shown in Table 19 and Table 20.

8.3 Motorcycles

The speed correction factors for motorcycles are not changed from those used in MOBILE5.[23] However, the SADJ factor discussed in the light duty diesel vehicle section were also applied to motorcycle speed correction factors in MOBILE5. In MOBILE6, the SADJ factor will be set to 19.6 mph. The coefficients used in MOBILE6 are shown in Table 21.

The speed correction factors for motorcycles were developed in earlier versions of the model only for speeds up to 55 mph. In MOBILE5, for average speeds above 55 mph for THC and CO and 48 mph for NOx, the speed correction factor used for motorcycles was derived from the speed correction factor used for light duty gasoline vehicles for 65 mph. The speed correction factor (SCF) calculated for motorcycles is adjusted using the ratio of the difference between the light duty vehicle SCF at 65 mph and the motorcycle SCF at the target speed divided by the difference between 65 mph and the target speed.

$$\text{RATIO} = (\,\text{LDGVSCF}(65) - \text{MCSCF}(s)\,) / (65 - \text{SPD}\,)$$

$$\text{MCSCF}(s) = \text{MCSCF}(s) * (1.0 + (\,\text{RATIO}*(s - \text{SPD})\,)\,)$$

Where : s = average speed (mph) target speed

LDGVSCF(65) = light duty gasoline vehicle SCF at 65 mph
MCSCF(s) = motorcycle SCF at the target speed (s)
SPD = average speed where adjustment begins in mph
- 55 mph for THC and CO emissions
- 48 mph for NOx emissions

This adjustment was retained for the calculation of motorcycle speed correction factors in MOBILE6.

8.4 High Speeds

The driving cycles developed for MOBILE6 were derived from data collected before national speed limits were increased from 55 mph to 70 mph. The average speed of driving for uncongested freeways in the data sample was 59.7 mph (73.1 mph maximum). Another driving cycle, developed using a subset of vehicles driving over 55 mph, has an average speed of 63.2 mph. It is clear that using the existing driving behavior information collected before the increase in the national speed limit cannot provide a credible estimate of the driving behavior at average speeds above about 65 mph. Existing research[24] has shown that even minor variations in driving at high speeds can have a significant effect on driving emissions at those speeds. For this reason, until new information about driving behavior at high speeds and their effect on emissions is available, MOBILE6 will not directly predict emission impacts of average speeds over 65 mph.

9.0 COMPARISON TO MOBILE5

Figures 6a, 6b, and 6c show the MOBILE6 speed correction factors (SCFs) for freeways compared to selected speed correction factors used in MOBILE5. This comparison cannot be made clearly, since the two versions of the model use very different approaches.

- The MOBILE6 SCFs depend on emission level and the MOBILE5 SCFs do not.
- The MOBILE5 SCFs are applied to a composite exhaust emission rate, including engine start emissions. The MOBILE6 SCFs will only be applied to the hot running exhaust emissions, before the effects of engine start are added.
- The MOBILE6 SCFs are intended to estimate the effects on freeways excluding ramp activity, but the MOBILE5 SCFs are a composite of all roadway types.
- The MOBILE6 SCFs include the effect of additional aggressive driving effects on emissions missing from the MOBILE5 SCFs.

The overall shape of the MOBILE5 and MOBILE6 SCFs is similar. The MOBILE6 SCFs are flatter at speeds greater than 55 mph than in MOBILE5, especially for CO and NOx. This may be due largely to the fact that the old speed cycles above 48 mph all started from idle (zero mph) and accelerated to a speed higher than the average speed of the cycle. This extra acceleration, which is not generally found on cruising vehicles on limited access freeways, adds to the power demand, therefore likely increasing emissions in the old high speed cycles relative to lower speed cycles. The acceleration to reach freeway speeds is now contained in the separate ramp cycle. This additional ramp cycle will allow this effect to be weighted appropriately with freeway driving. The effect from starting and ending at idle is less pronounced in the lower speed cycles since they inherently have a higher percentage of driving at idle.

In Figure 6a (THC), the MOBILE6 SCF for the lowest emission level (based Tier 1 vehicles) has a positive slope beyond about 30 mph, indicating increasing THC emissions with increasing average speed. However, as shown in Figure 4a, Tier 1 vehicles are much cleaner at all speeds than the normal emitting Tier 0 vehicles. The shape of the THC MOBILE6 SCFs for the higher emission levels (based on Tier 0 vehicles, Normal and High) is very close to the shape of MOBILE5 SCFs.

For higher average speeds (above 19.6 mph) the MOBILE6 SCFs for CO emissions (Figure 6b) have a strongly positive slope at lower emission levels (based on Tier 0 Normals and Tier 1 vehicles). This is very different from the SCFs used in MOBILE5. The MOBILE6 SCFs for THC/NMHC emissions for Tier 0 Normal vehicles have a negative slope. However CO emissions are more sensitive to aggressive driving than THC/NMHC emissions, which may explain the difference in the trends.

The MOBILE6 SCFs for NOx emissions (Figure 6c) for the higher emission levels (based on Tier 0 vehicles) have a slight upward trend at higher speeds, similar to the MOBILE5 trends. The lowest emission level SCFs (based on Tier 1 vehicles) has a steep slope, similar to the oldest MOBILE5 SCF. All of the MOBILE6 SCFs tend to rise as average speeds decrease, which is expected with more accelerations and decelerations (stop and go driving) present in the driving patterns. However, the MOBILE6 SCFs rise much more steeply and to higher levels than the MOBILE5 SCFs.

Similar graphs comparing MOBILE6 speed correction factors for arterial/collector roadways and freeways with MOBILE5 speed correction estimates are shown in Figures 7a through 7i. Speed correction factors for arterial/collector roadways and freeways are the same below 7.1 mph and above about 30 mph. In general, speed correction factors for arterial/collector roadways are higher between those speeds.

Since the Freeway Ramp and Local Roadway emissions are estimated directly from the basic exhaust emission rate (based on the hot running LA4 emissions), they cannot be compared to the speed correction factor used in MOBILE5.

References

[1] See the EPA web site http://www.epa.gov/otaq/sftp.htm for more information.

[2] Federal Test Procedure, or FTP means the test procedure as described in the Combined Federal Register § 86.130-00(a) through (d) and (f) which is designed to measure urban driving tail pipe exhaust emissions and evaporative emissions over the Urban Dynamometer Driving Schedule as described in Appendix I to this part. (See also http://www.epa.gov/otaq/labmthod.htm.)

[3] See the EPA web site http://www.epa.gov/otaq/sftp.htm for more information.

[4] Carlson, T.R., et al., "Development of Speed Correction Cycles," MOBILE6 Stakeholder Review Document (M6.SPD.001). Prepared for EPA by Sierra Research, Inc., 1997. (http://www.epa.gov/otaq/m6.htm)

[5] See the California Air Resources Board web site, http://www.arb.ca.gov/msei/msei.htm.

[6] Gammariello, R.T. and Long, J.R., "Development of Unified Correction Cycles," California Air Resources Board, Sixth CRC On-Road Vehicle Emissions Workshop, March 1996. This report is available at the CARB web site (http://www.arb.ca.gov/msei/pubs/ucc_crc5.pdf).

[7] *ibid*

[8] *ibid*

[9] *ibid*

[10] See the EPA web site, http://www.epa.gov/otaq/regs/ld-hwy/tier-1/ for more information.

[11] Brzezinski, D.J., et al., "Coefficients for the Determination of Engine Start and Running Emissions From FTP Bag Emissions," MOBILE6 Stakeholder Review Document (M6.STE.002), 1997. (http://www.epa.gov/otaq/m6.htm)

[12] "Federal Test Procedure Review Project: Preliminary Technical Report," EPA Office of Mobile Sources Certification Division, (EPA420-R-93-007), May 1993. This report is available at the EPA web site (http://www.epa.gov/otaq/sftp.htm).

[13] *ibid*

[14] "Final Regulations for Revisions to the Federal Test Procedure for Emissions From Motor Vehicles," Federal Register, 40 CFR Part 86 Volume 61, Number 205, Oct 22, 1996, Page 54869 (http://www.epa.gov/otaq/ld-hwy.htm).

[15] "Regulatory Impact Analysis (Final Rule) : Federal Test Procedure Revisions," EPA Office of Mobile Sources, August 15, 1996 (http://www.epa.gov/otaq/ld-hwy.htm).

[16] M6.SPD.003, *op cit*

[17] "Development of Methodology for Estimating VMT Weighting by Facility Type," MOBILE6 Stakeholder Review Document (M6.SPD.003) EPA420-P-99-006. Prepared for EPA by Systems Applications International, Inc., 1998. (http://www.epa.gov/otaq/m6.htm)

[18] "Guidance for the Development of Facility Type VMT and Speed Distributions," MOBILE6 Stakeholder Review Document (M6.SPD.004) EPA420-P-99-004. Prepared for EPA by Systems Applications International, Inc., 1998. (http://www.epa.gov/otaq/m6.htm)

[19] Glover, E.L., et al., "Soak Length Activity Factors for Start Emissions," MOBILE6 Stakeholder Review Document (M6.FLT.003). (http://www.epa.gov/otaq/m6.htm)

[20] See the EPA web site for MOBILE6 reports, http://www.epa.gov/otaq/m6.htm

[21] "AP-42 Volume II, Compilation of Air Pollution Emission Factors, Mobile Sources," Appendix H, June 30, 1995. (http://www.epa.gov/otaq/models.htm)

[22] *ibid*

[23] *ibid*

[24] Barth, M., et al., "Estimating Emissions and Fuel Consumption for Different Levels of Freeway Congestion," University of California, Riverside. 78th Annual Transportation Research Board Meeting, Washington, D.C., January 1999. This report is available from TRB (http://nationalacademies.org/trb/bookstore).

Tables

Table 1

New Facility-Specific/Area-Wide Speed Correction Cycle Statistics

Cycle*	Average Speed (mph)	Maximum Speed (mph)	Maximum Accel Rate (mph/s)	Length (seconds)	Length (miles)
Freeway, High Speed	63.2	74.7	2.7	610	10.72
Freeway, LOS A-C	59.7	73.1	3.4	516	8.55
Freeway, LOS D	52.9	70.6	2.3	406	5.96
Freeway, LOS E	30.5	63.0	5.3	456	3.86
Freeway, LOS F	18.6	49.9	6.9	442	2.29
Freeway, LOS “G”	13.1	35.7	3.8	390	1.42
Freeway Ramps	34.6	60.2	5.7	266	2.56
Arterial/Collectors LOS A-B	24.8	58.9	5.0	737	5.07
Arterial/Collectors LOS C-D	19.2	49.5	5.7	629	3.36
Arterial/Collectors LOS E-F	11.6	39.9	5.8	504	1.62
Local Roadways	12.9	38.3	3.7	525	1.87
Non-Freeway Area-Wide Urban Travel	19.4	52.3	6.4	1,348	7.25

* LOS (level of service) refers to roadway congestion categories. See Section 4.6.

Table 2 **Comparison of Key Statistics For Facility-Specific Cycle Schedules Versus Total Vehicle Observations**								
	Mean Speed (mph)		Maximum Speed (mph)		Maximum Accel Rate (mph/sec)		Total SAFD Difference * (%)	High-Power Difference** (%)
Driving Cycle	Cyc.	Obs.	Cyc.	Obs.	Cyc.	Obs.		
Freeway High-Speed	63.2	62.7	74.7	80.9	2.7	5.8	9.41	0.16
Freeway LOS A-C	59.7	59.2	73.1	83.2	3.4	6.8	12.12	0.39
Freeway LOS D	52.9	52.0	70.6	75.8	2.3	6.1	15.10	0.35
Freeway LOS E	30.5	32.1	63.0	71.3	5.3	8.5	25.17	0.18
Freeway LOS F	18.6	19.9	49.9	69.5	6.9	9.6	23.83	0.06
Freeway LOS G	13.1	14.4	35.7	49.1	3.8	5.7	18.80	0.10
Freeway Ramp	34.6	35.4	60.2	79.1	5.7	9.3	42.74	0.99
Arterial LOS A-B	24.8	25.2	58.9	74.9	5.0	14.9	17.04	0.40
Arterial LOS C-D	19.2	18.9	49.5	71.3	5.7	10.4	16.86	0.21
Arterial LOS E-F	11.6	12.0	39.9	56.8	5.8	10.2	17.86	0.24
Local Roadways	12.8	14.6	38.3	62.7	3.7	12.5	21.80	0.11
Unified Cycle	24.6	26.3	67.2	80.3	6.9	10.4	30.27	0.19

* The SAFD is the speed/acceleration frequency distribution based on time at each speed. Total SAFD Difference is the sum of the differences between the final cycle distribution and the target population distribution from which the cycle micro trips are chosen. (See M6.SPD.001)

** Specific power was calculated from the following equation:

$$P_t = \begin{cases} S_t^2 - S_{t-1}^2 & \text{, if } S_t > S_{t-1} \\ 0 & \text{, if } S_t \leq S_{t-1} \end{cases}$$

where S_t and S_{t-1} are the vehicle speeds at times *t* and *t-1*, respectively. High power is the seconds in which the specific power is greater than or equal to 200 mph^2/sec. The High-Power Difference is the difference between the fraction of high power in the final cycle and the target population from which the cycle micro trips are chosen.

Table 3

Statistics for Additional Tested Cycles

Cycle	Average Speed (mph)	Maximum Speed (mph)	Maximum Accel Rate (mph/s)	Length (seconds)	Length (miles)
LA4 (Urban Dynamometer Driving Cycle)	19.6	56.7	3.3	1368	7.45
Running 505 (First 505 seconds of the Urban Dynamometer Driving Cycle)	25.6	56.7	3.3	505	3.59
Unified Cycle (LA92)	24.6	67.2	6.9	1435	9.81
ST01 (Engine Start Cycle)	20.2	41.0	5.1	248	1.39
New York City Cycle (NYCC)	7.1	27.7	6.0	600	1.18

Table 4

Distribution of the Vehicle Sample
By Emission Standard and Technology

Fuel Delivery	TIER 0 Emission Standard	TIER 1 Emission Standard	Total Sample
Carburetor	7	--	7
Throttle Body FI	27	1	28
Multi-Port FI	39	11	50
Total Sample	73	12	85

Table 5

Vehicle Sample Description

Site	Veh. No.	Veh. Class	VIN	Mod. Yr.	Make	Mod.	Std.	Miles	Eng. Size	Fuel Inj.	IM240
E.LIB	5001	LDV	1G4AH51R7J6401871	88	BUICK	CENT	Tier 0	129,698	2.5	TBI	PASS
E.LIB	5002	LDV	1G3NL54UXKM283722	89	OLDSMOBILE	CUTL	Tier 0	61,956	2.5	TBI	FAIL
E.LIB	5003	LDV	2FACP74F3MX162914	91	FORD	CROW	Tier 0	53,003	5.0	PFI	PASS
E.LIB	5005	LDV	1G1JC14GOM7126454	91	CHEVROLET	CAVA	Tier 0	54,658	2.2	TBI	PASS
E.LIB	5006	LDV	1G1JC111XK7150483	89	CHEVROLET	CAVA	Tier 0	107,611	2.0	TBI	PASS
E.LIB	5007	LDV	1G3HY54C9JW312653	88	OLDSMOBILE	DELT	Tier 0	101,534	3.8	PFI	PASS
E.LIB	5008	LDV	1FACP57U5NG145893	92	FORD	TAUR	Tier 0	74,078	3.0	PFI	PASS
E.LIB	5009	LDV	1G2WP14T6KF307905	89	PONTIAC	GRAN	Tier 0	155,181	3.1	PFI	FAIL
E.LIB	5010	LDV	4T1SK12E9PU184046	93	TOYOTA	CAMR	Tier 0	29,392	2.2	TBI	PASS
E.LIB	5011	LDV	2C1MS2468P6704533	93	GEO	METR	Tier 0	105,445	1.0	TBI	PASS
E.LIB	5012	LDV	1G2NV54D9JC821314	88	PONTIAC	GRAN	Tier 0	89,764	2.3	TBI	PASS
E.LIB	5013	LDV	1G2NE5434PC795009	93	PONTIAC	GRAN	Tier 0	72,348	2.3	PFI	PASS
E.LIB	5014	LDV	1G6CD53B7M4272204	91	CADILLAC	SEDA	Tier 0	51,707	4.9	TBI	FAIL
E.LIB	5015	LDV	1G2NE5438PC758996	93	PONTIAC	GRAN	Tier 0	58,538	2.3	PFI	PASS
E.LIB	5016	LDV	1G4HR54C5KH488839	89	BUICK	LESA	Tier 0	65,212	3.8	TBI	FAIL
E.LIB	5017	LDV	WVWEB5159MK012875	91	VW	CABR	Tier 0	67,496	1.8	TBI	PASS
E.LIB	5018	LDV	1B3ES27C9SD221573	95	DODGE	NEON	Tier 1	20,855	2.0	TBI	PASS
E.LIB	5019	LDV	1G1FP23TXLL111092	90	CHEVROLET	CAMA	Tier 0	71,258	3.1	PFI	FAIL
E.LIB	5020	LDV	1FACP5245NG196687	92	FORD	TAUR	Tier 0	84,148	3.8	TBI	PASS
E.LIB	5021	LDV	1B3ES67C2SD188892	95	DODGE	NEON	Tier 1	28,525	2.0	PFI	PASS
E.LIB	5022	LDV	1G1JC1112KJ207455	89	CHEVROLET	CAVA	Tier 0	110,929	2.0	TBI	PASS
E.LIB	5023	LDV	1FAPP36X6JK249611	88	FORD	TEMP	Tier 0	107,979	2.3	PFI	PASS
E.LIB	5024	LDV	2FAPP36X8MB116542	91	FORD	TEMP	Tier 0	97,522	2.3	PFI	FAIL
E.LIB	5025	LDT1	1N6SD16S6MC351945	91	NISSAN	HARD	Tier 0	103,346	2.4	PFI	PASS
E.LIB	5026	LDV	1MEBM50U3KG663746	89	MERCURY	SABL	Tier 0	107,075	3.0	PFI	FAIL
E.LIB	5027	LDV	JE3CU14A1NU003588	92	EAGLE	SUMM	Tier 0	129,457	1.5	PFI	FAIL
E.LIB	5028	LDV	1YVGE22A8P5138202	93	MAZDA	626	Tier 0	103,171	12	PFI	FAIL
E.LIB	5029	LDT1	1P4FH4430KX568849	89	PLYMOUTH	VOYA	Tier 0	118,586	3.0	PFI	PASS
E.LIB	5030	LDV	1FABP29D9GA165884	86	FORD	TAUR	Tier 0	50,755	2.5	TBI	FAIL
E.LIB	5031	LDV	JT2SV24E8J3189405	88	TOYOTA	CAMR	Tier 0	197,090	2.0	PFI	FAIL
E.LIB	5032	LDV	1MEBP923XFA603099	85	MERCURY	COUG	Tier 0	113,584	14	TBI	FAIL
E.LIB	5033	LDT1	1GCBS14E3H2170996	87	CHEVROLET	S10	Tier 0	128,681	2.5	TBI	PASS
E.LIB	5034	LDT1	1GCBS14A3F2156946	85	CHEVROLET	S10	Tier 0	89,435	1.9	NO	PASS
E.LIB	5035	LDV	1FABP37X6HK239681	87	FORD	TEMP	Tier 0	118,148	2.5	TBI	FAIL
E.LIB	5036	LDV	JN1HM05S8HX081093	87	NISSAN	STAN	Tier 0	58,173	2.0	PFI	PASS
E.LIB	5037	LDV	1P3BP49CXDF305484	83	PLYMOUTH	RELI	Tier 0	94,399	2.2	NO	FAIL
E.LIB	5038	LDV	2G1WL52M2T9212643	96	CHEVROLET	LUMI	Tier 1	16,557	3.1	PFI	PASS
E.LIB	5039	LDV	1HGED3554JA017137	88	HONDA	CIVI	Tier 0	184,457	1.5	TBI	FAIL
E.LIB	5040	LDV	2HGED6359KH534893	89	HONDA	CIVI	Tier 0	161,598	12	TBI	PASS
E.LIB	5041	LDV	JT2EL32G3H0076681	87	TOYOTA	TERC	Tier 0	136,654	1.5	NO	PASS
E.LIB	5042	LDT1	1GCDM15NXFB180388	85	CHEVROLET	ASTR	Tier 0	179,855	4.3	NO	FAIL
E.LIB	5043	LDV	2HGED6349KH537915	89	HONDA	CIVI	Tier 0	122,821	1.5	TBI	PASS
E.LIB	5044	LDT1	1GTBS14E5J2520442	88	CHEVROLET	S15	Tier 0	115,693	2.5	TBI	FAIL

Table 5

Vehicle Sample Description

E.LIB	5045	LDV	1G2WH54T6PF250844	93	PONTIAC	GRAN	Tier 0	85,789	3.4	PFI	FAIL
E.LIB	5046	LDT1	1FTCR1056FUD20466	85	FORD	RANG	Tier 0	56,488	2.8	NO	FAIL
E.LIB	5047	LDT1	1FTDE14N8MHB05052	91	FORD	ECON	Tier 0	79,573	5.8	PFI	FAIL
E.LIB	5048	LDT1	1FTCR10A2KUB93426	89	FORD	RANG	Tier 0	123,419	2.3	TBI	PASS
E.LIB	5049	LDV	2G1AW19X5G1258479	86	CHEVROLET	CELE	Tier 0	131,601	2.8	NO	PASS
E.LIB	5050	LDT1	1FDDE14F9FHA59240	85	FORD	ECON	Tier 0	86,203	5.8	NO	PASS
E.LIB	5051	LDV	1G1JF11W1K7156403	89	CHEVROLET	CAVA	Tier 0	123,581	3.1	PFI	PASS
E.LIB	5052	LDV	1G1JC14GXM7146551	91	CHEVROLET	CAVA	Tier 0	90,945	2.2	TBI	PASS
E.LIB	5053	LDT2	1FDEE14N0MHB15171	91	FORD	E150	Tier 0	97,531	5.8	PFI	FAIL
E.LIB	5054	LDV	1FAPP1282MW314230	91	FORD	ESCO	Tier 0	105,861	1.8	PFI	FAIL
E.LIB	5055	LDT1	2P4GH25K6MR240965	91	PLYMOUTH	VOYA	Tier 0	72,032	2.5	TBI	PASS
E.LIB	5056	LDT1	1GNDM15Z4MB190115	91	CHEVROLET	ASTR	Tier 0	90,880	4.3	TBI	PASS
E.LIB	5057	LDV	1G1LT53T9PY237873	93	CHEVROLET	CORS	Tier 0	41,766	3.4	PFI	PASS
E.LIB	5058	LDT1	1GCCS19Z5P0178401	93	CHEVROLET	S10	Tier 0	48,578	4.3	TBI	PASS
E.LIB	5059	LDV	4T1SK11E4PU252562	93	TOYOTA	CAMR	Tier 0	67,344	2.2	PFI	PASS
E.LIB	5060	LDV	1HGCB7658PA075439	93	HONDA	ACCO	Tier 0	61,163	2.2	PFI	PASS
E.LIB	5061	LDV	JN1HJ01P0LT397615	90	NISSAN	MAXI	Tier 0	120,786	3.0	PFI	PASS
E.LIB	5062	LDV	JE3CA11A7PU098450	93	EAGLE	SUMM	Tier 0	52,447	1.5	PFI	PASS
E.LIB	5063	LDV	1G2WJ52M7TF204255	96	PONTIAC	GRAN	Tier 1	20,451	3.1	PFI	PASS
AA	5213	LDV	JT2AE94A5N0273089	92	TOYOTA	CORO	Tier 0	77,310	1.6	PFI	NULL
AA	5217	LDV	1HGCD5632TA260884	96	HONDA	ACCO	Tier 1	7,573	2.2	PFI	NULL
AA	5218	LDV	1G8ZF5498NZ175489	92	SATURN	SL	Tier 0	89,995	1.9	TBI	NULL
AA	5219	LDV	1G1LW13T4NY109988	92	CHEVROLET	BERR	Tier 0	94,316	3.1	PFI	NULL
AA	5220	LDT2	1FTEF14N3RLB27661	94	FORD	F150	Tier 0	97,629	5.8	PFI	NULL
AA	5221	LDT2	1FTEF1549TLB25543	96	FORD	F150	Tier 1	12,877	4.9	PFI	NULL
AA	5222	LDV	JM1BG2263N0464490	92	MAZDA	PROT	Tier 0	10,727	1.8	PFI	NULL
AA	5223	LDV	2G1WL52M2T9212643	96	CHEVROLET	LUMI	Tier 1	17,233	3.1	PFI	NULL
AA	5224	LDV	1G1JC5447N7116728	92	CHEVROLET	CAVA	Tier 0	90,196	2.2	PFI	NULL
AA	5225	LDT1	1FTCR10A9TPB08548	96	FORD	RANG	Tier 1	10,064	2.3	PFI	NULL
AA	5227	LDT2	1GNEV16K9LF116974	90	CHEVROLET	SURB	Tier 0	97,658	5.7	TBI	NULL
AA	5228	LDV	2C3ED56F7RH211101	94	CHRYSLER	LHS	Tier 0	59,937	3.5	PFI	NULL
AA	5229	LDV	1HGEJ8142TL073569	96	HONDA	CIVI	Tier 1	9,433	1.6	PFI	NULL
AA	5230	LDT1	1GNDM19WXRB229457	94	CHEVROLET	ASTR	Tier 0	77,178	4.3	PFI	NULL
AA	5231	LDV	1G8ZK5570RZ145840	94	SATURN	SL	Tier 0	25,930	1.9	PFI	NULL
AA	5232	LDV	KMHJF22M5RU669848	94	HYUNDAI	ELAN	Tier 0	57,960	1.8	PFI	NULL
AA	5233	LDT1	1GNDU06D3NT126706	92	CHEVROLET	LUMI	Tier 0	33,872	3.1	PFI	NULL
AA	5234	LDV	1FARP15J9RW262996	94	FORD	ESCO	Tier 1	51,168	1.9	PFI	NULL
AA	5235	LDT1	2P4FH5532LR534285	90	PLYMOUTH	VOYA	Tier 0	98,530	3.0	PFI	NULL
AA	5237	LDV	2G1WN54X7N9117726	92	CHEVROLET	LUMI	Tier 0	16,133	3.4	PFI	NULL
AA	5239	LDT1	1GMDU06LXRT234029	94	PONTIAC	TRAN	Tier 1	68,305	3.8	PFI	NULL
AA	5240	LDV	4T1BF12K3TU871236	96	TOYOTA	CAMR	Tier 1	18,992	3.0	PFI	NULL
AA	5241	LDV	1B3XC56R3LD749334	90	DODGE	DYNA	Tier 0	6,813	3.3	PFI	NULL

Table 6

Distribution of Vehicle Sample By Vehicle Class and Model Year

Model Year	Passenger Car	Light-Duty Truck (0-6000 GVW)	Light-Duty Truck (6000-8500 GVW)	Total
1983	1	--	--	1
1985	1	4	--	5
1986	2	--	--	2
1987	3	1	--	4
1988	6	1	--	7
1989	9	2	--	11
1990	3	1	1	5
1991	7	4	1	12
1992	9	1	--	10
1993	10	1	--	11
1994	4	2	1	7
1995	2	--	--	2
1996	6	1	1	8
TOTAL	63	18	4	85

Table 7a
Facility-Specific/Area-Wide Speed Correction Cycles Test Results
Total Hydrocarbons (THC)

Cycle	Normal Emitters			High Emitters		
	# of veh.	Mean (g/mile)	Std. Dev.	# of veh.	Mean (g/mile)	Std. Dev.
Freeway at 63.2 mph	61	0.15	0.19	24	1.80	1.66
Freeway at 59.7 mph	61	0.16	0.17	24	1.77	1.69
Freeway at 52.9 mph	61	0.14	0.17	24	1.70	1.38
Freeway at 30.5 mph	61	0.21	0.26	24	2.52	2.12
Freeway at 18.6 mph	61	0.25	0.30	24	3.67	3.75
Freeway at 13.1 mph	61	0.27	0.33	24	4.13	4.06
Freeway Ramps (34.6 mph)	61	0.34	0.46	24	3.04	2.21
Arterial/Collectors at 24.8 mph	61	0.22	0.26	24	3.03	3.07
Arterial/Collectors at 19.2 mph	61	0.26	0.32	24	3.97	4.79
Arterial/Collectors at 11.6 mph	61	0.45	0.84	24	5.15	5.63
Local Roadways (12.9 mph)	61	0.28	0.34	24	4.48	5.07
Non-Freeway Area-Wide Urban Travel (19.4 mph)	60*	0.26	0.31	24	3.57	3.06
FTP (19.6 mph)	61	0.38	0.27	24	3.49	2.77
Running 505 (25.6 mph)	61	0.17	0.23	24	2.57	2.51
Unified Cycle (24.6 mph)	60*	0.24	0.27	24	3.16	3.33
ST01(20.2 mph)	61	2.32	2.29	23*	6.88	5.36
NYCC (7.1 mph)	61	0.62	1.09	24	7.31	7.82

* Test not done

Table 7b
Facility-Specific/Area-Wide Speed Correction Cycles Test Results
Carbon Monoxide (CO)

Cycle	Normal Emitters			High Emitters		
	# of veh.	Mean (g/mile)	Std. Dev.	# of veh.	Mean (g/mile)	Std. Dev.
Freeway at 63.2 mph	70	6.96	7.71	15	66.76	52.09
Freeway at 59.7 mph	70	6.96	6.12	15	65.63	54.63
Freeway at 52.9 mph	70	5.53	5.33	15	54.45	41.82
Freeway at 30.5 mph	70	4.48	4.01	15	66.38	43.18
Freeway at 18.6 mph	70	5.19	4.90	15	74.39	63.48
Freeway at 13.1 mph	70	4.79	4.45	15	82.09	77.01
Freeway Ramps (34.6 mph)	70	10.06	10.79	15	84.02	57.32
Arterial/Collectors at 24.8 mph	70	4.28	3.87	15	75.24	59.12
Arterial/Collectors at 19.2 mph	70	5.22	5.01	15	80.79	62.65
Arterial/Collectors at 11.6 mph	70	5.94	5.65	15	116.57	94.9
Local Roadways (12.9 mph)	70	4.23	4.14	15	92.41	87.81
Non-Freeway Area-Wide Urban Travel (19.4 mph)	69*	4.80	4.62	15	86.63	62.32
FTP (19.6 mph)	70	5.05	3.70	15	79.92	56.89
Running 505 (25.6 mph)	70	3.04	2.75	15	74.04	57.5
Unified Cycle (24.6 mph)	69*	5.93	5.34	15	77.94	58.19
ST01 (20.2 mph)	70	24.55	16.54	14*	111.2	70.30
NYCC (7.1 mph)	70	7.88	8.12	15	158.04	136.34

* Test not done

Table 7c
Facility-Specific/Area-Wide Speed Correction Cycles Test Results
Nitrogen Oxides (NOx)

Cycle	Normal Emitters			High Emitters		
	# of veh.	Mean (g/mile)	Std. Dev.	# of veh.	Mean (g/mile)	Std. Dev.
Freeway at 63.2 mph	72	0.77	0.71	13	3.35	1.07
Freeway at 59.7 mph	72	0.74	0.65	13	3.27	1.02
Freeway at 52.9 mph	72	0.70	0.60	13	3.20	0.97
Freeway at 30.5 mph	72	0.63	0.54	13	3.15	1.00
Freeway at 18.6 mph	72	0.72	0.59	13	3.73	1.34
Freeway at 13.1 mph	72	0.51	0.39	13	2.81	0.99
Freeway Ramps (34.6 mph)	72	0.98	0.81	13	4.00	1.43
Arterial/Collectors at 24.8 mph	72	0.68	0.55	13	3.47	1.07
Arterial/Collectors at 19.2 mph	72	0.79	0.66	13	3.77	1.46
Arterial/Collectors at 11.6 mph	72	0.96	0.78	13	4.44	1.84
Local Roadways (12.9 mph)	72	0.73	0.63	13	3.74	1.46
Non-Freeway Area-Wide Urban Travel (19.4 mph)	71*	0.71	0.57	13	3.56	1.18
FTP (19.6 mph)	72	0.70	0.53	13	3.25	1.04
Running 505 (25.6 mph)	72	0.59	0.50	13	3.67	1.13
Unified Cycle (24.6 mph)	71*	0.84	0.66	13	3.83	1.23
ST01 (20.2 mph)	72	1.85	1.11	12*	3.78	1.34
NYCC (7.1 mph)	72	0.95	0.69	13	4.07	1.45

* Test not done

Table 8
Analysis of Variance Results (ANOVA P-Values)

	Factor*	THC	CO	NOx	NMHC
All Roadways	Speed	0.0000	0.0000	0.0000	0.0001
	Emitter Class	0.0000	0.0000	0.0000	0.0000
	Speed*Emitter Class	0.1411	0.0152	0.9894	0.1271
======================== Normal Emitters ========================					
	Factor*	THC	CO	NOx	NMHC
Arterial/Collector and Freeway	Roadway Type**	0.0046	0.0006	0.0000	0.0050
	Speed*Roadway Type**	0.0354	0.0020	0.0000	0.0440
	Vehicle Class	0.0016	0.0031	0.0012	0.0404
	Speed*Vehicle Class	0.1754	0.8680	0.5723	0.1802
	Standard***	0.0000	0.0000	0.0000	0.0000
	Speed*Standard***	0.0002	0.0576	0.6491	0.0001
Local Roadway	Vehicle Class	0.0830	0.4038	0.0124	0.5008
	Standard***	0.0000	0.0000	0.0028	0.0000
Freeway Ramp	Vehicle Class	0.2922	0.0443	0.0018	0.7707
	Standard***	0.0003	0.0002	0.0000	0.0007
======================== High Emitters ========================					
	Factor*	THC	CO	NOx	NMHC
Arterial/Collector and Freeway	Roadway Type**	0.1236	0.3307	0.0000	0.1307
	Speed*Roadway Type**	0.1176	0.6233	0.0000	0.1203
	Vehicle Class	0.5942	0.8984	0.3961	0.5693
	Speed*Vehicle Class	0.0641	0.0241	0.9560	0.0699
Local Roadway	Vehicle Class	0.8787	0.5511	0.6093	0.8821
Freeway Ramp	Vehicle Class	0.3701	0.1471	0.6942	0.4075

* All emissions in Log (gram/hour) scale.

** Freeways versus Arterial/Collectors limited to speeds < 30 mph, including a vehicle term.

*** There are no Tier 1 High emitters in sample. Some low emitting Tier 0 vehicles are considered both as Tier 0 and as Tier 1 vehicles (see text).

Table 8
Analyses of Variance Results (ANOVA p values)

Factor*	THC	NMHC	CO	NOx
Emitter Level	.0000	.0000	.0000	.0000
	Normal Emitters Only			
Roadway type**	.0006	.0003	.0206	.0000
Vehicle Class	.0001	.0004	.0001	.0001
Standard***	.0001	.0001	.0001	.0001
Local/Vehicle Class	.0476	.1490	.0325	.2753
Local/Standard	.0001	.0001	.0001	.0001
Ramp/Vehicle Class	.0396	.0983	.0107	.0871
Ramp/Standard	.0001	.0001	.0001	.0001
	High Emitters Only			
Roadway type**	.3094	.3281	.0318	.0000
Vehicle Class	.067	.067	.0004	.144
Standard***	NA	NA	NA	NA

* All emissions in Log (gram/hour) scale.

** Freeways versus Arterial/Collectors limited to speeds < 30 mph, including a vehicle term.

*** There were no Tier 1 High emitters in sample. Some low emitting Tier 0 vehicles were considered both as Tier 0 and as Tier 1 vehicles (see text).

Table 9
Description of Sample Vehicles Used for Tier 1 Analysis

Veh No.	Test Site	Tier Std.	Mileage	FTP NMHC	FTP NOx	Veh Class	Model Yr.	Eng. Size	Fuel Inj.	IM240 Status	VIN
5007	E.LIB	0	101536	0.13	0.23	LDV	88	3.80	PFI	PASS	1G3HY5C9JW312653
5010	E.LIB	0	29392	0.12	0.21	LDV	93	2.20	TBI	PASS	4T1SK12E9PU18406
5013	E.LIB	0	72348	0.08	0.18	LDV	93	2.30	PFI	PASS	1G2NE5438PC758996
5015	E.LIB	0	58538	0.07	0.41	LDV	93	2.30	PFI	PASS	1G2NE5438PC758996
5017	E.LIB	0	67496	0.15	0.13	LDV	91	1.80	TBI	PASS	WVWEB5159MK012875
5018	E.LIB	1	20855	0.12	0.10	LDV	95	2.00	TBI	PASS	1B3ES27C9SD221573
5021	E.LIB	1	28525	0.12	0.10	LDV	95	2.00	PFI	PASS	1B3ES67C2SD188892
5038	E.LIB	1	16557	0.12	0.34	LDV	96	3.10	PFI	PASS	2GIWL52M2T9212643
5059	E.LIB	0	6734	0.13	0.28	LDV	93	2.20	PFI	PASS	4T1SK11E4PU252562
5060	E.LIB	0	61163	0.11	0.27	LDV	93	2.20	PFI	PASS	1HGCB7658PA075439
5063	E.LIB	1	20451	0.16	0.26	LDV	96	3.10	PFI	PASS	1G2WJ52M7TF204255
5217	AA	1	7573	0.09	0.20	LDV	96	2.20	PFI	NULL	1HGCD5632TA260884
5218	AA	0	89995	0.19	0.39	LDV	92	1.90	PFI	NULL	1G8ZF5498NZI75489
5221	AA	1	12877	0.10	0.53	LDT2	96	4.90	PFI	NULL	1TEF1549TLB25543
5223	AA	1	17233	0.21	0.49	LDV	96	3.10	PFI	NULL	2G1WL52M2T9212643
5225	AA	1	10064	0.12	0.40	LDT1	96	2.20	PFI	NULL	1FTCR10A9TPB08548
5229	AA	1	9433	0.17	0.10	LDV	96	1.60	PFI	NULL	1HGEJ8142TL073569
5234	AA	1	51168	0.15	0.26	LDV	94	1.90	PFI	NULL	1FARP15J9RW262996
5239	AA	1	68305	0.19	0.71	LDT1	94	3.80	PFI	NULL	1GMDU06LXRT234029
5240	AA	1	18992	0.21	0.31	LDV	96	3.00	PFI	NULL	4T1BF12K3TU871236

Table 10
Tests of Convergence in Arterial and Freeway Estimates at 30 mph

Tier 0 Normal Emitter Sample

Parameter	Estimate	T for H0: Parameter = 0	p value Pr > | T |	Standard Error of the Estimate
THC	0.18089092	1.84	0.0670	0.09840365
NMHC	0.15532642	1.83	0.0688	0.08503405
CO	1.63652794	2.96	0.0033	0.55229111
NOx	0.05946957	1.24	0.2160	0.04797825

Tier 0 High Emitter Sample

Parameter	Estimate	T for H0: Parameter = 0	p value Pr > | T |	Standard Error of the Estimate
THC	0.95357931	1.52	0.1304	0.62676490
NMHC	0.84766279	1.58	0.1161	0.53612496
CO	24.7784634	1.48	0.1430	16.7645083
NOx	-0.00945343	-0.04	0.9705	0.25464544

Tier 1 Normal Emitter Sample

Parameter	Estimate	T for H0: Parameter = 0	p value Pr > | T |	Standard Error of the Estimate
THC	0.01509669	1.15	0.2534	0.01310665
NMHC	0.00615421	0.71	0.4813	0.00869272
CO	0.25453921	0.83	0.4114	0.30796933
NOx	0.04101364	1.20	0.2350	0.03423678

Table 11a
Average Emissions by Emission Standard and Emission Level
Total Hydrocarbons (THC)

Cycle	Tier 1*			Tier 0 Normal			Tier 0 High		
	# of veh.	Mean (g/mi)	Std. Dev.	# of veh.	Mean (g/mi)	Std. Dev.	# of veh.	Mean (g/mi)	Std. Dev.
Freeway at 63.2 mph	20	0.050	0.032	49	0.183	0.200	24	1.798	1.656
Freeway at 59.7 mph	20	0.066	0.038	49	0.187	0.180	24	1.771	1.688
Freeway at 52.9 mph	20	0.035	0.019	49	0.171	0.178	24	1.702	1.384
Freeway at 30.5 mph	20	0.038	0.031	49	0.253	0.272	24	2.523	2.124
Freeway at 18.6 mph	20	0.044	0.036	49	0.305	0.318	24	3.672	3.745
Freeway at 13.1 mph	20	0.046	0.040	49	0.330	0.341	24	4.127	4.063
Freeway Ramps (34.6 mph)	20	0.083	0.080	49	0.408	0.488	24	3.036	2.205
Arterial/Collectors at 24.8 mph	20	0.044	0.035	49	0.262	0.278	24	3.028	3.072
Arterial/Collectors at 19.2 mph	20	0.060	0.054	49	0.318	0.341	24	3.970	4.794
Arterial/Collectors at 11.6 mph	20	0.063	0.045	49	0.551	0.917	24	5.155	5.630
NYCC (7.1 mph)	20	0.122	0.111	49	0.744	1.183	24	7.306	7.824
Local Roadways (12.9 mph)	20	0.053	0.056	49	0.336	0.360	24	4.478	5.075
Non-Freeway Area-wide Urban Travel (19.4 mph)	19	0.057	0.047	49	0.311	0.325	24	3.571	3.060
Hot Running LA4 (19.6 mph)	20	0.036	0.019	49	0.199	0.201	24	3.175	2.945
Unified Cycle (24.6 mph)	19	0.060	0.049	48	0.282	0.287	24	3.158	3.328

Table 11b Average Emissions by Emission Standard and Emission Level Carbon Monoxide (CO)									
Cycle	Tier 1			Tier 0 Normal			Tier 0 High		
	# of veh.	Mean (g/mi)	Std. Dev.	# of veh.	Mean (g/mi)	Std. Dev.	# of veh.	Mean (g/mi)	Std. Dev.
Freeway at 63.2 mph	20	1.862	1.765	58	8.157	7.945	15	66.763	52.094
Freeway at 59.7 mph	20	3.045	1.446	58	7.755	6.410	15	65.632	54.628
Freeway at 52.9 mph	20	1.381	1.179	58	6.449	5.403	15	54.448	41.822
Freeway at 30.5 mph	20	1.305	1.636	58	5.218	3.998	15	66.377	43.185
Freeway at 18.6 mph	20	1.513	1.570	58	5.978	4.997	15	74.390	63.484
Freeway at 13.1 mph	20	1.264	1.564	58	5.596	4.464	15	82.087	77.005
Freeway Ramps (34.6 mph)	20	2.803	2.651	58	11.665	11.170	15	84.016	57.322
Arterial/Collectors at 24.8 mph	20	1.271	1.215	58	4.934	3.921	15	75.235	59.118
Arterial/Collectors at 19.2 mph	20	1.562	1.638	58	6.052	5.103	15	80.793	62.646
Arterial/Collectors at 11.6 mph	20	1.538	1.699	58	6.902	5.727	15	116.56 9	94.897
NYCC (7.1 mph)	20	2.652	3.068	58	9.061	8.384	15	158.04 1	136.341
Local Roadways (12.9 mph)	20	1.249	1.727	58	4.924	4.212	15	92.412	87.806
Non-Freeway Area-wide Urban Travel (19.4 mph)	19	1.357	1.580	58	5.497	4.696	15	86.628	62.322
Hot Running LA4 (19.6 mph)	20	0.892	0.846	58	3.569	2.997	15	82.194	64.114
Unified Cycle (24.6 mph)	19	1.892	2.104	57	6.855	5.394	15	77.941	58.194

Table 11c
Average Emissions by Emission Standard and Emission Level
Oxides of Nitrogen (NOx)

Cycle	Tier 1			Tier 0 Normal			Tier 0 High		
	# of veh.	Mean (g/mi)	Std. Dev.	# of veh.	Mean (g/mi)	Std. Dev.	# of veh.	Mean (g/mi)	Std. Dev.
Freeway at 63.2 mph	20	0.331	0.353	60	0.840	0.736	13	3.354	1.069
Freeway at 59.7 mph	20	0.340	0.287	60	0.806	0.674	13	3.270	1.021
Freeway at 52.9 mph	20	0.241	0.164	60	0.789	0.619	13	3.200	0.970
Freeway at 30.5 mph	20	0.234	0.158	60	0.709	0.558	13	3.155	0.996
Freeway at 18.6 mph	20	0.231	0.168	60	0.817	0.591	13	3.727	1.339
Freeway at 13.1 mph	20	0.187	0.143	60	0.585	0.386	13	2.805	0.995
Freeway Ramps (34.6 mph)	20	0.324	0.222	60	1.106	0.823	13	3.998	1.435
Arterial/Collectors at 24.8 mph	20	0.233	0.163	60	0.769	0.559	13	3.473	1.068
Arterial/Collectors at 19.2 mph	20	0.376	0.476	60	0.905	0.660	13	3.774	1.461
Arterial/Collectors at 11.6 mph	20	0.416	0.605	60	1.093	0.777	13	4.435	1.841
NYCC (7.1 mph)	20	0.353	0.292	60	1.093	0.672	13	4.072	1.455
Local Roadways (12.9 mph)	20	0.311	0.426	60	0.830	0.637	13	3.735	1.463
Non-Freeway Area-wide Urban Travel (19.4 mph)	19	0.253	0.159	60	0.796	0.583	13	3.561	1.179
Hot Running LA4 (19.6 mph)	20	0.191	0.123	60	0.591	0.457	13	3.245	1.045
Unified Cycle (24.6 mph)	19	0.357	0.255	59	0.943	0.678	13	3.830	1.230

Table 11d
Average Emissions by Emission Standard and Emission Level
Non-Methane Hydrocarbons (NMHC)

Cycle	Tier 1			Tier 0 Normal			Tier 0 High		
	# of veh.	Mean (g/mi)	Std. Dev.	# of veh.	Mean (g/mi)	Std. Dev.	# of veh.	Mean (g/mi)	Std. Dev.
Freeway at 63.2 mph	19	0.038	0.023	49	0.148	0.177	24	1.633	1.524
Freeway at 59.7 mph	20	0.052	0.035	49	0.154	0.162	24	1.601	1.518
Freeway at 52.9 mph	19	0.026	0.015	48	0.140	0.159	24	1.537	1.231
Freeway at 30.5 mph	19	0.025	0.020	49	0.207	0.246	24	2.290	1.847
Freeway at 18.6 mph	16	0.031	0.031	48	0.250	0.288	24	3.347	3.295
Freeway at 13.1 mph	17	0.027	0.022	49	0.259	0.310	24	3.740	3.463
Freeway Ramps (34.6 mph)	18	0.068	0.069	47	0.357	0.444	24	2.767	1.957
Arterial/Collectors at 24.8 mph	20	0.029	0.028	49	0.214	0.252	24	2.737	2.672
Arterial/Collectors at 19.2 mph	18	0.042	0.041	48	0.264	0.304	24	3.616	4.291
Arterial/Collectors at 11.6 mph	20	0.034	0.022	49	0.458	0.805	24	4.665	4.888
NYCC (7.1 mph)	19	0.082	0.089	49	0.622	1.024	24	6.571	6.609
Local Roadways (12.9 mph)	17	0.038	0.045	48	0.280	0.334	24	4.059	4.426
Non-Freeway Area-wide Urban Travel (19.4 mph)	18	0.038	0.033	49	0.257	0.301	24	3.245	2.635
Hot Running LA4 (19.6 mph)	20	0.020	0.009	49	0.157	0.176	24	2.945	2.770
Unified Cycle (24.6 mph)	19	0.041	0.039	48	0.232	0.265	24	2.860	2.930

Table 12a
Regressions of Emissions Versus Average Speed
Total Hydrocarbons (THC)

Emissions = Constant + a*(Average Speed)

Roadway Type	Emission Level	Speed Data Range (mph)	Constant (p value)	a (p value)	Emission Units
Freeway	1 (Tier 1)	7.1 - 13.1	1.034*	-0.032*	grams per hour
Freeway	1 (Tier 1)	13.1 - 30.5	0.202 (.4780)	0.032 (.0175)	grams per hour
Freeway	1 (Tier 1)	30.5 - 63.2	0.019 (.2157)	0.001 (.0533)	grams per mile
Freeway	2 (Tier 0 Normal)	7.1 - 13.1	6.672*	-0.170*	grams per hour
Freeway	2 (Tier 0 Normal)	13.1 - 30.5	1.933 (.2284)	0.192 (.0094)	grams per hour
Freeway	2 (Tier 0 Normal)	30.5 - 63.2	0.315 (.0000)	-0.00226 (.0570)	grams per mile
Freeway	3 (Tier 0 High)	7.1 - 13.1	44.558** (.0013)	1.202** (.0908)	grams per hour
Freeway	3 (Tier 0 High)	13.1 - 30.5	44.558** (.0013)	1.202** (.0908)	grams per hour
Freeway	3 (Tier 0 High)	30.5 - 63.2	3.193 (.0000)	-0.024 (.0836)	grams per mile
Arterial/ Collector	1 (Tier 1)	7.1 - 24.8	0.690 (.0009)	0.017 (.0958)	grams per hour
Arterial/ Collector	2 (Tier 0 Normal)	7.1 - 24.8	4.891 (.0001)	0.081 (.1930)	grams per hour
Arterial/ Collector	3 (Tier 0 High)	7.1 - 24.8	44.558** (.0013)	1.202** (.0908)	grams per hour

* The values are calculated based on the NYCC at 7.1 mph and Freeway at 13.1 mph cycles.
** Freeway and Arterial/Collector cycles were combined.

Table 12b
Regressions of Emissions Versus Average Speed
Carbon Monoxide (CO)

Emissions = Constant + a*(Average Speed)

Roadway Type	Emission Level	Speed Data Range (mph)	Constant (p value)	a (p value)	Emission Units
Freeway	1 (Tier 1)	7.1 - 13.1	14.730*	0.280*	grams per hour
Freeway	1 (Tier 1)	13.1 - 30.5	1.655 (.9045)	1.278 (.0454)	grams per hour
Freeway	1 (Tier 1)	30.5 - 63.2	0.246 (.7436)	0.032 (.0263)	grams per mile
Freeway	2 (Tier 0 Normal)	7.1 - 13.1	46.679*	2.390*	grams per hour
Freeway	2 (Tier 0 Normal)	13.1 - 30.5	15.273 (.4824)	4.788 (.0000)	grams per hour
Freeway	2 (Tier 0 Normal)	30.5 - 63.2	2.398 (.1526)	0.0872 (.0060)	grams per mile
Freeway	3 (Tier 0 High)	7.1 - 13.1	1206.641*	-9.747*	grams per hour
Freeway	3 (Tier 0 High)	13.1 - 30.5	365.822 (.4888)	54.438 (.0275)	grams per hour
Freeway	3 (Tier 0 High)	30.5 - 63.2	64.691 (.0147)	-0.0269 (.9559)	grams per mile
Arterial/ Collector	1 (Tier 1)	7.1 - 24.8	10.036 (.1950)	0.941 (.0138)	grams per hour
Arterial/ Collector	2 (Tier 0 Normal)	7.1 - 24.8	36.128 (.0054)	3.877 (.0000)	grams per hour
Arterial/ Collector	3 (Tier 0 High)	7.1 - 24.8	863.64 (.0114)	38.563 (.0202)	grams per hour

* The values are calculated based on the NYCC at 7.1 mph and Freeway at 13.1 mph cycles.

Table 12c
Regressions of Emissions Versus Average Speed
Oxides of Nitrogen (NOx)

Emissions = Constant + a*(Average Speed)

Roadway Type	Emission Level	Speed Data Range (mph)	Constant (p value)	a (p value)	Emission Units
Freeway	1 (Tier 1)	7.1 - 13.1	4.625*	-0.154*	grams per hour
Freeway	1 (Tier 1)	13.1 - 30.5	-0.855 (.5289)	0.264 (.0001)	grams per hour
Freeway	1 (Tier 1)	30.5 - 63.2	0.126 (.2886)	0.0031 (.1667)	grams per mile
Freeway	2 (Tier 0 Normal)	7.1 - 13.1	8.291*	0.121*	grams per hour
Freeway	2 (Tier 0 Normal)	13.1 - 30.5	-0.957 (.7262)	0.761 (.0000)	grams per hour
Freeway	2 (Tier 0 Normal)	30.5 - 63.2	0.594 (.0008)	0.00373 (.2575)	grams per mile
Freeway	3 (Tier 0 High)	7.1 - 13.1	24.889*	1.364*	grams per hour
Freeway	3 (Tier 0 High)	13.1 - 30.5	0.423 (.9717)	3.232 (.0000)	grams per hour
Freeway	3 (Tier 0 High)	30.5 - 63.2	2.980 (.0000)	0.00512 (.6389)	grams per mile
Arterial/ Collector	1 (Tier 1)	7.1 - 24.8	2.325 (.1066)	0.170 (.0167)	grams per hour
Arterial/ Collector	2 (Tier 0 Normal)	7.1 - 24.8	5.123 (.0027)	0.567 (.0000)	grams per hour
Arterial/ Collector	3 (Tier 0 High)	7.1 - 24.8	14.609 (.0471)	2.812 (.0000)	grams per hour

* The values are calculated based on the NYCC at 7.1 mph and Freeway at 13.1 mph cycles.

Table 12d
Regressions of Emissions Versus Average Speed
Non-Methane Hydrocarbons (NMHC)

Emissions = Constant + a*(Average Speed)

Roadway Type	Emission Level	Speed Data Range (mph)	Constant (p value)	a (p value)	Emission Units
Freeway	1 (Tier 1)	7.1 - 13.1	0.685*	-0.028*	grams per hour
Freeway	1 (Tier 1)	13.1 - 30.5	0.00266 (.9892)	0.0236 (.0105)	grams per hour
Freeway	1 (Tier 1)	30.5 - 63.2	0.00475 (.6971)	0.000592 (.0115)	grams per mile
Freeway	2 (Tier 0 Normal)	7.1 - 13.1	5.796*	-0.176*	grams per hour
Freeway	2 (Tier 0 Normal)	13.1 - 30.5	1.328 (.3602)	0.165 (.0131)	grams per hour
Freeway	2 (Tier 0 Normal)	30.5 - 63.2	0.259 (.0000)	-0.00189 (.0773)	grams per mile
Freeway	3 (Tier 0 High)	7.1 - 13.1	40.178*	1.103*	grams per hour
Freeway	3 (Tier 0 High)	13.1 - 30.5	37.404 (.0580)	1.107 (.2142)	grams per hour
Freeway	3 (Tier 0 High)	30.5 - 63.2	2.899 (.0000)	-0.022 (.0773)	grams per mile
Arterial/ Collector	1 (Tier 1)	7.1 - 24.8	0.399 (.0082)	0.0118 (.1048)	grams per hour
Arterial/ Collector	2 (Tier 0 Normal)	7.1 - 24.8	4.111 (.0003)	0.0617 (.2612)	grams per hour
Arterial/ Collector	3 (Tier 0 High)	7.1 - 24.8	42.589 (.0023)	1.017 (.1299)	grams per hour

* The values are calculated based on the NYCC at 7.1 mph and Freeway at 13.1 mph cycles.

Table 13
Freeway Ramp and Local Roadway Emissions
As a Function of Hot Running LA4 Emissions
In Grams/Hour

Emissions (g/hr) = Constant + a*(LA4) + b*($LA4^2$)
where LA4 is the hot running LA4 emissions in g/hr

Roadway Type	Pollutant	Constant (p value)	a (p value)	b (p value)	R^2
Freeway Ramp (34.6 mph)	THC	4.560 (.0302)	2.046 (.0000)	-0.00356 (.0000)	0.934
Freeway Ramp (34.6 mph)	CO	224.333 (.0010)	2.040 (.0000)	-0.000145 (.0074)	0.848
Freeway Ramp (34.6 mph)	NOx	5.353 (.1103)	2.863 (.0000)	-.0101 (.0019)	0.866
Freeway Ramp (34.6 mph)	NMHC	4.368 (.0193)	2.014 (.0000)	-0.00387 (.0000)	0.934
Local Roadways (12.9 mph)	THC	0.00	1.0319 (.0000)	-0.0007 (.2960)	0.804
Local Roadways (12.9 mph)	CO	0.00	0.7405 (.0000)	0.000 (.9242)	0.831
Local Roadways (12.9 mph)	NOx	0.00	0.8156 (.0000)	-0.0005 (.4656)	0.952
Local Roadways (12.9 mph)	NMHC	0.00	1.1097 (.0000)	-0.0015 (.0172)	0.804

Table 14 Emission Offset (Predicted Freeway Emissions - Average Hot Running LA4 Emissions)									
	Level 1 (Tier 1) (grams per mile)			Level 2 (Tier 0) (grams per mile)			Level 3 (High Emitters) (grams per mile)		
	Fwy	LA4	Offset	Fwy	LA4	Offset	Fwy	LA4	Offset
THC	0.042	0.036	0.006	0.290	0.199	0.091	3.476	3.175	0.301
CO	1.363	0.892	0.471	5.567	3.569	1.998	73.102	82.194	-9.092
NOx	0.220	0.191	0.029	0.712	0.591	0.121	3.253	3.245	0.008
NMHC	0.024	0.020	0.004	0.233	0.157	0.076	3.153	2.945	0.208

Table 15
Arterial/Collector Emission Offsets (AEO)

(Predicted Arterial/Collector Emissions - Predicted Freeway Emissions)

Pollutant	Average Speed* (miles per hour)	Level 1 (grams per mile)	Level 2 (grams per mile)	Level 3 (grams per mile)
THC	10	0.014	0.073	0
	15	0.018	0.086	0
	20	0.009	0.037	0
	25	0.005	0.007	0
	30	0.001	0	0
CO	10	0.192	0.431	14.010
	15	0.222	0.479	17.313
	20	0.082	0.131	9.016
	25	0	0	4.038
	30	0	0	0.719
NOx	10	0.094	0.171	0.420
	15	0.118	0.211	0.526
	20	0.065	0.110	0.290
	25	0.033	0.049	0.148
	30	0.012	0.009	0.053
NMHC	10	0.012	0.069	0
	15	0.015	0.082	0
	20	0.008	0.035	0
	25	0.004	0.008	0
	30	0.001	0	0

* Arterial/Collector Emission Offsets below 10 mph and over 30 mph are zero.

Table 16 Speed Correction Factors For Freeways By Emission Level*												
Avg. Speed (mph)	Total Hydrocarbons (THC)			Carbon Monoxide (CO)			Oxides of Nitrogen (NOx)			Non-Methane HC (NMHC)		
	Level 1	Level 2	Level 3	Level 1	Level 2	Level 3	Level 1	Level 2	Level 3	Level 1	Level 2	Level 3
7.1	2.71	2.65	2.15	1.73	1.61	2.19	2.26	1.81	1.50	2.87	2.75	2.14
10	1.71	1.71	1.63	1.29	1.27	1.52	1.40	1.28	1.18	1.69	1.73	1.62
15	1.08	1.10	1.20	1.02	1.04	1.08	0.94	0.98	1.00	1.00	1.09	1.20
19.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
20	1.00	0.99	0.99	1.00	1.00	0.99	1.00	1.00	1.00	1.00	0.99	0.99
25	0.95	0.93	0.86	0.99	0.97	0.94	1.04	1.01	1.00	1.00	0.94	0.86
30	0.91	0.88	0.77	0.98	0.95	0.91	1.07	1.02	1.00	1.00	0.90	0.77
35	0.91	0.81	0.68	1.00	0.98	0.87	1.07	1.02	1.00	1.07	0.83	0.68
40	0.97	0.77	0.64	1.12	1.06	0.87	1.14	1.04	1.00	1.20	0.79	0.64
45	1.04	0.73	0.61	1.24	1.14	0.87	1.21	1.07	1.00	1.32	0.74	0.61
50	1.10	0.69	0.57	1.36	1.21	0.87	1.28	1.09	1.00	1.45	0.70	0.57
55	1.17	0.65	0.54	1.47	1.29	0.86	1.35	1.12	1.00	1.57	0.66	0.54
60	1.24	0.61	0.50	1.59	1.37	0.86	1.42	1.15	1.01	1.70	0.62	0.50
65	1.30	0.57	0.47	1.71	1.45	0.86	1.49	1.17	1.02	1.82	0.58	0.47

* Emission levels shown as Fwy emissions in Table 14. See Section 4.6.

Table 17
Speed Correction Factors
For Arterial/Collector Roadways
By Emission Level*

Avg. Speed (mph)	Total Hydrocarbons (THC)			Carbon Monoxide (CO)			Oxides of Nitrogen (NOx)			Non-Methane HC (NMHC)		
	Level 1	Level 2	Level 3	Level 1	Level 2	Level 3	Level 1	Level 2	Level 3	Level 1	Level 2	Level 3
7.1	2.71	2.65	2.15	1.73	1.61	2.19	2.26	1.81	1.50	2.87	2.75	2.14
10	2.04	1.96	1.63	1.43	1.35	1.71	1.82	1.52	1.31	2.18	2.03	1.62
15	1.49	1.40	1.20	1.18	1.13	1.32	1.47	1.28	1.16	1.62	1.44	1.20
20	1.22	1.12	0.99	1.06	1.02	1.12	1.30	1.16	1.09	1.34	1.15	0.99
25	1.05	0.95	0.86	0.99	0.97	1.00	1.19	1.08	1.04	1.17	0.97	0.86
30	0.95	0.88	0.77	0.98	0.95	0.92	1.12	1.04	1.01	1.06	0.90	0.77
35	0.91	0.81	0.68	1.00	0.98	0.87	1.07	1.02	1.00	1.07	0.83	0.68
40	0.97	0.77	0.64	1.12	1.06	0.87	1.14	1.04	1.00	1.20	0.79	0.64
45	1.04	0.73	0.61	1.24	1.14	0.87	1.21	1.07	1.00	1.32	0.74	0.61
50	1.10	0.69	0.57	1.36	1.21	0.87	1.28	1.09	1.00	1.45	0.70	0.57
55	1.17	0.65	0.54	1.47	1.29	0.86	1.35	1.12	1.00	1.57	0.66	0.54
60	1.24	0.61	0.50	1.59	1.37	0.86	1.42	1.15	1.01	1.70	0.62	0.50
65	1.30	0.57	0.47	1.71	1.45	0.86	1.49	1.17	1.02	1.82	0.58	0.47

* Emission levels shown as Fwy emissions in Table 14. See Section 4.6.

Table 18 Speed Correction Factors for Light Duty Diesel Vehicles			
SCF(s) = EXP(B*(s-sadj) + C*(s**2-sadj**2)) s = average speed (mph) sadj = basic test procedure speed; adjusted for VMT fraction of cold start operation x (0.206) and VMT fraction of hot start operation w (0.273), assuming FTP weighting. 1/sadj = (w+x)/26 + (1-w-x)/16 sadj = 19.6 mph			
Pollutant	Model Years	Coefficient Values	
		(B)	(C)
THC	All	-0.055	0.00044
CO	All	-0.088	0.00091
NOx	All	-0.048	0.00071

From "AP-42 Volume II, Compilation of Air Pollution Emission Factors, Mobile Sources," Appendix H, Table 5.6 and Table 6.6 (June 30, 1995)

Table 19 **Speed Correction Factors for Heavy Duty Gasoline Vehicles**				
SCF(s) = EXP(A + B*s + C*s**2), for THC & CO SCF(s) = A + B*s + C*s**2, for NOx s = average speed (mph)				
Pollutant	Model Years	Coefficient Values		
		(A)	(B)	(C)
THC	All	1.608	-0.097	0.00083
CO	All	1.520	-0.098	0.0011
NOx	All	0.824	0.0088	0.00

From "AP-42 Volume II, Compilation of Air Pollution Emission Factors, Mobile Sources," Appendix H, Table 4.6 (June 30, 1995)

Table 20 **Speed Correction Factors for Heavy Duty Diesel Vehicles**				
SCF(s) = EXP(A + B*s + C*s**2) s = average speed (mph)				
Pollutant	Model Years	Coefficient Values		
		(A)	(B)	(C)
THC	All	0.924	-0.055	0.00044
CO	All	1.396	-0.088	0.00091
NOx	All	0.676	-0.048	0.00071

From "AP-42 Volume II, Compilation of Air Pollution Emission Factors, Mobile Sources," Appendix H, Table 7.6 (June 30, 1995)

Table 21
Speed Correction Factors for Motorcycles

SCF(s) = SF(s)/ SF(sadj)

SF(s) = EXP(A + B* s + C* s** 2+ D* s** 3+ E* s** 4+ F* s** 5), for THC & CO

SF(s) = A + B* s + C* s** 2+ D* s** 3+ E* s** 4 + F* s** 5, for NOx

s = average speed (mph)

sadj = 19.6 mph

Pollutant	Model Years	Coefficient Values					
		(A)	(B)	(C)	(D)	(E)	(F)
Low Altitude							
THC	Pre-1978	2.31E+00	-2.90E-01	1.53E-02	-4.47E-04	6.48E-06	-3.63E-08
	1978-1979	2.41E+00	-3.08E-01	1.68E-02	-5.07E-04	7.54E-06	-4.32E-08
	1980+	2.25E+00	-2.88E-01	1.57E-02	-4.73E-04	7.08E-06	-4.08E-08
CO	Pre-1978	2.34E+00	-2.97E-01	1.60E-02	-4.77E-04	7.07E-06	-4.04E-08
	1978-1979	2.78E+00	-3.19E-01	1.53E-02	-4.22E-04	5.85E-06	-3.15E-08
	1980+	2.71E+00	-3.31E-01	1.76E-02	-5.39E-04	8.17E-06	-4.78E-08
NOx	Pre-1978	1.69E+00	-1.18E-01	6.55E-03	-1.37E-04	1.01E-06	0.00E+00
	1978+	1.28E+00	-8.05E-02	5.36E-03	-1.19E-04	9.01E-07	0.00E+00
High Altitudes							
THC	Pre-1978	2.25E+00	-2.91E-01	1.59E-02	-4.72E-04	6.94E-06	-3.93E-08
	1978-1979	2.15E+00	-2.84E-01	1.54E-02	-4.42E-04	6.29E-06	-3.46E-08
	1980+	2.12E+00	-2.91E-01	1.69E-02	-5.26E-04	8.03E-06	-4.70E-08
CO	Pre-1978	1.82E+00	-2.55E-01	1.52E-02	-4.87E-04	7.58E-06	-4.50E-08
	1978-1979	1.82E+00	-2.72E-01	1.70E-02	-5.52E-04	8.63E-06	-5.11E-08
	1980+	2.05E+00	-3.11E-01	2.05E-02	-7.09E-04	1.16E-05	-7.16E-08
NOx	Pre-1978	2.44E+00	-2.50E-01	1.38E-02	-2.87E-04	2.08E-06	0.00E+00
	1978+	1.45E+00	-1.22E-01	7.95E-03	-1.71E-04	1.26E-06	0.00E+00

From “AP-42 Volume II, Compilation of Air Pollution Emission Factors, Mobile Sources,” Appendix H, Table 8.6.1 and Table 8.6.2 (June 30, 1995)

Figures

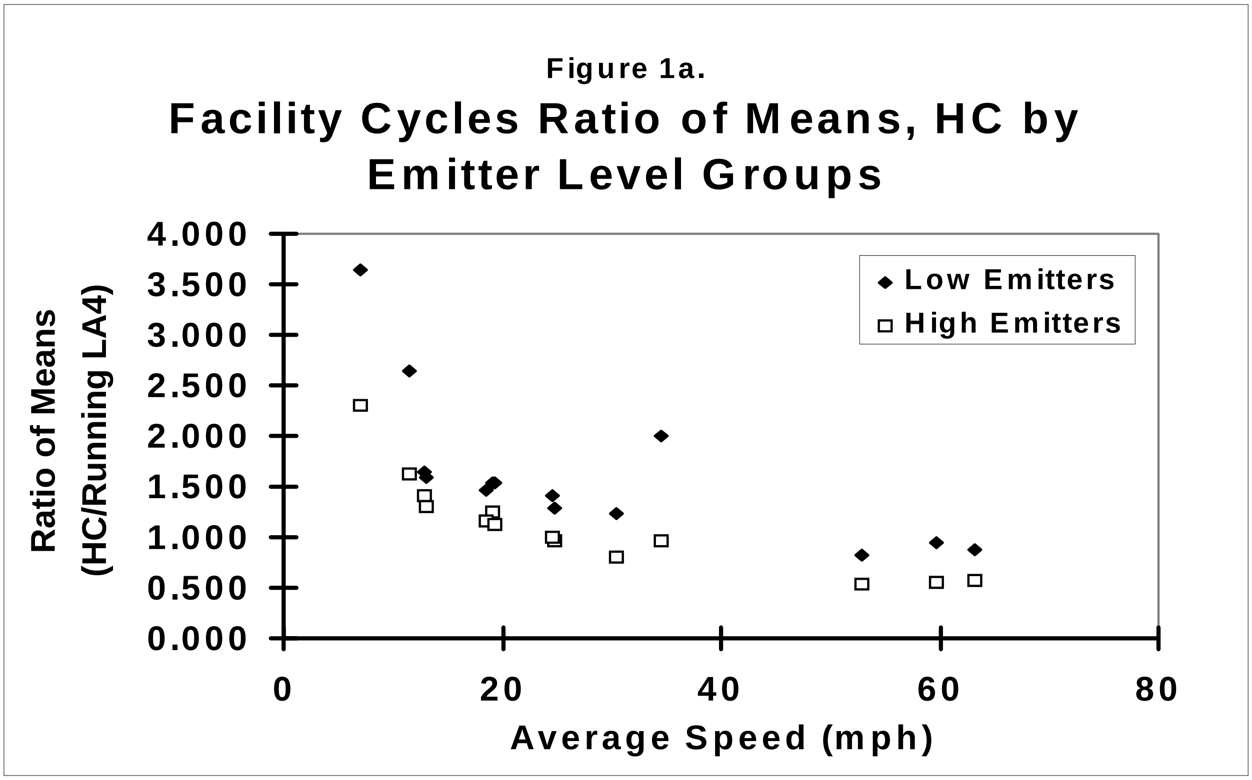


Figure 1a.
Facility Cycles Ratio of Means, HC by Emitter Level Groups
Ratio of Means (HC/Running LA4)
Average Speed (mph)
Low Emitters
High Emitters
4.000
3.500
3.000
2.500
2.000
1.500
1.000
0.500
0.000
0
20
40
60
80

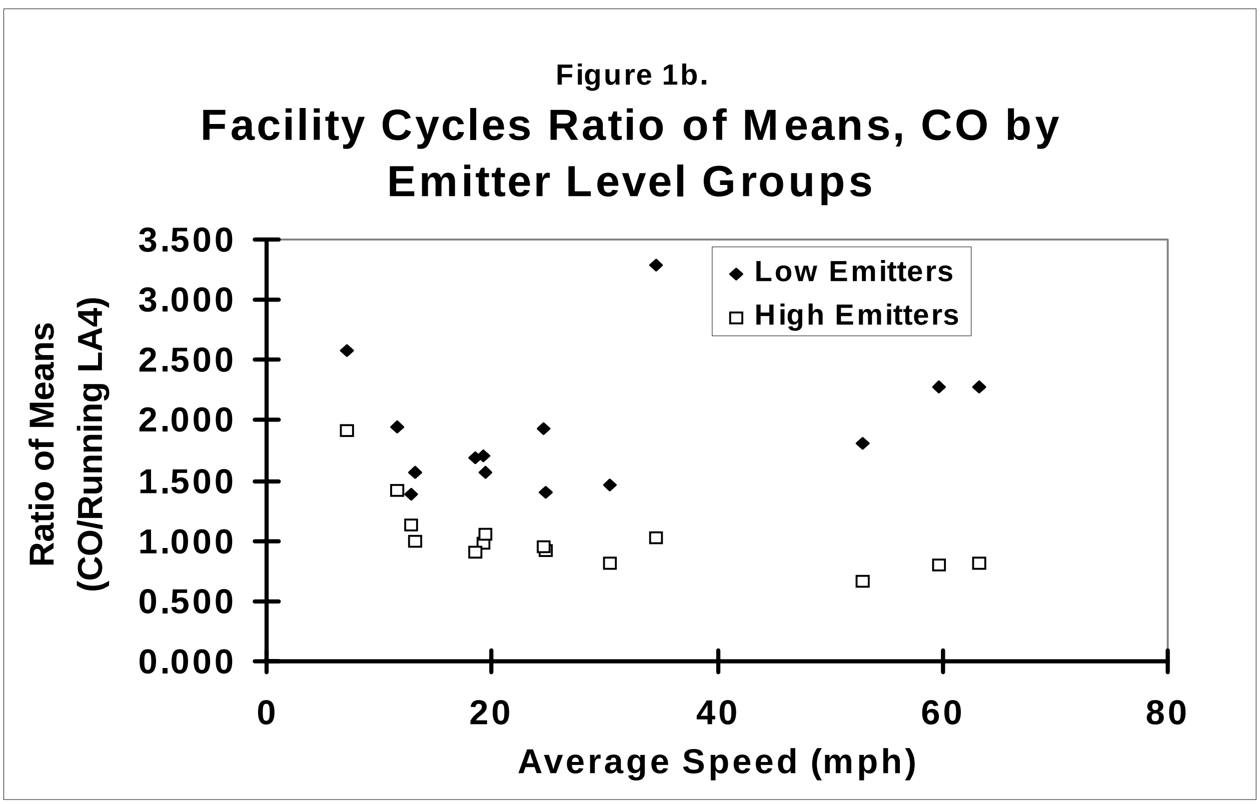


Figure 1b.
Facility Cycles Ratio of Means, CO by Emitter Level Groups
Ratio of Means (CO/Running LA4)
Average Speed (mph)
Low Emitters
High Emitters
3.500
3.000
2.500
2.000
1.500
1.000
0.500
0.000
0
20
40
60
80

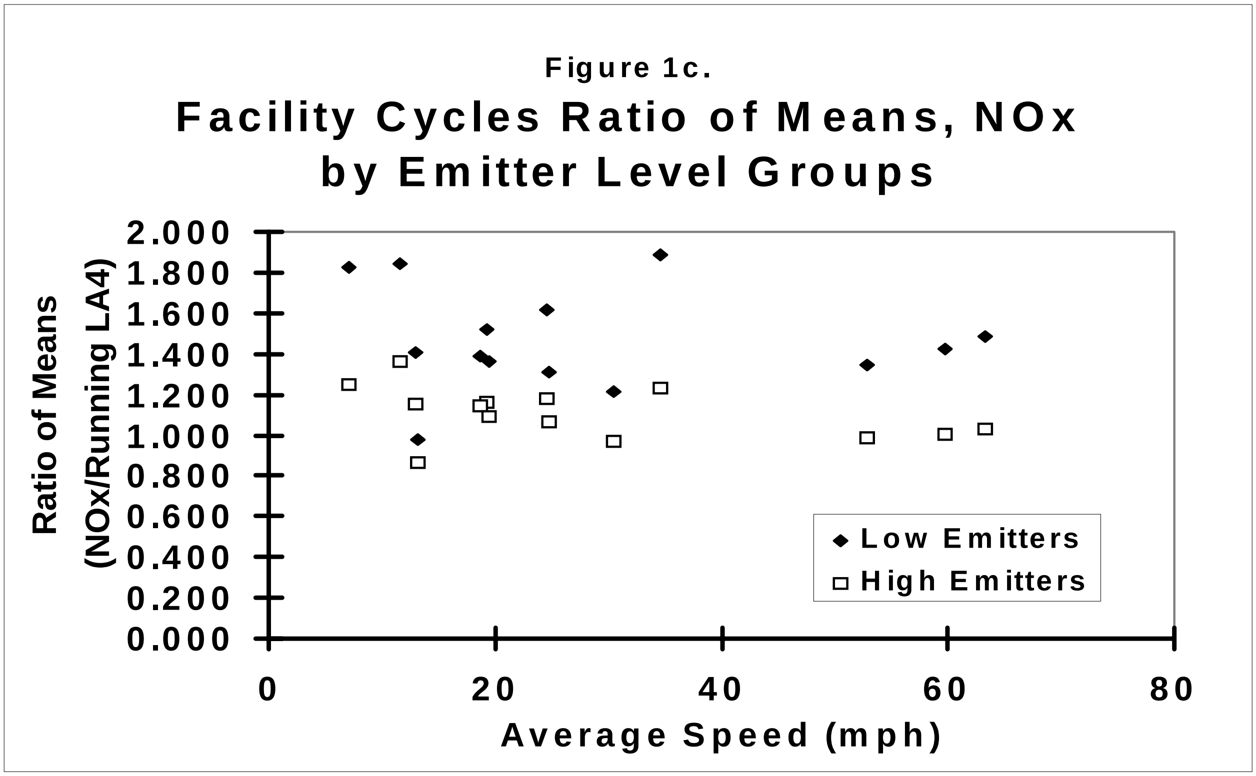


Figure 1c.
Facility Cycles Ratio of Means, NOx
by Emitter Level Groups
Ratio of Means
(NOx/Running LA4)
2.000
1.800
1.600
1.400
1.200
1.000
0.800
0.600
0.400
0.200
0.000
0
20
40
60
80
Average Speed (mph)
Low Emitters
High Emitters

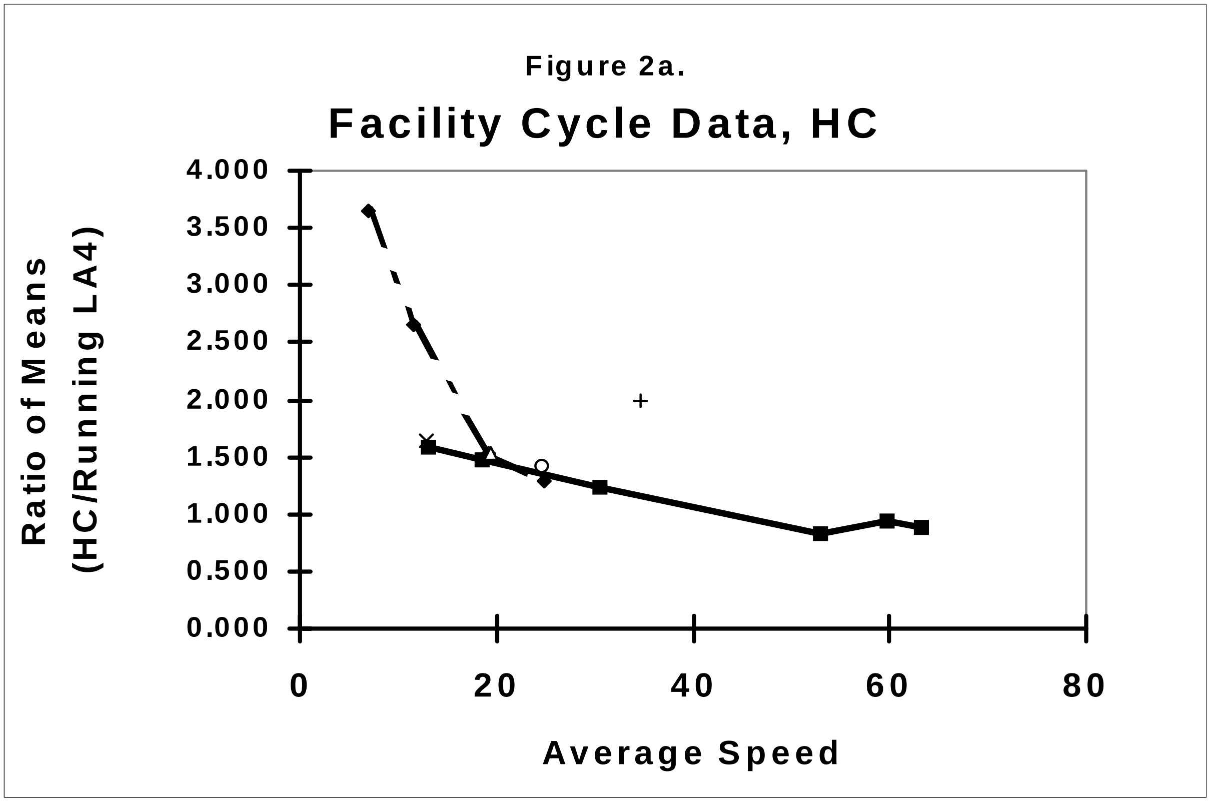
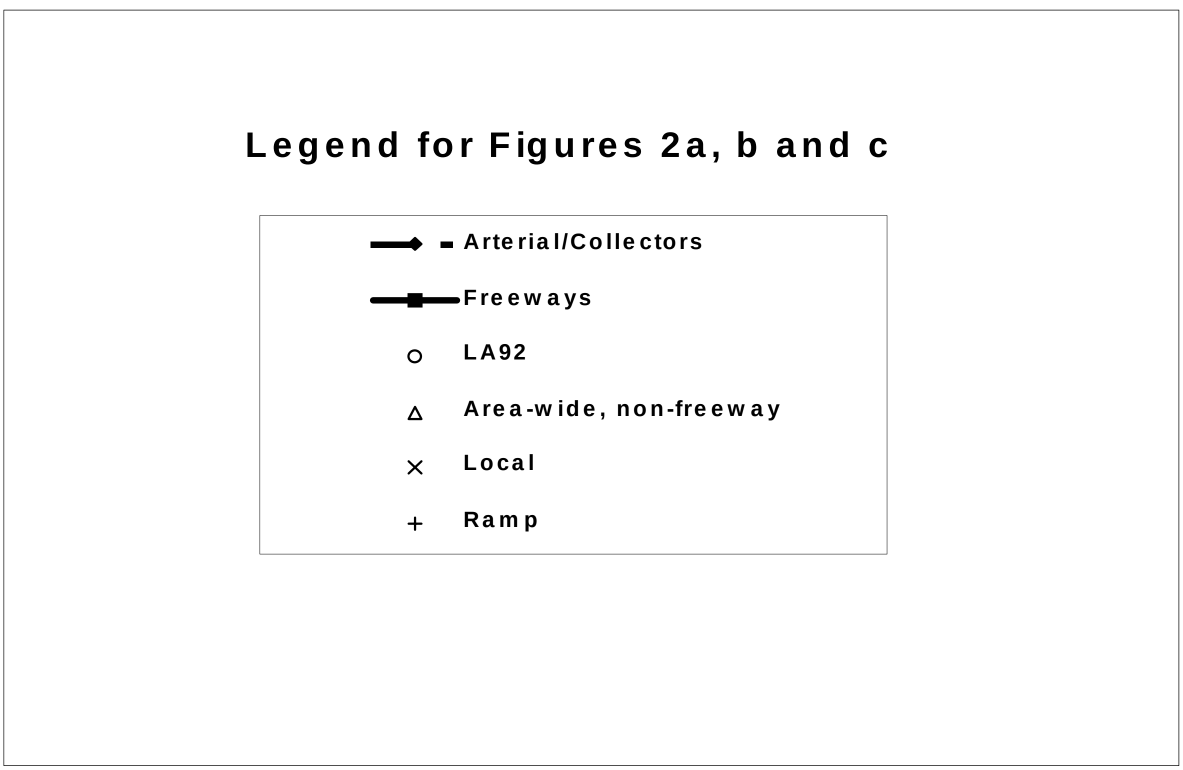


Figure 2a.
Facility Cycle Data, HC
Ratio of Means
(HC/Running LA4)
4.000
3.500
3.000
2.500
2.000
1.500
1.000
0.500
0.000
0
20
40
60
80
Average Speed



Legend for Figures 2a, b and c
Arterial/Collectors
Freeways
LA92
Area-wide, non-freeway
Local
Ramp

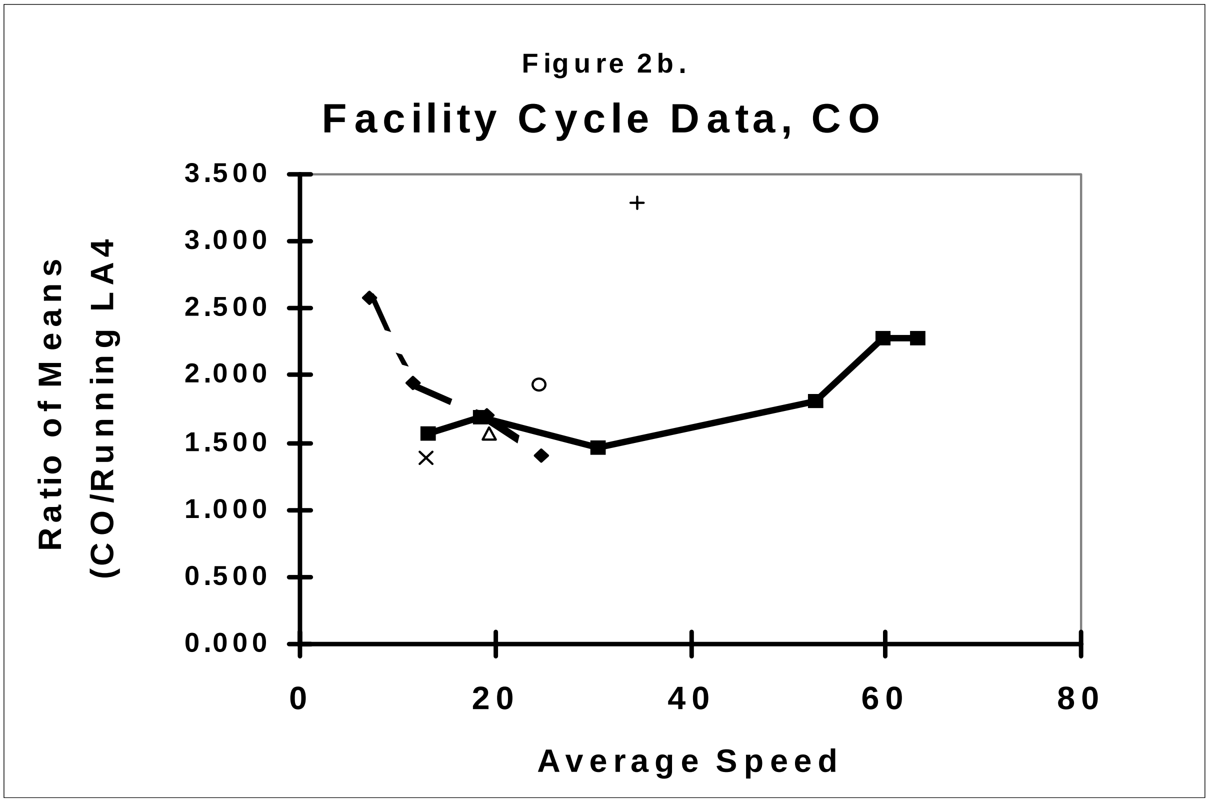


Figure 2b.
Facility Cycle Data, CO
Ratio of Means
(CO/Running LA4
3.500
3.000
2.500
2.000
1.500
1.000
0.500
0.000
0
20
40
60
80
Average Speed

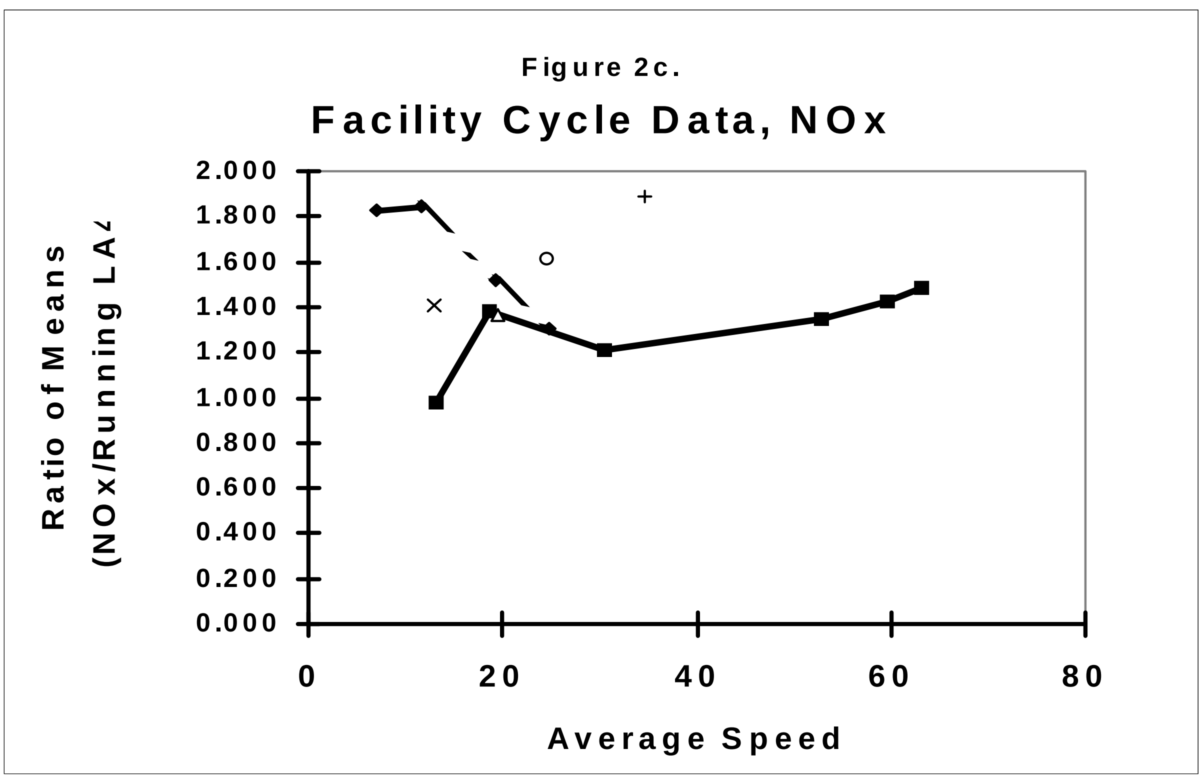
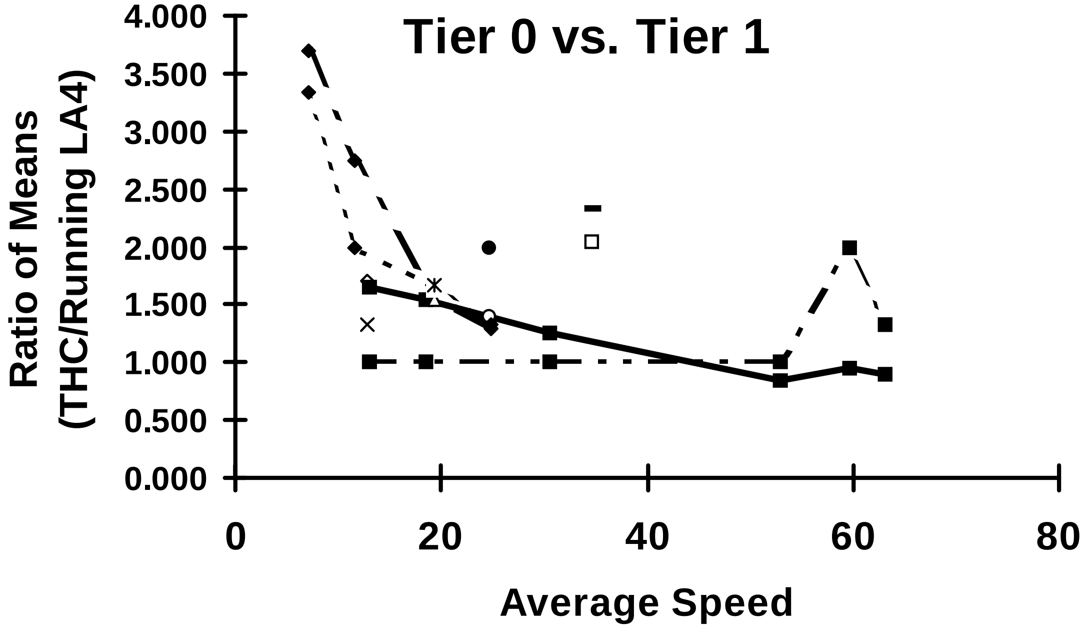


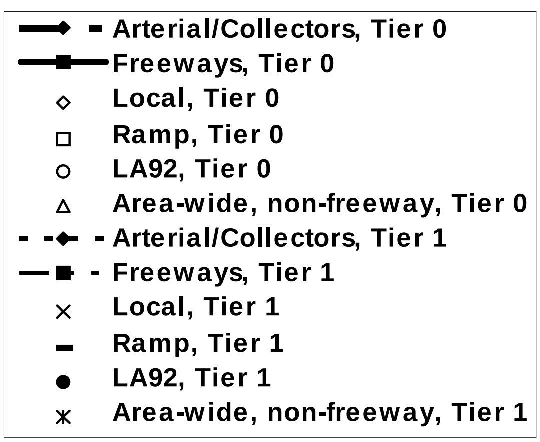
Figure 2c.
Facility Cycle Data, NOx
Ratio of Means
(NOx/Running LA4
2.000
1.800
1.600
1.400
1.200
1.000
0.800
0.600
0.400
0.200
0.000
0
20
40
60
80
Average Speed

Figure 3a.

Facility Cycle Data, THC
Tier 0 vs. Tier 1



Legend for Figures 3a, 3b and 3c



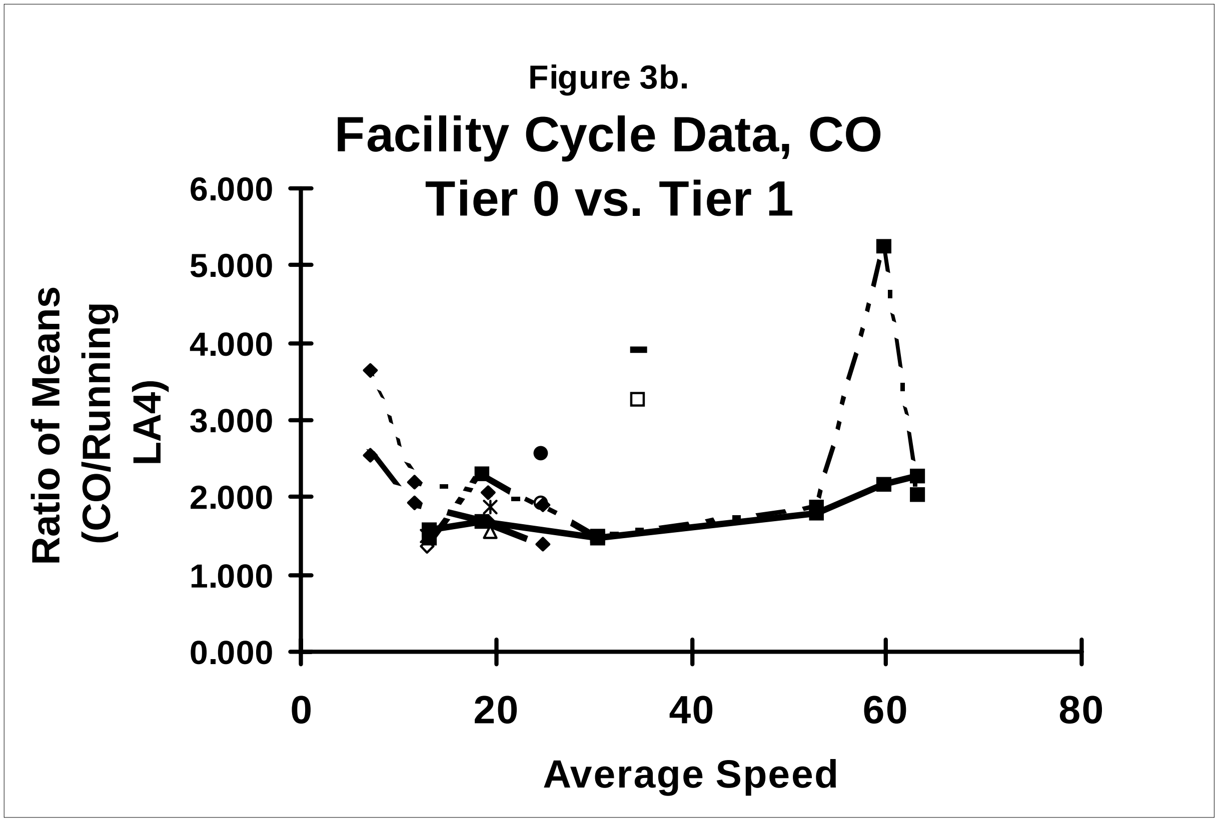


Figure 3b.
Facility Cycle Data, CO
Tier 0 vs. Tier 1
6.000
5.000
4.000
3.000
2.000
1.000
0.000
Ratio of Means (CO/Running LA4)
0
20
40
60
80
Average Speed

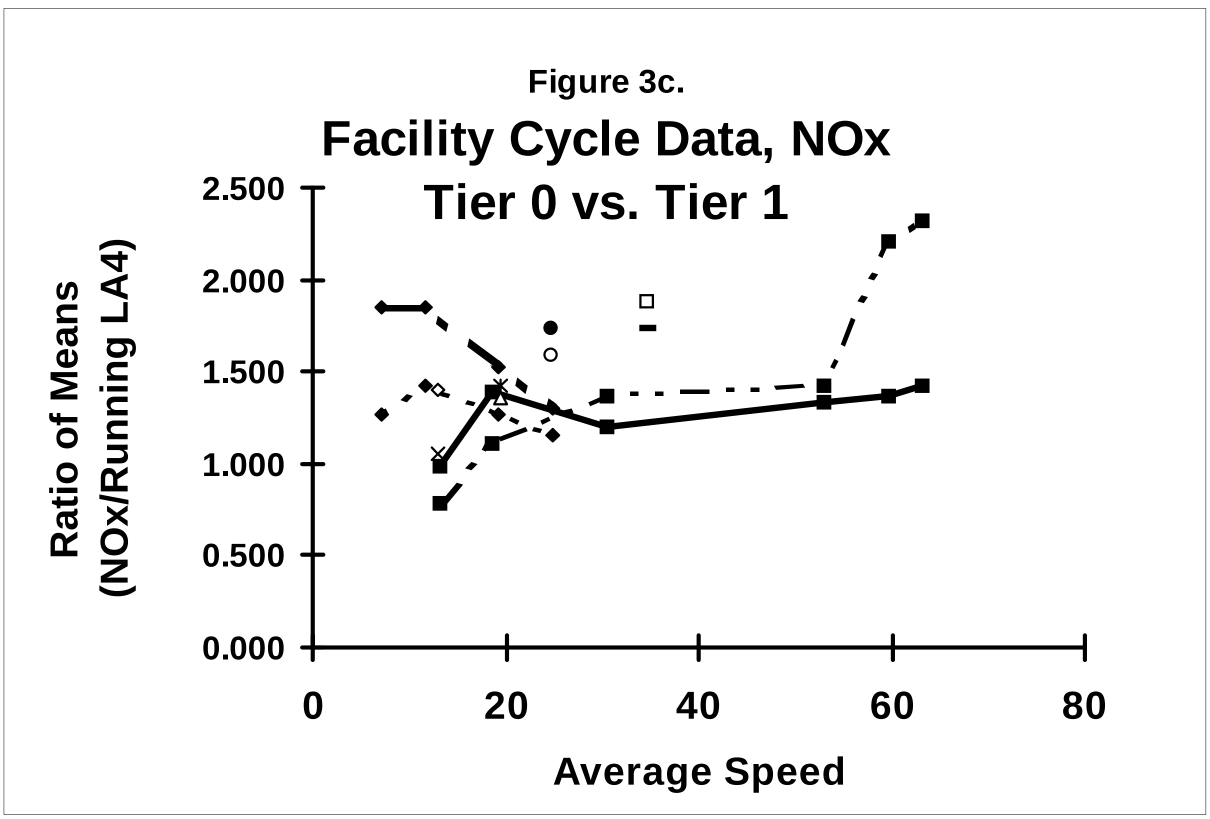


Figure 3c.
Facility Cycle Data, NOx
Tier 0 vs. Tier 1
2.500
2.000
1.500
1.000
0.500
0.000
Ratio of Means (NOx/Running LA4)
0
20
40
60
80
Average Speed

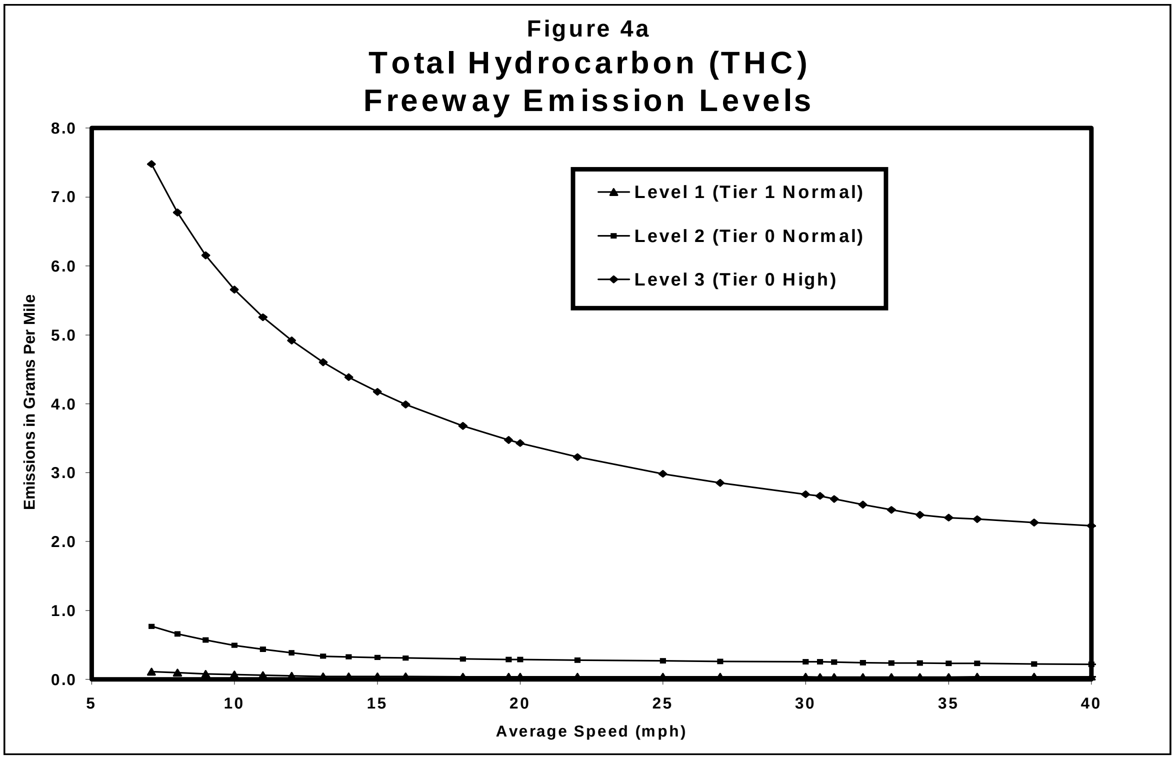


Figure 4a
Total Hydrocarbon (THC)
Freeway Emission Levels
Level 1 (Tier 1 Normal)
Level 2 (Tier 0 Normal)
Level 3 (Tier 0 High)
Emissions in Grams Per Mile
Average Speed (mph)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
5
10
15
20
25
30
35
40

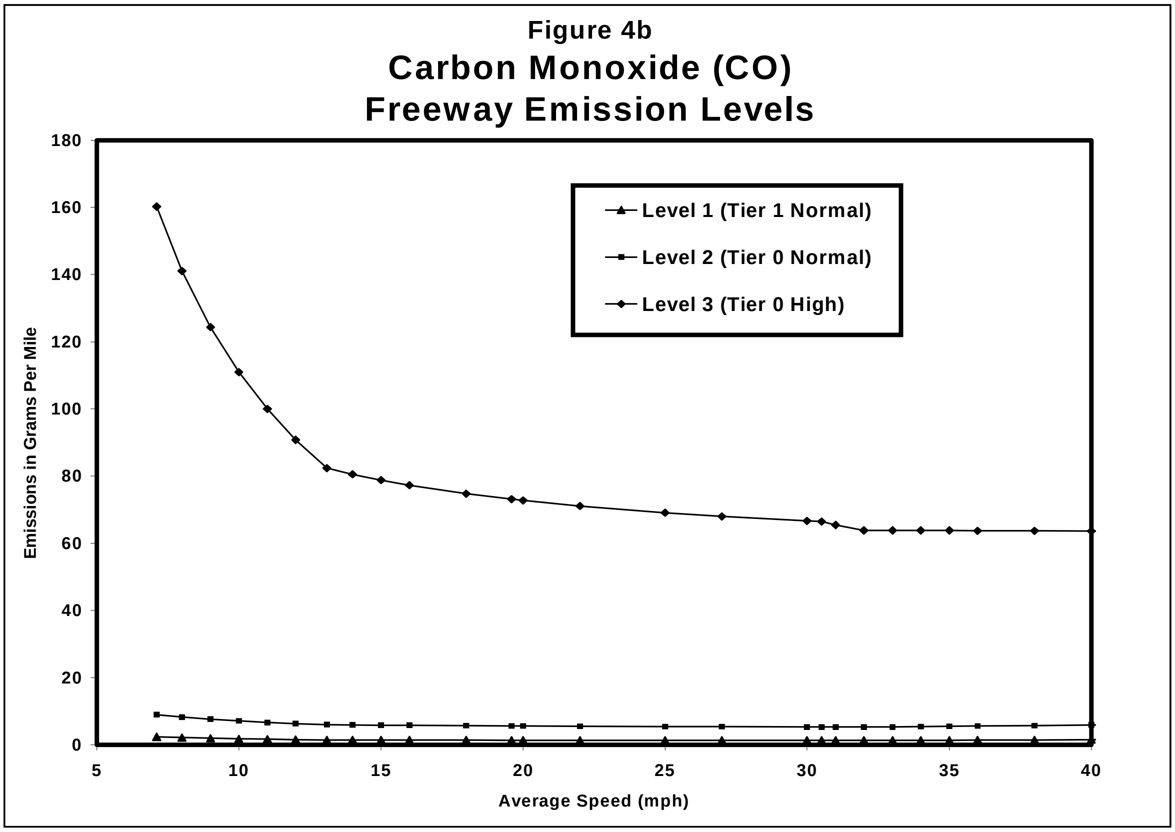


Figure 4b
Carbon Monoxide (CO)
Freeway Emission Levels
Level 1 (Tier 1 Normal)
Level 2 (Tier 0 Normal)
Level 3 (Tier 0 High)
Emissions in Grams Per Mile
Average Speed (mph)
0
20
40
60
80
100
120
140
160
180
5
10
15
20
25
30
35
40

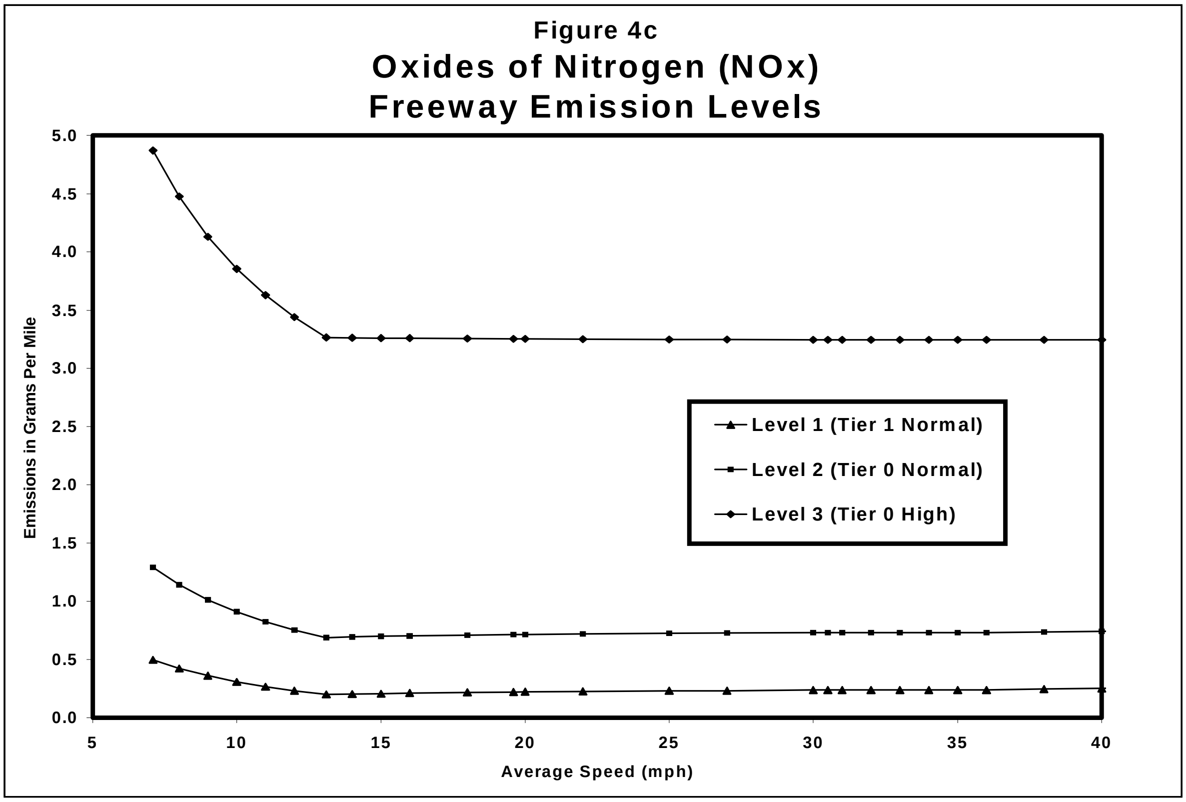


Figure 4c
Oxides of Nitrogen (NOx)
Freeway Emission Levels
Emissions in Grams Per Mile
Average Speed (mph)
Level 1 (Tier 1 Normal)
Level 2 (Tier 0 Normal)
Level 3 (Tier 0 High)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5
10
15
20
25
30
35
40

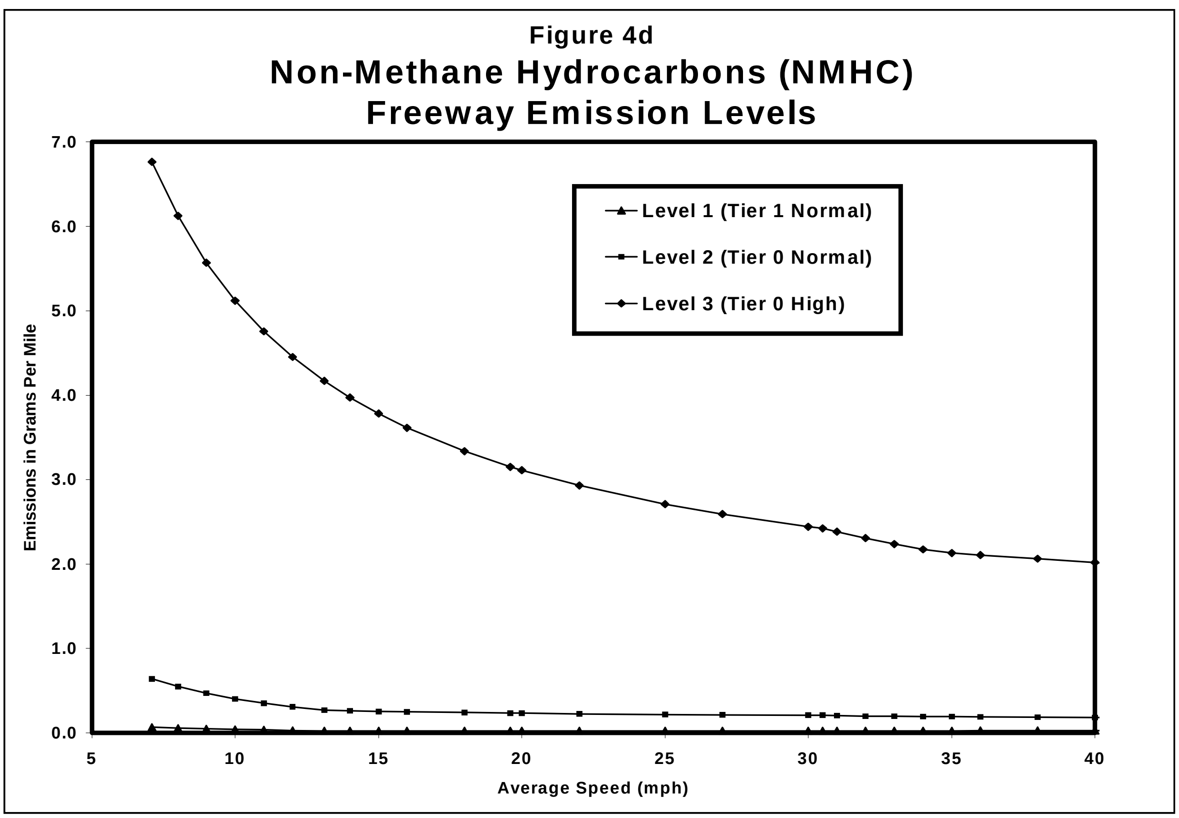


Figure 4d
Non-Methane Hydrocarbons (NMHC)
Freeway Emission Levels
Emissions in Grams Per Mile
Average Speed (mph)
Level 1 (Tier 1 Normal)
Level 2 (Tier 0 Normal)
Level 3 (Tier 0 High)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
5
10
15
20
25
30
35
40

Figure 5a

Freeway Speed Correction Factors for Total Hydrocarbons (THC)

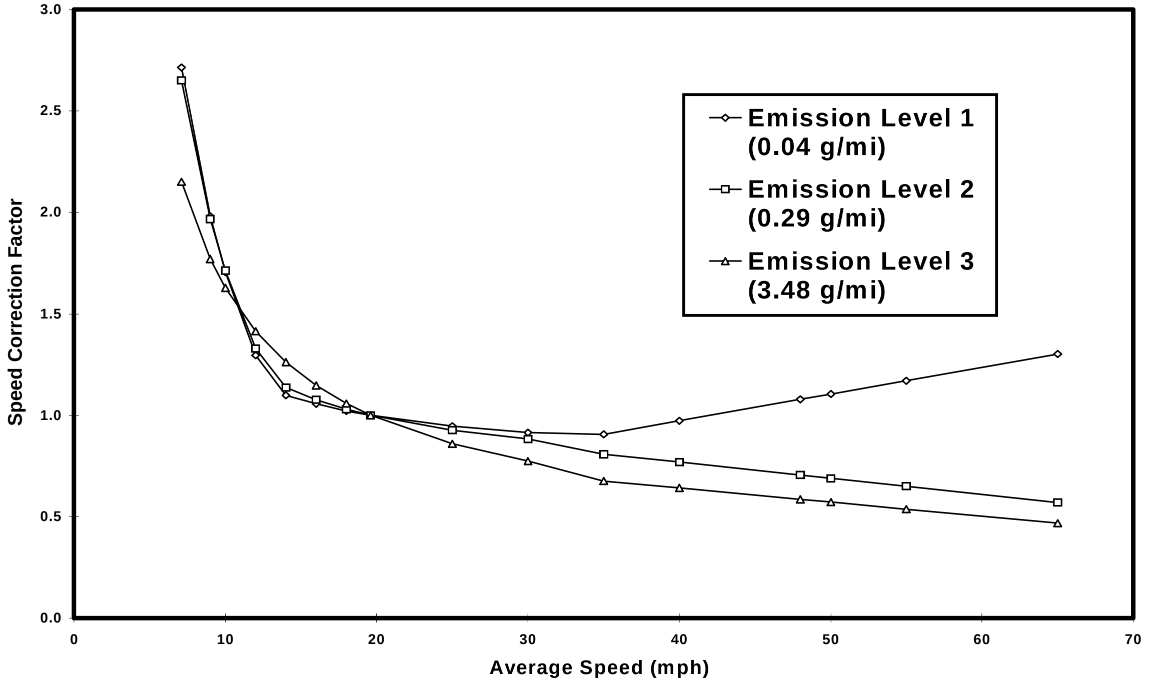
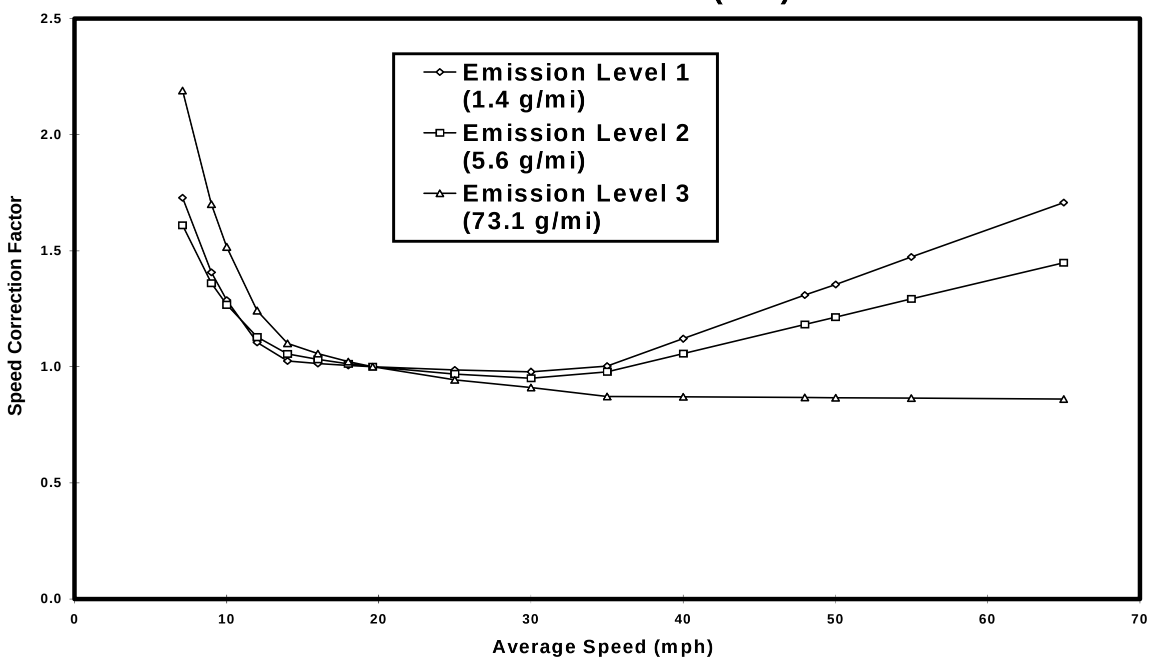


Figure 5b

Freeway Speed Correction Factors for Carbon Monoxide (CO)



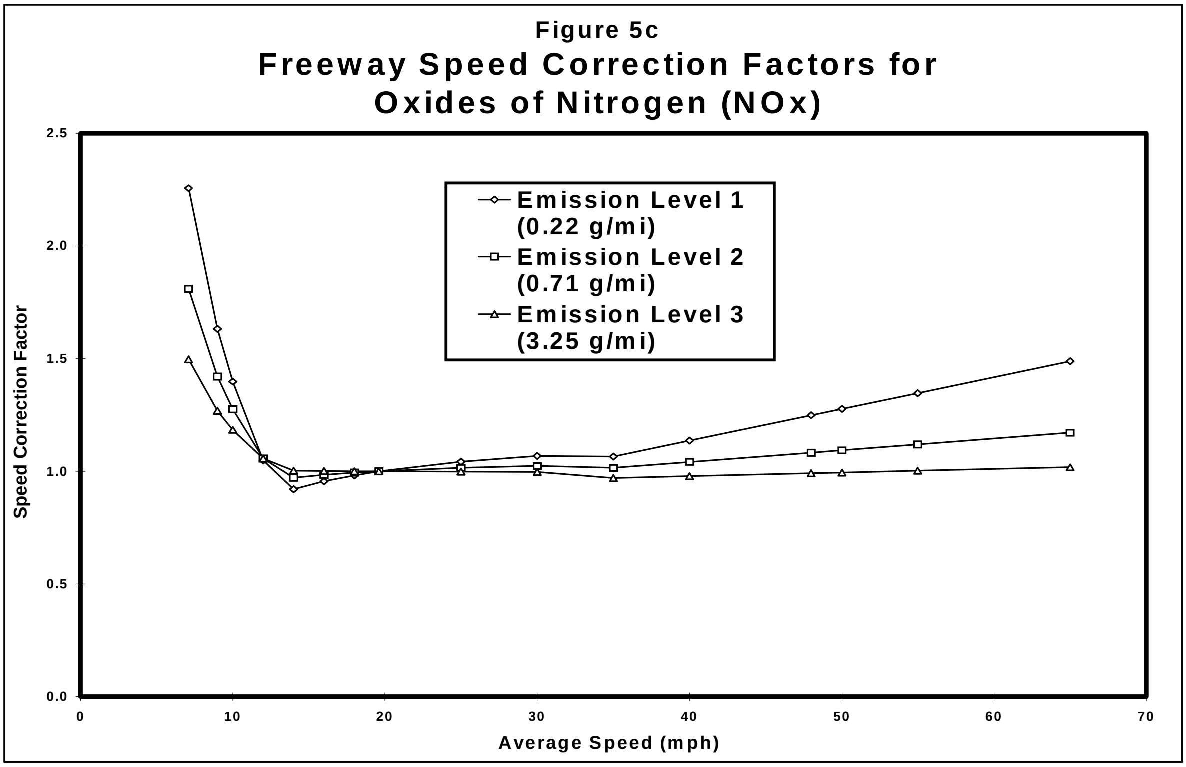


Figure 5c
Freeway Speed Correction Factors for
Oxides of Nitrogen (NOx)
Emission Level 1
(0.22 g/mi)
Emission Level 2
(0.71 g/mi)
Emission Level 3
(3.25 g/mi)
Speed Correction Factor
Average Speed (mph)
0.0
0.5
1.0
1.5
2.0
2.5
0
10
20
30
40
50
60
70

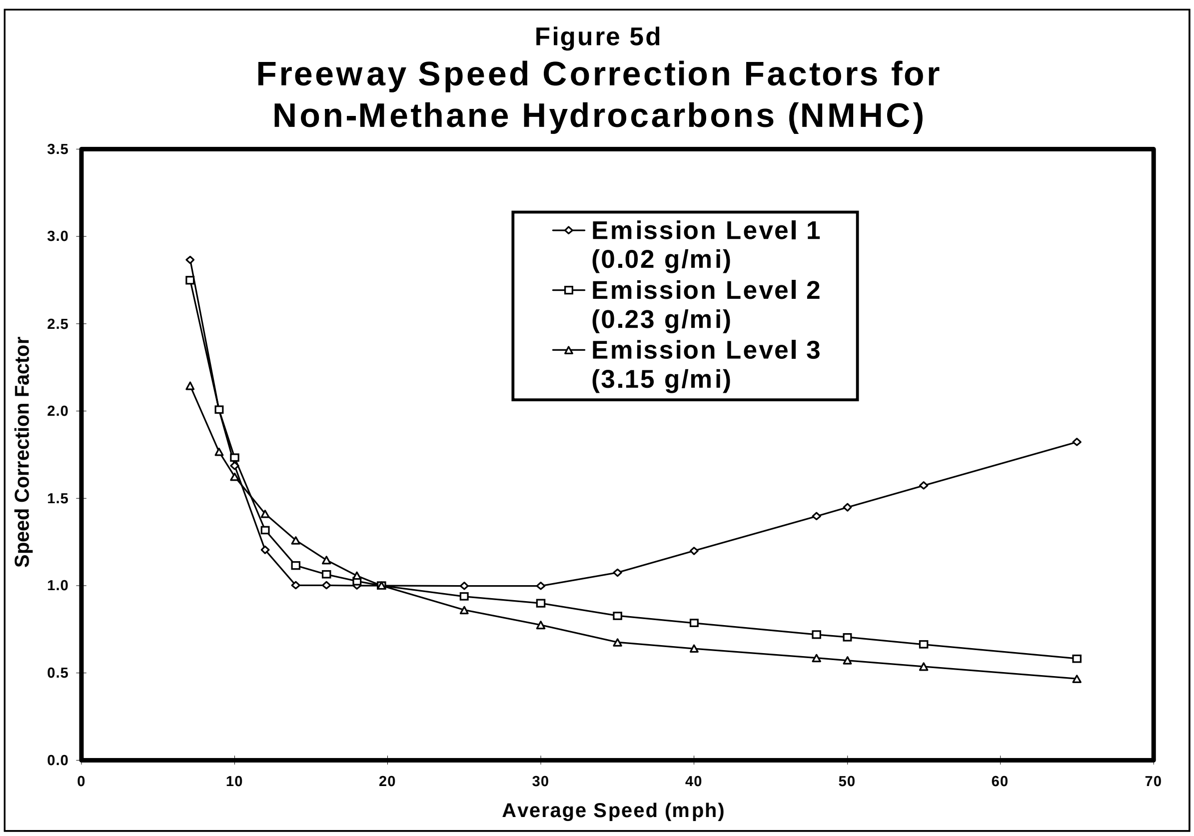


Figure 5d
Freeway Speed Correction Factors for
Non-Methane Hydrocarbons (NMHC)
Emission Level 1
(0.02 g/mi)
Emission Level 2
(0.23 g/mi)
Emission Level 3
(3.15 g/mi)
Speed Correction Factor
Average Speed (mph)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
0
10
20
30
40
50
60
70

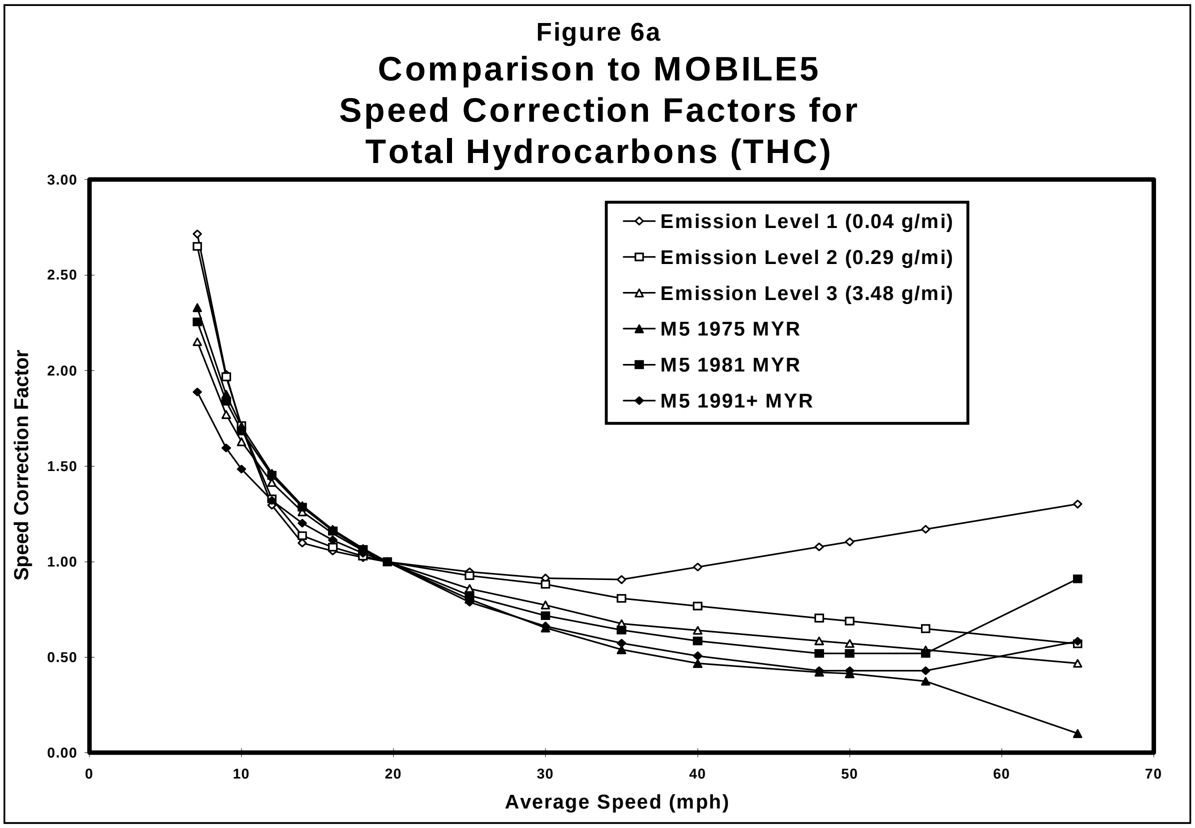


Figure 6a
Comparison to MOBILE5
Speed Correction Factors for
Total Hydrocarbons (THC)
Emission Level 1 (0.04 g/mi)
Emission Level 2 (0.29 g/mi)
Emission Level 3 (3.48 g/mi)
M5 1975 MYR
M5 1981 MYR
M5 1991+ MYR
Speed Correction Factor
Average Speed (mph)
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0
10
20
30
40
50
60
70

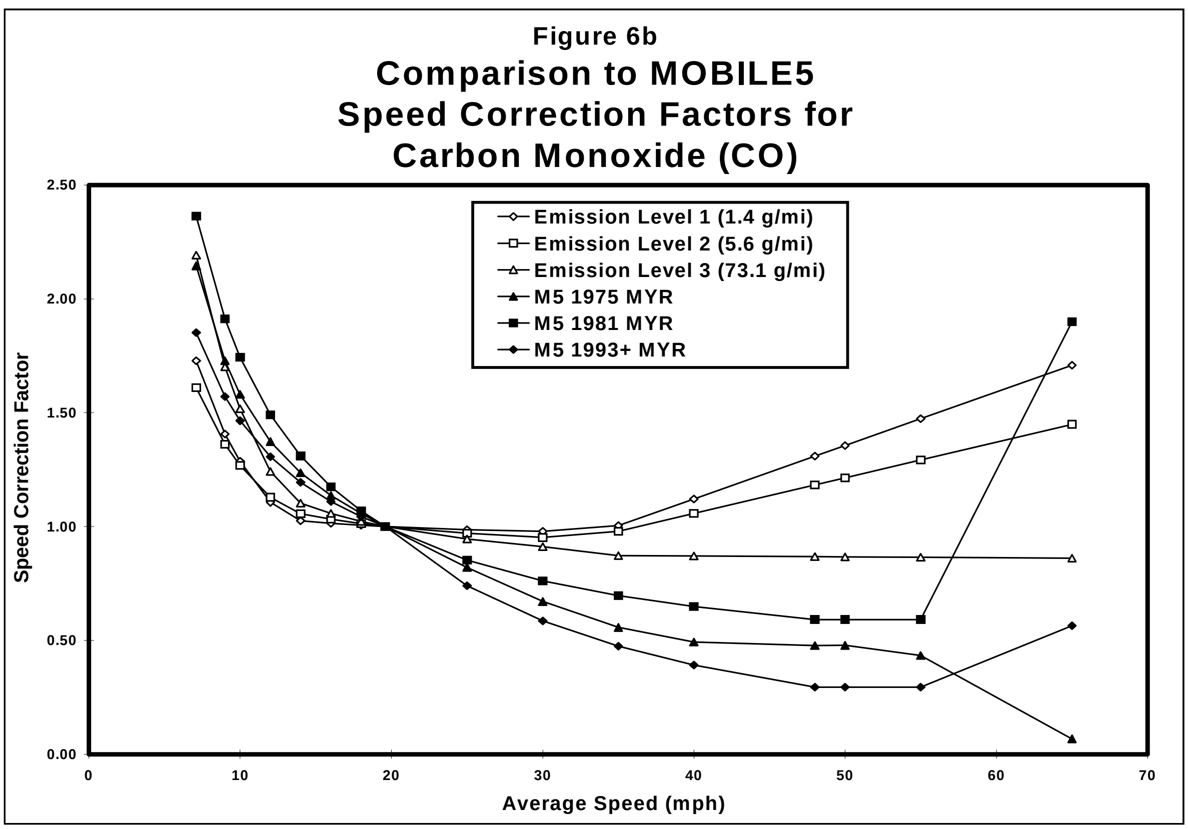


Figure 6b
Comparison to MOBILE5
Speed Correction Factors for
Carbon Monoxide (CO)
Emission Level 1 (1.4 g/mi)
Emission Level 2 (5.6 g/mi)
Emission Level 3 (73.1 g/mi)
M5 1975 MYR
M5 1981 MYR
M5 1993+ MYR
Speed Correction Factor
Average Speed (mph)
2.50
2.00
1.50
1.00
0.50
0.00
0
10
20
30
40
50
60
70

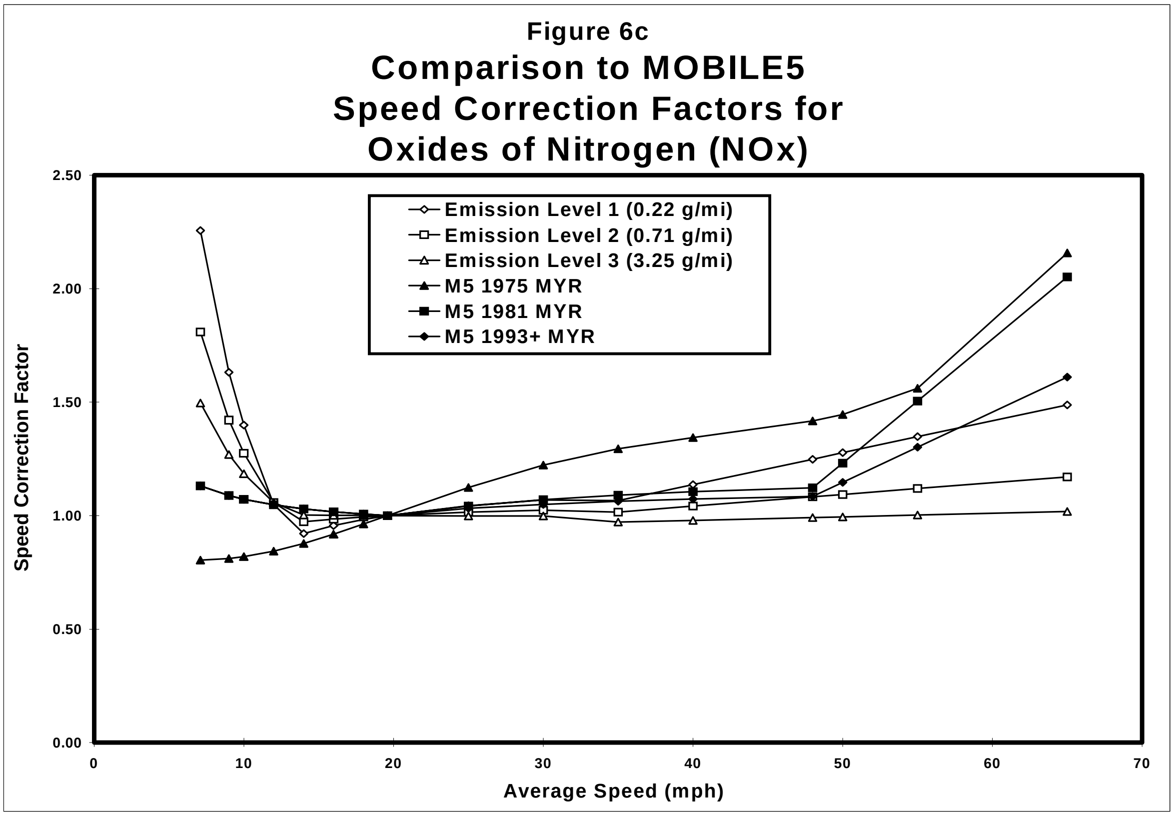


Figure 6c
Comparison to MOBILE5
Speed Correction Factors for
Oxides of Nitrogen (NOx)
Emission Level 1 (0.22 g/mi)
Emission Level 2 (0.71 g/mi)
Emission Level 3 (3.25 g/mi)
M5 1975 MYR
M5 1981 MYR
M5 1993+ MYR
Speed Correction Factor
Average Speed (mph)
0.00
0.50
1.00
1.50
2.00
2.50
0
10
20
30
40
50
60
70

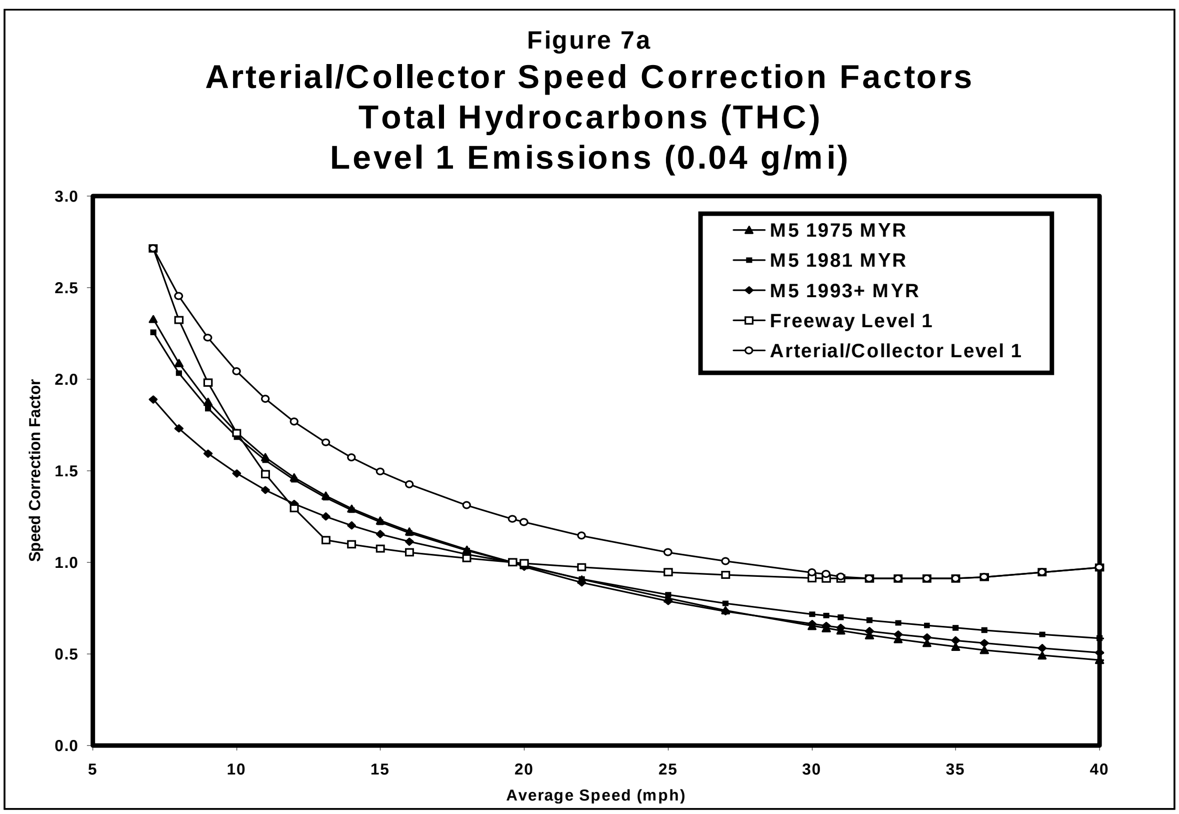


Figure 7a
Arterial/Collector Speed Correction Factors
Total Hydrocarbons (THC)
Level 1 Emissions (0.04 g/mi)
M5 1975 MYR
M5 1981 MYR
M5 1993+ MYR
Freeway Level 1
Arterial/Collector Level 1
Speed Correction Factor
Average Speed (mph)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
5
10
15
20
25
30
35
40

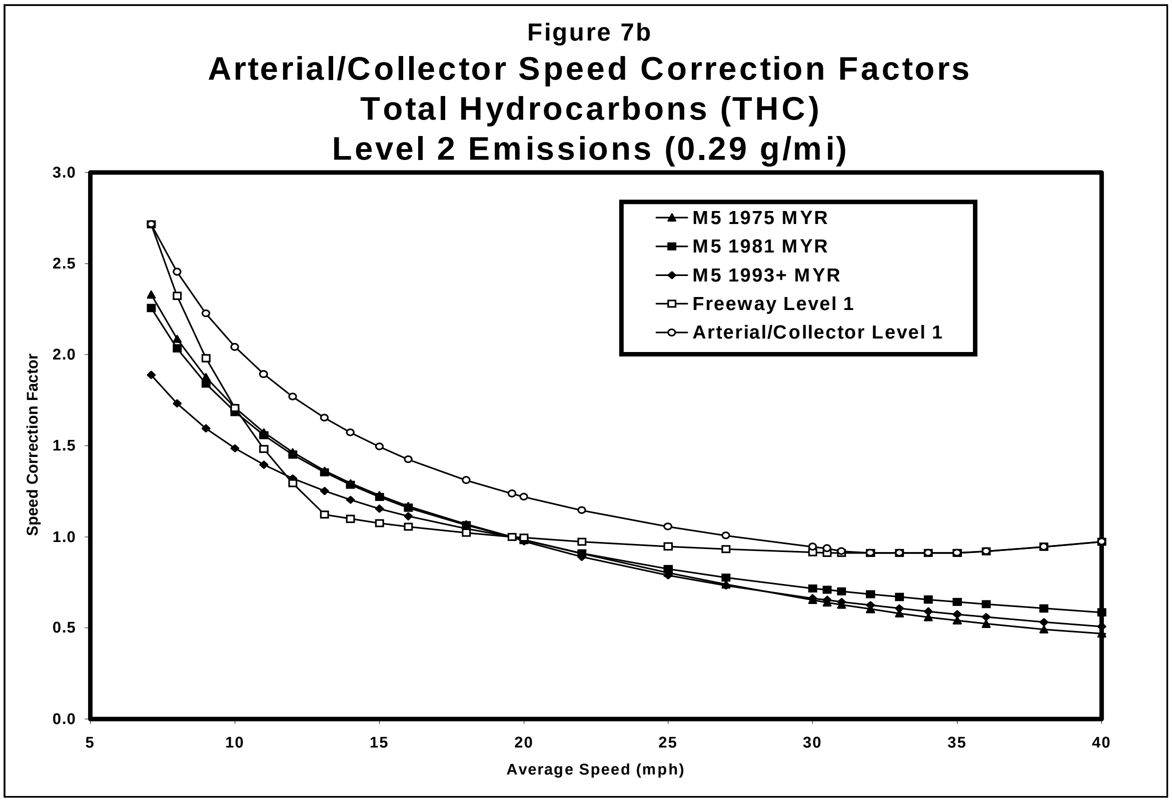


Figure 7b
Arterial/Collector Speed Correction Factors
Total Hydrocarbons (THC)
Level 2 Emissions (0.29 g/mi)
M5 1975 MYR
M5 1981 MYR
M5 1993+ MYR
Freeway Level 1
Arterial/Collector Level 1
Speed Correction Factor
Average Speed (mph)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
5
10
15
20
25
30
35
40

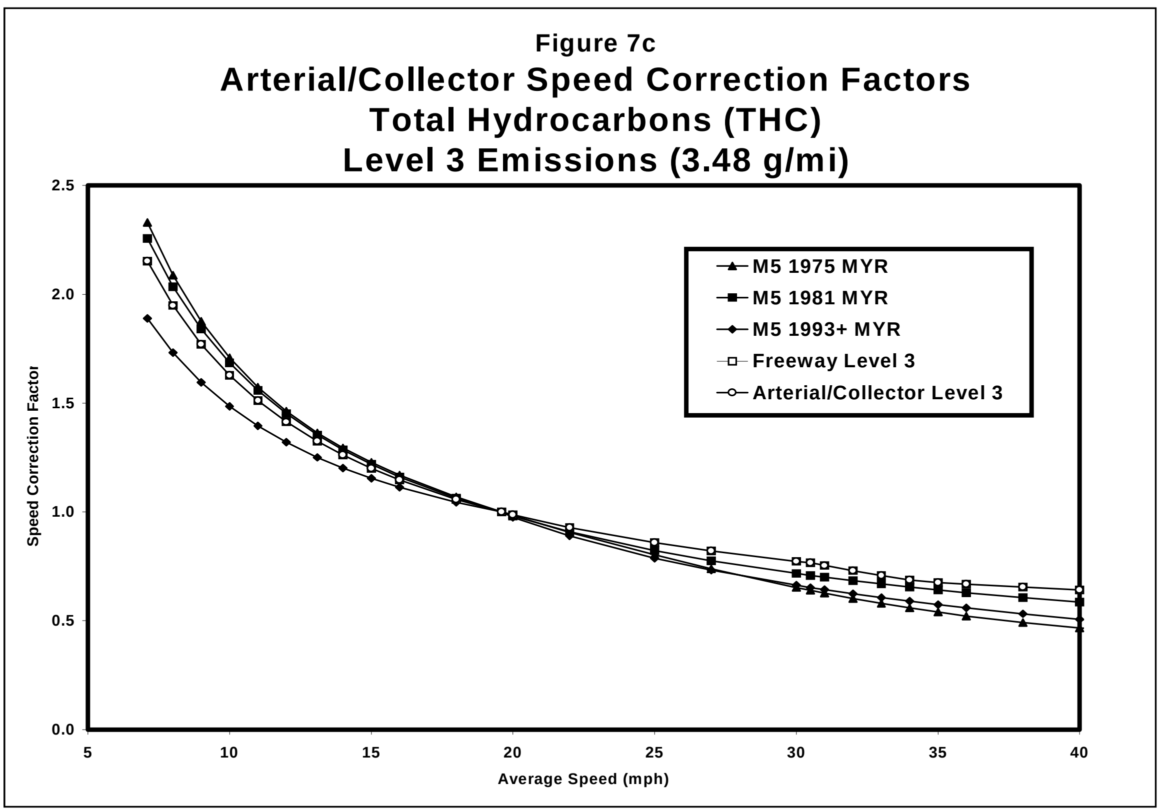


Figure 7c
Arterial/Collector Speed Correction Factors
Total Hydrocarbons (THC)
Level 3 Emissions (3.48 g/mi)
M5 1975 MYR
M5 1981 MYR
M5 1993+ MYR
Freeway Level 3
Arterial/Collector Level 3
Speed Correction Factor
Average Speed (mph)
2.5
2.0
1.5
1.0
0.5
0.0
5
10
15
20
25
30
35
40

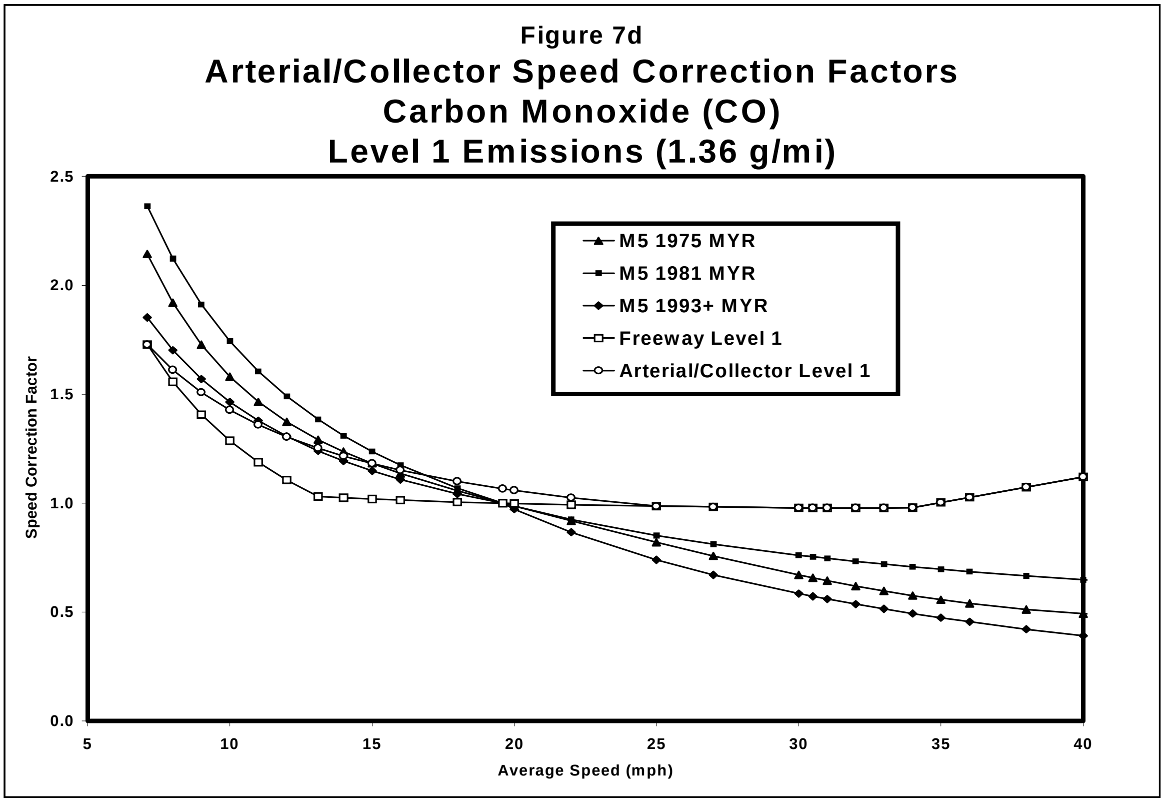


Figure 7d
Arterial/Collector Speed Correction Factors
Carbon Monoxide (CO)
Level 1 Emissions (1.36 g/mi)
Speed Correction Factor
Average Speed (mph)
M5 1975 MYR
M5 1981 MYR
M5 1993+ MYR
Freeway Level 1
Arterial/Collector Level 1
0.0
0.5
1.0
1.5
2.0
2.5
5
10
15
20
25
30
35
40

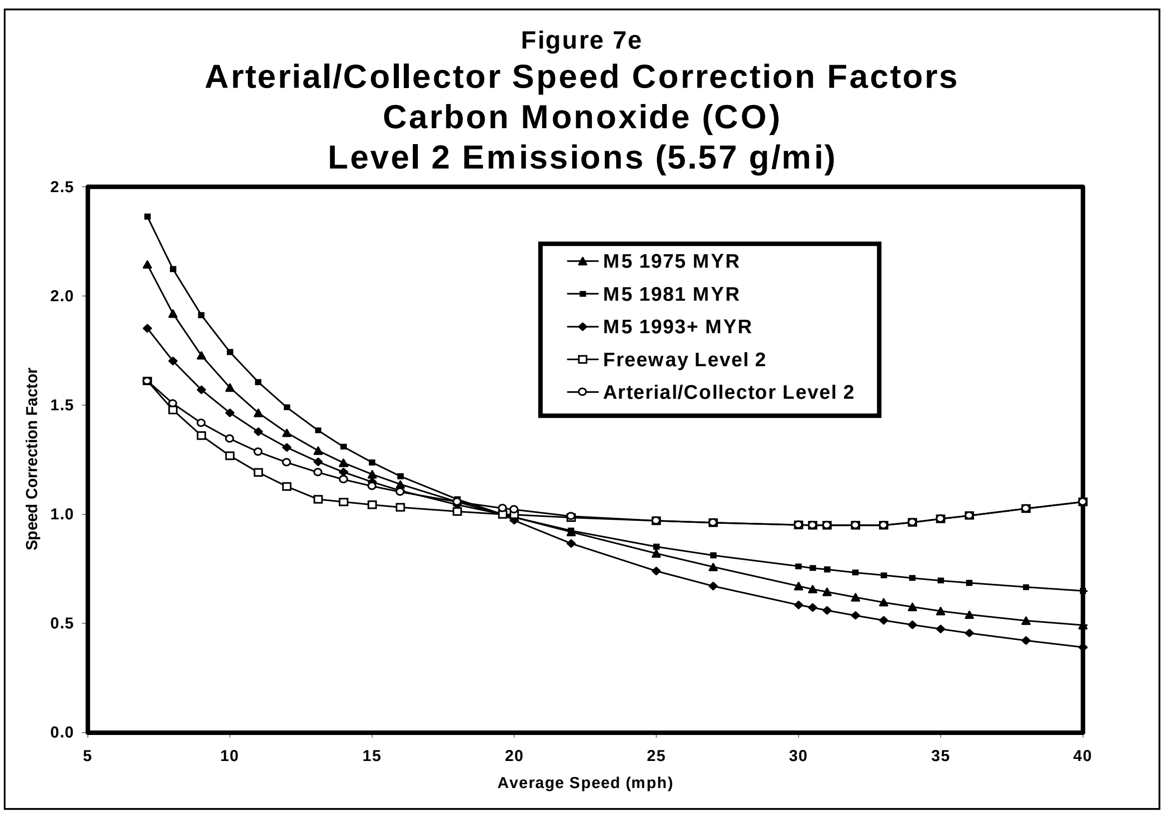


Figure 7e
Arterial/Collector Speed Correction Factors
Carbon Monoxide (CO)
Level 2 Emissions (5.57 g/mi)
Speed Correction Factor
Average Speed (mph)
M5 1975 MYR
M5 1981 MYR
M5 1993+ MYR
Freeway Level 2
Arterial/Collector Level 2
0.0
0.5
1.0
1.5
2.0
2.5
5
10
15
20
25
30
35
40

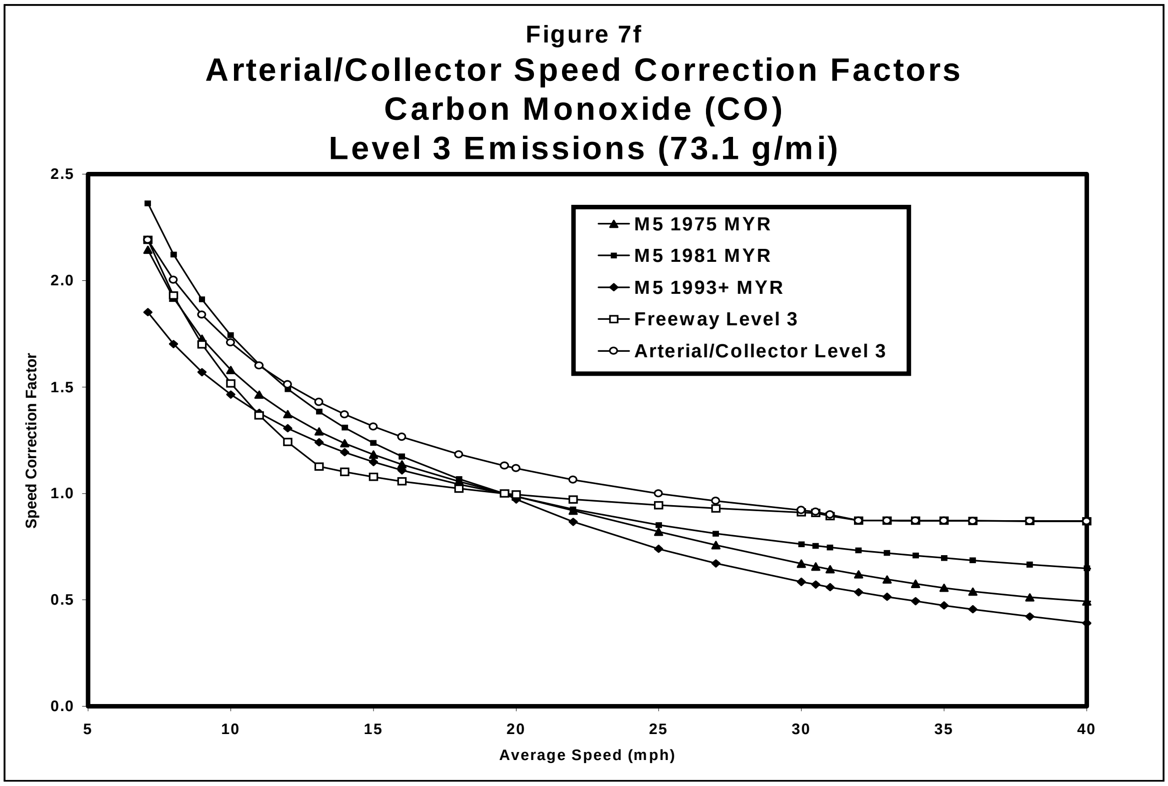


Figure 7f
Arterial/Collector Speed Correction Factors
Carbon Monoxide (CO)
Level 3 Emissions (73.1 g/mi)
M5 1975 MYR
M5 1981 MYR
M5 1993+ MYR
Freeway Level 3
Arterial/Collector Level 3
Speed Correction Factor
Average Speed (mph)
0.0
0.5
1.0
1.5
2.0
2.5
5
10
15
20
25
30
35
40

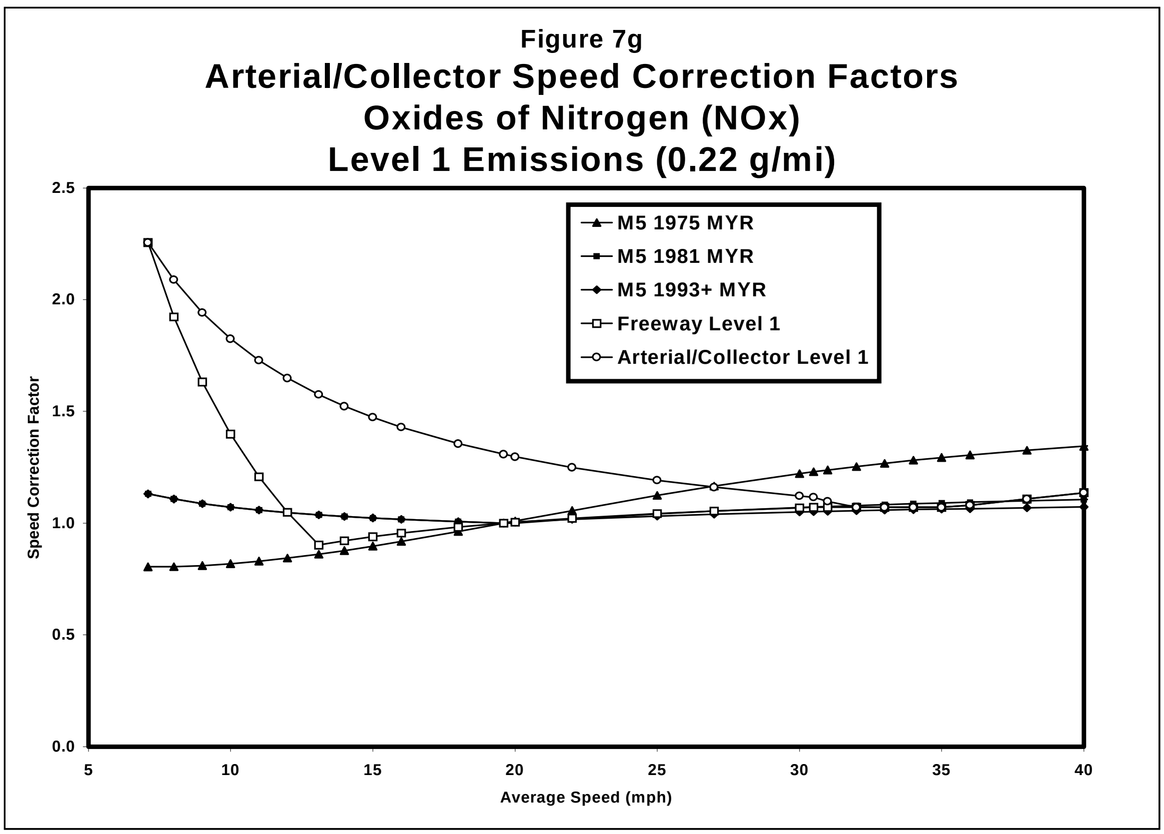


Figure 7g
Arterial/Collector Speed Correction Factors
Oxides of Nitrogen (NOx)
Level 1 Emissions (0.22 g/mi)
M5 1975 MYR
M5 1981 MYR
M5 1993+ MYR
Freeway Level 1
Arterial/Collector Level 1
Speed Correction Factor
Average Speed (mph)
0.0
0.5
1.0
1.5
2.0
2.5
5
10
15
20
25
30
35
40

Figure 7h

Arterial/Collector Speed Correction Factors
Oxides of Nitrogen (NOx)
Level 2 Emissions (0.71 g/mi)

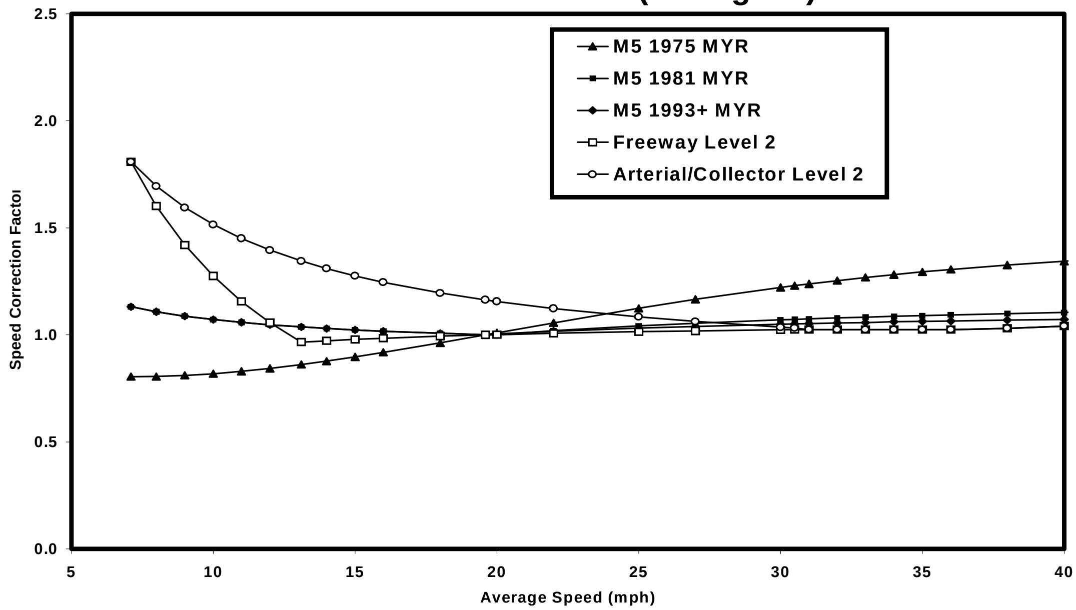


Figure 7i

Arterial/Collector Speed Correction Factors
Oxides of Nitrogen (NOx)
Level 3 Emissions (3.25 g/mi)

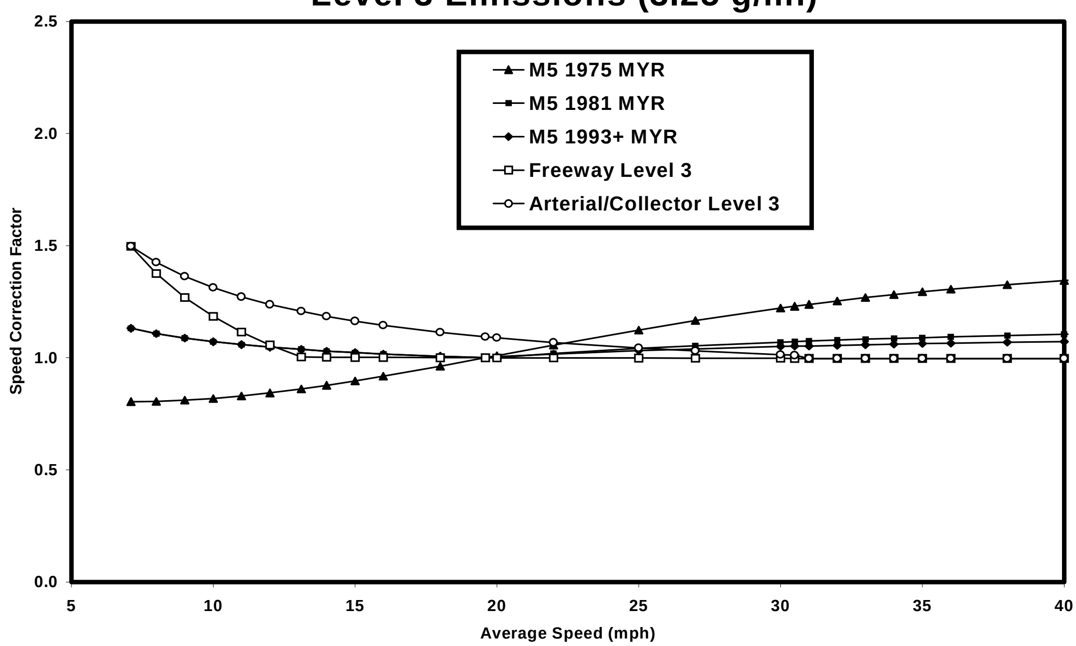


Figure 8a
CO Off-Cycle Emissions

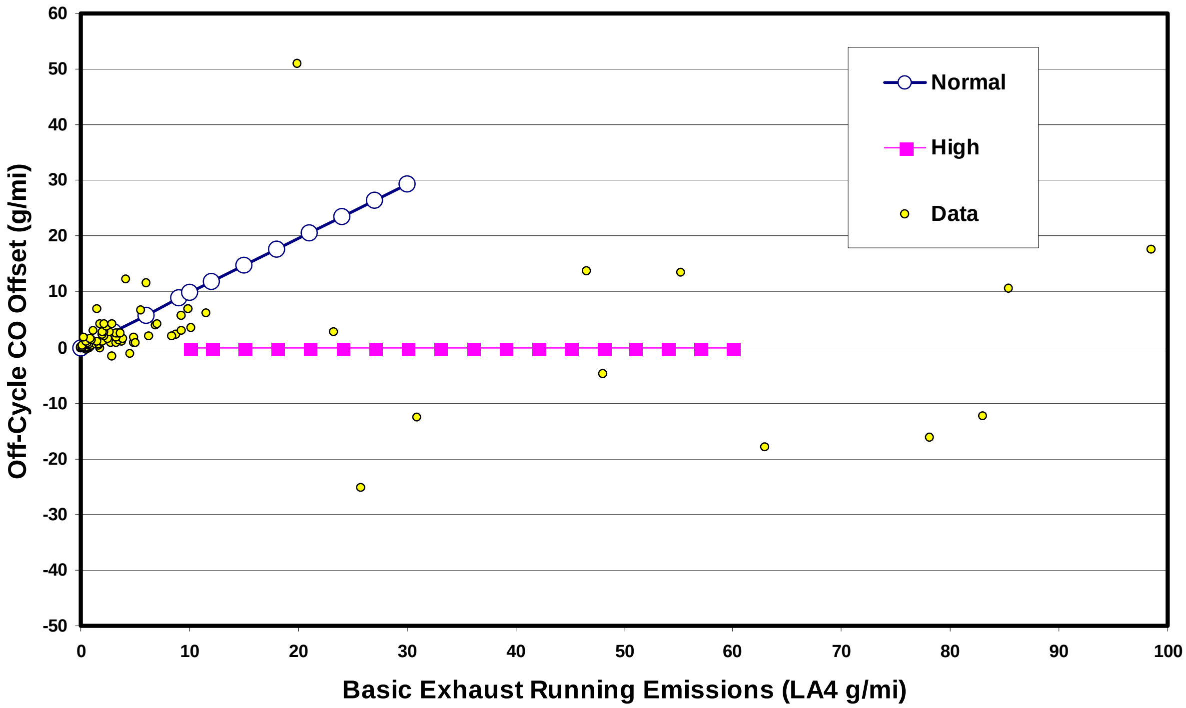


Figure 8b
THC Off-Cycle Emissions

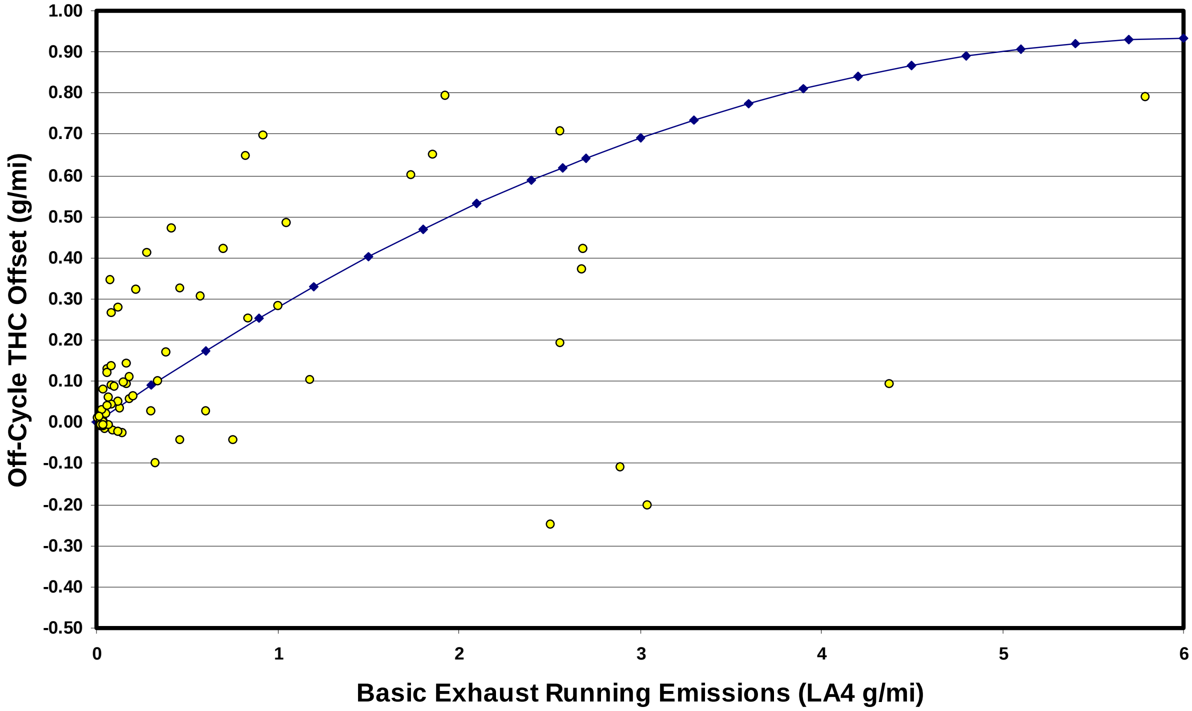


Figure 8c
NOx Off-Cycle Emissions

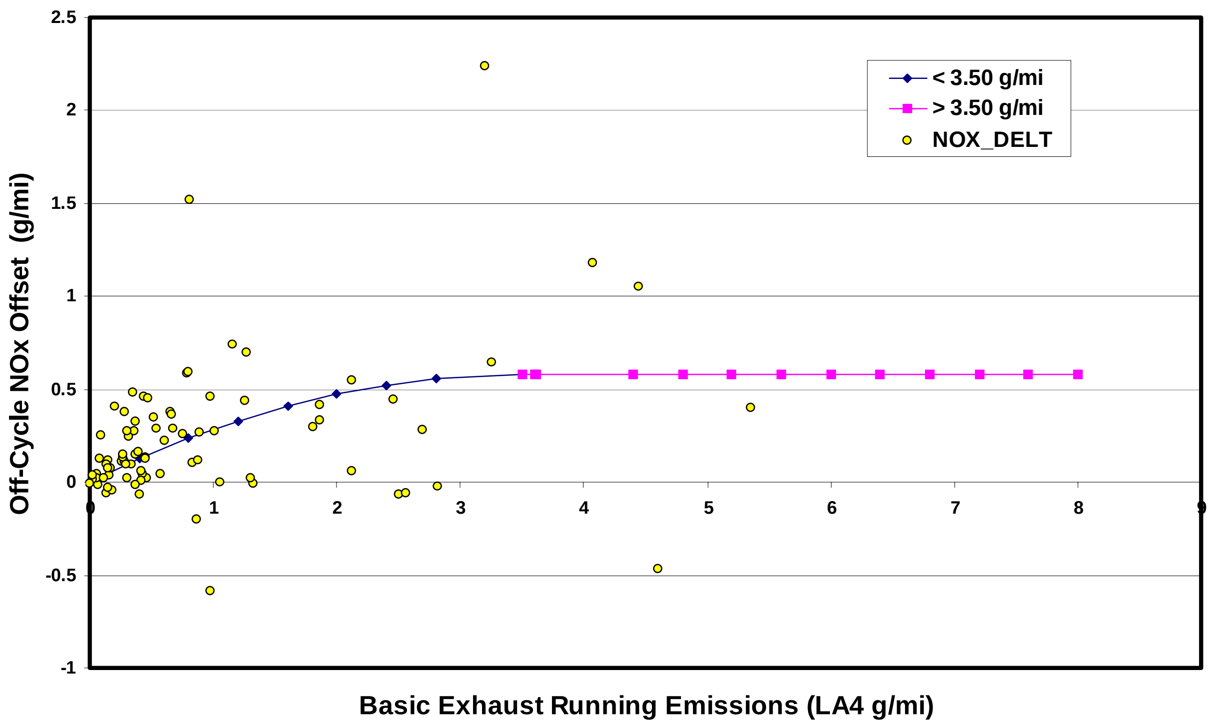


Figure 9a

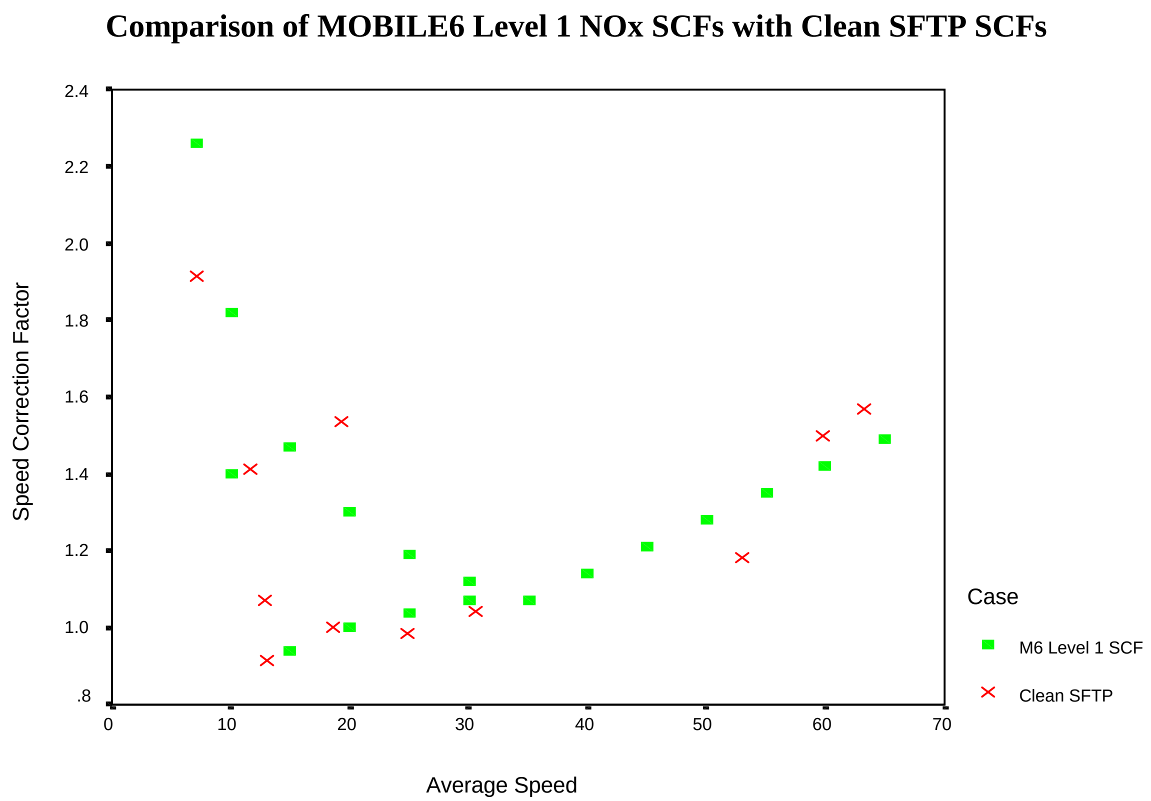
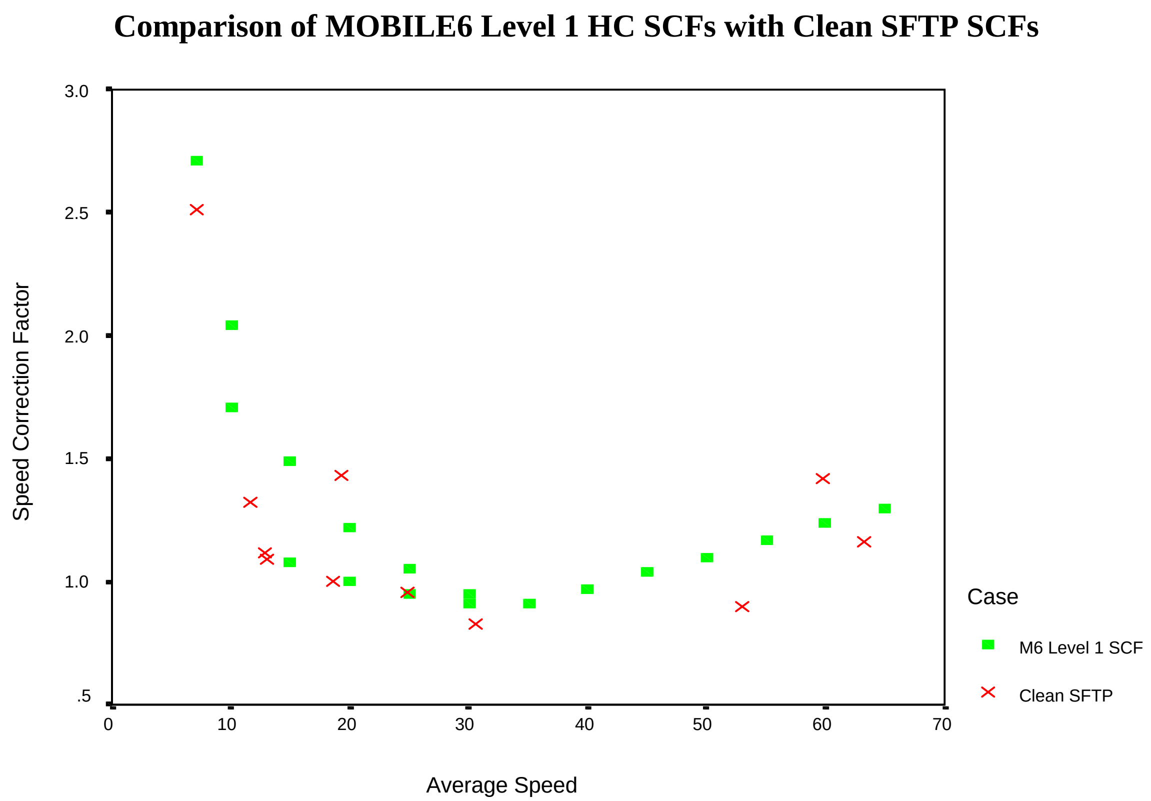

Comparison of MOBILE6 Level 1 NOx SCFs with Clean SFTP SCFs
Speed Correction Factor
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
0
10
20
30
40
50
60
70
Average Speed
Case
M6 Level 1 SCF
Clean SFTP

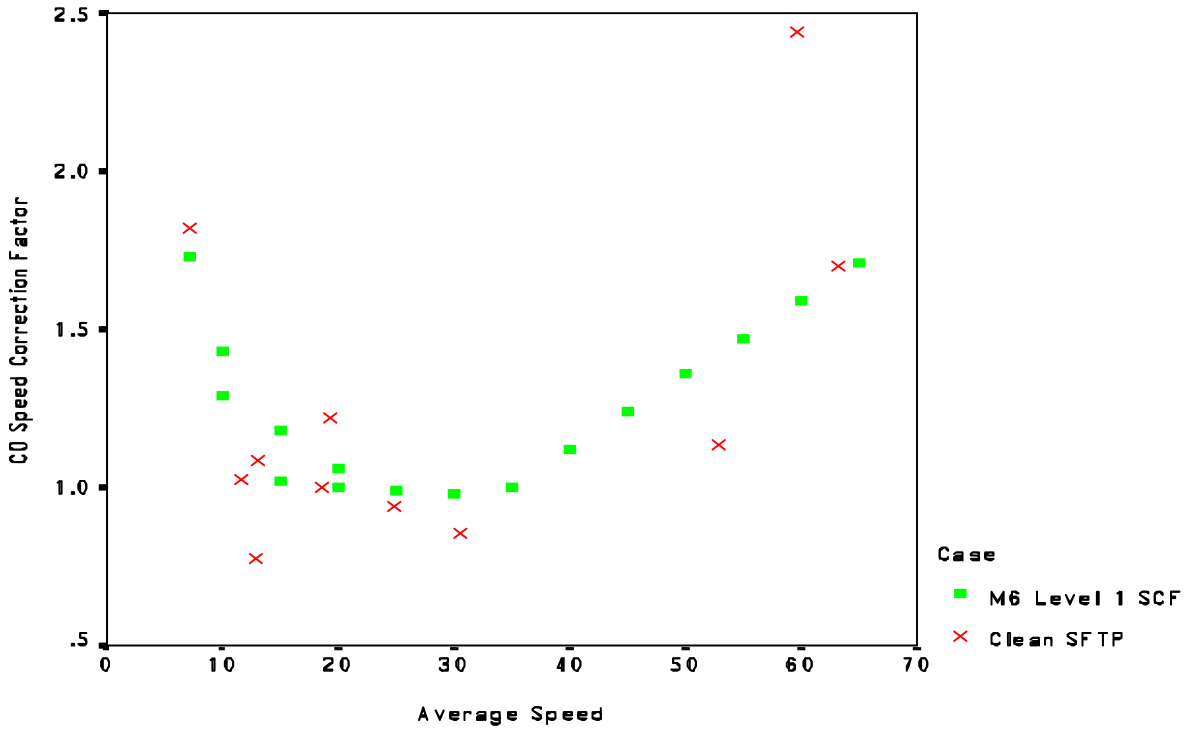
Figure 9b



Comparison of MOBILE6 Level 1 HC SCFs with Clean SFTP SCFs
Speed Correction Factor
3.0
2.5
2.0
1.5
1.0
.5
0
10
20
30
40
50
60
70
Average Speed
Case
M6 Level 1 SCF
Clean SFTP

Figure 9c

Comparison of MOBILE6 Level 1 CO SCFs with Clean SFTP CO SCFs



Appendices

MAIN EFFECTS & INTERACTIONS WITH SPEED

All Vehicles

FACTOR	THC	NMHC	CO	NOX
S	0.0000	0.0001	0.0000	0.0000
EMIT_CLASS	0.0000	0.0000	0.0000	0.0000
S*EMIT_CLASS	0.1411	0.1271	0.0152	0.9894

EMIT NORMAL - ACTUAL TIER CLASS

ROAD	FACTOR	THC	NMHC	CO	NOX
ART/FWY	ROADTYPE	0.0046	0.0050	0.0006	0.0000
	S*ROADTYPE	0.0354	0.0440	0.0020	0.0000
	VEH_TYPE	0.0016	0.0404	0.0031	0.0012
	S*VEH_TYPE	0.1754	0.1802	0.8680	0.5723
	STANDARD	0.0000	0.0000	0.0000	0.0000
	S*STANDARD	0.0002	0.0001	0.0576	0.6491
LOCAL	VEH_TYPE	0.0830	0.5008	0.4038	0.0124
	STANDARD	0.0000	0.0000	0.0000	0.0028
RAMP	VEH_TYPE	0.2922	0.7707	0.0443	0.0018
	STANDARD	0.0003	0.0007	0.0002	0.0000

EMIT HIGH - ACTUAL TIER CLASS

ROAD	FACTOR	THC	NMHC	CO	NOX
ART/FWY	ROADTYPE	0.1236	0.1307	0.3307	0.0000
	S*ROADTYPE	0.1176	0.1203	0.6233	0.0000
	VEH_TYPE	0.5942	0.5693	0.8984	0.3961
	S*VEH_TYPE	0.0641	0.0699	0.0241	0.9560
	STANDARD	N/A	N/A	N/A	N/A
	S*STANDARD	N/A	N/A	N/A	N/A
LOCAL	VEH_TYPE	0.8787	0.8821	0.5511	0.6093
	STANDARD	N/A	N/A	N/A	N/A
RAMP	VEH_TYPE	0.3701	0.4075	0.1471	0.6942
	STANDARD	N/A	N/A	N/A	N/A

EMIT NORMAL - CLEAN TIER 0 CLASS

ROAD	FACTOR	THC	NMHC	CO	NOX
ART/FWY	ROADTYPE	0.0046	0.0050	0.0006	0.0000
	S*ROADTYPE	0.0354	0.0440	0.0020	0.0000
	VEH_TYPE	0.0004	0.0243	0.0062	0.0026
	S*VEH_TYPE	0.1322	0.1476	0.8361	0.5608
	CLEANT0	0.0000	0.0000	0.0000	0.0000
	S*CLEANT0	0.0002	0.0001	0.0576	0.6491
LOCAL	VEH_TYPE	0.0572	0.4049	0.1660	0.0184
	CLEANT0	0.0000	0.0000	0.0000	0.0028
RAMP	VEH_TYPE	0.1570	0.5501	0.0201	0.0009
	CLEANT0	0.0003	0.0007	0.0002	0.0000

EMIT HIGH - CLEAN TIER 0 CLASS

ROAD	FACTOR	THC	NMHC	CO	NOX
ART/FWY	ROADTYPE	0.1236	0.1307	0.3307	0.0000
	S*ROADTYPE	0.1176	0.1203	0.6233	0.0000
	VEH_TYPE	0.5942	0.5693	0.8984	0.3961
	S*VEH_TYPE	0.0641	0.0699	0.0241	0.9560
	CLEANT0	.	.	.	.
	S*CLEANT0	.	.	.	.
LOCAL	VEH_TYPE	0.8787	0.8821	0.5511	0.6093
	CLEANT0	.	.	.	.
RAMP	VEH_TYPE	0.3701	0.4075	0.1471	0.6942
	CLEANT0	.	.	.	.

EMIT NORMAL

ROAD	FACTOR	P THC PROB	P NMHC PROB	P CO PROB	P NOX PROB
ART/FWY	ROADWAY TYPE	0.0001	0.0000	0.0405	0.0000
	VEHICLE CLASS	0.0000	0.0640	0.0000	0.0000
	STANDARD	0.0000	0.0000	0.0000	0.0000
LOCAL	VEHICLE CLASS	0.1017	0.5022	0.1380	0.0408
	STANDARD	0.0000	0.0000	0.0000	0.0000
RAMP	VEHICLE CLASS	0.2047	0.6109	0.0213	0.0035
	STANDARD	0.0000	0.0000	0.0000	0.0000

EMIT HIGH

ROAD	FACTOR	P THC PROB	P NMHC PROB	P CO PROB	P NOX PROB
ART/FWY	ROADWAY TYPE	0.9736	0.9570	0.0151	0.0201
	VEHICLE CLASS	0.0667	0.0873	0.0004	0.1444
	STANDARD	.	.	.	.

Note: these probabilities are for tests of factor main effects, not interactions with speed.

EMIT NORMAL - CLEAN TIER 0 CLASS

ROAD	FACTOR	THC	NMHC	CO	NOX
ART/FWY	ROADTYPE	0.0001	0.0000	0.0405	0.0000
	VEH_TYPE	0.0000	0.0186	0.0000	0.0000
	STANDARD	0.0000	0.0000	0.0000	0.0000
LOCAL	VEH_TYPE	0.0572	0.4049	0.1660	0.0184
	STANDARD	0.0000	0.0000	0.0000	0.0028
RAMP	VEH_TYPE	0.1570	0.5501	0.0201	0.0009
	STANDARD	0.0003	0.0007	0.0002	0.0000

EMIT NORMAL - ACTUAL TIER CLASS

ROAD	FACTOR	THC	NMHC	CO	NOX
ART/FWY	ROADTYPE	0.0001	0.0000	0.0405	0.0000
	VEH_TYPE	0.0000	0.0686	0.0001	0.0000
	STANDARD	0.0000	0.0000	0.0000	0.0000
LOCAL	VEH_TYPE	0.0830	0.5008	0.4038	0.0124
	STANDARD	0.0002	0.0001	0.0000	0.0024
RAMP	VEH_TYPE	0.2922	0.7707	0.0443	0.0018
	STANDARD	0.0013	0.0002	0.0001	0.0010

EMIT HIGH

ROAD	FACTOR	THC	NMHC	CO	NOX
ART/FWY	ROADTYPE	0.9736	0.9570	0.0151	0.0201
	VEH_TYPE	0.0667	0.0873	0.0004	0.1444
	STANDARD	.	.	.	.
LOCAL	VEH_TYPE	0.8787	0.8821	0.5511	0.6093
	STANDARD	.	.	.	.
RAMP	VEH_TYPE	0.3701	0.4075	0.1471	0.6942
	STANDARD	.	.	.	.

GLM P-VALUES FOR MODELS WITH NO SPEED INTERACTIONS (FROM FACVEHA.SAS)

EMIT NORMAL - CLEAN TIER 0 CLASS

ROAD	FACTOR	P THC PROB	P NMHC PROB	P CO PROB	P NOX PROB
ART/FWY	S*ROADTYPE	0.0354	0.0440	0.0020	0.0000
	S*VEH_TYPE	0.1322	0.1476	0.8361	0.5608
	S*STANDARD	0.0002	0.0001	0.0576	0.6491

EMIT HIGH - CLEAN TIER 0 CLASS

ROAD	FACTOR	P THC PROB	P NMHC PROB	P CO PROB	P NOX PROB
ART/FWY	S*ROADTYPE	0.1176	0.1203	0.6233	0.0000
	S*VEH_TYPE	0.0641	0.0699	0.0241	0.9560
	S*STANDARD	.	.	.	.

EMIT NORMAL - CLEAN ACTUAL TIER CLASS

ROAD	FACTOR	P THC PROB	P NMHC PROB	P CO PROB	P NOX PROB
ART/FWY	S*ROADTYPE	0.0354	0.0440	0.0020	0.0000
	S*VEH_TYPE	0.1754	0.1802	0.8680	0.5723
	S*STANDARD	0.0024	0.0020	0.0560	0.0151

EMIT HIGH - CLEAN ACTUAL TIER CLASS

ROAD	FACTOR	P THC PROB	P NMHC PROB	P CO PROB	P NOX PROB
ART/FWY	S*ROADTYPE	0.1176	0.1203	0.6233	0.0000
	S*VEH_TYPE	0.0641	0.0699	0.0241	0.9560
	S*STANDARD	.	.	.	.

GLM P-VALUES FOR MODELS WITH NO SPEED INTERACTIONS (FROM FACVEHA.SAS)

EMIT NORMAL - CLEAN TIER 0 CLASS

ROAD	FACTOR	P THC PROB	P NMHC PROB	P CO PROB	P NOX PROB
ART/FWY	ROADTYPE	0.0046	0.0050	0.0006	0.0000
	VEH_TYPE	0.0004	0.0243	0.0062	0.0026
	STANDARD	0.0000	0.0000	0.0000	0.0000

EMIT HIGH - CLEAN TIER 0 CLASS

ROAD	FACTOR	P THC PROB	P NMHC PROB	P CO PROB	P NOX PROB
ART/FWY	ROADTYPE	0.1236	0.1307	0.3307	0.0000
	VEH_TYPE	0.5942	0.5693	0.8984	0.3961
	STANDARD	.	.	.	.

EMIT NORMAL - CLEAN ACTUAL TIER CLASS

ROAD	FACTOR	P THC PROB	P NMHC PROB	P CO PROB	P NOX PROB
ART/FWY	ROADTYPE	0.0046	0.0050	0.0006	0.0000
	VEH_TYPE	0.0016	0.0404	0.0031	0.0012
	STANDARD	0.0000	0.0000	0.0000	0.0000

EMIT HIGH - CLEAN ACTUAL TIER CLASS

ROAD	FACTOR	P THC PROB	P NMHC PROB	P CO PROB	P NOX PROB
ART/FWY	ROADTYPE	0.1236	0.1307	0.3307	0.0000
	VEH_TYPE	0.5942	0.5693	0.8984	0.3961
	STANDARD	.	.	.	.

GLM P-VALUES FOR MODELS WITH NO SPEED INTERACTIONS (FROM FACVEHA.SAS)

Regression statistics for CO Off-Cycle Emissions Analysis (Normal emitters)

Variables Entered/Removed(a,b)

Model	Variables Entered	Variables Removed	Method
1	LA4COSQR	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).
2	LA4CO	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).
a Dependent Variable: CO_DELT			
b Linear Regression through the Origin			

Model Summary

Model	R	R Square(a)	Adjusted R Square	Std. Error of the Estimate
1	.678(b)	.459	.450	3.0755
2	.889(c)	.791	.784	1.9279
a For regression through the origin (the no-intercept model), R Square measures the proportion of the variability in the dependent variable about the origin explained by regression. This CANNOT be compared to R Square for models which include an intercept.				
b Predictors: LA4COSQR				
c Predictors: LA4COSQR, LA4CO				

ANOVA(d,e)

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	497.694	1	497.694	52.618	.000(a)
	Residual	586.440	62	9.459		
	Total	1084.134(b)	63			
2	Regression	857.399	2	428.700	115.336	.000(c)
	Residual	226.735	61	3.717		
	Total	1084.134(b)	63			
a Predictors: LA4COSQR						
b This total sum of squares is not corrected for the constant because the constant is zero for regression through the origin.						
c Predictors: LA4COSQR, LA4CO						
d Dependent Variable: CO_DELT						
e Linear Regression through the Origin						

Coefficients(a,b)

		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
Model		B	Std. Error	Beta			Lower Bound	Upper Bound
1	LA4COSQR	-3.277E-02	.005	-.678	-7.254	.000	-.042	-.024
2	LA4COSQR	-7.638E-02	.005	-1.579	-14.520	.000	-.087	-.066
	LA4CO	.984	.100	1.070	9.837	.000	.784	1.184
a Dependent Variable: CO_DELT								
b Linear Regression through the Origin								

Regression statistics for CO Off-Cycle Emissions Analysis (Normal emitters)

Excluded Variables(c,d)

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	LA4CO	1.070(a)	9.837	.000	.783	.290
	FINJ	.500(a)	6.731	.000	.653	.923
	VTYP	.416(a)	5.120	.000	.548	.939
	MODEL_YR	.470(a)	6.206	.000	.622	.946
2	FINJ	.064(b)	.638	.526	.082	.341
	VTYP	-.035(b)	-.397	.693	-.051	.442
	MODEL_YR	.037(b)	.395	.694	.051	.388

a Predictors in the Model: LA4COSQR
b Predictors in the Model: LA4COSQR, LA4CO
c Dependent Variable: CO_DELT
d Linear Regression through the Origin

Regression statistics for CO Off-Cycle Emissions Analysis (High Emitters)

Case Processing Summary

		Cases					
		Valid		Missing		Total	
	HIGHCO	N	Percent	N	Percent	N	Percent
CO_DELT	Normal	63	100.0%	0	.0%	63	100.0%
	High	22	100.0%	0	.0%	22	100.0%
LA4CO	Normal	63	100.0%	0	.0%	63	100.0%
	High	22	100.0%	0	.0%	22	100.0%

Regression statistics for CO Off-Cycle Emissions Analysis (High Emitters)

Descriptives

	HIGHCO			Statistic	Std. Error
CO_DELT	**Normal**	**Mean**		1.1968	.5044
		95% Confidence Interval for Mean	**Lower Bound**	.1884	
			Upper Bound	2.2051	
		5% Trimmed Mean		1.3587	
		Median		1.0782	
		Variance		16.031	
		Std. Deviation		4.0038	
		Minimum		-25.29	
		Maximum		12.42	
		Range		37.71	
		Interquartile Range		2.1735	
		Skewness		-4.346	.302
		Kurtosis		32.170	.595
	High	**Mean**		-1.9790	7.2988
		95% Confidence Interval for Mean	**Lower Bound**	-17.1576	
			Upper Bound	13.1996	
		5% Trimmed Mean		1.7699	
		Median		5.0273	
		Variance		1171.982	
		Std. Deviation		34.2342	
		Minimum		-128.76	
		Maximum		51.06	
		Range		179.82	
		Interquartile Range		24.5018	
		Skewness		-2.481	.491
		Kurtosis		9.106	.953
LA4CO	**Normal**	**Mean**		2.73210603	.45566035
		95% Confidence Interval for Mean	**Lower Bound**	1.82125397	
			Upper Bound	3.64295809	
		5% Trimmed Mean		2.25774861	
		Median		1.98924000	
		Variance		13.080	
		Std. Deviation		3.61669191	
		Minimum		.019160	
		Maximum		25.774990	
		Range		25.755830	
		Interquartile Range		2.76831000	
		Skewness		4.438	.302
		Kurtosis		26.534	.595
	High	**Mean**		57.94719000	13.56327504
		95% Confidence Interval for Mean	**Lower Bound**	29.74081545	
			Upper Bound	86.15356455	
		5% Trimmed Mean		51.19508025	
		Median		38.69987500	
		Variance		4047.173	
		Std. Deviation		63.61739899	
		Minimum		1.729990	
		Maximum		239.809000	
		Range		238.079010	
		Interquartile Range		73.66766000	
		Skewness		1.631	.491
		Kurtosis		2.391	.953

Regression statistics for HC Off-Cycle Emissions Analysis

Variables Entered/Removed(b,c)

Model	Variables Entered	Variables Removed	Method
1	LA4HCSQR, LA4HC(a)	.	Enter

a All requested variables entered.
b Dependent Variable: THC_DELT
c Linear Regression through the Origin

Model Summary

Model	R	R Square(a)	Adjusted R Square	Std. Error of the Estimate
1	.255(b)	.065	.043	1.1960

a For regression through the origin (the no-intercept model), R Square measures the proportion of the variability in the dependent variable about the origin explained by regression. This CANNOT be compared to R Square for models which include an intercept.
b Predictors: LA4HCSQR, LA4HC

ANOVA(c,d)

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	8.268	2	4.134	2.890	.061(a)
	Residual	118.715	83	1.430		
	Total	126.982(b)	85			

a Predictors: LA4HCSQR, LA4HC
b This total sum of squares is not corrected for the constant because the constant is zero for regression through the origin.
c Dependent Variable: THC_DELT
d Linear Regression through the Origin

Coefficients(a,b)

		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
Model		B	Std. Error	Beta			Lower Bound	Upper Bound
1	LA4HC	.305	.134	.571	2.283	.025	.039	.570
	LA4HCSQR	-2.492E-02	.014	-.437	-1.748	.084	-.053	.003

a Dependent Variable: THC_DELT
b Linear Regression through the Origin

Regression statistics for NOx Off-Cycle Emissions Analysis

Variables Entered/Removed(b,c)

Model	Variables Entered	Variables Removed	Method
1	LA4NOSQR, LA4NOX(a)	.	Enter
a All requested variables entered.			
b Dependent Variable: NOX_DELT			
c Linear Regression through the Origin			

Model Summary

Model	R	R Square(a)	Adjusted R Square	Std. Error of the Estimate
1	.615(b)	.378	.363	.3521
a For regression through the origin (the no-intercept model), R Square measures the proportion of the variability in the dependent variable about the origin explained by regression. This CANNOT be compared to R Square for models which include an intercept.				
b Predictors: LA4NOSQR, LA4NOX				

ANOVA(c,d)

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	6.253	2	3.126	25.219	.000(a)
	Residual	10.289	83	.124		
	Total	16.542(b)	85			
a Predictors: LA4NOSQR, LA4NOX						
b This total sum of squares is not corrected for the constant because the constant is zero for regression through the origin.						
c Dependent Variable: NOX_DELT						
d Linear Regression through the Origin						

Coefficients(a,b)

		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
Model		B	Std. Error	Beta			Lower Bound	Upper Bound
1	LA4NOX	.332	.066	1.107	4.998	.000	.200	.464
	LA4NOSQR	-4.745E-02	.018	-.582	-2.627	.010	-.083	-.012
a Dependent Variable: NOX_DELT								
b Linear Regression through the Origin								

Appendix B : Example

Example Application of Speed Adjustment to Exhaust Emissions

The following description is meant as an example of how the basic exhaust emission rates estimated by MOBILE6 will be adjusted for the effects of average speed and roadway type. The example will show how the various parts of the overall emission estimate are weighted together. It is beyond the scope of this document to explain fully the derivation of the basic exhaust emission estimates or the weighting factors. The derivation of these distributions are described in other documents. It is also not the intent of this example to reveal the values for emissions or weighting factors that are used in MOBILE6. All of the values shown in this example should, therefore, be considered as draft and may not match values shown in other documents. This should not detract from the value of this example in showing the process of how the basic emission rates are adjusted for speed.

Basic Emission Rates

For each scenario, MOBILE6 will calculate a basic exhaust emission rate (BER) for two emission levels (high and normal) for each pollutant for each model year for each vehicle class. The basic unit for the BER is the hot running LA4 (with an average speed of 19.6 mph) at standard operating conditions (i.e., temperature, humidity, etc.). The effect of engine starts on emissions is calculated separately and is not adjusted for the effects of average speed.

MOBILE6 calculates the emissions for each hour of the day, so the first step is to adjust the BER for the conditions that affect exhaust emissions. For example, the temperature at 6 a.m. will be different than the temperature at 1 p.m., so the BER at 6 a.m. will not be the same as the BER at 1 p.m. after adjustment for temperature. Some adjustments (such as the effects of fuel sulfur content) will not vary by time of day. Ultimately, there will be 24 values, one for each hour of the day calculated from the same BER, adjusted for hourly conditions. There will be two sets of adjusted BER values, one for normal emissions and one for high emitters.

Example Basic Emission Rates

For this example, we will follow the calculation of NOx emissions from a 1990 model year passenger car. The calculation would be similar for the other pollutants and other vehicle classes. This example will not fabricate values for all hours. The calculations will be similar in all hours, so a single hour example is all that should be required. So, for a given hour, the NOx emissions (BERs) for our vehicles will be assumed to be:

- 0.65 g/mi for normal emitters
- 2.10 g/mi for high emitters

After adjustment, these values must be weighted together by their occurrence in the fleet. The number of high emitters will depend on many things (i.e., age, I/M programs, OBD, etc.), but for our example, we will assume that high emitters are 10% of 1990 model year passenger cars in this scenario.

Freeway Ramps and Local Roadways

There are four basic roadway types; freeways, arterial/collectors, freeway ramps and local roadways. The freeway ramps and local roadways can be determined directly from the BER, since they do not vary with average speed. The freeway ramp and local roadway emissions are a function of the BER (see Table 13). The NOx BERs we will use (described above) are in grams per mile units and must be converted to grams per hour. The average speed of the hot running LA4 is 19.6 miles per hour. For normal emitters, 0.65 grams per mile times 19.6 miles per hour is 12.74 grams per hour. For high emitters, 2.10 grams per mile times 19.6 miles per hour is 41.16 grams per hour. Using the equation shown in Table 13, the freeway ramp and local roadway emissions in grams per hour are:

Normal Ramp = $5.353 + 2.863*(12.74) - 0.0101*(12.74)^2 = 40.19$ g/hr
Normal Local = $1.870 + 0.701*(12.74) + 0.000609*(12.74)^2 = 10.90$ g/hr

High Ramp = $5.353 + 2.863*(41.16) - 0.0101*(41.16)^2 = 106.08$ g/hr
High Local = $1.870 + 0.701*(41.16) + 0.000609*(41.16)^2 = 31.75$ g/hr

The results will be weighted using VMT and must be converted to grams per mile units. The freeway ramp cycle has an average speed of 34.6 miles per hour and the local roadway cycle has an average speed of 12.9 miles per hour.

Normal Ramp = (40.19 g/hr) / 34.6 mph = 1.16 g/mi
Normal Local = (10.90 g/hr) / 12.9 mph = 0.84 g/mi

High Ramp = (106.08 g/hr) / 34.6 mph = 3.07 g/mi
High Local = (31.75 g/hr) / 12.9 mph = 2.46 g/mi

Since we have assumed that 10% of the vehicles are high emitters, we can now weight the normal and high emitter results to give a complete freeway ramp and local roadway estimate for the 1990 model year in this hour.

Freeway Ramp = 1.16* 0.90 + 3.07 * 0.10 = 1.35 g/mi
Local Roadway = 0.84 * 0.90 + 2.46 * 0.10 = 1.01 g/mi

Each hour will have its own basic exhaust emission rate. Since the Freeway Ramp and Local Roadway emission levels depend on the basic exhaust emission rate, a separate calculation will be done for each hour of the day.

Emission Offset

The emission offset (EO) represents the difference between the LA4-based BER and freeway emissions at 19.6 miles per hour. The values for the EO are shown in Table 14. Since the BER values lie between the LA4 values (0.591 and 3.245 g/mi) shown in Table 14, the EO must be calculated using interpolation.

Normal EO = 0.121 + ((0.008-0.121)/(3.245-0.591))*(0.65-0.591) = 0.12 g/mi
High EO = 0.121 + ((0.008-0.121)/(3.245-0.591))*(2.10-0.591) = 0.06 g/mi

An additional emission offset is used for arterial/collector roadways, however this offset depends on average speed and emissions. These are shown in Table 15. The ratio of the freeway emission level at each speed plus the arterial/collector offset for that speed, divided by the freeway emission level at 19.6 miles per hour is the arterial/collector speed correction factor. These are shown in Table 17.

Freeway Emissions

Freeway emissions depend on average speed. For each hour of the day, MOBILE6 has a default distribution of average speeds for freeways. Users will be able to enter local distributions of freeway average speeds. This is not the same as a distribution of speeds on a particular freeway.

The MOBILE6 default distribution of average speeds for freeways assumes that there are many freeways in the area and the distribution represents the average speeds observed from the different freeways at that hour. The cycles used to develop the speed correction factors each contain the entire range of vehicle speeds on freeways grouped by ranges of observed congestion. So, changing speed in the MOBILE6 model is changing the average speed of the combination of all vehicles on freeways. MOBILE6 does not effectively model the effect of average speed on individual vehicles or small groups of vehicles within a single freeway section. If you wish to model a specific freeway, you would want to reduce the default distribution down to a single, average speed for the freeway of interest.

In each hour, MOBILE6 will calculate values for each average speed "bin" from 5 to 65 mph in 5 mph increments and for 2.5 mph (14 speed bins) by applying the speed correction factors from Table 16 to the base freeway emission level at 19.6 mph. The base freeway emission level is simply the sum of the BER and the adjusted emission offset (EO).

Normal Base Freeway Emission at 19.6 mph = 0.65 + 0.12 = 0.77 g/mi
High Base Freeway Emission at 19.6 mph = 2.10 + 0.06 = 2.16 g/mi

There are three sets of speed correction factors in Table 16, one for each of three emission levels. Both the Normal and High base freeway emission levels we have calculated lie between the Level 2 and Level 3 emission levels, shown in Table 16. So the speed correction factor will be interpolated between the values for Level 2 and Level 3 in Table 16. However, these speed correction factors do not apply below 7.1 mph. MOBILE6 will use the MOBILE5 speed correction factors (See Table 1.6B in AP-42) for speeds below 7.1 mph. For our example, the NOx speed correction factors for the 1990 model year have A and B coefficients of 1.456 and 0.926 respectively, where the form of the equation is A/speed + B, resulting in the following speed correction factors:

SCF for 2.5 mph = (1.456/2.5) + 0.926 = 1.51
SCF for 5.0 mph = (1.456/5.0) + 0.926 = 1.22
SCF for 7.1 mph = (1.456/7.1) + 0.926 = 1.13

The MOBILE5 speed correction factor at 7.1 mph (1.13) was applied to all emission levels in MOBILE5. The MOBILE5 speed correction factors will be adjusted to match the speed correction factors in Table 16 for NOx at 7.1 mph of 2.26, 1.81 and 1.50 for emission levels 1, 2 and 3 respectively by adding the difference to each value.

Level 1 SCF for 2.5 mph = 1.51 + (2.26 - 1.13) = 2.63
Level 1 SCF for 5.0 mph = 1.22 + (2.26 - 1.13) = 2.34

Level 2 SCF for 2.5 mph = 1.51 + (1.81 - 1.13) = 2.19
Level 2 SCF for 5.0 mph = 1.22 + (1.81 - 1.13) = 1.90

Level 3 SCF for 2.5 mph = 1.51 + (1.50 - 1.13) = 1.87
Level 3 SCF for 5.0 mph = 1.22 + (1.50 - 1.13) = 1.58

Using the average emissions for each speed correction factor emission level (from Table 14) of 0.712 and 3.253 g/mi NOx for Level 2 and Level 3 respectively and the predicted base freeway emission rates of 0.77 and 2.16 g/mi for Normals and High categories, weighting factors can be derived for interpolating between the speed correction factors. The sum of the two weighting factors will equal 1.

Normal Level 2 Weighting = (3.253 - 0.77)/(3.253 - 0.712) = 0.978
Normal Level 3 Weighting = (1.0 - 0.978) = 0.022

High Level 2 Weighting = (3.253 - 2.16)/(3.253 - 0.712) = 0.431
High Level 3 Weighting = (1.0 - 0.431) = 0.569

These weighting factors are used to combine the Level 2 and Level 3 speed correction factors for the calculated base freeway emission case. A new weighted speed correction factor is calculated for each of the fourteen speed bins for Normals and Highs. For example, the 10 mph speed bin speed correction factors (using values from Table 16) would be:

Normal SCF for 10 mph = 0.978 * 1.28 + 0.022 * 1.18 = 1.28
High SCF for 10 mph = 0.431 * 1.28 + 0.569 * 1.18 = 1.22

These speed correction factors are applied to the predicted base freeway emission rates to determine speed corrected emission rates for each speed bin. For example the speed corrected emission rates for the 10 mph speed bin would be:

Normal emission level for 10 mph = 1.28 * 0.77 = 0.99 g/mi
High emission level for 10 mph = 1.22 * 2.16 = 2.64 g/mi

Each hour has a default VMT distribution of average freeway speeds that correspond to these speed bins. The emission rates for each of the bins can be weighted, using this VMT distribution, to give a composite freeway emission rate. This weighting is repeated for normal and high emitters, and the two emitter groups can be combined to give an overall freeway NOx emission rate for 1990 model year vehicles for that hour of the day.

Arterial/Collector Emissions

The arterial/collector speed correction factors shown in Table 17 are applied to the base freeway emission rate calculated for the freeway emission levels. Since the three emission level groups are identical for arterial/collector roadways and freeways, the same weighting factors are used to interpolate between the speed correction factors. For example, the 10 mph speed bin speed correction factors (using values from Table 17) would be:

Normal SCF for 10 mph = 0.978 * 1.52 + 0.022 * 1.31 = 1.52
High SCF for 10 mph = 0.431 * 1.52 + 0.569 * 1.31 = 1.40

These speed correction factors are applied to the base freeway emission levels to determine emission levels for each speed bin. For example the emission levels for the 10 mph speed bin would be:

Normal emission level for 10 mph = 1.52 * 0.77 = 1.17 g/mi
High emission level for 10 mph = 1.40 * 2.16 = 3.02 g/mi

Since the speed correction factors for arterial/collectors (shown in Table 17) converge with freeway speed correction factors (shown in Table 16) at higher speeds and below 7.1 mph, the emission rate for arterial/collectors and freeways will be the same for some speed bins. All of the speed bins are combined, weighted by the fraction of VMT in that speed bin for that hour. The composite arterial/collector emissions for Normals and Highs are combined weighted by their proportions in the fleet for that model year.

Area-wide Emissions

Once a fleetwide (combined Normal and High), hourly (combined speed bins) estimate is available for each roadway type (freeway, arterial/collector, freeway ramp and local roadway), these estimates can be combined in a variety of ways, depending on the needs of the user. If an area-wide, hourly result is needed, the results for the four roadway types can be combined, weighted by the fraction of VMT for each roadway for that hour. An area-wide daily result can be obtained by combining the hourly results weighted by the VMT fraction for each hour. Although there are default values for the fraction of VMT for each roadway and the VMT fraction for each hour, users may substitute their own values.

Composite Engine Start and Running Emissions

The emission rates addressed in this document do not contain the effects of engine starts. The effect of engine start on emissions is calculated separately and is calculated in units of grams per engine start. These emission effects resulting from engine starts are not determined by roadway type and do not depend on average trip speed. They can, however, be combined with the running emissions to give an overall exhaust emission estimate.

Since the MOBILE6 model does not include a distribution of the effects of engine start on emissions by roadway type, the combination of the effects of engine start and running emissions is best done on area-wide (combined roadway) emission results. This can be done on an hourly or daily basis.

MOBILE6 has an estimate of the average daily vehicle miles traveled (VMT) for each model year in a given calendar year and a distribution of that average VMT over the day by hour. MOBILE6 also has an estimate for the number of engine starts per day and the distribution of those starts over the day by hour. For a given hour, the grams due to engine starts in that hour are calculated as:

Grams / Engine Start * Fraction of Starts in the Hour * Number of Starts / Day

This value can be converted to grams per mile by determination of the average number of miles traveled by vehicles in that hour:

Hourly VMT = Daily VMT * Fraction of VMT in the Hour

Once the effect of engine start on emissions is converted to grams per mile, it can be added directly to the area-wide emission estimate for that hour.

Total Exhaust = Engine Start / Hourly VMT + Area-wide Emissions for the Hour

Similarly, a daily total exhaust emission rate can be calculated. Although there are default values for the number of daily engine starts, the fraction of engine start in each hour, the daily VMT and the fraction of VMT in each hour, users may substitute their own values.

A calculation is done for each model year of each vehicle class. These values are weighted using travel fractions (as is done in MOBILE5) to calculate area-wide, daily emission rates for highway mobile sources.

FTP Emissions

The Federal Test Procedure (FTP) is a special case of vehicle driving. It can be simulated in MOBILE6 by careful choice of weighting factors for engine start soak time, vehicle miles traveled and roadway types. Since this case will be of special interest for comparison of MOBILE6 emission rates to Federal certification standards, we plan to build in the appropriate weighting factors so that calculation of FTP emission estimates using MOBILE6 can be done simply and consistently.

Appendix C : Response to Comments

Comment numbers refer to EPA indexing of comments received for easy reference. All EPA responses are shown in italics.

Lance Freeman, October 12, 1999:

I think there may be a fallacy, started by misinterpreting previous speed curves, that lower speeds are correlated to higher emissions. But I'm guessing that those speed curves were heavily weighted with emissions from the start mode.

*All of the speed correction driving cycles were done *without* engine starts, so engine starts are not a factor in the effect of low average speeds on emissions. However, since the speed correction factors are applied to emission levels in grams per mile, the corrections are very large for low speeds. This makes sense, since at low speeds you get very few miles (the denominator) for each gram of emissions generated. For example, at idle (average speed=0) the speed correction factor is infinite. So, at low speeds it often makes more sense to examine the emissions in terms of grams per unit of time (usually grams per hour). In those units, the effect of lower speeds on emissions is much different. EPA uses units of grams per mile for travel in MOBILE6, since we consider the miles traveled as the appropriate unit of work (i.e., purpose of travel) as opposed to travel as a way to spend your time. Mathematically, however, they should be equivalent.*

Sam Long, IL EPA (Comment #9) March 13, 1997:

Under “Transportation Models" section, the paragraph is not clear. It should be made clearer that 35 mph on a local street or collector (or even some arterials) would be a good speed, but would be slow and represent very congested conditions on a freeway. (I presume this is what was meant.)

Some additional text was added to clarify this issue.

HPMS facility types do not include specifically include on-and off-ramps, but quite often metropolitan planning organizations (MPOs) list [some] on-and off-ramps on their network. Data of this sort may or may not be readily available.

Guidance will be available to help areas determine appropriate inputs for MOBILE6. Default values will be available for issues such as the fraction of freeway VMT that occurs on freeway ramps.

What is a "micro trip"? (One one thousandth of a mile is 5ft!)

A "micro trip" is any portion of a trip between the time the engine is started and the engine is shut down which begins and ends with a period of idling. One example would be the driving from one signal to the next. Separating driving into micro trips allows an unambiguous dividing of long trips into smaller parts that can be used in cycle development. More information about micro trips are in the report M6.SPD.001 listed in the references.

What is meant by "Average Speed per %VMT" or indeed %VMT? In as much as area-wide estimates (of emissions) are what emissions inventories and emission reduction strategies are all about, I suggest that much effort go into [non-attainment] area-wide estimates. Similarly for statewide inventories, which are needed for some circumstances.

Each roadway link has a distance (in miles) and an average speed (in miles per hour). Average speed is the length of the link (distance) divided by the time (in hours) it takes for vehicles to drive from one end of the link to the other. If a set of average speed bins are created (i.e., every 5 mph) and the link distances are put into the bins depending on the average speed, this will create a distribution of miles traveled (VMT) by average speed.

"Signal density"? What's that? The number of traffic signals in a given area? If that's the case, I imagine each transportation model zone would have a different signal density. What about stop signs? Are they traffic signals within the meaning of the act, or are we just talking about traffic lights? Four-way stops are different from one- or two-way stops. How and where are users to obtain such data? The MPOs presumably; but not all NAAs are completely covered by a transportation network. Even where a comprehensive network exists, why, there are thousands of zones in the Chicago area, for example.

EPA had originally discussed ways to account for the number of traffic signals on roadways, but such plans were dropped from the final version of the model. Signal density would allow users to better account for roadways with similar average speeds, but with different driving behavior.

William Benjey, HPCC EPA (Comment #10) March 19, 1997:

Moving to facility-type output with short-term (hourly instead of daily?) mobile emission factor outputs for specific road types would in a sense be more consistent with hourly time scale of most episodic air quality modeling. However, because the VMT data needed to use the emission factors for specific road segments usually does not exist outside of a few urban areas, it will be difficult to apply the Mobile 6 emission factors on a regional basis. Consequently think that your efforts to provide a weighted running emission factor for all roadway types in addition to the hourly facility-based factor information is crucial.

Users who do not have specific vehicle activity data will still be able to run MOBILE6 using the national average default values. Guidance will be needed to specify the local *data that must be provided for specific modeling situations.*

Given that the input and output file formats are likely to change appreciably, it would a very significant help to regional modelers if the input and output data could be tagged with geographic identifier information. In other words, since the input options affecting the emission factors vary geographically, the output files vary geographically. Ideally, the mobile model could be set to generate a set of geographically-specific emission factors for a region defined by the user. Currently ,it is tedious and resource-intensive to sequentially run the mobile model separately for all the different areas included in a regional air quality model run and then in turn perform sequential air quality model runs or manually tag many mobile output files for different geographic areas before a air quality model run. If the Mobile 6 input and output files were tagged (or at least had the option of allowing the user to easily tag them) with geographic identifiers, we could combine the output files and read them by identifier. Areas with only county-level VMT data available would be identified with state and county-level FIPS codes and would use the weighted average running emission factors. Areas with road link specific VMT data would be identified by state and county FIPS codes plus latitude and longitude data for the road link nodes (end points) and could use the facility-type emission factors.

MOBILE6 has an option for "database" output, where the emission values are written to an ASCII file formatted for importing to database software. Since the output includes run and scenario numbers, the database software can be used to easily "tag" the emission results for linking with geographic information.

Harold Brazil, SEMCOG, MI (Comment #16) April 4, 1997:

Is this "short time period emission factors" for a one hour period or peak hour period? Would this be used for Photochemical Modeling purposes?

MOBILE6 will only provide information as hourly or daily, with all hours aggregated. The hourly results can be aggregated by the user into other useful time periods, such as peak hours, for use in photochemical modeling.

Celia Shih, NY DEP (Comment #17) April 7, 1997:

Were there any new data collected under various speed cycles since MOBILE5? Will there be any update on the "regular" speed correction factors in MOBILE6?

This report represents the only new data collection since MOBILE5 specifically to address speed correction factors. New driving cycles were developed from the new data and these new driving cycles were used to develop the speed correction factors used in MOBILE6.

John Walsh, EPA #2, NY (Comment #18) April 3, 1997:

How many facility types are there? Should there be a switch between facility-specific emissions and more general area-specific emissions?

MOBILE6 will always calculate emissions for four facility types, but will automatically aggregate the results for the descriptive output. These results are also available in the database output using the AGGREGATED OUTPUT command. Facility specific emission rates are only available using the database output.

Sam Long, Illinois EPA (Comment #21) April 10, 1997:

The necessary [non-default] inputs may not be available to all users. Also, daily emission rates will still be needed, and by no means everyone has link-based or hourly information. Link-based information is not very adaptable to forecasting ROP or conformity. If you come up with typical speeds for various facility types (at various levels of service), will these speeds be published and be acceptable as MOBILE inputs for inventory and other purposes?

Although MOBILE6 will have national average speed distribution estimates, this is likely one area where EPA guidance may require that local information be used, since driving behavior has a significant effect on emissions and overall driving behavior (speed) distributions will vary from area to area because of different roadway types available.

If link-based speeds (free-flow or congested) are available, it is possible to estimate an average or representative speed for each functional class on the network. I did so in the '90 inventory, rounding off to the nearest 5 mph, and used the results in off-network areas. However, the arithmetic average speed will differ from the average speed weighted by link-length, and both will differ from the median and modes of the speeds. You should specify which of these speeds is to be used as representative, and how they are to be calculated, if you want users to derive them from link-based data.

Guidance on how to calculate average speed VMT distributions for MOBILE6 will be needed. Briefly, each roadway link has a distance (in miles) and an average speed (in miles per hour). Average speed is the length of the link (distance) divided by the time (in hours) it takes for vehicles to drive from one end of the link to the other. If a set of average speed bins are created (i.e., every 5 mph) and the link distances are put into the bins depending on the average speed, this will create a distribution of miles traveled (VMT) by average speed.

What facility types do you have in mind? The HPMS facility types loom large in USEPA and FHWA planning, but those twelve types do not include such things as ramps and bridges. On the other hand, some transportation model networks do have ramps and bridges as facility types, but those and the other facility types in such networks may not—often do not—match the HPMS facility types. Do you have suggestions for equating various non-HPMS functional classes to HPMS classes, apart from the methods appearing in Sections 2 and 3 of publication

MD?

The need to distinguish between roadway types will be a new feature of MOBILE6. However, there are only four categories of roadway types in MOBILE6. Guidance will be needed to assist users in determining which of these four roadway types should be used to model each particular roadway.

Congestion-level weighting factors: In-use level-of-service data are not, in my experience, easy to come by. “Congested” and “free” speeds in transportation model outputs from CATS represent two different levels of service, of course, but offhand I don’t remember just which ones they are; I don’t think they were specified to me. I looked at some 1990 traffic-by-hour data from IDOT for several continuous-traffic-count stations in Illinois, and estimated that about 75% of VMT in the Chicago area occurs under more or less congested conditions, and 25% under free-flow conditions, and weighted total emissions accordingly, using the modeled “congested” and “free” speeds as MOBILE inputs. My proportion above may be somewhat of an overestimate; it may be closer to 60% congested/40% free, or even down to 50/50; but the congested-free proportion, as long as it’s within reasonable limits, doesn’t affect the final emission estimates all that much, as I noted in our ‘90 inventory document.

MOBILE6 will use average speed as a surrogate for roadway congestion. The driving cycles were developed by grouping trips by level of congestion, but the emission results are grouped by average speed. Lower speeds will correlate to higher congestion and higher speeds to more free flow. There will be no need to specify the congestion levels for roadways in MOBILE6.

The numbers in the speed-correction table (Table 1) in the Workshop handout, especially average and maximum speeds, look reasonable and plausible.

Marion R. Poole, DOT, NC (Comment #25) April 16, 1997:

Facility specific drive cycles are perhaps the most significant of the proposed improvements to the MOBILE Model. North Carolina approves of the move in this direction. The current model uses an average drive cycle to represent all possible driving conditions. This leads to counterintuitive results in some cases. However, we have some concerns based on the amount of aggregation and disaggregation in the supporting materials.

Is the variability of stop/delay time implicit in the drive cycle that will be used to develop the basic emissions rates for each facility type? Our experience is that stop/delay time varies across facility types. We believe that any future version of the MOBILE model should account for this variation. An alternative method would be to allow the user to specify stop/delay time for each facility type.

In MOBILE6, the amount of stop/delay is implicit in the average speed. Average speed is defined as the distance traveled (in miles) divided by the time (in hours). Stop/delay would increase the amount of time, without changing the distance traveled, and decrease the average speed. The stop/delay involved in each driving cycle is fixed, but when a specific average speed is input to MOBILE6, an implicit amount of stop/delay will be assumed based on the driving cycle at that speed. More detailed analysis of specific roadways will likely require new emission modeling approaches that do not depend on fixed driving cycles.

We also note that arterials and collectors will share a driving trace. As noted above our experience indicates the existence of significant differences in stop/delay time and start mode between facility types. Collectors resemble locals streets more than arterial streets.

It was not possible, using the available data, to make a finer distinction between roadway types for MOBILE6. As discussed above, differences in stop/delay time are accounted for in the average speed input. Although collectors may resemble local streets in terms of stop/delay, there are important differences in the maximum speed and congestion levels that, for purposes of emission modeling, make them more like arterials.

The proposed freeway drive cycles also provided some surprises. The proposed drive cycles include: High Speed, LOS A-C, LOS D, LOS F, and LOS G. We recommend that the High speed drive cycle and the LOS A drive cycle be combined, and that the drive cycle for LOS B-C be kept together. Our understanding of the Highway Capacity Manual indicates that high speed driving occurs under LOS A. We also propose that LOS F and LOS G be combined. To the best of our knowledge, the Highway Capacity Manual does not recognize a LOS G. From the associated driving trace, this drive cycle represents breakdown conditions and might best be consolidated into the drive cycle for LOS F.

MOBILE6 will not use congestion levels as the method to associate driving with emission levels. Instead, average speed will be used. The driving cycles were designed to give the widest range of average speeds, adding a high speed cycle and a LOS G category. Average speed will be used as a surrogate for congestion levels.

Gary Flispart, Jefferson Cty, KY (Comment #26) April 25, 1997:

Many of the proposed changes suggest a movement away from the coarse focus of SIP inventory modeling and toward the fine focus of transportation simulation. Accurately approximating real-world behavior and associated emissions has clearly been the long-term goal of both transportation evaluators and air quality regulators. The key difference, of course, has been in the relative time focus: short-term (hour by hour) versus long-term (daily or annual average). Traffic planners deal in peaks and valleys throughout a day, while the SIP focuses on an annual inventory based on a typical summer day (for VOC). Both in the sharing of traffic--related data and in mutual needs to comply with mandated SIP conformity, the relationship between transportation users and SIP users of MOBILE models is critical. MOBILE6 developments impact both the traffic-related data which must be gathered to prepare a SIP and the eventual build-no-build evaluation of highway projects. It is essential that MOBILE6 not support one type of user at the expense of the other, because the two are interdependent.

Since SIP inventories are currently based on daily average emissions, any change which disfavors such daily estimates has profound effect on inventories and targets.

The new subclasses of facility type could either be ignored, force-fitted to existing categories, or adopted by APCDJC. Because KDOT does not currently measure traffic for all the proposed categories, if they were adopted the HPMS data gathering process would need to be altered or supplemented, which could involve anywhere from a week's analysis of data from other sources to a complete restructuring of transportation measurement in the area. Coordination with KIPDA and KDOT would be essential.

Comment: SIP inventories are currently performed using daily averages and are reasonably calculable when handled that way. In the District's experience, the people who used MOBILE to compile SIP inventories and evaluate SIP strategies were not the same people who compiled the link or trip models. The District is concerned that by shifting the emphasis toward detailed transportation modeling, the primary efforts of SIP modeling may be undercut. Trying to produce an annual inventory by summation of all trips or links in a simulation would add tremendous complexity which APCDJC sees as unwarranted. The District strongly suggests the need for MOBILE6 and other future models to continue to produce daily average emission factors in a manner similar to that in MOBILE5, to support SIPs and tracking.

The need for daily average emissions was recognized by the MOBILE6 team. MOBILE6 will continue to support daily average emission results in both the descriptive and database output options. This will not completely eliminate the need for areas to produce more detailed vehicle activity data, disaggregated by time of day, vehicle type and roadway. Guidance will be needed to assist areas to determine what new data is needed and generate the needed information.

Harold Nudelman, NYCDEP, NY (Comment #27) April 28, 1997:

Have the new facility-specific cycles been reviewed by DOT/FHWA personnel? We are especially concerned about in-City roadways (arterials/collectors and local) where there are speed limits that may only allow 30-35mph. The maximum and average speeds for the bottom 3 cycles on Table 1, for congested in-City arterials and local roads, may be too high for many congested New York City streets during peak hours. New York City is likely to have a traffic control sign and signal density which is at the extreme end of the range in the nation. Frequency of starts and stops, and therefore of acceleration/deceleration, will not only affect average speeds but also the emissions associated with a given speed. We support any efforts by EPA to develop operating mode data that would allow us to project the impact on emissions of a high density of traffic signals on local streets as well as on arterials. Will speed corrections for arterials/collectors also utilize data from the NYCC and FTP cycles? Will the speeds on local streets be adjusted? If yes, what cycles will be used other than the NYCC?

The data available for MOBILE6 development did not allow for creation of new driving cycles and data for extreme low speeds. However, each vehicle was tested using the New York City Cycle to allow modeling of average speeds to that level (7.1 mph) and to allow connection to the existing data from driving cycles below 7.1 mph. The speed correction factors from these older driving cycles will be used in MOBILE6 for speeds below 7.1 mph.

Extreme conditions will always be difficult to model without data gathered to specifically address those conditions. The driving cycle for local roadways has only a single average speed, so changes in average speed on local roadways cannot be modeled. Guidance will be needed to indicate the best methods to deal with specific situations where using the default values would not be appropriate.

How will idle CO emissions be calculated? Will they be calculated from the 2.5 mph emissions estimates? If yes, will the 2.5 mph emissions for local streets be the same as the 2.5 mph emissions for arterial/collectors? If they are not the same, how will they be calculated? How different can we expect the low speed correction factors to be in the new model compared to those used in MOBILE 5? Is there any reason why idle emissions data is not directly collected to use in the model instead of adjusting the 2.5 mph emissions?

No new analysis of idling emissions has been performed since the release of MOBILE5b. In MOBILE5b, idling emissions are calculated from the emission estimates for 2.5 mph, as described in the MOBILE5 User Information Sheet #2. MOBILE6 will not explicitly estimate idling emissions at all. However, idling emissions will still be calculated using the method described in the MOBILE5 User Information Sheet #2. The speed correction factor (and thus the emission estimate) for emissions at 2.5 mph will be the same for both roadway types in MOBILE6 (freeway and arterial/collectors), since the speed correction factor curves converge at extreme low (and high) speeds.

Collecting data for and analysis of idling emission data has not been a high priority for EPA. Programs to develop idling emission factors have been proposed repeatedly, but pushed aside by higher priority issues. An independently funded research project specifically targeted at developing idling emission factors may be needed.

Dale Aspy, EPA #4, GA (Comment #30) April 30, 1997:

A number of Region 4 states have requested the ability to model idle emissions for project level analyses. Many of these same states have also requested the ability to conduct facility specific modeling on an hourly basis to allow for peak use times. The Region supports the inclusion of non-FTP emission factors and the option of user supplied information regarding non-FTP speed and acceleration activity factors.

Idling emissions were also discussed in the previous comment (#27). MOBILE6 will not explicitly generate idling emission rates. However, idling emissions may still be calculated using the method described in the MOBILE5 User Information Sheet #2. Idling emissions were left out of MOBILE6 since idling is a specific mode. Modal emission rates (i.e., acceleration, deceleration, cruise and idling) were considered outside the scope of the MOBILE6 project. Existing guidance (i.e., MOBILE5 User Information Sheet #2) was considered sufficient for estimating idling emissions.

MOBILE6 does model emissions by hour and allows for user supplied speed VMT distributions. MOBILE6 does not allow for adjustment of the amount of off-cycle driving behavior, which is implicit in the driving cycles used to develop the speed correction factors.

Michael Keenan, NYSDEC (Comment #31) April 30, 1997:

Refocusing the Mobile model to the premise that most driving is non-FTP should prove to be a most worthwhile development.

The attached tables contain the minimum and maximum average roadway type speeds presently available for SIP modeling in New York State. The values shown are the estimates for calendar year 1999. Comparison with EPA's New Facility-Specific Speed Correction Cycles (i.e., Table 1 at March 1997 Workshop) indicates that the proposed Freeway Average Speeds of 13.1 to 63.2 mph would encompass New York's input range of 19.7 to 59.6 for Interstates, Freeways and Expressways. However, for the various roadway types encompassing Arterials and Collectors, New York's speed range of 7.2 to 55.9 mph is much broader than EPA's average speed range of 11.6 to 24.8 mph. A large variance also exists within New York's Local average speed range of 3.0 to 39.2 mph. Using a single local cycle with an average value of 12.9 mph would appear to be most inappropriate for modeling such a variable speed range. Because the range of possible average speeds for any given roadway type varies significantly, speed should continue to be an input variable to the Mobile model.

However, by modifying the nomenclatures, the new facility specific cycles would prove useful in better defining which speed correction factors should be applied. For instance, although Freeways are limited access highways, the driving cycle traces may be applicable to certain rural roadways as well. For example, the High Speed, Level of Service (LOS) A-C and LOS D Freeway cycles appear to be suitable for any road that has unimpeded, nonstop free flow. Freeway LOS E and perhaps even LOS F could be of use for modeling speed corrections on roads which have a quick stop at a stop sign or slowing down to make a turn. Perhaps differentiating roadways among nonstop, brief stops and many stops would be a more useful approach for identifying which speed correction algorithm to use. This is perhaps what was meant by “signal density” in Issue #3.

The speed correction factors for freeways and arterial/collector roadways in MOBILE6 converge at low and high speeds. In this way, any speed from 2.5 mph to 65 mph can be modeled on both freeways and arterial/collector roadways. Guidance will be needed to assist users in choosing the appropriate roadway type in MOBILE6 for the specific road to be modeled.

Issue #1 points out that the “disaggregation . . . by facility-type” is most appropriate for short time periods. Shorter time periods generally have less variability of speed, temperature, vehicle mix, etc. Further, four-step transportation models are now being developed for short time frames (i.e., peak travel times). In addition, from the modeling perspective, combining variables complicates input development. Thus, the Mobile model input at the scenario level should reflect input appropriate to a discrete roadway type for a time period short enough to minimize large differences in any input variable over that time period.

MOBILE6 allows for different VMT by facility type and vehicle type for each hour of the day. However, guidance will be needed to choose the appropriate level of aggregation for development of MOBILE6 inputs for specific emission inventory analysis.

“Weighted running emission factors” and inputting %VMT by roadway type (ala Issue #2's methodology) would complicate using the Mobile model and jeopardize input integrity. While this concept may sound attractive and efficient, the model already suffers enough uncertainty without introducing more. With today’s desktop computers, multiple scenario runs can be performed quite rapidly. Ample software and/or software packages are available for preprocessing and postprocessing (e.g., G/mi times VMT). Therefore, the Mobile model does not have to become its own postprocessor!

As was noted in other comments, daily average emissions continues to be a highly desired output of the MOBILE model. As a result, MOBILE6 must be capable of producing emission results for a given day that aggregates all hours, roadways and vehicle types. However, it will be possible, with appropriate input commands, to get results specific to a less aggregate scenario, such as for an individual roadway.

Shengxin Jin, NY DOT (Comment #36) May 6,1997:

Average vehicle speed is another important issue in CO intersection dispersion modeling. Vehicle speeds differ from intersection to intersection. Even at the same intersection, vehicle speeds can vary depending on the directions of traveling vehicles. Without a vehicle speed option as a model input, the differences in vehicle emissions due to speeds can not be determined. This will significantly affect CO dispersion modeling results.

Average speed will still be a user input for the MOBILE6 model. However, the *complexity of the input will be increased due to the need for speed VMT distributions.*

Marcel Halberstadt, AAMA, MI (Comment #37) June 5,1997:

The EPA approach is somewhat different than the ARB's approach, in which a single, self-weighted inventory cycle was developed (the LA92, or Unified Cycle (UC)) and a significant number of cars and trucks were tested on this cycle. Also, ARB developed Unified Correction Cycles for developing speed correction factors for the UC. AAMA is unsure if EPA can devote enough resources to make their approach more accurate than ARB. Concern stems from EPA's desire to make one model fit all modeling purposes. The Unified Cycle approach is certainly more simple, and has the advantage that only a single, self-weighted cycle needs to be run for area-wide modeling. EPA's approach requires significantly more testing per vehicle, consequently, fewer vehicles can be tested. There is also an issue with respect to whether vehicles can be maintained at proper temperatures throughout the duration of the EPA cycle testing. AAMA recommends that EPA also have all of the vehicles tested on ARB's Unified Cycle as well as the other cycles, so the Unified Cycle can be compared to a weighted average of EPA's cycles. AAMA will reserve further comments on both ARB's approach and EPA's approach until it evaluates the data from EPA's test program, and particularly how EPA compares the data on the Unified Cycle to the data from the EPA's test cycles. If EPA's approach of many factor-specific correction cycles remains unchanged for MOBILE6, it is essential that the model contain default (nationwide) statistics to develop average emission rates for a nationwide inventory.

EPA understands and accepts the advantages of the California approach to emission modeling. However, the EPA approach meets the important requirement that emission estimates on smaller scales (i.e., individual roadways) be as accurate as possible. California knows that transportation planners will use their model to estimate emissions for individual roadways, despite the fact that this is not appropriate, because there is no reasonable alternative. The EPA approach is more appropriate for modeling individual roadways, which can then be aggregated to create area wide daily emission estimates.

EPA agrees that the current EPA approach will require significantly more testing per vehicle and will result in fewer vehicle tests. However, EPA is confident that improvements in instrumented vehicle technology will allow for the use of emission testing results from in-use vehicles on roadways to create emission estimates for future models. In this way, MOBILE6 is a transition model which can be used to improve our understanding of how emission inventories can be improved using a better designed emission model.

EPA must also allow users to output emissions based solely on current FTP certification test results, for ready comparison with the current and historical emission standards.

MOBILE6 is designed to estimate "real world" driving emissions and cannot easily *replicate the exhaust emission certification procedure (FTP). Doing so would require elimination of "real world" driving behavior effects on emissions and altering the default vehicle activity distributions. This will be possible using diagnostic commands, but is not an expected typical use of the model.*

Marcel Halberstadt, AAMA (Comment #53) December 4, 1997:

EPA is proposing to use data currently being developed from the testing of in-use vehicles over a variety of driving cycles. This testing has been performed at ATL and EPA. Data collected at the two different sites shows remarkably different sensitivity of emissions to average speed. The ATL data generally showed lower emissions, and a lower emissions sensitivity to the different test cycles. EPA indicated that because of the differences, it would run a correlation program to try to determine the reason for the differences, but also indicated that EPA may base the speed effects for current vehicles in MOBILE6 on the EPA data alone because the ATL data "may be underloaded."

AAMA supports EPA's efforts to conduct a correlation program. AAMA believes the differences between the ATL and EPA data must be thoroughly understood before EPA makes significant decisions about which data to base the speed effects on. EPA did not indicate why it thought the ATL data may be "underloaded". Another possible explanation, which was not addressed at the workshop, is that the EPA data may be in error (or "overloaded"). If the reasons for the differences are not thoroughly understood, EPA should combine the data, but not omit the ATL data without very good reason.

EPA thoroughly investigated the differences between the results at the two testing sites (including testing the same vehicle at both sites) and resolved that the differences are not due to errors or differences in the testing procedures at the two sites. EPA has concluded that the differences observed are vehicle to vehicle variance and all test results at both sites have been used in the analysis.

Another issue relates to how EPA plans to use the freeway ramp driving cycle. AAMA understands that EPA intends to develop national weighting factors for different types of roadway operation, and allow users to input these fractions as well. The model would then weight the emissions from the different cycles together. It is not clear, however, whether EPA will also have speed correction factors, which will adjust emissions between the speeds of the different cycles. If EPA plans to do this, then it should develop such speed correction factors from the new data, but omit the data from the freeway ramp cycle. This cycle appears to result in emissions that do not lie on the typical emissions/speed curve (see Figures 1a-1c of the above report).

MOBILE6 separates driving into four roadways types, with freeway ramps as it's own roadway, separate from other freeway driving. However, since there is only one ramp driving cycle, ramp emissions will not be a function of average speed.

Facility-type Speed Correction Factors – It is still not clear to AAMA how the facility-type speed correction factors (SCFs) are being developed. Is EPA developing separate SCFs by facility types, or a single SCF curve across the entire speed range? If SCFs are being developed for different facility types, then how will EPA divide the facility types and levels of service? How will high emitters be handled? Will the SCFs for low and high emitters be estimated separately, and then combined by the estimated fraction of low and high emitters?

As this final report should make clear, MOBILE6 divides driving into different facility types with a speed correction curve for freeways and arterial collectors. Levels of service are not used directly. Instead, average speed is used as a surrogate for the congestion level on roadways. Speed correction factors for high emitting vehicles were determined separately from normal emitting vehicles.

Effect of SFTP Standards for Tier 1s and LEV-Type Vehicles – EPA is proposing to include the effects of off-cycle aggressive driving through the use of the facility-specific speed correction factors. Thus, the SCFs will include the effect of speed as well as off-cycle effects. How does EPA plan to incorporate the effects of the SFTP rules on Tier 1 and LEV vehicles, using the facility cycle data on Tier 0 vehicles?

The development of the speed correction factors included an emissions offset which attempts to capture the difference between the base exhaust emission factor, based on the FTP driving cycle (LA4), and truly representative driving, which includes aggressive driving behavior. A full discussion of the emission offset is in Section 6.0. This emission offset is the portion of the overall adjustment to the base emission rate that will be affected by the SFTP. The effects of the SFTP on emissions are discussed in the report, "Determination of Off-Cycle Emissions and Supplemental FTP Control Modeling in MOBILE6," (M6.SPD.005).

EPA estimated the benefits of SFTP rules in its support document to its supplemental FTP final rule. However, in that analysis, EPA estimated emissions over ST01, REM01 and REP05 from testing over the FTP and US06, along with some Tier 0 vehicle data. This methodology contains a number of assumptions which have not been confirmed with data. Therefore, AAMA does not recommend that EPA use this methodology in MOBILE6 without a thorough review of it appropriateness.

Likewise, how does EPA plan to estimate these factors for LEVs with and without non-FTP controls? ARB assumed that the impact of non-FTP driving on LEV emissions was the same in relative terms as for Tier 1 vehicles in EMFAC7G. In its supporting analyses for its proposed non-FTP standards, ARB also estimated the impact of non-FTP driving on LEV emissions both with and without SFTP controls. However, as was the case above, this methodology involves many unconfirmed assumptions. Also, the technology assumed by ARB to enable compliance with the non-FTP standards (i.e., rich-bias) is not likely to be the technology of choice for most manufacturers. Therefore, AAMA again recommends that EPA publish the details of any methodology which it plans to use to estimate LEV emission impacts for public comment prior to its incorporation into MOBILE6.

The report, "Determination of Off-Cycle Emissions and Supplemental FTP Control Modeling in MOBILE6," (M6.SPD.005) describes how MOBILE6 handles off-cycle emissions and the effects of the SFTP. It should be of some comfort to know that off-cycle emissions and the effects of the SFTP are added to the base exhaust emission rates. This means that only the small increment of remaining off-cycle effects left after the effectiveness of the SFTP has been applied is added to the base emissions of vehicles affected by the SFTP. This should mitigate the effects of uncertainty in the estimate of what off-cycle emissions might be for LEVs. The true effectiveness of the SFTP cannot be known until vehicles certified under the new certification procedures can be tested.

Gary McVoy, Ph.D., Director, Environmental Analysis Bureau, New York State Department of Transportation (Comment #86) August 2, 1999:

Vehicle speeds on local roads are much different from project to project and from area to area. For example, the local speed and driving pattern in New York City are much different from those in the NY upstate cities. No speed adjustment for the local roadways affects our ability to perform accurate and publicly defensible air quality analysis.

The limited data available on the driving behavior and their emission impacts on local roadways make it impossible to accurately determine the effects of average speeds on local roadways. However, it may be possible, with proper guidance, to account for the differences in the average speeds on local roadways, using MOBILE6, in a manner consistent with EPA policy. This issue will be addressed in guidance from EPA.

Gerry Kelpin, New York City Department of Environmental Protection (Comment #93) October 5, 1999:

We would like to raise a number of concerns with some of the assumptions proposed for the model. The areas of our concern are as follows:

1) The use of the Mobile5 low speed relation to estimate CO emissions for speeds below 7.1 mph, and the subsequent use of the estimated 2.5 mph emissions for estimating CO idle emissions.

OMS views the Mobile Model as essentially a tool for developing emissions inventories. However, the use of the model for providing link by link carbon monoxide emissions to be used as input for intersection air quality modeling to determine compliance with the NAAQS has also been an important function of the model. We believe that the proposed assumptions for adjusting the extremely low speed emissions and using the resultant 2.5 mph emissions to estimate the idle emissions overestimates CO emissions for these conditions and will result in overestimated modeled intersection impacts. If the Mobile6 CO emissions are not sufficiently lower than the Mobile5 emissions then this could even result in erroneous determinations of non-compliance.

In order to explain our concern about the Mobile Model assumptions for low speeds and idle, and their potential for generating incorrect results, we have to discuss how the emissions input for the CAL3QHC(R) air quality model, that EPA designated as the reference model for modeling CO at intersections in 1992, is generated. The CAL3QHC(R) model does not utilize average speed emissions. The CAL3QHC(R) model utilizes free flow, or running speed emissions, and idle emissions for each link. (In the air quality model, a link is usually the distance on a roadway between traffic signals, or other types of intersection controls.) The emissions on a given link are divided into idle emissions over the length of the queue for the vehicles stopped in the queue, and the moving emissions from all the vehicles passing through the link over the entire length of the link. The moving emissions for the CAL3QHC(R) model, therefore, should reflect the running speed (speed when vehicles are in motion) and not the average speed.

The running speed for a link is calculated by subtracting the stopped delay time from the total travel time, and dividing that time into the link distance. The average speed includes the stopped delay time in the total travel time. Running speeds will therefore always be higher than the average speed on any link with a stopped delay. The running speed should contain no stopped delay, and therefore no idle emissions. When we use the Mobile Model emissions for a given speed that is equal to the running speed, we are using emissions for an average speed that includes some percentage of idle emissions. In general the amount of time that is spent in idle decreases with increasing average speed. If idle emissions are higher than the moving emissions, the greater the percentage of idle time in the average speed, the more the running or moving emissions will be overestimated.

It must be noted that although CAL3QHC(R) may request that running emissions estimated from a free flow speed be used, this has never been the case. None of the versions of the MOBILE model has ever been able to produce free flow emission estimates. This is true no matter how the speed is calculated. EPA has allowed the use of the MOBILE model as an input to the CAL3QHC(R) model only because there is no credible alternative. In this respect, the MOBILE6 model in general will be no better, but no worse, than current practice.

The truly appropriate model for use with CAL3QHC(R) is a modal model, which estimates emissions base on modes instead of trips. A properly developed modal model would be able to estimate free flow emission rates appropriate for input into models such as CAL3QHC(R). EPA is currently working with researchers in California and Georgia to develop such modeling tools.

The impact from the potential overestimation of moving CO emissions, however, is not believed to be as significant as the impact from overestimating the idle emissions. The impact of idle emissions has generally been responsible for the major portion of the modeled local impact at intersections that have been near the standard. This is related to the CAL3QHC model assumption that all the cars in a queue on a link will idle for the entire red phase of the light cycle. This means idle emissions from the entire queue on a link is modeled for a percentage of the hour that is proportional to the red time divided by the total cycle time.

Given the major contribution of idle emissions to local CO predicted impacts, we do not agree with the proposal to use the relationships between the 2.5 mph emissions and those at 7.1 mph from Mobile5 in Mobile6, and then use the 2.5 mph emissions to calculate idle emissions. When this methodology for calculating idle emissions was adopted for Mobile5, it was recognized that it should be replaced. This is indicated by the statement on page 1-8 of the May 1994 User's Guide to Mobile5 - "EPA will continue to collect data and to work to develop a more satisfactory approach to estimating idle emission factors." We believe that a more satisfactory method is needed because as we understand it, the speed relationship for the low speeds is based primarily on data from older technology, primarily carburetor, vehicles, and has not been demonstrated to be appropriate for the current and future fuel injected vehicles. The relationships that were included in Mobile5 for that speed range go back to Mobile4.1. The current and future fuel injected vehicles, with air/fuel ratios controlled by computer chips, should be much more efficient than the carburetor vehicles at controlling emissions at idle. Therefore, the relationship of emissions at these low speeds, and the idle emissions themselves for the newer vehicles should be different from what would be estimated utilizing the relationships developed for the early technology vehicles.

Given the importance of the idle emissions to local CO impact prediction, we would recommend that CO idle emissions for current and future conditions be estimated based on actual measurements of idle. Is it possible to extract measured idle emissions data from the data generated in "grams second by second" for the vehicle cycles that were tested and described in the report ? If this is possible, we would recommend using relatively continuous periods of idle conditions (over 10 seconds) rather than shorter periods to measure the idle emissions so that they will be based on conditions that are similar to how they are modeled in the CAL3QHC model. Other sources of idle emissions may also be available (I/M programs, certification tests, etc.).

No new analysis of idling emissions has been performed since the release of MOBILE5b. In MOBILE5b, idling emissions are calculated from the emission estimates for 2.5 mph, as described in the MOBILE5 User Information Sheet #2. MOBILE6 will not explicitly estimate idling emissions at all. However, idling emissions will still be calculated using the method described in the MOBILE5 User Information Sheet #2. The speed correction factor (and thus the emission estimate) for emissions at 2.5 mph will be the same for both roadway types in MOBILE6 (freeway and arterial/collectors), since the speed correction factor curves converge at extreme low (and high) speeds.

Collecting data for and analysis of idling emission data has not been a high priority for

EPA. Programs to develop idling emission factors have been proposed repeatedly, but pushed aside by higher priority issues. An independently funded research project specifically targeted at developing idling emission factors may be needed to properly resolve these issues.

However, all investigations on the existing data to date have supported the assumption that emissions at 2.5 mph are similar to those during idle. There is no reason, based on data, to be overly concerned about the idle emission estimates. One clear advantage of basing idling emission on the emissions at 2.5 mph is that is allows the idling emissions to be affected by all of the correction factors that are applied to running emissions, such as fuels and temperature. It will be very difficult to replicate these corrections specifically for idling emissions, even once base idle emission data becomes available.

The issue of estimating running CO emissions between 7.1 mph and 2.5 mph, without using the old speed relationship from Mobile5, for intersection modeling must also be addressed. We do not believe that these running speeds will occur very often. For example the running speed for the low speed NYCC, whose average speed is 7.1 mph, is about 12 mph, after subtracting out the 40 % of the time in the cycle that the vehicle is in idle. We have not evaluated alternative solutions. However, one possible method that could be examined is to extrapolate the curves down to 2.5 mph from the 7.1 mph emissions measured in the new cycles. In addition, if new idle emissions data are available, it should be reasonable to use the idle emissions as an approximation of the emissions at an average speed of 2.5 mph. This should not introduce much error since an average speed of 2.5 mph will have a very high percentage of idle time. (The 7.1 mph average speed cycle has 40 % of its time in idle.) A best fit curve utilizing this additional point, with the other points, could then be developed.

In the future, having an idle test done as part of the certification process or as part of a mandated I/M program would seem to be a simple and inexpensive way of providing updated information for future revisions to the models' idle emissions.

Although we have made our comments about the low speed adjustments with respect to CO, there should probably be an examination of whether the low speed relationships for the old technology vehicles is appropriate for estimating the emissions of HC and NOx from the new technology vehicles. Unless the applicability of the adjustments can be demonstrated, an approach similar to that mentioned above for CO might be worth evaluating.

There is no particular advantage to using the New York City Cycle (NYCC) results from the new data set to estimate idling emissions in place of using the low speed (2.5 mph) cycle. Extrapolating low speed emission corrections from higher speed results is very difficult, since the low speed portion of the curve is quite steep. A very small error can produce large differences. Basing the low speed portion of the curve on data (whatever it's minor flaws) is a better choice than extrapolation.

It is obvious that the only way to know what is happening with emissions at low speeds and idle will be to properly analyze the existing data and collect new data specifically to address these issues. There are new tools, such as the University of California modal model (NCHRP Project 25-11) which can directly address the effects of driving behavior on emissions at low speeds and idle and there is new data imbedded in any driving cycle containing idling and low speeds which has been collected on a second by second basis. However, much effort will be needed to review this information and propose a new set of low speed and idling emission rates. This effort is beyond the scope of the MOBILE6 project and will have to be addressed as an update to the model.

2) The adjustment of low speed emissions for aggressive driving.

Since we do not think that the old speed adjustment factors should be utilized below 7.1 mph for CO, the issue of adjusting the old adjustments for the aggressive driving in the new cycles becomes moot. We have reservations about correcting emissions for very low speeds, characteristic of severely congested conditions, for aggressive driving. One would think that under these type of conditions there would not be very much opportunity for this type of behavior. This would be even more true for idle emissions, if they were estimated from a 2.5 mph emission.

The proposed adjustment for CO at 7.1 mph and lower speeds for level 1 and level 2 vehicles would result in a reduction of the old speed factors. This is because the new speed factor for 7.1 mph is lower than the old factor. Could this reflect the reduced contribution of the idle component to the total emissions in the NYCC for the vehicles recently tested as compared to the tests of earlier technology vehicles?

The New York City Cycle (NYCC) is based on "real world" driving and includes aggressive driving behavior not found in the FTP. Since the FTP, which was the base emission rate in MOBILE5, did not include enough aggressive driving behavior, the speed adjustment in MOBILE5 from the base (FTP) to low speeds (NYCC) was large and the speed adjustment included some effects from aggressive driving. In MOBILE6, the speed correction factor is applied to a base emission rate after the effects of aggressive driving have been added as an emission offset. This may be the reason the speed correction is less moving from the base emission rate to the low speeds, since both now contain the effects of aggressive driving.

Not much is really known about driving behavior at low speeds. The current instrumented vehicle data does not allow us to easily separate roadway types, so that a more thorough analysis of low speeds cannot be done. The chase car data, on which the MOBILE6 freeway and arterial/collector roadway cycles were based, did not follow vehicles onto local roadways, where most low speed driving occurs. New instrumented vehicle data will include global positioning sensing (GPS) technology, which will allow precise locating of the vehicle on the roadway system.

3) The assumption that freeway and arterial emissions converge and have the same emissions at, and below 7.1 mph.

We agree that the emissions for all types of roadways will converge as the average speed approaches zero and the emissions become essentially idle. Given the different way arterials and freeways function, however, we are not certain that the assumption that their emissions converge at 7.1 mph and are the same below 7.1 mph is an accurate description of their behavior. Generally freeways, because of the lack of traffic signals that create stopped delay, should have the same running speeds and average speeds, while this is not the case at signalized arterials or collectors. Would a low average speed of 7.1 mph on a freeway be characterized by the same or a similar amount of idle time as the same speed on an arterial? It might be useful to compare how the percentage of idle time changes for freeways and arterials as their average speed cycles approach 7.1 mph (Freeways, LOS F to LOS G and arterials/collectors, LOS C-D to LOS E-F) . In addition, is the percentage of idle time in the lowest speed cycle (which had relatively close average speeds) for each type of roadway consistent with their both converging to the 40 % idle at 7.1 mph in the NYCC? If the above does not support the assumption that the emissions from both roadway types converge at 7.1 mph, then it may be necessary to modify this assumption.

The lowest speed arterial/collector cycle has an average speed of 11.6 mph and 31.3% of the cycle time is at idle. The lowest speed freeway cycle has an average speed of 13.1 mph and 3.3% of the cycle time is at idle. The New York City Cycle (NYCC) has an average speed of 7.1 mph and 32.4% of the cycle time is at idle. Table 11b shows the average CO emissions from vehicles on these cycles. The NYCC has higher CO emissions than the other two cycles in all cases. The arterial/collector cycle is higher than the freeway cycle in all cases. Based on this information, CO emissions will increase as average speed decreases and as the fraction of cycle time spent idling increases.

Logically, EPA concluded that the speed correction factors for freeways and arterial/collector roadways must be identical when 100% of cycle time was spent at idle. However, based on the available information, it is not possible to determine precisely where the two speed curves statistically converge. The odd cycle of the three is clearly the freeway cycle, where very little of the driving time is at idle (3.3%). However, freeway driving at these very low speeds is not typical, in terms of the daily VMT on freeways. EPA concluded that it would be best to converge the speed correction curves at the NYCC where an actual data point existed. This assumption should only affect the limited amount of VMT that occurs on freeways at very low speeds.

Why isn't the estimation of local roadway emissions variation with speed based on the relationships derived for arterials and collectors, since they would appear to be very similar to these roads in the way they operate?

A detailed analysis of the emissions from the local driving cycle and the arterial/collector *driving cycles has not been done. As you suggest, it is likely that use of the arterial/collector speed corrections may be appropriate for modeling local roadways as well. However, since local roads are not usually included in traffic demand models, MOBILE6 includes an overall local roadway emission estimate. The issue of whether local roadways can be modeled as arterial/collectors will be addressed in EPA guidance.*

Appendix D : Peer Review of Speed Corrections

Review of: Facility-Specific Speed Correction Factors, Draft
US EPA Report Number M6.SPD.002
By David J. Brzezinski, Phil Enns, and Constance J. Hart
Assessment and Modeling Division
Office of Mobile Sources, U.S. Environmental Protection Agency

Reviewed by: Simon Washington, Transportation Systems Group, School of Civil & Environmental Engineering, Georgia Institute of Technology
October 20, 1999

NOTE:

Most of the following comments have been addressed by making changes in the text of the report to clarify or add information. However, some comments are addressed below the comments. All EPA responses are shown in italics.

General Review Comments:
The comments below reflect three different types of comments. First are editorial comments that I believe would improve the read of the document, or would make for more precise interpretation of some of the statements made in the document. Second are short-term improvements, which I believe could be addressed in the immediate future to improve the development of driving cycles as proposed in MOBILE 6. The last section lists longer-term improvements, which could be considered after MOBILE 6 has been released.

Overall the document is very thorough, well written, and concise. The authors have done an excellent job documenting a difficult project, and should be commended for their professional work. I would like to caveat all my comments by saying that they are intended merely to improve the document, and not in any way to offend any of the highly qualified and experienced authors who have prepared the document. The comments are my opinion only, and certainly can be over ridden by consensus of the authors or other reviewers.

I have attached three asterisks (***) to those comments which I believe are the most pressing—that is those areas of concern that I believe raise some serious questions as to the validity of the currently proposed approach, and whose impact might be significant on the results and conclusions of this work.

Editorial Comments:

Page 1, 4th paragraph: The first sentence should probably read, "The proposed……basic emissions levels of the vehicles."

Page 1, 4th paragraph: The fact that ramps and local roadways cannot be adjusted for average speeds other than the national average is a bit confusing. It suggests that the same average speed be assumed for all local roads, regardless of the city that is being modeled. If this is the case, then this is a problem when modelers may want to assess the effect of peak spreading (some TCM's) or shrinking (some advanced ITS technologies), which would have an affect on local road traffic volumes and therefore speeds as well. This statement should be clarified.

Page 2, 1st paragraph: The first line should read, "Since the data for this analysis were collected….". The document should be searched for occurrences of the plural data to check verb agreement, as this occurs elsewhere as well (e.g. see page 16, paragraph 4).

Page 2, 1st paragraph. The first sentence uses the word "realistic", which I think should not be used. Any conceivable driving cycle obtained from real driving is realistic. The appropriate word to use might be "representative", since what EPA is trying to do is bring into the fold a greater number of driving cycles that represent collectively a greater number of driving conditions. Even the "old" driving cycles are representative in and of themselves; however, there are fewer of them, so driving cycle heterogeneity is not being captured. I think it is worth keeping in mind (and perhaps in the text also) that there is a continuum of representation of real driving, ranging from one assumed driving cycle (and its assumed emissions profile) to simulation, which derives any speed-time profile of a fleet of vehicles given, roadway, traffic, and environmental conditions. Of course the latter begs for an emissions model that can handle any feasible driving cycle, which in fact can be accomplished by either UC Riverside's or Georgia Tech's Measure model. The point is that the continuum of driving activity is getting further disaggregated, and this is what MOBILE 6 is doing.

Page 3, Background: Last sentence refers again to real world driving behavior, which implies an alternative to non-real world driving behavior (see previous comment).

Page 4, 5th paragraph: Last sentence refers to the difficulty of differentiating vehicle activity across facilities. It might be worth emphasizing that this has particular consequences in the planning process, whereby plans or program that might impact modal activity cannot be modeled adequately.

Page 5, paragraph 4: The second sentence should read, "Readers are encouraged to obtain information directly from California for comparison with the results documented in this report".

Page 6, paragraph 2: The last sentence is unclear, please clarify.

Page 6, paragraph 3: EPA's objective to match the power distribution is right on track, it is a strong point of the current driving cycle project update.

Page 6, paragraph 3: I'm not sure that the authors want to use the word "We", and instead might use "the US EPA". See also page 20, third paragraph. The authors should probably search and replace entire document to be safe.

Page 7, paragraph 4: The second sentence should begin, “Testing of vehicles was done…..”

Page 8, 5th full paragraph: The word “special” should be removed from the second sentence.

Page 9, 3rd paragraph: I suggest changing the phrase in the third sentence “agrees with” to “provides support for”.

Page 15, paragraph 2: The authors state, “All of the slope coefficients are statistically significant, meaning that the increase or decrease in emissions versus average speed is different than zero.” This is not technically correct. The correct interpretation of a hypothesis test is as follows: If repeated many times (i.e. many samples drawn from the population), the outcome (data) observed by the analyst/engineer and reflected in a computed test statistic (e.g. t-statistic, F-ratio, chi-square, etc.) would occur *x* percent of the time *if the null hypothesis were true*. In other words, the probability of occurrence is conditional upon the null hypothesis being true. If *x* is less then alpha, then the null hypothesis is rejected. When the null hypothesis is rejected, the statistical evidence suggests that the null hypothesis is not true, and that some alternative hypothesis provides a better account of the data. What is important to understand (and which is commonly misinterpreted), is that the result does not provide the probability of the null hypothesis being true, nor does it provide evidence that the particular alternative hypothesis is true. In contrast, however, it provides the probability of observing the data if the null hypothesis were true.

Page 38, Table 8: The first asterisk footnote should probably read “All emissions in Log (gram/hour) scale”, thus replace space with scale for this table and all similar tables.

Potential Short Term Improvements:

Page 1, bullets: Where do 2-lane highways fit into the picture? It is known from operational aspects of traffic that 2-lane highways have very different emergent traffic than do interstates with more than two lanes, due to a number of factors including limited access, truck activity and restrictions, passing maneuvers, and weaving. The entire paper has not mentioned 2-lane highways, and perhaps should address somewhere how this is being handled. In the longer term perhaps some empirical data on two-lane highways could be collected to determine whether they should server as a “separate facility type”.

Page 5, paragraph 2: The second sentence states, “Given limited testing budgets,…., thus increasing the statistical confidence in the emission test results”. It puzzles this reviewer that this is even a consideration, given that statistical confidence has never been considered in any of the modeling in MOBILE or CARB to date, particularly with regard to confidence in model outputs. So what if the confidence is better if it is not used in the modeling process? My point is that the US EPA and CARB need to do a better job of carrying through the uncertainty in forecasted outputs, not just in the internal decisions being made as to “how many” cycles should be generated. It is actually a good point being made in the text, but is largely irrelevant because of its limited use in policy and practice.

Page 6, paragraph 3: Although the authors feel that the emissions generated from the new cycles are representative of driving behavior "under specific conditions", it is not clear that the forecasting of the particular "specific conditions" can be done accurately. The authors might want to suggest that there is additional uncertainty in matching the specific conditions in the lab with the same conditions in the field, due to the mismatch between LOS defined by air agencies and DOT's.

*** Page 7: 1st paragraph: It seems an awful lot to ask from 85 vehicles to infer emissions for a fleet of millions. It would be nice to add a table to show how representative (or not) these vehicles are of the national fleet. Perhaps a cross-classification of model-year by technology classes. Of course all the estimated means are dependent on a random sample of vehicles, and it is not clear whether this is the case. More documentation needs to be provided here, with perhaps some clues as to how the final estimates might be biased as a result of the biased sample. Also, much more needs to be added about recruitment and acceptance, since these are two separate issues. Specifically, what was the proportion of rejections, and how was recruitment performed. Again, random sampling is fundamental to probabilistic methods, and without it properties of probability can not be expected to hold. More information would inform the reader here.

> *It is understandable that the typical reader will not be aware of the EPA standard vehicle recruitment practices. However, it is not reasonable to attempt to fully describe and defend these practices in this report. It should be sufficient to understand the analysis to know that EPA was attempting to recruit vehicles in either a random or stratified random fashion. Certainly, it will be hard to evaluate the total uncertainty in the overall result without some sense of the bias in the recruitment. However, there are plenty of opportunities in a sample this small to be concerned about uncertainty without the addition of recruitment bias.*

Page 7, 4th paragraph: It would be helpful to add a table comparing the sum of second-by-second emissions to bag emissions, or at least to discuss it in the text. There has been some concern about the difference in some of these testing discrepancies, and it would be a nice addition to the text.

> *The second by second emissions were not analyzed at all for purposes of this report, since their results were not used. The issues related to second by second measurements are important, but beyond the scope of this report. The data from this testing, including the second by second results, are publically available in our Mobile Source Observation Database.*

Page 7, 5th paragraph: I suggest removing the words (throughout) "real world" with another phrase, such as "additional" or "additional representative", or "further disaggregated", for reasons explained previously.

"Real world" is a term used in the National Research Council report on the MOBILE model. It is used in this report to refer to data that addresses the concerns of the NRC. I have changed all occurrences of "real world" to "real world" representative to address this concern.

Page 8, 1st paragraph: The list of parameters thought to be important really includes of host of parameters, especially list item 3, which includes catalytic converter type, fuel delivery system, engine size, etc. The text should be amended to explain that list items reflect the variability in emissions from a larger set of parameters that are subsumed in the list item.
Page 9, paragraph 1: Please show the plot of grams per mile versus speed that the authors claim does not fit the data. It is always helpful for the reviewer to be able to concur with the authors assessment of lack of fit, and this cannot be done here.

The real issue is not a true lack of fit, but an engineering judgement of the expected trends. Linear fits in grams per hour units lead to curves, when converted to gram per mile units, which "tail" downward as average speed increases. This is not what is expected and is not suggested by the few data points at the higher speeds. Using gram per mile units removes this artifact of the modeling approach (the tailing off of emissions using grams per hour) from the model, without introducing more complex curve fits into the model.

*** Page 9, paragraph 3: It is not clear that the homogeneity of variance assumption in ANOVA was checked for reasonableness. This should be done and reported in the documentation. Also, there are many ANOVA tests being conducted, thus, the expected number of type I and type II errors is increased. For instance, with alpha = 0.05, and 20 rejections of the null hypothesis, one would expect on average (20)(0.05)=1 error The authors should keep in mind the number of tests they are conducting in concert with their selected alpha and beta levels. The authors might consider giving the beta level associated with some of the tests conducted.

*** The authors have seemed to ignore (or simply not report) the type II error rate. Type II errors often are ignored in the development of statistical models—which of course is embedded with statistical tests of hypotheses. Analysts might set an alpha level associated with a t-statistic to 0.05, only to find that several variables in their models, which were thought to be important on theoretical grounds, had p-values associated with t-statistics greater than 0.05—and so they subsequently removed them from consideration. In some cases these variables have suffered from type II errors, and should still be included in the model, especially when there is theoretical support for such variables. Systematically removing 'non-significant' variables from a model, therefore, ignores the possibility of important variables and related t-tests that have suffered from type II errors.

The determination of which statistical error is less desirable depends on the research question and consequences of the errors. Because these errors are related—smaller alpha equals larger beta, all else being equal—careful decisions need to be with regard to selection of alpha and beta, and attempts need to be made to quantify beta when appropriate. There are various software packages available for calculating type II error rates, and many textbooks also provide the necessary tools.

> *The number of parameters examined were carefully selected on a theoretical basis to reduce their number. Non-significant variables were removed from this pre-selected list based on the type I error statistics and consideration of the theoretical implications. EPA has not investigated the additional statistical parameters, but it is not likely that the additional work would result in a different choice for the model.*

*** Page 11, paragraph 3: The authors state "….a method was developed for increasing sample size by…..". It seems a bit unorthodox to increase sample size using this technique (or any other technique that does not simply collect additional appropriate data). I understand the motivation for this action; however, it is not clear that this will lead to satisfactory results. My concern is that vehicles 'substituted' for the Tier 1 vehicles (Tier 0 vehicles) will not perform similarly on the range of driving cycles used to estimate the MOBILE 6 emission factors. Theoretically, it is presumed that for a given vehicle manufacturer and model, a vehicle that meets Tier 0 standards will be fundamentally different than the same vehicle meeting Tier 1 standards—either through computer control of the engine, technology enhancements, or engine tuning. My skepticism also stems from the fact that the FTP, which is a fairly 'tame' driving cycle, was used to 'classify' Tier 0 vehicles as Tier 1. The ultimate manifestation of this action could be mild to fairly extreme bias in the mean emission response over non-FTP driving cycles of the "Tier 1" group of enhanced vehicles, most likely biased high. My recommendation is to not enhance the sample, or provide a much stronger justification and demonstrate that the Tier 0 vehicles used also were "clean" on non FTP cycles compared to their Tier 1 counterparts.

> *EPA shares the authors concerns in this area. However, when it became clear that MOBILE6 would need a set of speed correction factors for emission levels below the average for Tier 0 vehicles, a reasonable approach to estimate the factors was needed. In the absence of more actual data from Tier 1 vehicles, some approach would need to be used. The low emitting Tier 0 vehicles did have low emission rates on the more extreme facility cycles as well as on the FTP. The actual technical differences between Tier 0 and Tier 1 vehicles is not large and can be largely arbitrary based on the model year in which the vehicle is certified for sale. It should be noted that because the speed correction factors are applied by emission level, not emission standard, that low emitting Tier 0 vehicles will be using the factors as well.*

Page 17, 2nd paragraph: I agree with the statement, "the equations above would define a rational, smooth relationship for emissions versus average speed for…". The statement deserves some further caveats, however; we might expect a piece-wise linear relation to occur when changing roadway functional classes, vehicle classes, etc. In other words, a smooth line might not be expected when comparing discretely different groups or traffic cases. However, we would (as the authors assert) expect this to be the case for a homogenous vehicle class on a facility. The authors then point out that this does not in fact happen in the case of freeways. It is problematic that the models predict two different values for the same average speed on the same facility. I recommend truncating the portion of the curve where the relationship is in doubt, which is essentially using the stated rule 1 to omit the portion of the curve that is not used.

This is in fact what was done for the final version of the model.

Page 17, 1st list item: An accompanying figure would be nice to show here, as the text is a bit difficult to follow. The idea seems acceptable, however.

Page 19, Emission Offsets: The concept of emission offsets seems to be reasonable, however; I'm not sure why the US EPA has replaced the use of the FTP as the BER with the FTP + EO. This should be explained better in the text.

*** My bigger concern, however, is that Table 14 shows emission offsets computed by differencing the means of Fwy and LA4 driving cycles without taking into account the variability in the means of these tests. How many of the offsets are statistically significant, and how many are spurious? The offsets for level 1 THC and NOx, and level 3 NOx seem to be rather small, but one cannot tell 'how small' without knowing the variability in means. It is troubling to employ emissions offsets when in fact the offset could be in fact could be in the reverse direction. The authors should compute 95% confidence intervals on the offsets and only employ offsets whose values are convincingly significant and that can be theoretically justified.

Whether the emission offsets are statistically significant or not will not affect the calculations of the speed correction factors themselves, since they assume a base emission level on the freeway speed correction curve. This fact is taken advantage of in MOBILE6 by allowing the emission offset to change, due to factors such as the SFTP, without significantly affecting the speed correction factors. The emission offsets should be considered as part of the basic emission rate and any uncertainty included in the uncertainty of the basic emission rate. The SFTP report mentioned above discusses the emission offset in more detail.

Page 22, NLEV standards: The authors seem to be approaching the NLEV issue intelligently, and I have no comments about the proposed method other than keep updating the method as new information about the performance of the NLEV's is forthcoming. An average approach seems reasonable at this point in time. I would suggest that what will become more critical in the future (I believe) is the ability to predict and detect failures of the cleaner vehicles and subsequent remediation of them. As vehicles become cleaner, the difference between 'failed' vehicles and clean vehicles will become larger, and thus failed vehicles will provide even more bang for the buck (in relative terms) then they do now. How failures are modeled will also become important, and how various I & M strategies can be modeled by adjusting failure rates will also become important.

Page 30, Table 2: Need to define the terms SAFD Difference and High-Power Difference. It is presumed that these are statistics of the difference between the cycle and the FTP.

Page 31, Table 4: As stated previously, a companion table showing the distribution of vehicles for the national fleet would be helpful for determining whether the sample data is representative nationally.

National average technology distributions used in MOBILE6 are described in the report, "Emission Control Technology Distributions," (M6.FLT.008). These statistics can be summarized numerous ways, depending on the concerns of the reader. Readers should refer to the complete description of the technology distributions.

Page 32-33, Table 5: Again, it seems that a comparison by manufacturer would be useful. For instance, I only see one German vehicle in the sample; does the German proportion of vehicles really represent about $1/85^{th}$ of the national fleet? Again, a companion or enhanced table could show whether the sample of vehicles used for testing was representative.

Manufacturer designation is almost never used in generating emission estimates for the MOBILE model. Comparison by manufacturer is only an indirect way to compare technologies, which are the real parameters that most affect emissions. It is nearly always better in emission modeling to project technology trends rather than to predict trends in sales by particular manufacturers.

Page 35-37, Table 7: It appears that the standard deviation is larger than the mean for some cycles and emitter classes, see for instance FTP for normal emitters, or Running 505. This suggests a non-normal distribution of emissions, since negative emissions cannot result. This supports the notion that the ANOVA test assumption of normality and homogeneity of variance needs to be tested and shown (a comment detailed previously).

EPA concedes, without additional statistical testing, that emission distributions are not normal. As noted, this makes sense, since emission measurements cannot be less than zero on any sample vehicle.

*** Page 38-39, Table 8: The results in the table may be very deceiving and/or misleading. Of course one of the objectives here is to identify which factors are "important" for classifying fundamentally different emission conditions, whether they be vehicle, roadway, or environmental factors. But since all the ANOVA results are done individually, and the results were not obtained from controlled experiments, there are many factors that are correlated, and will subsume all of the variability in emissions simply because they are correlated with the "real" culprit. As a vivid (and perhaps overly simplistic example), if one were to compare emissions up a grade for a vehicle with a driver only and with three passengers, one might correctly conclude in an ANOVA that the presence of additional load would result in significantly increased emissions. If one also collected information on the number of seatbelts buckled, say 1 in one case and 4 in the other, the ANOVA would give identical results—it would suggest that buckling seatbelts increases emissions. Of course it is known that the load caused the excess emissions. My concern is that the whole gamut of potential factors has been ‘thrown’ into the ANOVA without regard for potentially overlapping or confounding effects. My suggestion is to provide a table with a correlation matrix of the factors used in the table (using the correctly computed correlation coefficients for nominal and ordinal data), and provide some discussion in the text to justify theoretically the factors thought to be important in the emissions process.

EPA carefully selected the parameters to be tested based on engineering judgement of which parameters were expected to be most important. This choice was based on the extensive experience of the staff involved and, hopefully, did not include spurious factors such as those in the above example. Admittedly, a more thorough investigation would include many other potentially important factors. However, the sample size suggested that a more rigorous search for significant factors would be fruitless.

*** Page 58-61: Figures 2 and 3: I am very concerned about these figures, and what they potentially represent (analytically), and consider this to be a potentially fatal flaw in the proposed methodology. The following discussion assumes that the figures are regressions through the ratio of means. There are several deep concerns I have about these graphs: 1) incorrectly specified random variables; 2) data aggregation bias; and 2) biased estimators of emission ratios. Each of these is now discussed in detail.

1. The random variable of interest is the ratio of emissions, such that:

$$SCF = \hat{\theta} = \frac{emissions_{cyclex}}{emissions_{FTP}}$$

where θ is the ratio of two random variables. To find the average of the random variable θ, one would compute:

$$\overline{\theta} = \frac{\sum_{i=1}^{n}\left(\frac{emissions_{cyclex}}{emissions_{FTP}}\right)_i}{n} = mean\ of\ the\ ratios$$

which is the *mean of the ratios* not the *ratio of the means*:

$$ratio\ of\ means = \frac{\sum_{i=1}^{n}\left(emissions_{cycle\ x}\right)_i}{\sum_{i=1}^{n}\left(emissions_{FTP}\right)_i}$$

To illustrate, suppose there are three thetas observed, 3/2, 1/5, and 5/3. The mean of the ratios is (3/2+1/5+5/3)/3 = 1.12, whereas the ratio of the means is [(3+1+5)/3]/[(2+5+3)/3] = 0.9. Thus, the use of the ratio of the means (as opposed to the means of the ratios) will not produce a good estimate of the desired quantity, theta, the ratio of cycle emissions to FTP emissions.

2. In addition to the problem specified above, the data have been aggregated (incorrectly as ratio of means) prior to regression. The data should be regressed using the original ratios from the 85 vehicles (or appropriate subsets thereof). Aggregation problems have been identified in previous research, and have been shown to result in incorrect relationships in the regression (the classic example is aggregation of trip generation by traffic analysis zone, which results in an incorrect sign of the relationship between trip generation and household auto ownership), and in inflation of R-Square and regression model statistics. Aggregation of the data prior to regression "throws away" the variability inherent in the data, and presents false confidence in the output.

3. Finally, the variable theta(hat), which represents the ratio of two random variables (emission test results), is in fact a biased estimator of the true population parameter . An unbiased estimator, obtained through the method of statistical differentials, is obtained as follows:

$$E\left[\hat{\theta}\right] = \frac{e_{cycle}}{e_{FTP}}\left\{1 + \left(\frac{1}{e_{FTP}{}^{2}}\right) VAR\left[e_{FTP}\right]\right\}$$

For additional information on the method of statistical differentials consult Hauer, 1997, "Before-After Studies in Road Safety, Pergamon.

Given these three important considerations, I recommend re-doing all regression equations that have used Ratio of Means with regression on original ratio units using all data points. I would omit the correction for bias (item 3), which should be neglible for large variance conditions, but would comment on it in the text of the bias of the parameter theta. Again, I find this to be a potentially large error in analysis, which could significantly alter the results of the analysis.

EPA agrees that regressions through the ratio of the means would present problems. However, careful reading of the report should show that regressions used for the speed correction factors were run on the emission levels of the individual vehicles themselves and not on the ratios or the ratios of the means. These figures were included only as a visual demonstration of the apparent effect of average speed (as defined by the driving cycles) on emissions based on the hot running LA4 cycle as a first step in understanding the analysis methodology. These figures are not a demonstration of the actual regression results, which are shown in Figure 4.

Potential Long-Term Improvements:

Page 1, bullets: Where do 2-lane highways fit into the picture? It is known from operational aspects of traffic that 2-lane highways have very different emergent traffic than do interstates with more than two lanes, due to a number of factors including limited access, truck activity and restrictions, passing maneuvers, and weaving. The entire paper has not mentioned 2-lane highways, and perhaps should address somewhere how this is being handled. In the longer term perhaps some empirical data on two-lane highways could be collected to determine whether they should server as a “separate facility type”.

Page 6, paragraph 1: The paper states, “These congestion levels have been roughly grouped into “levels of service” LOS using letters A through G, similar to congestion category designations used in transportation models.

The definition of level-of-service (LOS) used to ‘bin’ vehicular activity used by EPA and CARB is different than LOS used by traffic engineers and transportation planners. LOS has been assumed (by air agencies) to be an attribute of an entire facility (as viewed from a platoon of vehicles), not segments of a facility as defined by traffic engineers and planners. Traditional LOS categories A through F have been used to bin vehicular activity, despite the fact that these categories may not optimally separate characteristically different emissions-producing vehicular behavior. Only density has been used to ‘bin’ vehicular activity, and it has been determined through windshield observation. There are many factors that engineers used to compute level of service such as number of lanes, speed, flow, percent truck volume, type of freeway section, percent of weaving volume, etc. Future work should focus on improving the “gap” between the two working definitions of level of service. A recent paper by Debbie Neimeyer at UC Davis has quantified the vast difference between LOS as approximated by the CARB and EPA methods of car-following cycle development, and has shown that the imprecision of this measure of LOS is significant.

Page 7: 1st paragraph: It seems an awful lot to ask from 85 vehicles to infer emissions for a fleet of millions. Perhaps future testing programs could incorporate a larger number of vehicles in the testing programs.

> *The data available and the methods for collecting and analyzing new data have been changing rapidly. EPA is seriously investigating methods that will not require fixed, laboratory driving cycles to estimate the emissions from highway vehicles at a variety of operating conditions, such as speed, load and acceleration. These new methods will be able to better address the above issues in future versions of EPA models. We look forward to working with everyone in the stakeholder community in developing these methodologies.*

Appendix E : Peer Review of Off-Cycle Effects

MEMORANDUM

To: US Environmental Protection Agency
Office of Mobile Sources

From: Randall Guensler
Trans/AQ, Inc.

Date: June 10, 2000

Review of Off-Cycle Correction Factors for MOBILE6
This report constitutes a review of the EPA report entitled: Determination of Off-Cycle and Supplemental FTP Control Modeling in MOBILE6 (Draft Report M6.SPD.005)." Hereinafter, this EPA report is identified as the "Off Cycle Report." Randall Guensler of Trans/AQ, Inc. conducted this review under contract with the USEPA. The Off-Cycles report content as well as the data and statistical methods used to develop the documented relationships were the primary components reviewed. However, the methods and assumptions employed in developing off-cycle corrections inherently tie to the methods employed in developing EPA's new cycles-based correction factors and engine start emissions rates. In performing a review of the Off-Cycle Report, it was also necessary to review the methodologies outlined in the EPA report entitled: Facility-Specific Correction Factors (EPA-420-P-99-002). Hereinafter, the second EPA report is identified as the "Cycle Correction Factor Report."

Off-Cycle Emissions

Instrumented vehicle studies have indicated that the grams/second emissions of CO and HC from well-maintained vehicles remain low and stable under conditions of nominal engine load. Exhaust emissions under nominal engine load conditions do scale with engine rpm (exhaust gas throughput) but remain at low levels. Given the inherent variability in second-by-second emissions at these low levels, an average emission rate can represent the emission rates under nominal load conditions very well. Once engine loads increase past certain threshold levels (where engine load is a function of speed, acceleration, vehicle weight, grade, wind resistance, tire rolling resistance, and accessory loads), engine computers respond by enriching the air:fuel mixture.[1] The enriched mixture can increase emissions by orders of magnitude for short periods of operation. Under enrichment conditions, engine power output increases, and peak combustion temperatures and peak combustion and exhaust manifold gas temperatures drop. Hence, manufacturers program engine computers to undergo enrichment to improve on-demand vehicle

[1] Further, when engine loads begin to cycle rapidly from loaded to unloaded conditions (such as under conditions of throttle dither) emissions also increase significantly.

performance and to protecting valves, rings, and catalysts under high load conditions. Engine computer programs may also use other input variables, such as rate of change of throttle position, as an indicator that increased power output is requested and therefore send a signal to undergo enrichment. Enrichment can also occur as the result of faulty sensor input. Under extreme enrichment conditions, NOx emissions can drop significantly as a function of the drop in peak combustion temperature. However, under most operating conditions, NOx emissions in grams/second tend to scale well with engine load (NOx emission rates are a function of temperature and pressure of combustion). Computer-programmed enleanment (and increased NOx emissions) can occur for some vehicles under conditions of extended cruise when manufacturers have programmed the vehicle to run lean to improve fuel economy. In addition, the demands of air conditioning increase engine load and cause vehicles to experience increased CO, HC, and NOx emissions.[2]

Modeling Paradigm

The key with any in-use vehicle emissions modeling approach is simultaneously accomplish two goals: 1) adequately represent the stable baseline emission rates in the model, and 2) represent the cause-effect relationships that result in significantly higher or lower emission rates under environmental and onroad operating conditions that differ from those experienced during collection of baseline emission rate data. These two components must be prepared simultaneously so that the baseline emission rates and the emissions modifiers are appropriate for the group of vehicles modeled. That is, if there is little variability baseline emission rates within the group "fuel injected vehicles" and if all fuel-injected vehicles respond similarly to changes in external operative variables (such as changes in acceleration rates), the baseline emission rates and correction factors are likely to be appropriate. However, if there are subgroups of fuel-injected vehicles that exhibit statistically significant differences in baseline emission rates or responses to changes in environmental/operating parameters, then the subgroups need to be modeled separately. Identifying these mutually exclusive technology groups requires a great deal of up-front statistical analysis. In reviewing the EPA documents, the methodologies employed are compared to this modeling paradigm. Deviations from the methods described above are reviewed and the potential impact of each deviation is qualitatively assessed.

Baseline Emission Rates

The LA4 cycle is composed of the 505-second and 866-second dynamometer cycles employed in the FTP. The full FTP test consists of an LA4 test (with the 505-second cycle being conducted in cold start mode and the 866-second cycle conducted in hot stabilized mode), followed by a repeat of the 505-second component of the LA4 cycle under hot start conditions. The report sometimes uses LA4 and FTP composite emissions interchangeably. EPA staff should clarify the definitions

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[2] Some impact may result from cycling of the compressor and engagement/disengagement of the a/c clutch, and transient changes in EGR or other parameters potentially affected by the cycling. More studies are needed in this area to fully understand the cause-effect relationships at work..

of the LA4, FTP, and the relationship between the two, throughout the Off-Cycle Report.

In testing the 85 vehicles in the Cycle Correction Factor study, EPA and EPA contractors also tested all 85 hot-stabilized vehicles on the 505-second component of the LA4 (the FTP Bag1 and Bag3 cycle). Normally, certification laboratories would only test these vehicles on the 505-second cycle under cold transient (FTP Bag1) and hot transient (FTP Bag3 conditions). EPA performed the hot-stabilized test so that incremental engine start emission rates (grams/start) could be developed for the 85 vehicles (see EPA's documentation associated with MOBILE6 engine start emission rate development). Because hot stabilized FTP Bag1 and FTP Bag2 were available for these 85 vehicles, EPA staff computed a Hot Running LA4 test result for each vehicle by adding these two test results together (in grams) and dividing by the miles traveled on the LA4 cycle. The exact methodology used to develop the hot stabilized LA4 base emissions rates in MOBILE6 should be stated in both the Off-Cycle and Cycle Correction Factor reports as they impact the application of the algorithms discussed in these reports. The report should contain language similar to that provided by EPA staff below:

> "When we refer to a hot running LA4, we mean the LA4 cycle run without any starts at all. This should be equivalent to running all three bags of the FTP without a start, but the results of Bag1 and Bag3 should be the same. So, instead you can just add a hot running 505 to Bag2 of the FTP to give a hot running LA4. The "trip" in each case (FTP and HRLA4) would be the LA4 cycle (7.5 miles), but the FTP would contain engine start effects (43% cold and 57% hot) and the HRLA4 would contain no starts at all. So you could use the FTP weightings and substitute the HR505 for Bag1 and Bag3, but this should be the same as just adding the grams in the HR505 and Bag2 (Brzezinski, 2000)."

To develop hot stabilized LA4 MOBILE6 baseline emission rates, the EPA developed a model to predict hot stabilized 505 emission rates from FTP test results (using the data collected from the 85 vehicles in the cycle correction factor database). The EPA engine starts report indicates that a linear model was developed to predict hot stabilized Bag1 emissions as a function of FTP Bag1 transient, Bag2 hot stabilized, and Bag3 transient test results. This way, EPA staff could generate an artificial hot stabilized LA4 emission rate using the FTP Bag2 emissions and the artificial Hot Stabilized Bag1 for all vehicles in the comprehensive emissions testing database. Again, the methods employed need to be clearly defined in the Off-Cycle and Cycle Correction Factor reports.

There are two distinct advantages of using FTP emission rate data for developing baseline emission rates. First, the EPA has maintained a continuous testing program (although spotty at times) that has resulted in a database of more than 23,000 in-use vehicle tests for which FTP emission rates are available. Second, the FTP test cycle is gentle enough to keep most vehicles from undergoing enrichment or enleanment. Because the FTP cycle does not usually induce enrichment, due to moderate speeds and low acceleration rates, researchers can more readily identify and quantify differences in emissions behavior for vehicles across the FTP test and alternative test cycles. Of further importance, the FTP Bag2 cycle is even less likely to induce enrichment than the LA4 cycle because the 505-second sub-cycle contains a significant initial hill of acceleration that is more likely to induce enrichment. Hence, I believe that using Bag2 as an emissions baseline is a sound modeling approach and better for noting systematic changes in emissions behavior than the LA4 cycle. In fact, the MEASURE model even predicts higher emissions on the FTP 505-second hot stabilized Bag1 activity profile relative to the FTP Bag2 activity profile.

It is important to note at the outset that the FTP composite emission rate is composed of contributions from a cold transient test, a hot stabilized test, and a hot transient test. Hence, the engine and catalyst behavior during warm up stages of operation affect Bag1 and Bag3 values and therefore the composite emissions rate. In MOBILE6, start emissions are being modeled as an increment (grams/start) and separated from the hot stabilized emissions component. Because EPA was developing incremental engine start emission rates in MOBILE6, EPA staff made the sound decision to avoid using the FTP composite emission rate as an emissions baseline. EPA selected the hot stabilized LA4 as the emissions baseline because it would better reflect onroad activity than other cycles. The LA4 emission rate can serve as an adequate baseline in modeling. With LA4 as the baseline, the model needs to be able to predict vehicle emissions response when vehicles experience nominal engine load conditions (such as those resulting on FTP Bag2 cycle). Such nominal engine loads and lower emissions rates would be expected to occur when traffic calming TCMs are implemented. The important consequence of using the LA4 as the emissions baseline is that there is no comprehensive database of hot stabilized 505 emission rates. These emission rates must be predicted for the comprehensive emission testing database as a function of the composite emission test results. The basic problems with doing this are: 1) there is a question as to whether the 85-vehicle data set used to develop these relationships is representative, and 2) there is a large variability in vehicle-to-vehicle emissions response across transient versus stabilized test conditions.

> 1. Representativeness of Sample Fleet - Based upon the statistical analyses associated with MEASURE model development, it is apparent that the 85 vehicles employed in MOBILE6 model development are not representative of the vehicle fleet. There is a good distribution of model years and fuel-delivery technologies. However, the data set does not control for other technology variables that Georgia Tech has found to be statistically significant in terms of establishing baseline emission rates and emission responses. Given the resource constraints that EPA has faced in collecting in-use emissions data for use in MOBILE6 model development, the 85-vehicle is probably the best that could be expected. However, when a vehicle sample set does not adequately control for the variables suspected of being involved in cause-effect relationships, the real-world statistical prediction intervals of the model cannot be determined. All of the statistical tests associated with confidence bounds assume that a representative sample has been analyzed. The impact of a non-representative sample fleet cannot be determined statistically. Hence, the uncertainty associated with using the 85-vehicle data set cannot be ascertained. It is impossible to determine whether the use of the 85-vehicle data will

overestimate or underestimate baseline LA4 emission rates, or whether the emissions response equations (i.e. cycle correction factors) will overestimate or underestimate the real-world emissions response.

2. Large Variability in Vehicle-to-Vehicle Emissions Response Under Transient Conditions - In conducting engine start emissions analyses for the MEASURE model, Georgia Tech staff analyzed the contributions of Bag1, Bag2, and Bag3 emissions to the composite emissions for normal and high emitting vehicles. GT analysts noted that the major contribution to high emitter status often came from the cold and/or hot transient tests, but for many vehicles, the contribution came from all three bags. There was a large variability associated whether the transient tests or the hot stabilized portions of the tests contributed to high composite emission rates and pushed the vehicle into high-emitter status. Unfortunately, many of the suspected causal links could not be assessed because second-by-second emissions were required to determine when these vehicles achieved catalyst light-off. The issue that arises here is that the derived statistical relationship that EPA is using to predict Hot 505 emissions from FTP Bag1, Bag2, and Bag3 is suspect. All of the MOBILE6 modeling methods that follow the development of the LA4 emission rates (cycle correction factors, off-cycle corrections, engine start algorithms, etc.) are contingent upon the viability of the relationship between the FTP tests and LA4 tests.

It would have been more appropriate to use the FTP Bag2 (hot stabilized) emission rate as the baseline emissions rate for all modeling work. True, emissions are lower on FTP Bag2 than they would be under a Hot Stabilized 505 test, but this is not critical. As discussed earlier, statistical analyses are designed to develop corrections from a baseline. It is advantageous to select a cycle with driving conditions that do not induce enrichment/enleanment so analysts can identify the factors that induce such enrichment/enleanment. The LA4 cycle contains higher load conditions than FTP Bag2 and therefore provides less stable test results from which to determine correction factors. Plus, hot-stabilized emission rates on the LA4 are simply not available for the vehicle fleet and have to be derived from FTP Bag1, Bag2, and Bag3 data. Given the methodologies and limited data employed, it is not possible to forecast whether the FTP baseline emissions are likely to be biased high or biased low.

Off-Cycle Corrections

The Freeway Level of Service (LOS) F test cycle represents the activity likely to be experienced by vehicles under congested freeway conditions (Off-Cycle Report, page 3). Both the LA4 test and the LOS F cycle have approximately the same average speed of 19 mph. However, the measured emission rates for almost every vehicle in the 85-vehicle data set under Freeway LOS F conditions were significantly greater than their corresponding LA4 emission rates. In effect, the off-cycle report indicates that the increase in emissions results from the fact that the congested freeway test cycle conditions are more strenuous than the FTP or LA4 test conditions. That is, the emissions increase results from the testing activity that is outside of the boundary of FTP or

LA4 test cycles.[3] The Off-Cycles Report states that a correction factor should be applied to the baseline LA4 data to account for the higher level of emissions noted for the freeway test cycle with the same average speed as the LA4 cycle. Hence, EPA staff developed an off-cycle correction factor to elevate the FTP emissions to the levels noted at the desired baseline testing condition. This way, cycle correction factor statistical analyses would generate a correction passing through an emissions ratio of 1:1 for the Freeway LOS F cycle (average speed of 19mph).

In reviewing both the Off-Cycle Report and the Cycle Correction Factor Report, it was not possible to determine the point in model development at which EPA staff determined an off-cycle correction factor was required for developing MOBILE6. The Off-Cycle Report indicates that there is a need to account for emissions that occur under operating conditions that differ from those experienced in the LA4 test. The Off-Cycle Report also argues that there is a need to correct the LA4 emissions to the emissions level observed on under the Freeway Level of Service (LOS) F testing cycle. The Off-Cycle Report then states that the Cycle Correction Factor must equal 1.0 at these testing conditions. In contrast, the Cycle Correction Factor report simply starts with the premise that an off-cycle correction was to be applied to all FTP data for the 85 vehicles before model development was to proceed (Cycles Report, page 18 and 19).

Although both reports argue that an off-cycle correction factor would be required, neither report justifies the creation of such a correction. Given the nature of correction factor development, there really is no compelling need to create such an off-cycle correction factor. Correction factors are applied to a baseline emission rate, irrespective of whether the baseline emission rate is an FTP Bag2 or a Hot Stabilized LA4. Introduction of an off-cycle correction factor to the test results that are subsequently used in development of cycle correction factors is unnecessary. In fact, such a correction is detrimental to the development of the cycle correction factors. This is because the first correction factor algorithm yields a predicted value that must by its nature reduce the variability in emissions response for a variable that is employed in the next algorithm development process. It would have been more appropriate to model the net effect of the two correction factors within a single cycle correction factor (statistical reasons are described in the next section). True, the new cycles correction factor would not equal 1.0 at 19mph on a freeway, but this is not a necessary condition for correction factor algorithms.

Assessment and Validation of Off-Cycle Analytical Methods

It was not possible to reproduce the analytical results presented in the Off-Cycle Report using the emission rate data provided by EPA staff. Presumably, this is because the database provided only contained test results for 84 of the 85 vehicles indicated in the report. The fact that the beta coefficients were significantly different between the modeling runs for the 84 and 85 vehicle data sets is a reflection of the inter-correlation of the LA4 and LA4-squared variables employed in the

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[3] The emissions increase may also result from other factors such as increased throttle dithering that affect computer-controlled enrichment.

model. The standard errors of the model beta coefficients are extremely high under conditions of independent variable correlation. Hence, there can be large fluctuations in the beta coefficients developed from model run to model run, as a function of the actual vehicle data employed in model development. However, the predictions from two different models that use a 95% subset of the original data can still be similar, even though the beta coefficients are wildly different. This makes interpreting the meaning of the beta coefficients difficult. It is best to think of the EPA off-cycle correction factor modeling approach as a curve fit rather than an explanatory model.

The fact that the statistical analyses did not indicate statistically significant differences in vehicle emissions as a function of model year, fuel delivery system, trucks vs. cars, etc. is a reflection of the small sample size. Emissions variability within same-vehicle tests, let alone across vehicle tests, is very large. The report should reflect that there are likely significant differences in emission response across the various vehicle technology groups, but the database is of insufficient size to distinguish and separate any systematic effects across these variables from the highly variable emissions response.

EPA staff used engineering judgement to prevent the algorithms from predicting negative offset increments. EPA staff clipped the quadratic form for high LA4 emissions levels. This way the equation retains a maximum offset level, rather than predicting a decline in the offset for higher baseline LA4 emissions levels. The report provides no scientific theory (i.e. cause-effect relationships related to emissions production) to support the functional form of the model (hot stabilized LA4 and LA4 squared) or to support the decision to truncate the model for high-emitting vehicles. It is not clear that "off-cycle" emissions increments would not decline or even go negative for certain high-emitting vehicles when onroad operations move from LA4 driving to freeway LOS F driving (especially for NOx). Despite the mention in the report that there are few onroad vehicles with sufficient emissions levels to invoke the clipped portion of the algorithm, the validity concern that should be addressed through additional analyses.

Assessment of Corresponding Cycle Correction Factors

In developing the MOBILE6 mobile source emission rate model, the USEPA has attempted to significantly improve the general modeling approach for predicting emissions as a function of on-road vehicle operating conditions. Previous versions of MOBILE modeled emission rates as a direct function of average speed, irrespective of actual on-road operating conditions. Hence, previous model versions predicted the same emissions rates for vehicles at 25 mph, regardless of whether the vehicles were operating under congested freeway conditions or free-flow arterial conditions. Researchers have identified numerous theoretical and technical flaws with the previous average speed modeling approach (see Guensler, 1993 and the CRC review of EMFAC conducted by Environ). MOBILE6 attempts to dis-aggregate on-road emission rates by integrating two new explanatory variables into the existing speed-related modeling framework: facility type and level of service condition (reflective of congestion conditions). To develop the new corrections, EPA staff contracted with Sierra Research to develop new testing cycles designed to be representative of the operating conditions on various facility classes (e.g. freeways, ramps, arterial) under different level of service conditions. EPA and EPA contractors used these new cycles to collect laboratory emissions data from 85 vehicles. Then, EPA contractors derived cycle correction factors, or new relationships between emission rates and operating conditions specifically associated with a facility class and the congestion conditions noted to occur at various levels of service on these facility types. The cycle correction factor approach disaggregates the MOBILE5a relationship between emissions and average speed, providing a significant theoretical improvement over the previous speed correction factor modeling approach.

Cycle-based correction factors are multipliers to baseline emission rates. That is, MOBILE6 predicts emissions under onroad driving conditions as a multiple of the emissions occurring under baseline testing conditions. To develop cycles-based correction factors, EPA developed statistical relationships between measured emission rates on test cycles designed to represent operating conditions on different facility types and level of service conditions and the calculated (and then off-cycle-adjusted) LA4 baseline emission rates. If laboratory tests yielded significant increases in emissions when vehicles changed from baseline-like operations to alternative operating conditions, the model algorithms reflected the effect in the cycles-based correction factors (by roadway class).[4]

In MOBILE6, the cycle correction factors were determined as a ratio of predicted average emissions (average predicted emissions on a freeway test cycle divided by the average predicted emissions on the Freeway level of service cycles). These predicted emissions are based upon the results of a regression analysis for the 85 vehicles that simply predicted grams/second emissions (by emitter class) as a function of average speed for the test cycles used to collect the data. Before running these regressions, the emissions data were corrected by the off-cycle emissions offset. The basic methodology employed in developing the cycle correction factors is a problem unto itself. The prediction of gram/second emissions, calculation of the ratio of predicted emissions for each cycle, and then the subsequent prediction of the relationships of the emissions ratios to average speed is a fundamental flaw in the modeling approach. Such estimations toss away all vehicle-to-vehicle emissions response variability. The best fit curve is forced through the mean of the ratio of the average predictions for each cycle test result set, rather than being allowed to provide a best overall fit to the entire range of vehicle emissions responses expressed

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[4] Strictly speaking, MOBILE6 models emissions as a function of the level of service conditions reflected in the test cycles used to collect the laboratory data for cycles correction factors. MOBILE6 does not predict emissions as a function of average speed. Instead, average speed plays a role in a best-fit interpolation between these test cycle conditions. EPA staff simply plotted the average emissions from each testing cycle by average speed of testing cycle. Then, staff derived a best-fit interpolation between averaged values of the test cycle results as a function of average speed. Although the modeling approach provides significant improvement over the average speed regime in MOBILE5a, EPA should caution MOBILE6 users that the average speed relationships in MOBILE6 are still highly uncertain. If bootstrap regression and Monte Carlo analysis were performed on the derived relationships, both the average emissions response value for each LOS test cycle and the curve fits between the test cycle results would exhibit wide confidence bounds (see Guensler, 1993 for more information on this modeling technique).

across all of the cycles. Given the methodology employed, it is impossible to perform a standard statistical assessment to determine if the modeling approach is more likely to be biased high or biased low. The algorithms could be assessed using a combination bootstrap and Monte Carlo assessment approach, but the task would be very time consuming.

With respect to the role of the off-cycle correction, one is to assume that if a cycle other than freeway LOS F had been selected as the off-cycle offset baseline, the same cycle-correction factor curves would have resulted. That is, the predicted incremental increase in baseline emissions to account for off-cycle effects will not affect the derivation of cycle correction factors. If appropriate statistical techniques were employed that retained response variability, this would be highly unlikely, given the nature of the small data set and highly variable emissions responses across these vehicles and test cycles. However, EPA staff can readily check this hypothesis. The question is how significant the differences will be. EPA staff should replicate the model estimation approach used to develop the off-cycle correction and the cycle correction factors using a different assumed off-cycle correction baseline. The alternative model would use the emission test results from freeway LOS B or LOS C cycle (instead of the LOS F cycle) as the basis for developing the LA4 off-cycle increment. The same multi-step procedure would be used to generate the alternative off-cycle correction (as a function of LA4 and LA4 squared) and the subsequent cycle correction factors. If the model estimation approach is stable, this procedure will yield the same net predictive algorithm for the range of LOS conditions. That is, when EPA staff apply the original and alternative model to the 85-vehicle data set (or any validation data set) both models will predict approximately the same emission rates for any specified operating condition. The issue of whether the 85-vehicle fleet provides representative responses will still be a major concern. However, even though standard statistical methods cannot be applied to assess the adequacy of the current MPOBILE6 algorithms, at least the modeling approach taken will be more defensible if the original and alternative modeling achieves the same correction factors.

Correction of Correction Factors

One issue that is a major concern with the modeling methods outlined in MOBILE6 is the interrelationships between the various algorithms and correction factors employed. The presumption is that all of the relationships developed in a stepwise fashion from the 85-vehicle test are applicable to the fleet.

- o MOBILE6 hot stabilized baseline LA4 emission rates are predicted from FTP transient data.
- o Off-cycle correction factors (as a function of LA4 and LA4 squared) are applied to the predicted LA4 test result to generate a corrected LA4 baseline.
- o The various correction factors do not always account for high-emitter status, Tier 1 vs. Tier 0, and their interactions, meaning that the "technology groups"

employed in the offset development are different than those used in the cycle-correction factor development.

- o The predicted corrected LA4 baseline emission rate is multiplied by an emission ratio that is derived from predicted and adjusted gram/second emissions as a function of average speed.

Every time a predicted variable is used as an explanatory variable in a subsequent algorithm, data variability is reduced. That is, the error terms associated with the first algorithm, representing random error and problems with model specification, do not carry forward into the development of the subsequent algorithm. As such, each modeling step appears to provide a more systematic response and better statistical fit. Using predicted variables as independent variables is not a significant problem, provided that no important explanatory variables are omitted in the primary steps. However, when a model has a large error element relative to the model output signal, such as the case in emissions testing, it is difficult to argue that all of the important variables have been included. This issue provides a compelling reason to derive all of the correction factor relationships simultaneously.[5]

The complex step-wise modeling approach used in developing MOBILE6 results in a final model structure that cannot be falsified by field experiments. Given the number of general assumptions, and corrections to corrections employed in the modeling routines, it will not be possible to pinpoint the source of error when the model is determined to over-estimate or under-estimate emission rates under certain operating conditions. Simultaneous development of the modeled relationships (which would have admittedly required a larger testing data set than EPA had available) could have avoided the problems noted above. With simultaneous development of baseline emissions rates and correction factors, the emissions from various subgroups of the fleet under different operating conditions could be examined through ongoing roadway and laboratory experiments.

There is an important bottom-line conclusion that arises from review of the various modeling methodologies employed in developing MOBILE6. EPA management needs to be aware that emission rate models cannot improve significantly until EPA has acquired the necessary resources to test many more vehicles under testing conditions that differ from the FTP. As a side note, it is not nearly as important that these laboratory tests be representative of real-world driving as it is that these tests reflect the range of operating conditions that vehicles experience in the real world. Statistical modeling approaches can generate appropriate baseline emission rates and correction factors once second-by-second data under alternative testing conditions are available.

Supplemental FTP Emissions Effects

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[5] Simultaneous development of baseline emission rates and modal correction algorithms was the basis of MEASURE model development.

By integrating two new emissions testing cycles into the FTP certification process, EPA is effectively raising the bar for new vehicle certification. The first supplemental test, the US06 cycle, contains significantly higher speeds and acceleration conditions than the existing FTP. The second supplemental test, the AC03 cycle, contains harder acceleration rates and must be conducted while the vehicle's air conditioning is operating. The higher load test conditions and the operation of air conditioning put significantly greater engine loads on the tested vehicles. Consequently, the SFTP provides more opportunity for vehicles to undergo sustained high load conditions (leading to higher NOx) and power-demand enrichment (greatly increasing CO and HC emissions). The change in the test method, designed to capture more emissions from in-use vehicles, results in a defacto change in emissions standards (even though the actual gram/mile compliance limits remain unchanged. If manufacturers do not implement additional control strategies, many of their vehicles will fail the SFTP certification test. The question that arises in the Off-Cycle Report is what emission benefits will result from implementing the new SFTP test?

In principle, the emissions benefit of the SFTP is the difference between in-use emissions before implementation of the new test method and in-use emissions after the implementation of the new test method and composite SFTP standard.[6] If one assumes that manufacturers will comply with the regulations, but will not provide significant reductions beyond compliance, the net reduction of in-use emissions is represented by change in vehicle activity reflected in the new testing cycle. There is a subset of onroad vehicle activity included in the SFTP and not included in the FTP that leads to elevated in-use emissions with the current fleet. Under the SFTP, these activities will likely yield normal stabilized operating emissions. Hence, the SFTP emission rate benefits are associated with the change in capture of emissions by the new cycles, multiplied by the overall fraction of onroad vehicle activity that is included within the operating boundaries of the new test conditions.

Quantifying the emissions benefits of the SFTP requires comparative testing of vehicles on the facility cycles as well as the US06 and AC03 cycles. Reduction in off-cycle emissions could be estimated by comparing the percentage reduction in emissions that will occur for current vehicles as they move from their current emissions levels on the composite SFTP to the compliance emission rates for the 5year/50,000 mile US06 standard of 0.65 grams/mile HC+NOx and (perhaps lower than this level to account for the benefit of compliance headroom). One could then make the argument that if the US06 and AC03 cycles contain the conditions in the facility cycles that currently lead to enrichment, the onroad emissions will be reduced by a similar percentage (or by a percentage weighted by the 65% contribution of these cycles to the composite SFTP). In plotting the cycle characteristics of the various freeway level of service cycles, the US06, and the AC03, it is clear that then new cycles contains a significant fraction of high-speed activity that appears in the Freeway LOS cycles. The acceleration rates associated with the high-speed ranges in US06 are also on par with the acceleration ranges found in the Freeway LOS Cycles and the US06 contains harder decelerations at higher speeds and harder accelerations at

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[6] Composite FTP is determined as a weighting of 35% FTP composite, 37% AC03, and 28% US06 contributions.

higher speeds. Three-dimensional Watson plots of fraction of operation under given speed and acceleration ranges could be used to determine whether the US06 and AC03 cycles cycle contain a wider range of load-inducing activity than the various level of service cycles. EPA could then effectively argue that because the SFTP cycles (which contribute 65% to the SFTP composite emission rate calculation) are more likely to induce off-cycle emissions than the LOS cycles, and because manufacturers will comply with the SFTP, off-cycle emissions under all LOS cycles will decline. However, EPA SFTP benefit estimation methods did not take such an approach. As discussed below, it is difficult to follow the logical progression of the benefit calculation and it is not possible to verify many of the assumptions employed in the methods reported in the Off-Cycle Report.

For Tier 1 vehicles, the Off-Cycle Report indicates that the off-cycle increment[7] will be adjusted downward by 88%, 72%, and 78% for HC, CO, and NOx respectively. The argument put forward is that the implementation of the SFTP will reduce the emissions difference noted across the LA4 test and the freeway LOS F test by these percentages. The Off-Cycle Report cites to "rule-estimated benefits," presumably contained in the Tier 1 rule development report as the source for the reduction claims. However, the basis for these claims is unverifiable in the Off-Cycle Report. No scientific theory or empirical data are provided to justify the values.[8] It would be beneficial to test these hypotheses using new modal emissions models applied to the cycle tests and weighted by fraction of onroad activity expected to occur under each operating condition. New modal models could also be employed to assess the likelihood that these estimates are reasonable.

The implementation of the SFTP stands to flatten the future cycle correction factor curves in MOBILE6 for the future vehicle fleet. As discussed earlier, there was no compelling reason to prepare a linear bump-up in emissions and deem it to be an off-cycle correction factor. Similarly, there is no compelling reason to create a linear bump-down to adjust this off-cycle increment for SFTP implementation. This is because the effects of operations that differ in engine load from LA4 (or any other baseline) will be reflected in the final curve that result from the statistical method (or combination of statistical methods) employed. To the extent that operating conditions in the cycle correction factor test cycles are now reflected in the SFTP, there is reason to believe that future vehicles will behave differently on the new facility cycles used to generate the cycle correction factors. The Off-Cycle Report's discussion and re-derivation of cycle correction factors using the test results from 10 vehicles that behaved well on the ramp cycle does not provide adequate evidence to assess the validity of keeping the proposed cycle correction factors when the SFTP is implemented. This seems especially true considering the highly aggregated modeling approaches (and averaging of predicted values) employed in

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[7] Calculated as the difference between the hot stabilized LA4 test results and the freeway LOS F test results and then predicted as a function of LA4 and LA4 squared.

[8] There also appears to be no basis for the 50% decrease in off-cycle emission reduction effectiveness for SFTP controls that are coded into the MOBILE6 model (noted in Appendix A, Table 3, and Table 4). This aspect needs to be discussed and justified in the report.

developing the cycle correction factors. Had the baseline emission rates and cycle correction factors been modeled in a single statistical operation, as suggested earlier, significantly different relationships would likely have resulted and the cycle correction factors may have taken on different shapes both pre- and post-SFTP implementation. Unfortunately, it does not appear that a scientific and statistical method that can be used to test the relationships presented in the report. As such, EPA should propose a comprehensive testing program designed to collect data from new SFTP certified vehicles when they become available. The goal of the testing program should verify the onroad emissions response behavior reflected in MOBILE6 both pre-and post-implementation of the SFTP.

The methodology used to develop the LEV benefits from implementation of the SFTP is not clear and concise. Although the calculation methods have been conveyed in the text and tables, it is impossible to follow the logical flow of the multi-step procedure outlined in the report. The first step splits the effective SFTP standards (identified as US06 in Table 2) NHHC+NOx compliance levels into separate components cannot be evaluated (theory, logical reasoning, empirical evidence, and appropriate references should be provided to support the splits). The second step of estimating average 1999 certification emissions levels from the Certification and Fuel Economy Information System (CFEIS) should be clarified and additional detail on the number of vehicles tested should be provided. Presumably, the CFEIS tests reported are test results on the SFTP (indicated by the provision of 4K and 50K mileage accrual values corresponding to SFTP standards) and not the FTP.[9] The third step of estimating running emissions levels is not clear and requires separate evaluation of the referenced MOBILE6 exhaust emissions report to ascertain why the adjustment was made (0.9 for NOx and 0.23 for HC). The fourth step consists of calculating the ratio of the SFTP effective emissions standard (Step 1 result) and the running certification level for 1999 model year vehicles (Step 3 result). A discussion as to why the ratio of SFTP standard to current new vehicle certification emissions is lacking. In using this value in emissions benefit assessment, it seems that EPA is asserting that the certification standard is somehow responsible for the compliance headroom noted in the CFEIS and that such headroom is systematic and will remain consistent over time.

The logical reasoning behind the next set of steps in the benefit assessment process is completely lost in the text. The goal appears to be to determine the increased stringency of the ARB LEV standards relative to the EPA standards and then to adjust the SFTP benefits accordingly. Presumably, the calculation is designed to represent how much cleaner in use LEVs will be under the California LEV standard (at 4,000 miles) relative to the 49-state standard (at 50,000 miles). That is, the certification of LEVs under the California program is expected to garner additional emissions reductions. Tables 2 and 3 illustrate the calculation method employed to represent the increased stringency of the ARB standard relative to the EPA standard. However, the text does

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[9] The Tables indicate that "FTP Certification Levels" are reported. If this is the case, another major issue arises. The use of a ratio of future SFTP certification limits to current FTP running certification emission rates would be meaningless in the calculations employed. There is no reason to believe that current FTP certification emission rates will correspond to future SFTP test results.

not explain the logic behind the calculation. While a more stringent ARB requirement is likely to capture emissions that the EPA requirement leaves in the in-use fleet, no compelling argument is provided that indicates why the calculation methodology makes sense.

As mentioned above, it seems that the calculation methods are based upon the assertion that compliance headroom (represented in the ratio surrogate) in the certification database is systematic and the result of the differences in certification standards. The method also inherently assumes that such headroom will remain consistent over time. Even if EPA staff provided the logical flow of the equation derivation, it is unclear whether the logic behind the calculation methodology would hold into the future. As manufacturers produce more reliable and durable vehicles in response to the SFTP mandate, the compliance headroom or safety margin currently experienced in the certification database may drop significantly. Plus, it is unclear how these ratios will change for LEVs versus the 49-state fleet. Furthermore, there is no way of knowing whether these respective vehicle fleets will age similarly and whether the effect predicted from SFTP calculations based upon 1999 vehicle data will still be appropriate for these vehicles in 5 or 6 years. Changes in these factors would be evidenced as significant changes to the ratios calculated in Step 4, significantly influencing the predicted CARB-related LEV benefit. Without additional information and explanation, it is simply not possible to evaluate the algorithms provided in the Tables. Since it is unlikely that EPA will be able to answer the question of benefit estimation stability over time, it imperative that a comprehensive testing program be implemented to check these significant MOBILE6 assumptions over time and make corrections based upon observation.

Similar to the methods used to develop benefit estimates for the US06 cycle, the text discussion of AC03 benefits also lack sufficient documentation to perform an assessment of the methodologies employed. The first problem is failure to support the determination of the EPA SFTP AC03 benefit of 50% for NOx. As mentioned earlier, the justification for using the ratio of AC Standard to Running Certification Level (or even certification level in the CFEIS database) as a measure of relative effectiveness across the EPA and ARB certification programs is lacking. The fact that CARB has required the elimination of "commanded enrichment" is unclear. Presumably, CARB has prescribed that vehicles cannot be pushed into commanded enrichment simply whenever the air conditioning is turned on (i.e. the issue that apparently arose in the Cadillac dispute). However, the text is unclear as to the extent to which CARB has prescribed the elimination of A/C induced commended enrichment. When the air conditioning is in operation, a vehicle will undergo enrichment more readily unless an A/C clutch causes the air conditioning to disengage under these conditions (is thus what CARB actually prescribed?). If so, the assumption of HC eradication does not seem unreasonable. Scaling CO emissions with vehicle load also seems reasonable (this probably could have been done for HC as well) where vehicle load is predicted as a function of predicted fuel consumption increases. However, equations used to derive the increase in fuel consumption as a function of speed and speed squared are not supported in the text of the report. A multitude of alternative fuel consumption equations could have been employed. The concern here, given the discussions earlier regarding the representativeness of vehicles tested, representativeness of test conditions, and treatment of data in developing regression models, is that these relationships may or may not be justified. The report should provide more detail on how the equations were developed and how the predicted changes in fuel consumption are used to estimate changes in CO. The derivation of the actual values in Tables 4 and 5 must be supported with additional text material so that the reader can follow the logical flow from calculation method to calculation method. As it stands, reasonable readers could not be expected to understand the reasoning behind the development of the benefits estimates.

Conclusions:

The methods used to develop the off-cycle corrections, cycle correction factors, and SFTP benefits employ multiple assumptions that cannot be verified. Modeled relationships are derived from a small fleet that is not representative of the on-road fleet. Data treatment is such that averaged values and predicted values are often used as independent variables in the statistical techniques from which MOBILE6 algorithms are based. A number of relationships are modeled as independent effects when they are actually co-dependent (e.g. off-cycle correction and cycle-correction factors). Given these problems, it is not possible to apply standard statistical techniques to the model derivation process to determine confidence bounds around the algorithms employed in MOBILE6. Further, given the model development discussed above, it is not even possible to assess whether the predicted mean responses are likely to be biased high or low.

Because confidence bounds around the MOBILE6 algorithms cannot be generated, a combined bootstrap and Monte Carlo assessment could be undertaken to determine inherent model uncertainty. In such an analysis, each algorithm discussed in this report would be derived 1000+ times using subsets of the original data set (with replacement). The modeled relationships would then be represented as probability distributions in MOBILE. Then, MOBILE would be run in a Monte Carlo fashion to develop a distribution of model output results. Guensler and Leonard did this for the MOBILE5a speed correction factors; however, a similar assessment for MOBILE6 would be extremely labor-intensive. One is left to conclude that there is little for EPA to do to assess the adequacy of the algorithms in MOBILE6 than to assess the mean squared error and bias of the model in its application to validation data sets. When the algorithms are fully integrated in MOBILE6, EPA should use the model to predict the emissions of a validation data set and examine the prediction errors of the model, comparing them to the prediction errors of MOBILE5a and other alternative modeling approaches.

Recommendations:

- The actual definitions of the LA4, FTP, and the relationship between the two should be clarified in the report whenever the terms are employed.

- The exact methodology used to develop the hot stabilized LA4 base emissions rates in MOBILE6 should be stated in both the Off-Cycle and the Cycle Correction Factor reports as they impact the application of the algorithms discussed in these reports.

- o The relationships between the methods used to develop off-cycle corrections and other correction factors should be delineated in a text and graphic (flowchart) format.

- o All methods need to be better documented so that the reader can follow both the logical reasoning behind the proposed analytical method and the estimation techniques themselves.

- o EPA would be better off to use FTP Bag 2 as the baseline standard (rather than LA4) from which to determine the emissions effects that result from changes in vehicle operating conditions represented in the various emissions testing cycles employed in developing cycle correction factors and SFTP effects. At the very least, MOBILE6 LA4 baseline rates would not need to be predicted as a function of individual FTP Bag test results.

- o EPA presumably pursued the development of an independent "off-cycle" emissions offset to provide an estimate of the benefits that the new emissions testing cycles were likely to achieve. Alternative analytical methods could have, and should have, been applied to estimate the SFTP effect. The process employed in developing the estimates for MOBILE6 contains too many inter-correlated effects from testing on the FTP, SFTP, and cycle correction factor test cycles. Hence, the "off-cycle" offset cannot be reliably predicted from the analyses undertaken.

- o Cycle correction factors should have been developed directly from the laboratory test cycle data, rather than after artificially bumping up baseline emissions levels. The cycle correction factor would be more appropriate if derived from a single statistical analysis, rather than a staged analysis. Even if EPA retains the current method to estimate SFTP effects (for use in policy analyses), a single-step cycle correction factor approach would provide better estimates of the effect of changes in traffic conditions on emission rates.

Response to "Review of Off-Cycle Correction Factors for MOBILE6"

The response to specific comments made in "Review of Off-Cycle Correction Factors for MOBILE6" are contained throughout Section 6 of this report. A summary of the primary comments and responses follows:

- **Comment:** The comments suggested a lack of clarity in discussing the relationship between the off-cycle adjustment and speed correction adjustments, originally documented in separate reports.

  Response: In response to this comment, the discussion of off-cycle effects has been incorporated into M6.EXH.002 for improved cohesiveness.

- **Comment:** The comments criticized the application of two correction factors to address off-cycle and speed corrections, saying it artificially reduced statistical variability of the overall emission effects. The comments suggested that one correction be developed to address both issues.

  Response: A separate correction factor is necessary to isolate the effects of increased emissions due to "off-cycle" driving, for the purpose of applying benefit from the SFTP rule. Another source of increased emissions (on a grams per distance basis) is due to the "reduced travel efficiency" which results at lower speeds (i.e., less distance traveled). Emission increases due to the latter are reflected in the speed correction factors, but will not be reduced by the off-cycle provisions of the SFTP.

- **Comment:** The comments suggested that alternate facility cycles be used to derive an off-cycle correction, in order to demonstrate the stability of the modeling approach used in MOBILE6.

  Response: In response to this comment, an alternate model formulation was developed by deriving off-cycle corrections and speed correction factors from the Arterial E cycle rather than the Freeway F cycle, and the results compared to the MOBILE6 approach. The end results were less than 3 percent different, and were not statistically significant.

- **Comment:** The comments suggested that the derivation of SFTP benefits a) were not presented in a clear manner, b) were not based on an analysis of US06 data with and without SFTP control, and c) were based on reductions not clearly justified

  Response: In response to this comment, the source and derivation methodology of the SFTP reductions have been clarified. The Tier 1 reductions were in fact based on an analysis of vehicles with and without control measures intended to allow compliance with the SFTP. The dataset used for this analysis (performed as part of the SFTP rulemaking) is the only database containing vehicles which have been modified by manufacturers to demonstrate compliance with the SFTP. No such data exists for obtaining LEV benefits, hence an analytical approach was required. The derivation of LEV benefits have been clarified.

- **Comment:** The comments suggest that speed correction curves will change for vehicles complying with the SFTP requirement, and questions the EPA analysis provided to demonstrate the adequacy of the speed correction curves for SFTP vehicles.

  Response: Speed correction curves cannot be directly estimated for vehicles complying with the SFTP, since these vehicles have not begun to penetrate the market in substantial numbers. The analysis presented in M6.EXH.002 was intended to show that the magnitude of SCFs is not inappropriate for vehicles which would likely comply with the SFTP. This issue cannot be fully researched until a robust set of SFTP-compliant vehicles are exercised over the speed correction cycles; until this point, the analysis presented does provide an initial support for the assumption that Level 1 SCFs are applicable to vehicles with low off-cycle emissions.