III. ROADSIDE DATA ANALYSIS

A. Introduction

The intent of random roadside inspections is to collect tailpipe (exhaust) emissions data to evaluate overall performance of the Enhanced I/M program and to compare this data to that collected at licensed Smog Check stations. In 1997, BAR initiated its most comprehensive roadside inspection program to date using the Acceleration Simulation Mode (ASM or “loaded-mode”) test protocol, which is the same test performed in licensed smog inspection stations. We have used the results of BAR’s roadside inspections to evaluate the effectiveness of California’s Enhanced I/M program. Because roadside data assesses in-use vehicles, the effects of repair effectiveness, inspection and repair prior to an official Smog Check (to avoid failing the test – also known as “pre-inspection and pre-repair”), and fraud are accounted for in the collected data. Therefore, no assumptions are required to address these issues in the program evaluation (unlike other evaluation methodologies). It is this aspect that separates the random roadside evaluation methodology from other program evaluation methodologies and emissions models. ARB and BAR staff believe that roadside data analysis provides the most accurate means of determining the effectiveness of the Smog Check II program.

With the assistance of the California Highway Patrol, BAR conducts roadside pullover inspections of randomly selected vehicles at designated locations in Enhanced I/M program areas. At each inspection site, BAR personnel inspect these vehicles on a portable dynamometer using the ASM test protocol and conducts a gas cap check. The ASM test consists of two portions, one in which the vehicle is operated at 50 percent load and 15 miles per hour (ASM 5015), and one in which the vehicle is operated at 25 percent load and 25 miles per hour (ASM 2525) . The results of each inspection are collected by BAR and are used to evaluate the Enhanced I/M program.

Although BAR began collecting roadside test data in February 1997, only the most recent data – collected November 11, 1998 through October 29, 1999 – are used in this analysis. The data set includes 9,434 total test records, however we used 8,861 of these records because we could not identify past Smog Check histories for approximately 430 vehicles, approximately 20 vehicles had received an official Smog Check at current NOx cut points, and approximately 120 vehicles did not have valid NOx roadside test results (due to roadside test equipment calibration or failure). This data provides a unique opportunity to compare vehicles that *have been* tested at a Smog Check station with a loaded-mode test (“After ASM”) to those that *have not received* an ASM inspection ("Before ASM"). It is important to note that the two data sets were collected during the same timeframe and the vehicles are of the same vintage. Unfortunately, this will not be the case for future roadside studies because most, if not all, vehicles will have been through at least one cycle of Enhanced I/M.

The above referenced Before/After data set was also chosen because the total roadside data set (approximately 27,080 test records) was collected over a two and a half year period. Due to emission controls degradation, vehicles of the same model-year tested at the beginning of the period may not be comparable to the same model-year vehicle being tested at the end of the period. Even the Before/After data set is affected by degradation over the approximate 12-month collection period and the Before data set is probably more impacted than the After data set. However, we believe that the impact on the analysis due to degradation of emissions controls over the data collection period is minimal.

Using California's Vehicle Information Database (VID) records, the roadside data was separated into two groups:

- Vehicles that had completed the ASM test requirement. These are vehicles which had either passed the ASM test at a Smog Check station or had failed an ASM test at a Smog Check station. These vehicles were assumed to have completed the Enhanced I/M requirements and were designated as "After ASM." This group consists of 4,233 test records (3,629 of which were for vehicles of model-year 1974 to 1995).

- Vehicles which had not completed an Enhanced vehicle inspection cycle ("Before ASM"). These vehicles had only been tested under the two-speed idle test protocol used prior to implementation of Enhanced Smog Check. This group consists of 5,232 test records (4,628 of which were for vehicles of model-year 1974 to 1995).

The roadside data was analyzed to determine the average fleet emissions expressed as concentration (parts per million) and grams per mile (g/mi); and, to determine the percent change in emission rates between the "Before ASM" and "After ASM" vehicle groups.

B. Roadside Analysis Disclaimers

The Roadside Inspection Program is intended to provide on-road test data to determine *ASM fleet emission rates* with 95 percent confidence and a relatively small variance. To accomplish this, a "stratified sampling" methodology was used. Stratified sampling ensures that sufficient data from the older model-year vehicles are collected to calculate an accurate overall fleet emission rate. In this analysis, model-year emission rates are also calculated and shown. However, the variance by model-year is generally substantially greater than the fleet average variance. This can be explained by the substantial vehicle-to-vehicle emission differences within model-years, and the small sample size in some of the model-years. More specifically, the stratified sampling plan did not collect sufficient data in each model-year to accurately calculate a model-year emission rate with a small variance and high statistical confidence. Therefore, readers are cautioned against improperly using the model-year specific results.

The roadside data were collected between November 11, 1998 and October 29, 1999. Based on comments on the draft report, we analyzed the roadside data collected within this timeframe to determine the "After" vehicles that had been tested while the NOx cut points were at the very lax levels in place when loaded mode testing was first initiated. We found that 2,235 of the 1974 to 1995 vehicles had received a smog inspection under the very lax NOx cut points and 1,394 vehicles were tested under the gross polluter NOx cut points. While we considered calculating the program performance using each data set, and then comparing the results, we rejected this approach because sample sizes became too small to produce reliable and credible results. Therefore, we blended these data sets to evaluate the program performance in 1999.

We also received comments on the draft report regarding the “Before” data set. Because 430 of the vehicles contained in the “Before” data set did not have past smog inspection records, some commenters suggested that it was inappropriate to include them in the “Before” data set. There are a variety of reasons vehicles may not have past smog inspection records, legitimate (the vehicle was moved from a Change of Ownership area to an Enhanced area) and illegitimate (the vehicle has purposefully avoided the Smog Check program). Vehicles with legitimate reasons should be included in the “Before” data set (because they will eventually be tested as part of the Enhanced I/M program) while vehicles with illegitimate reasons should be included in the “After” data set (because they will likely remain on the road without obtaining an Enhanced inspection). Because we could not discern which vehicles had legitimate reasons for having no smog inspection records, we could not determine which data set each vehicle belonged in. Thus, we excluded these 430 vehicles from the re-analysis of roadside data. We analyzed the sensitivity of the results to removing these vehicles from the “Before” data set, and found that the program performance analysis was not very sensitive to the inclusion or exclusion of those vehicles. The overall fleet emission rate using the 430 vehicles removed from the data set was only 7.5 percent higher than the fleet emission rate of the “Before” data set (which has 5,232 vehicles). In addition, during this re-analysis, we discovered that approximately 200 vehicles were improperly included in the “Before” data set instead of the “After” data set. We moved these vehicles to the “After” data set.

This analysis depends on segregating the roadside data into the “Before/After” data groups. It should be noted that the average time since the last smog inspection for the “Before” data group is not the same as for the “After” group. Because of emission system degradation, this may lead to a slight *overestimation* of the emissions benefits of the Enhanced program. We received comments on the draft report that the differences between the “Before” and “After” data sets (with respect to the time since the smog inspection) could substantially affect the results of the analysis. Therefore, we analyzed both data sets to determine the actual difference between the data sets with respect to elapsed time since the smog inspection. Our findings are as follows (for 1974-1995 vehicles only):

- The overall average time between the roadside inspection and the vehicle’s last smog inspection for the “Before” data set is 223 days; and,
- The overall average time between the roadside inspection and the vehicle’s last smog inspection for the “After” data set is 157 days.

Our conclusion is that the respective elapsed times are close enough for the purposes of this analysis.

As a simplifying assumption, the calculations for 1999 using roadside data assume that a full biennial cycle of loaded mode testing had occurred by the end of 1999. To the extent that less than a full cycle had been completed by 1999, the calculations may overstate the actual reductions in that year. However, for the 1999 calculations based on roadside, this effect is at least partially offset by the fact that we did not account for the benefits from implementing more stringent NOx cut points in October 1999.

The calculations to determine both the fleet emission rates and the program benefits require assumptions regarding vehicle population. In this section of the report, we use EMFAC2000 vehicle populations for model-years 1966 through 1974 and 1996 through 1999. We use BAR-provided vehicle populations for model-years 1974 through 1995 because BAR bases these population estimates on actual smog certificates sold (with some adjustments). It should be noted that the vehicle populations provided by BAR only represent vehicles subject to loaded-mode testing.

Also, for purposes of this report, we use only the random roadside inspections for tested gasoline-powered passenger cars and light- and medium-duty trucks weighing less than 8,501 pounds. While heavy-duty trucks were subject to the random roadside inspections (two-speed idle test), the data is not analyzed because the number of these vehicles tested is so small. In addition, only the roadside tailpipe emission data is analyzed. Neither functional nor visual inspection data were available at the time of this report. Therefore, the fleet emission rates presented in this section of the report pertain only to tailpipe emissions for the classes of inspected vehicles.

In addition, the roadside analysis does not provide a means to evaluate the impact of vehicles that avoid the program and do not comply with the inspection requirements. This, too, can lead to over-estimating the program benefits because the assumption used in this report is that all vehicles eligible for smog inspection actually participate in the program. Additional study is needed to quantify actual participation rates.

Finally, readers are reminded that four independent inspection crews using four sets of test equipment collected the vehicle emission measurements under field, not laboratory, conditions. There may be some non-quantifiable crew-to-crew or equipment-to-equipment bias introduced into the results. However, every effort has been made to minimize this uncertainty.

C. Fleet Average ASM Concentrations and Predicted FTP Emission Rates

The roadside ASM testing generates emission data expressed as a concentration (e.g., parts per million). However, in order to compare the results to the

SIP, these concentrations must be converted to the grams per mile emissions that would be generated if the vehicle was tested using the Federal Test Procedure (FTP). The FTP is the certification test cycle for new passenger cars and light-duty trucks. The model-year emission concentrations and FTP emission rates were then weighted by the approved EMFAC2000 or BAR travel fractions to calculate the overall fleet average concentrations. Because older vehicles travel less than newer ones, we must weight the roadside data by the travel fractions to accurately reflect the actual in-use fleet average. Sections D through H of this Chapter describe this process in more detail.

D. <u>Fleet Average ASM Concentrations</u>

A more detailed description of the analysis methodology is included in Section E of this Chapter. However, simply stated, the fleet average ASM concentrations were calculated using the following methodology:

1. Calculate the average ASM concentrations by model-year;

2. Multiply the average ASM concentrations for each model-year by the respective EMFAC2000 travel fraction for that model-year; and

3. Sum the products for each model-year to determine the overall fleet average concentration for the “Before ASM” and “After ASM” cases.

This methodology was used for HC, NOx, and CO for both the ASM 2525 and ASM 5015 concentrations. Table III-1 and Table III-2 show "Before ASM" and "After ASM" fleet average ASM 2525/5015 concentrations by model-year, as well as the weighted average fleet emission rate.

Insert Table III-1 on this page.

Insert Table III-2 on this page.

E. Methodology for Fleet Average Emissions Calculation

The following describes the method used to calculate estimates of the fleet ASM concentrations as a function of model-year from the individual vehicle ASM concentration measurements of the roadside sample. Roadside sampling was performed for 34 model-years from 1966 to 1999 in five of the metropolitan areas where the vehicle population is subject to Enhanced I/M. In calculating concentration means and uncertainties that describe the vehicle population, we used weighting factors for model-year (based on EMFAC2000 travel fractions).

Step 1. Calculate Mean and Variance of the Mean for Each Model-Year.

For the vehicles for a given model-year *y*, the mean emission concentration $\bar{x}(y)$ and variance $s^2(y)$ are given by:

$$\bar{x}(y) = \frac{\sum_{i=1}^{n(y)} x(y)_i}{n(y)}$$

$$s^2(y) = \frac{\sum_{i=1}^{n(y)} \left(x(y)_i - \bar{x}(y)\right)^2}{n(y) - 1}$$

Where: $x(y)_i$ = emissions value for the *i*th sampled vehicle in the model-year (*y*)
$n(y)$ = the number of sampled vehicles in the model-year (*y*) .

The error variance of the mean for the emissions of the sampled vehicles in the model-year (*y*) is given by:

$$\operatorname{var}\left(\bar{x}(y)\right) = \frac{s^2(y)}{n(y)}$$

For the model-year under consideration, the 95% confidence interval for the mean emissions of the fleet is given by:

$$\bar{x}(y) \pm 1.96 * \sqrt{\operatorname{var}\left(\bar{x}(y)\right)}$$

Step 2. Calculate Travel Fraction Weighted Mean and Variance of the Mean for the Fleet.

The model-year means and uncertainties for the fleet are then combined to arrive at average emissions estimates for the fleet. The weighting factors are the travel fractions for each model-year.

The fleet average emissions $\bar{x}$ weighted by model-year travel fractions tf_y is given by:

$$\bar{x} = \frac{\sum_{y=1}^{34} tf_y \, \bar{x}(y)}{\sum_{y=1}^{34} tf_y}$$

where $\bar{x}(y)$ is the average emissions for the model-year (*y)*.

The error variance of the fleet mean is given by:

$$\text{var}\left(\bar{x}\right) = \frac{\sum_{y=1}^{34} tf_y^{\,2} \, \text{var}\left(\bar{x}(y)\right)}{\left(\sum_{y=1}^{34} tf_y\right)^2}$$

where $\text{var}\left(\bar{x}(y)\right)$ is the error variance of the mean for model-year (*y)*.

Finally, the 95% confidence interval on the fleet mean emissions is given by:

$$\bar{x} \pm 1.96\sqrt{\text{var}\left(\bar{x}\right)}$$

F. <u>Fleet Average Predicted FTP Emissions</u>

The ASM concentrations were converted into predicted federal test procedures (FTP) rates in gram per mile (g/mi) using the latest conversion equations developed by Radian/Eastern Research Group (Radian/ERG). These conversion equations are described in the Radian/ERG report, *Equations for Estimating California Fleet FTP Emissions from ASM Concentrations*, dated December 25, 1999.

Once the model-year average predicted FTP emission rates were determined, weighted fleet average FTP emission rates shown in Table III-3 were calculated using the following methodology:

- Calculate average predicted FTP emission rate by model-year for each pollutant (HC, CO and NOx);
- Multiply the average predicted FTP emission rate for each model-year and pollutant by the EMFAC2000 or BAR travel fraction for that model-year; and,
- Sum the products for each model-year by pollutant to determine the overall fleet average predicted FTP emission rate for each time period.

Table III-3 also shows the percent reduction in HC, CO, and NOx emission rate for each model-year, as well as for the overall fleet. The roadside data shows that Enhanced I/M in 1999 reduced emission rates of HC by 14 percent, NOx by 6 percent, and CO by 13 percent. Appendix A includes a discussion of the emission reductions achieved in terms of tons per day.

Insert Table III-3 here.

G. <u>Equations for Estimating California Fleet FTP Emissions</u>

This section describes the method used to calculate estimates of the fleet FTP emission rates as a function of model-year from the individual vehicle ASM concentration measurements of the roadside sample. In addition, this section describes the calculation of the estimated uncertainty in mean FTP values. These uncertainties are estimates of the precision of the mean values. They do not include estimates of biases in mean values.

Roadside sampling was performed across 34 model-years from 1966 to 1999 and throughout five metropolitan areas where the vehicle population is subject to Enhanced I/M. In calculating emission rate means and uncertainties that describe the vehicle population, weighting factors for model-year (based on travel fraction) were used.

Step 1. Convert ASM Concentrations to FTP Emission Rates.

The first step is to convert the ASM concentrations for each vehicle tested in the roadside sample to FTP emission rates. The estimated FTP HC, CO, and NO_x emission rates in grams per mile can be estimated based on ASM concentration measurements for the roadside data and the models given in the December 25, 1999 report.

These models explain a large portion of the variance in the predicted FTP emission rates. This explained variance is calculated just as if the predicted FTP emissions rates were actual measurements. In addition to the explained variance, an unexplained variance is associated with the use of each of the FTP prediction equations. These unexplained variances are a result of the imperfect prediction of FTP emission rates from ASM concentrations. The unexplained variances must be accounted for when predicting the FTP emission rates of the fleet. These variances s^2_{unexp, ln_i} were quantified during model development. The unexplained variances in natural log space for the HC, CO, and NO_x models are 0.2467, 0.3523, and 0.1692, respectively.

Step 2. Calculate Mean and Variance of the Mean for Each Model-Year.

For the vehicles in a given model-year *(y)*, the mean emission concentration $\bar{x}(y)$ and explained variance $s^2_{exp}(y)$ are given by:

$$\bar{x}(y) = \frac{\sum_{i=1}^{n(y)} x(y)_i}{n(y)}$$

$$s_{exp}^2(y) = \frac{\sum_{i=1}^{n(y)} \left(x(y)_i - \bar{x}(y)\right)^2}{n(y) - 1}$$

where: $x(y)_i$ = emissions value for the *i*th sampled vehicle in model-year *(y)*
$n(y)$ = the number of sampled vehicles in model-year (*y*).

The unexplained variance s_{unexp}^2 is calculated in linear space for each model-year using the model-year's mean FTP emission rate $\overline{\ln x(y)}$ in log space and the appropriate unexplained variance in log space $s_{unexp,\ln}^2$ described in Step 1.

$$s_{unexp}^2(y) = \exp\left(2\,\overline{\ln x(y)} + 2\, s_{unexp,\,ln}^2\right) - \exp\left(2\,\overline{\ln x(y)} + s_{\mathbf{unexp,\,ln}}^2\right)$$

$$\text{where}: \overline{\ln x(y)} = \frac{\sum_{i=1}^{n(y)} \ln x\,(y)_i}{n(y)}$$

Then, the explained and unexplained variances are summed and converted to the total error variance of the mean by dividing by the number of points in the sample for the model-year under consideration.

The error variance of the mean for the emissions of the sampled vehicles for model-year (*y)* is given by:

$$\operatorname{var}\left(\bar{x}(y)\right) = \frac{s^2(y)}{n(y)} = \frac{s_{unexp}^2\,(y) + s_{exp}^2\,(y)}{n(y)}$$

For the model-year under consideration, the 95% confidence interval for the mean emissions of the fleet is given by:

$$\bar{x}(y) \pm 1.96 * \sqrt{\operatorname{var}\left(\bar{x}(y)\right)}$$

Step 3. Calculate Travel Fraction Weighted Mean and Variance of the Mean for the Fleet.

The model-year means and uncertainties for the fleet are then combined to arrive at average emissions estimates for the fleet. The weighting factors are the travel fractions for each model-year.

The fleet average emissions $\bar{x}$ weighted by model-year travel fractions tf_y is given by:

$$\bar{x} = \frac{\sum_{y=1}^{34} tf_y \, \bar{x}(y)}{\sum_{y=1}^{34} tf_y}$$

where $\bar{x}(y)$ are the average emissions for model-year (*y)*.

The error variance of the fleet mean is given by:

$$\operatorname{var}\left(\bar{x}\right) = \frac{\sum_{y=1}^{34} tf_y^{\,2} \operatorname{var}\left(\bar{x}(y)\right)}{\left(\sum_{y=1}^{34} tf_y\right)^2}$$

where $\operatorname{var}(\bar{x}(y))$ is the error variance of the mean for model-year *(y)*.

Finally, the 95% confidence interval on the fleet mean emissions is given by:

$$\bar{x} \pm 1.96\sqrt{\operatorname{var}\left(\bar{x}\right)}$$

This confidence interval is an estimate of the precision of the average value. It does not include an estimate of any bias.

H. Results

Table III-4 shows the percent reduction in the emission rates after the Enhanced program was implemented. As can be seen, the percent reductions for HC and CO are approximately twice the reduction observed for NOx. In Chapter V, these results are used to determine emission reductions due to Enhanced I/M in “SIP currency.”

The NOx percent reduction is modest because during the time period that roadside data was being collected, the NOx cut points used to fail vehicles at Smog Check stations were set to identify “gross polluters” for NOx. Therefore, not many vehicles were failing for NOx and being repaired. However, since the roadside data was collected, BAR has significantly increased the stringency of the NOx cut points to levels specified in BAR regulations. Therefore, this analysis understates the actual emission reductions being achieved by the current I/M program; and, future analysis of roadside data should show significantly increased NOx reductions.

Table III-4
Roadside Results

	HC	**NOx**	**CO**
Before ASM [g/mi]	1.33	1.09	15.4
After ASM [g/mi]	1.14	1.02	13.4
Percent Reduction (Before to After)	14%	6%	13%

I. Roadside Gas Cap Testing

BAR also performed gas cap pressure testing as part of the visual and functional test during the Roadside program. During this portion of the test, BAR personnel consulted look-up charts to determine if an adapter was available to test the gas cap. (Because adapters are not available for all vehicle models, not all gas caps are tested.) This is the same procedure used in Smog Check stations. If the vehicle was subject to testing, the fuel cap was removed from the vehicle and attached to a portable fuel cap testing unit. The cap is subjected to a pressure of 30 inches of water. The cap must hold this pressure with a leak rate of no more than 60 cubic centimeters per minute. In addition to not being on the look-up chart, gas caps were not tested if the fuel cap tester did not pass the calibration test (in this situation, the test team was not able to test caps until the equipment was repaired). If the vehicle had an incorrect fuel cap or no fuel cap at all, the vehicle failed the gas cap test.