Eastern Research Group, Inc.

# Evaluation of the Texas Inspection and Maintenance Program in the Dallas-Fort Worth and Houston-Galveston-Brazoria Nonattainment Areas

**Prepared for:**

**Texas Commission on Environmental Quality**

**Prepared by:**

**Eastern Research Group, Inc.**

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# Evaluation of the Texas Inspection and Maintenance Program in the Dallas-Fort Worth and Houston-Galveston-Brazoria Nonattainment Areas

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## Executive Summary

This report documents the evaluation of the Texas Inspection and Maintenance (I/M) program for the 2012 and 2013 biennial period. Eastern Research Group (ERG) performed this evaluation for the Texas Commission on Environmental Quality (TCEQ) using the Texas Information Management System (TIMS) database data and Remote Sensing (RS) data from January 1, 2012 through December 31, 2013.

This evaluation generally follows the United States Environmental Protection Agency (EPA) draft guidance on using in-program data for the evaluation of the I/M program performance [Reference 1][1] and the EPA guidance on the use of RS for the evaluation of I/M program performance [Reference 2]. This study is focused on program coverage, the inspection process and the repair process. Additionally, program benefits were estimated on an annual basis.

Overall, the results for the Texas I/M program were positive; however, in the course of performing this evaluation a few areas were found where improvements could be made. Additionally, some of these suggestions will be helpful for future biennial evaluations and make the results more reflective of program performance. The last section of this Executive Summary provides a concise list of specific recommendations where ERG feels improvements in the program could be made.

### Coverage

The results of the coverage analysis using out-of-program data revealed a consistent, high rate of participation in the I/M program.

**Participation Rates** (Section 2.1) – The program participation rates were estimated by determining the fraction of vehicles seen on the road during RS studies that had recent records in the TIMS. This analysis found that in the Dallas-Fort Worth (DFW) and Houston-Galveston- Brazoria (HGB) areas the participation rate estimates were both 86%. These values are below the 96% that had been observed in the 2006 and 2009 Reports [Reference 3 and 4], but these used a different methodology to estimate the compliance rate. The current values are also a bit less than those in the 2012 Report [Reference 5] of 89-90% where the same estimation method was used.

[1] Citations for references are given in Section 7.

**Inspection**

**Appropriateness of Major TIMS Fields** (Section 3.1) – The TIMS is used to document the I/M program inspection process. The analysis in this activity checked the major fields in the TIMS using a series of basic data checks to demonstrate the accuracy and completeness of the data in the TIMS. ERG produced frequency distributions of almost all database variables to examine field values for in-range values, out-of-range values, and missing values. The following summarizes the major findings of this analysis:

- Frequency distributions of Acceleration Simulation Mode (ASM), hydrocarbon (HC), carbon monoxide (CO), and nitric oxide[2] ($NO_x$) and Two-Speed Idle (TSI) HC and CO were typical for vehicle emissions data, as the distributions are all positively skewed (that is, most observations are at low emissions concentrations), and there is no evidence of large numbers of very high concentration values. The shapes of the distributions look typical for a fleet of modern in-use vehicles. Overall, the figures indicate that no gross errors are being made in measuring and recording tailpipe emissions. Very few out-of-range emission values were found.

- The analysis of the TIMS data indicated that approximately 0.97% of the ASM carbon dioxide (CO2) measurements and 0.83% of the TSI CO2 measurements had concentrations greater than the theoretical limit of 16%. These values were comparable to those in the 2006 Report (0.9% and 0.5%), 2009 Report (1.0% and 0.7%) and 2012 Report (1.2% and 0.8%); however, they do appear to be trending higher over time.

- The analysis of the validity of vehicle identification numbers (VIN) in the TIMS indicated that roughly 0.105 % of the VINs had either illegal check digits or a check digit that did not agree with the check digit calculation, as compared to 2% in the 2009 Report and 0.15% in the 2012 Report. Clearly the VIN check software in use is working very well in the stations.

**Inspection Statistics** (Section 3.2) – Analysis of the TIMS data indicated that during the evaluation period over 14.7 million ASM, TSI, and On-board Diagnostics (OBD) tests were performed on more than 13.9 million vehicles. OBD tests are performed on 1996 and newer model year vehicles, ASM tests are performed on 1995 model year and older vehicles, and TSI tests are performed on 1995 and older model year vehicles where ASM tests cannot be performed such as on all-wheel-drive vehicles. Approximately 94% of the tests were OBD, 5% were ASM, and 0.7% were TSI. In 2006

[2] The ASM test measures NO; however, the Texas vehicle inspection record converts this value to estimate a NOx oxides of nitrogen value.

these numbers were: OBD 67%, ASM 30%, and TSI 3%, in 2009 they were 81%, 16% and 2%, in 2012 they were 91%, 8% and 1% respectively. The DFW and HGB areas had comparable test fail rates. About 4% of the OBD tests were fails, about 10% of the ASM tests were fails, and about 7% of the TSI tests were fails. Again, in 2006 these values were: OBD 4.5%, ASM 11% and TSI 6% and in 2009 4.4%, 9% and 5%. The test type failure rates in 2012 were essentially the same as in this current report. It is worth noting that the higher percentage of OBD tests in this report versus those seen in the previous studies will mean that fleet-wide, fewer vehicles are now initially failing, resulting in fewer repairs. This will impact any fleet-wide comparisons between the results from this report and the earlier studies.

**Repeat I/M Failure Patterns** (Section 3.3) – ERG examined the TIMS data to determine the relative frequencies of the I/M pass/fail patterns during each vehicle's inspection cycle.

- Approximately 99.7% of the test sequences were found to be made up of a verified initial test, or an initial test that could reasonably be assumed to be a true initial test, and a final test that was certified. This number was 99.3% in the 2006 Report, 99.9% in the 2009 Report and 99.6% in the 2012 Report.

**Emissions Analyzer Data Quality** (Section 3.4) – The TIMS data were analyzed to determine the quality of the emissions measurements made by the emissions analyzers. Specific analyses were made using instrument calibrations to check for drift, individual inspection results checking for the stoichiometrically correct measured concentrations of CO, $CO_2$, and oxygen ($O_2$), gas audit results to validate analyzer accuracy, and comparison of instrument calibrations with inspection results to check for proper lock-out of emissions equipment. The following provides a summary of the results:

- The drift of the emissions analyzers was measured by comparing the pre-calibration measurements of calibration gas with the post-calibration values. With the exception of the zero gas for HC, the analysis showed that more than 86% of the pre-calibrations fell within the tolerance of the analyzer after the analyzer had been given an opportunity to drift for 72 hours between calibrations. This indicates that results for more than 85% of the I/M inspections performed just before the calibration can be expected to be within the instrument tolerance except for very low values of HC. This value was 90% in the 2006 Report, 85% in the 2009 Report and 85% in the 2012 Report.

- The Environmental System Products (ESP) analyzers failed to calibrate the $O_2$ channel 50% of the time by recording oxygen values of less than 3% $O_2$ in air. All other analyzers measured near theoretical value of 20.7% $O_2$ in air over 99% of the time. In 2012 the ESP analyzers failure rate was also 50%. In the 2006 and 2009 Reports the ESP analyzers failed to calibrate the $O_2$ channel 97% of the time.

- More than 99.9% of calibration records included bottle gas label concentrations that were within the prescribed tolerances. However, the remaining small fraction of records did include some (7 records) surprisingly high and low bottle gas values. It is possible that the bottle gas concentration was entered incorrectly into the TIMS or that the outlying values represent real bottle gas mixtures that were occasionally used. In 2009 there were 63 records like this and in 2012 there were 300.

- Dilution correction factors based on $CO/CO_2$ compared with dilution correction factors based on $O_2$ for all inspections in the evaluation period indicated that 99% of the TSI & ASM tests produced measured CO, $CO_2$, and $O_2$ values that were consistent with the expected stoichiometric relationship for gasoline combustion. These numbers are higher to those in the 2006, 2009 and 2012 Reports, which were in the range of 85-89%.

- The Texas state implementation plan (SIP) requires that each analyzer be audited at least twice per year. The TIMS data indicates that over 95% of the analyzers in the state were audited at least twice per year and many of them were audited many more times than that. This result is similar to that in the 2006 Report, the 98% figure in the 2009 Report and the 95% in the 2012 Report.

- Calibration records, analyzer gas audit records, and vehicle inspection records were used to determine whether analyzer and dynamometer calibrations were taking place as required, and whether uncalibrated analyzers and dynamometers were locked out until passing a calibration. Comparison of ASM and TSI test records with analyzer gas calibration, leak check, and dynamometer coast-down check records appear to indicate that for the majority of analyzers, 72-hour lockouts are independently enforced for each of these three calibrations/checks (i.e., the analyzer/dynamometer system must pass all three tests every 72 hours or it will be locked out). However, 2.5% of all ASM inspections were performed when the dynamometer systems had not successfully passed their calibration check within the 72-hour window, with World Wide (WW) being the most prevalent in this category. Similarly, 0.3% of ASM and TSI inspections were performed when the analyzer should have been locked out, and in this case the ESP bench was the most frequent. The overall lock out values were 1.5% in the 2006 Report, 3% in the 2009 Report and 1.5% in the 2012 Report.

**OBD Inspection Analyzer Communication Performance** (Section 3.5) – Overall OBD communication rates between vehicle's computers and program analyzers was greater than 99.9%, essentially unchanged from the earlier reports.

**TIMS Handling of OBD Codes** (Section 3.6) – It appears that the OBD inspection logic used in Texas for light-duty gasoline-powered vehicles is in agreement with the EPA policies. For the very few cases where this was found not to be true, ERG believes these instances are due solely to a minor oversight such as operator error or analyzers not having the latest software update for a brief period that resulted in a small percentage of errors.

**Repair**

**Number and Types of Repairs** (Section 4.1) –Analysis of the TIMS data indicates that over 230,138 I/M program induced repairs were made to vehicles during the evaluation period. This figure was 291,611 in 2012, 414,999 in 2009 and 558,412 in 2006. The I/M program requires reporting the types of repairs in five categories: fuel system, ignition electrical system, emissions system, engine mechanical, and miscellaneous. The fractions of total repairs in these five categories were approximately 20%, 9%, 29%, 2%, and 40%, respectively. The values in the 2006 Report were 17%, 14%, 43%, 2%, and 25%, and in 2009 they were 16%, 12%, 36%, 2%, and 34%, respectively. In 2012 these values were 18%, 10%, 31%, 2%, and 40%, respectively.

The Department of Public Safety (DPS) collects separate repair information from stations that volunteer to be designated Recognized Emission Repair Facilities (RERF). The repairs reported from RERF stations have much more detailed descriptions than the five categories used in the TIMS. However, the RERF program is voluntary and only about 3,710 repairs were reported to DPS. This figure was 38,000 in the 2006 Report and 20,941 in 2009 and 9,635 in 2012.

A third source of repair information is the Drive a Clean Machine (DACM) program. Texas created the DACM program under the statutory authority granted in the Low Income and Repair Assistance, Retrofit, and Accelerated Vehicle Retirement Program legislation. This program provides assistance to low income individuals by repairing or retiring vehicles that have failed an emissions test. DACM numbers are reported quarterly so the evaluation period for the RERF numbers are from the dates 12/1/2011 through 11/30/2013. During that time there were 9,784 total DACM repairs made with 8,098 made in DFW and HGB under the DACM program. In the 2012

Report, 14,483 vehicle repairs were done at RERF stations under the DACM program, with 13,554 being made in the DFW and HGB programs. In the 2009 Report, this figure was 7,181, with 6,741 done in the DFW and HGB programs. In the 2006 Report there were 9,649 DACM driven repairs.

**Emissions Changes Associated with Repairs** (Section 4.2) – ERG analyzed the Texas TIMS data obtained during the evaluation period to determine the change in emissions of repaired vehicles before and after repair. The apparent emissions concentration changes for ASM HC, CO, and $NO_x$ were approximately decreases of 67%, 81%, and 70%, respectively, on approximately 193,288 repaired vehicles. In the 2006 Report these values were roughly 66%, 80% and 64% on 448,440 repaired vehicles and in the 2009 Report the HC, CO and $NO_x$ reductions were 68%, 82% and 66% on approximately 340,000 repairs. In the 2012 Report the HC, CO and $NO_x$ reductions were 67%, 82% and 69% on approximately 216,528 repairs. Note that almost all of these vehicles would have been fast-pass ASM tests; therefore, the after-repair emissions concentrations are biased high. However, because repair and emissions degradation begin immediately after certification and continues throughout the year until the next-cycle ASM inspection, the net emissions benefit of the repair over the one year annual cycle will be smaller than these percent reductions imply.

**OBD Repair Effectiveness** (Section 4.3 and 4.4) – ERG's analyses indicates approximately 85% of OBD tests that initially receive a fail for illuminated malfunction indicator light (MIL) with stored diagnostic trouble codes (DTCs) eventually receive a certificate. This value was 83% in the 2006 Report, 80% in 2009 and 84% in 2012. However, as also seen in the earlier studies, when evaluating repairs by failure category (evaporative emissions control system, $O_2$ Sensor, EGR System, air injection system and catalytic converter), unset readiness monitors were seen to potentially "hide" malfunctions in 2% to 41% of "repaired" vehicles.

**Average Repair Costs** (Section 4.5) – The analysis of the TIMS repair cost data with repair costs of zero and greater than $2,000 removed indicate that Texas motorists spent at least $22.4 million during this evaluation period performing 216,893 repairs so that they would be in compliance with the I/M programs, but it should be noted that TIMS inspectors hand-enter repair costs and, accordingly, these values can have errors. The same overall repair cost was $60 million in the 2006 Report on 348,694 repairs. In 2009 these figures were 240,665 repairs and $41 million. In 2012 these figures were 144,067 repairs and $25 million.

As in the previous studies, a large percentage (50%) of the repair costs in the Texas TIMS were recorded as zero. Again, with zero repair costs and those over $2,000 removed, the median and mean repair costs ranged from $40-$235 and $92-$296, as compared to $65-$220 and $110-$294 in the 2006 Report, $45-$225 and $95-$289 in 2009 and $45-$220 and $91-$274 in the 2012 Report.

The mean and median repair costs for repairs performed by the RERFs were $630 and $750, while these values were $658 and $647 in the 2012 Report. In 2009 they were $589 and $613 and in the 2006 Report they were $499 and $516. ERG does not believe the difference in repair costs between all repair stations and the RERF stations are inconsistent. It is expected that the repair costs for RERF stations will be higher than average repair stations since these stations voluntarily participate in the RERF program and, therefore, are more likely to make repairs that are more technically challenging and, therefore, more expensive.

**I/M Emissions Benefits**

The Annual I/M Benefit of an I/M program can be measured by the decrease in emissions for the I/M fleet at the time of vehicle repairs. The Annual I/M Benefit was estimated by looking at before and after repair emissions and also by pairing TIMS data with RS data.

**Estimate of Annual I/M Benefits from TIMS Data** (Section 5.1) – Using the initial and final emissions concentrations of annual inspection sequences as recorded in TIMS data, which is in-program data, we calculated the change in emissions concentrations at the time of inspection. About 94.6% of the I/M sequences were produced by vehicles that simply initially pass. Of course, the emissions reductions from these I/M events were zero. Additionally, about 4.6% of the ASM I/M sequences were produced by vehicles that initially failed, were repaired, and finally passed. These sequences were associated with emissions reductions at the I/M inspection of 62 to 85%. When all sequences were considered together using the TIMS data, the apparent changes in emissions concentrations at the inspection event were: ASM HC decreased 12 to 16%, ASM CO decreased 25 to 29%, ASM $NO_x$ decreased 15 to 17%. Overall these reductions were somewhat smaller than those reported in the 2006 Report and similar to those calculated in the 2009 Report (HC 13-18%, CO 28-36%, $NO_x$ 13-16%). The 2012 Report values were HC 12-16%, CO 26-32% and NOx 15-18%.

**Estimate of Annual I/M Benefits from Paired I/M and RS Data** (Section 5.2) – The analysis of RS data, which is out-of-program data, provides a different view of the Annual I/M Benefit of the I/M program. The average RS emissions from 30 to 90 days before I/M inspections were compared to the average RS emissions from 1 to 90 days after the I/M inspections. About 96% of the vehicles measured by RS had I/M sequences produced by passing their initial inspections, while 4% had a Fail-Pass I/M test sequence. This is very similar to the values of 96% and 4% in the 2012 Report, 96% and 4% in the 2009 Report and 95% and 5% in the 2006 Report. Initial pass vehicles had RS emissions increase by roughly 3.4% for HC, 6.1% for CO and 8.0% for $NO_x$ as compared to 5% for all three pollutants in the 2009 Report, 4-7% in the 2006 report and 6-17% in the 2012 Report. This increase in emissions may be indicative of an older vehicle fleet as people are keeping their vehicles longer due to the poor economy. Increasing emission trends in older vehicles is at times referred to as “emissions creep”. The fail-pass vehicles had emissions decrease by 11-13% in the 2012 Report, 4-8% in the 2009 Report, and 3-14% in the 2006 Report. However, in the current report HC and CO emissions increased by 6-7%, while NOx decreased 7.7%.

**Measures for Evaluating Station Performance** (Sections 6.1 and 6.2) – This section strives to consolidate the analyses performed that pertain to the evaluation of station performance. Distinctions between errors of commission vs. errors of omission were also identified whenever possible, with the former viewed as more likely attempts at committing a fraudulent test, while the latter could be viewed somewhat more leniently. An example of an error of commission would be a VIN mismatch, where the OBD-downloaded VIN does not correspond to the hand-entered VIN. In the benign case, the discrepancies are basically random. In a highly suspicious case, the exact same OBD-downloaded VIN may be found in roughly 1,000 tests, which seems to indicate a clear case of attempted clean-scanning. An example of an error of omission metric is a zero-value repair cost as this will not result in falsely passing or failing the I/M test. In all, there were 6 error of commission and 10 error of omission metrics developed and each station was ranked according to their respective overall score in these two categories. There was one station (2P31289) that was on the Top 50 Error of Commission list in 2009, 2012 and in this report, and 2 stations (2P12442 and 2P35737) that were on the Top 50 Error of Omission list in all three reports.

### Recommendations and Comments

As a result of performing this biennial evaluation of the Texas I/M program, ERG has developed a list of recommendations Texas should consider implementing. As in the earlier reports, the purpose of most of these recommendations is to improve the program, but some also are intended to improve future biennial I/M program evaluations. For each recommendation, ERG has provided an importance rating of High **(***)**, Medium **(**)**, or Low **(*)**. These ratings are provided to assist the TCEQ in prioritizing efforts to improve the I/M program.

### OBD Recommendations

The future of vehicle testing at I/M inspection stations in Texas will continue to be dominated by OBD testing, as it replaces TSI and ASM tailpipe emissions testing. Since 2006 the OBD test fleet has grown from 70% to 81% in 2009 and now is over 90%. Because this trend will continue, any OBD problems identified in this evaluation are viewed as more critical to the overall success of the program.

**Recommendation 1 (***): Investigate requiring a "set" status for certain monitors to prevent hiding malfunctions.** Our analysis found that in 2% to 41% of instances when a vehicle received an initial fail for a certain monitored component, the retest OBD result, which follows a repair, could be hidden by an "unset" readiness status for that monitor. This opens up the possibility that malfunctioning emissions control components could remain unrepaired even though the follow-up OBD test received a "pass." ERG recommends the TCEQ investigate implementing a software change that would require certain monitors to have a "set" readiness status on an OBD retest that follows certain types of initial failures.

**Recommendation 2 (***): Improve response to trigger flags.** ERG believes the current trigger system is well designed and well run. However, in some programs it has been found that the trigger system can identify more issues than can be addressed with available resources. Therefore, ERG's primary recommendation is to assess the current level of response to the existing triggers, and then determine if additional triggers would be beneficial to the program. Specifically, a simple count of the number of triggers and the corresponding number of responses would be helpful to assess the current effectiveness of the triggers program.

**Recommendation 3 (*): Diesel OBD and Heavy-duty Gasoline OBD.** Per the EPA guidance, Texas does not perform testing on OBD light or heavy-duty diesels or heavy-duty gasoline vehicles. However, this topic continues to be discussed in the I/M community. EPA's position on this may change in the near future or pilot testing could be performed in some jurisdiction and ERG would suggest the TCEQ stay abreast of any developments in this area.

**ASM and TSI Recommendations and Comments**

Even though OBD testing will eventually replace tailpipe emissions testing in Texas, tailpipe testing will probably be used on the 1995 and older vehicles for some time. Therefore, efforts need to continue to provide quality tailpipe tests and accurate TIMS records of them. Given the ever decreasing number of tailpipe tests, Texas may want to consider moving to an OBD-only program, although this would require of MOVES modeling analysis to quantify the projected loss in emission reductions.

**Recommendation 1 (***): Improve response to trigger flags.** The same recommendation and associated caveats for the OBD vehicles regarding triggers outlined above also apply to ASM and TSI tests.

**Recommendation 2 (*): Reject calibration bottle concentration values that are outside the specified range.** Our analysis of analyzer gas calibration data indicated that about 0.1% of the bottle gas label concentrations were outside of the acceptable tolerances. In this analysis there were 7 such records. In 2012 there were 300 records and in 2009 there were 62 records like this.

**Recommendation 3 (*): Dilution correction factors based on $CO/CO_2$.** As in the previous reports, the Snap-On analyzers are again predominantly responsible for the readings that have theoretically abnormal $O_2$ concentration readings. Since this has been a consistent occurrence with the Snap-On equipment, it may be worth investigating why it seems to happen.

**Comment 1: $O_2$ Channel Calibration.** The ESP analyzers failed to calibrate the $O_2$ channel over 50% of the time by recording oxygen values of less than 3% $O_2$ in air, while all other analyzers measured near theoretical value of 20.7% $O_2$ in air over 99% of the time. In the 2012 study that number was also 50%, in 2009 it was 97%.

**RS Recommendations and Comments**

In the past, initial measurements of tailpipe emissions at the annual I/M inspection could be used to track fleet emissions. However, as tailpipe emissions measurements are being replaced by OBD testing, vehicle emissions levels are no longer routinely measured and recorded. That leaves RS as the only major source of data to monitor the emissions of the fleet in the future. Because of this trend, it is important to address any RS problems seen in this evaluation as soon as possible, even if they appear to be relatively minor right now.

**Recommendation 1 (**): Collect RS data in San Antonio.** In the 2009 Report ERG was able to use RS data from San Antonio to analyze the DFW/HGB RS fleet data using the Reference Method. If possible, efforts should continue to obtain RS data from San Antonio for future evaluations. That analysis was not possible in this study as there was insufficient RS data from San Antonio to perform the analysis. However, as long as sufficient data is collected in the DFW and HGB I/M areas, a paired I/M TIMS / RS air quality analysis can be performed.

**Vehicle Tracking Recommendations**

Whether vehicles are inspected or measured by TSI, ASM, OBD, or RS, these sources of data on individual vehicles can be used effectively only if vehicles are identified and tracked accurately in all of the databases. A major part of the effort in this biennial evaluation was spent trying to properly identify TIMS and registration data for individual vehicles. Because transcription errors of VINs and plates were common in these databases, in the end ERG could provide only approximately correct vehicle histories that were needed for the analyses. The following two recommendations are the most important vehicle tracking recommendations resulting from this biennial evaluation.

**Repair Tracking Recommendations**

Whether malfunctioning vehicle emission control systems are detected by TSI, ASM, or OBD, Texas needs to improve the system of recording the repairs that are made to vehicles. The repairs, not the inspections, keep vehicle emission control systems operating properly and, in turn, maintain low vehicle emissions.

**Recommendation 1 (***): Use a more detailed, but short, list of repairs for I/M inspectors to choose from.** The TIMS gives inspectors five general repair categories to use to report I/M-induced repairs and these categories appear too broad to be useful. It is recommended that Texas develop an improved system for reporting I/M-induced vehicle repairs that contains more detail, providing inspectors a list of the 5 to 10 most emissions-influential repairs for the technology of the vehicle that the inspector is working on. These repair types have already been determined by an analysis of British Columbia I/M program repair and ASM emissions data. Other information on the myriad of other repairs that might have been performed is not needed because they have minor influences on emissions. This approach would make a convenient, short list of repairs for inspectors that would make the inspector's task simpler, while recording the valuable repair information that is most important for the I/M program. This is also a critical element in making program evaluation projections, as without reliable repair data, be it an OBD or non-OBD vehicle, it is not possible to link emission reductions to repair.

It might be worthwhile to consider a software change that would require the inspector to input repair information within set limits of price and from a menu selection of repair choices. Providing more standardized menu options would also help improve the accuracy of this data by standardizing the entries as well as making it more onerous for the technician to enter incorrect data than actually enter the real data. If it becomes more difficult to input bogus data than the actual real data, then technicians would be motivated to be more accurate when completing these electronic entry forms.

Finally, standardizing the RERF and TIMS repair forms might help improve repair data analysis in the future.

**Comment 1: Number of Vehicle Repairs.** The number of repairs in the TIMS database has been falling from 558,412 in 2006, to 414,999 in 2009 to 291,611 in 2012 and to the current 230,138. This may reflect the often heard assertion that OBD vehicles are less prone to emission component failures. However, it is probably worth seeing if similar trends are being seen in other programs.

# 1.0 Introduction

The EPA requires that states with I/M programs submit an evaluation of their programs every two years to their EPA Regional office. The TCEQ conducted the most recent biennial evaluation in the 2009 Report and, in consultation with ERG, has chosen a set of evaluation elements that will comprehensively, yet simply, document the performance of the Texas I/M program for the most recent two years and adhere to the program evaluation requirements outlined by the EPA.

## 1.1 Evaluation Analysis Approach

The Clean Air Act requires that states evaluate their I/M programs every two years. The Sierra Method was used to evaluate the previous version of the Texas I/M program in 2000 [Reference 6] and later ERG used the updated EPA guidance [References 1 and 2] as a framework for an evaluation performed in 2006 [Reference 3]. Since then, ERG has performed evaluations in 2009 [Reference 4] and 2012 [Reference 5] using the same approach as the 2006 Report.

This 2014 report follows the same general approach, as it focuses on analyzing and evaluating data to assess program coverage, the vehicle inspection process, the vehicle repair process, program air quality benefits, and station performance. These areas were chosen to provide the most useful information at reasonable cost, as well as provide an objective assessment on the overall status of the I/M program, with the intent of identifying both areas that may be improved upon and those that are performing well.

## 1.2 Structure of the Report

As previously stated, this report follows the same outline as the 2009 Report. Section 2 investigates coverage first by examining the results of a recent parking lot survey of windshield registration stickers and by comparing vehicle license plates read during RS measurements with the vehicles seen in the I/M program TIMS database.

Section 3 investigates the inspection process in various ways using the TIMS data for the evaluation period. For example, TIMS data fields were checked for appropriate ranges, the various types of inspections and failure patterns were counted, the emissions analyzer calibration and audit results were checked, and OBD communication rates and test outcomes were examined.

In Section 4, the TIMS data and Recognized Emission Repair Facility (RERF) data were analyzed to determine the level, cost, and emissions and OBD effects of repairs associated with the I/M program.

Section 5 provides emission benefits estimates based on TIMS and RS data. Some of the analyses done in this section were not part of the original work plan, but were performed at no additional cost.

Section 6 is a fairly detailed analysis of station performance based on TIMS data. It covers errors clear errors of commission, such as “clean-piping” or VIN mismatches, as well as errors that are more difficult to categorize such as data entry issues or anomalous test results.

# 2.0 Coverage

An important component of an I/M program is the level of fleet coverage, or the vehicle compliance rate. In this section, coverage is evaluated by estimating the fraction of vehicles observed on the road using RS data that also have a current and valid I/M program TIMS record.

## 2.1 Participation Rates

Estimates of the participation rate of vehicles subject to I/M in the DFW area and in the HGB area were made through a comparison of RS data and TIMS data. RS data provides a sample of vehicles that were driven on the road. If these vehicles were eligible for I/M, they should have been participating in the I/M program. TIMS and RS data were analyzed to determine the I/M compliance rate of on-road vehicles during the period of evaluation.

ERG first created a dataset of I/M-eligible and I/M-county registered vehicles captured on the road with RS at least once. This dataset does not include vehicles from out-of-state or registered in non-I/M counties. This dataset only consists of I/M-eligible model years. That is, vehicles newer than 2 years and older than 24 years at the time of the RS measurement are excluded from the analysis. Table 2-1 shows the counts of unique I/M-eligible vehicles from the DFW or HGB program areas which were measured by RS between January 2012 and December 2013.

**Table 2-1. Count of Unique I/M-Eligible Remote Sensing Vehicles Registered in I/M Program Areas**

| Registered at Time of Remote Sensing | Unique RS-Captured Vehicles |
|---|---|
| DFW | 384,521 |
| HGB | 300,871 |
| Total | 685,122 |

Next, the number of unique I/M-compliant vehicles (vehicles that were tested and ultimately passed or received a waiver) in each of the I/M Program Areas was determined. Table 2-2 shows the counts for the DFW and HGB program areas.

**Table 2-2. Count of Unique I/M-Compliant Vehicles in I/M Program Areas**

| I/M Area where Test Performed | Unique I/M-Tested Vehicles |
|---|---|
| DFW | 4,605,221 |
| HGB | 4,157398 |
| Total | 8,762,619 |

The I/M tests were then matched to RS measurements by GroupID, which is our best estimate of the correct VIN. If an I/M test occurred any time between January 2012, and December 2013, and was found to link up with a RS measurement taken any time between January 2012 and December 2013, this was a matched pair. Of the 384,251 RS measurements in DFW, there were 330,604 pairs of matched I/M-test and RS measurements for an 86.04% participation rate. Of the 300,871 RS measurements in HGB, there were 260,005 pairs of matched I/M-test and RS measurements for an 86.42% participation rate. While these percentages are our best estimate of I/M compliance, it is worth noting that some of the non-matches may be attributable to RSD OCR license plate errors, mismatches and/or typos on plates in registration data, and/or VIN/plate mismatches from TIMS I/M data.

A further refinement to the participation rate was to look at a distribution of time differences between the matched pairs of RS to certifying I/M tests. For this evaluation, I/M tests both before and after RS measurement events were considered. If no I/M test was performed within 15 months from the time an on-road RSD measurement was collected, then one may assume that vehicle is no longer participating in the I/M program. However, if the time difference is between 12-15 months, these vehicles may actually be participating in the I/M program - the motorist likely was late for the I/M test or the delay was a result of vehicle repairs (since the final test can occur a few months after the initial I/M test). Table 2-3 shows the distribution of time differences between matching pairs in each I/M program area. It should be noted that the 1.45% of vehicles in the DFW area and the 1.53% of vehicles in the HGB area may be attributed not only to non-compliance but also to vehicles becoming ineligible for the I/M program (vehicle becomes too old, leaves the program area, or is taken off the road). These figures do not include any vehicles retired by the DACM program.

**Table 2-3. Time Between Remote Sensing and I/M Test**

| I/M Program Area | Time Difference Between RS and I/M Test | Count | Percent |
|---|---|---|---|
| DFW | <12 months | 331,012 | 96.83 |
| | 12 -15 months | 5,880 | 1.72 |
| | > 15 months | 4,951 | 1.45 |
| | Total | 341,843 | 100.00 |
| HGB | <12 months | 260,704 | 96.50 |
| | 12 -15 months | 5,317 | 1.97 |
| | > 15 months | 4,141 | 1.53 |
| | Total | 270,162 | 100.00 |

# 3.0 Inspection

## 3.1 Check Major TIMS Fields for Appropriateness

The goal of this check was to analyze the ranges and values of the primary variables that make up the TIMS database. This analysis is an indication of the ability of the I/M program's analyzers and TIMS database system to accurately record the activities of the I/M program. If TIMS variables have values that are out of range or missing for unexplained reasons it suggests that the I/M program activities are not being conducted properly or adequately monitored.

Since in-program data is the primary basis of the I/M program evaluation, a series of steps were used to evaluate the accuracy and completeness of the data in the database.

1. All records which were created outside the period of evaluation were eliminated. The beginning and ending dates of the data under consideration include:
   - I/M Test Records: January 2012 – December 2013.
   - Remote Sensing Measurements: January 2012 – December 2013.
2. A frequency distribution was performed of nearly all database variables to evaluate the accuracy and completeness of data fields. These frequency distributions included only filtered data[3], so many missing values and unreasonable values were removed during the filtering process. Throughout this report, additional details about the accuracy and completeness of individual fields are noted.

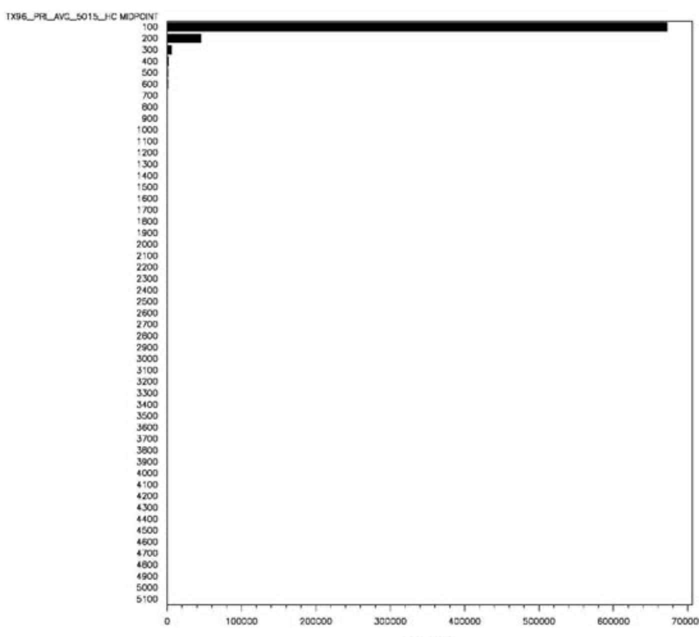
The following is a list of some findings after checking the various TIMS fields:

- 89.79% of the ASM tests had missing Dilution Pass/Fail Flags while only 0.05% of TSI tests had missing Dilution Pass/Fail Flags. Also, the Dilution Limit was set to zero on 30.3% of the ASM tests while 0.14% of the TSI tests had the Dilution Limit set to zero.
- Duration of tail pipe test times is missing on 30.2% of the ASM and 31.24% of the TSI tests. In addition, 0.67% of TSI tests had invalid negative test times.
- RPM bypass is used on 12.6% of both ASM and TSI tests.

[3] These filters included things such as keeping only HGB and DFW records, and flagging items such as aborted tests, covert vehicles, safety-only tests, vehicles with blank Pass/Fail results, etc.

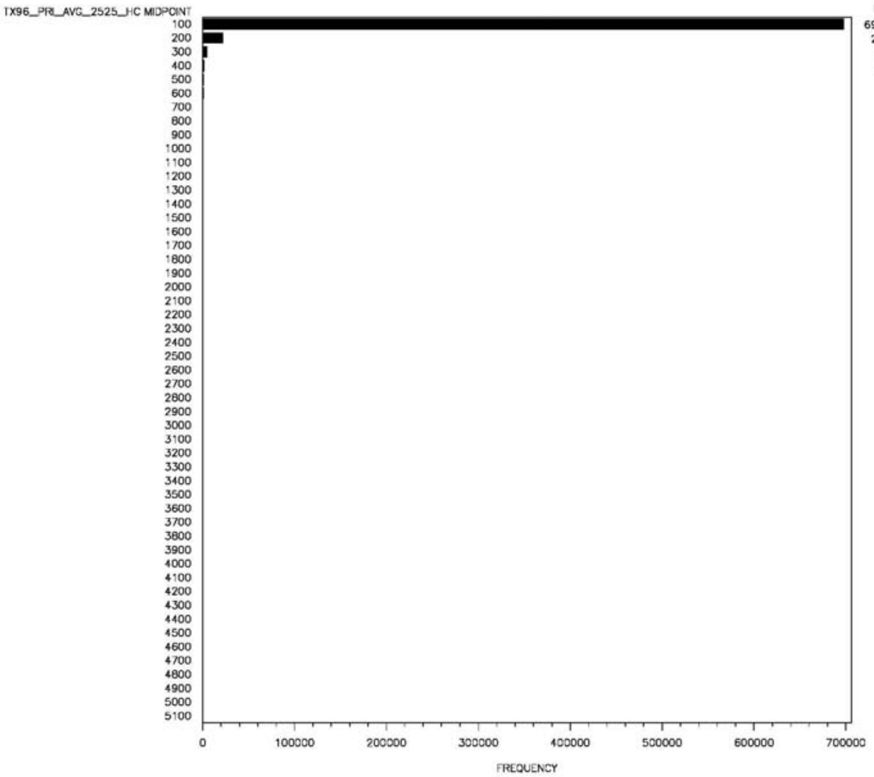
- A distribution of the emissions measurements is a special case of the above. Ideally, no observations with missing values should be present. Figures 3-1 through 3-10 show the distributions of the emissions measurements for HC, CO, and $NO_x$ for ASM tests and HC and CO for TSI tests in both program areas. The distributions are all positively skewed (that is, most observations are at low emissions concentrations), and there is no evidence of large numbers of very high concentration values. The shapes of the distributions look typical for a fleet of modern in-use vehicles. Overall, the figures indicate that no gross errors are being made in measuring and recording tailpipe emissions. Also, all observations should have a CO2 concentration between about 6% and 16%, since a combustion process must be present. Table 3-1 shows the distribution of CO2 measurements.

**Figure 3-1. Distribution of ASM HC5015 Concentrations for All Filtered I/M Tests**



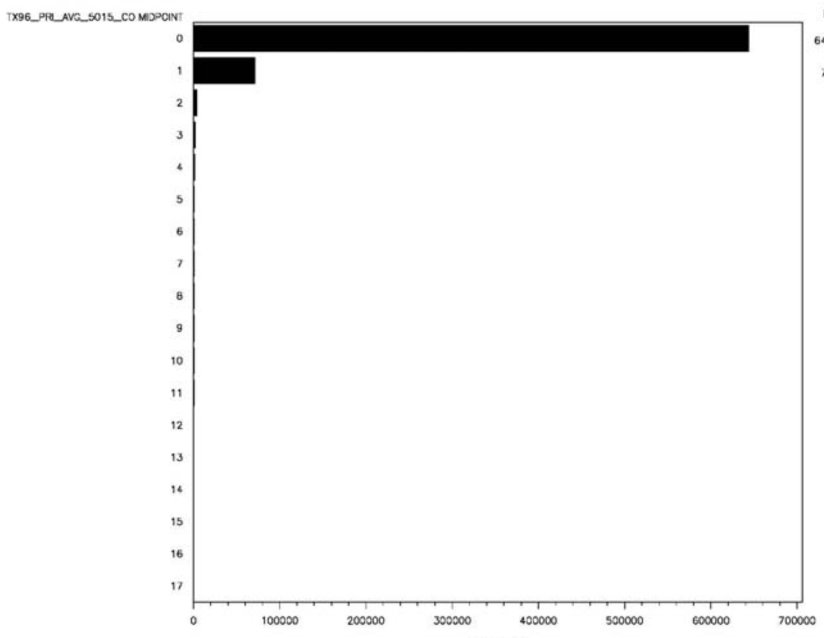

| TX96_PRI_AVG_5015_HC MIDPOINT | FREQ. | CUM. FREQ. | PCT. | CUM. PCT. |
|---|---|---|---|---|
| 100 | 672200 | 672200 | 92.37 | 92.37 |
| 200 | 45044 | 717244 | 6.19 | 98.56 |
| 300 | 5591 | 722835 | 0.77 | 99.33 |
| 400 | 1619 | 724454 | 0.22 | 99.55 |
| 500 | 766 | 725220 | 0.11 | 99.66 |
| 600 | 471 | 725691 | 0.06 | 99.72 |
| 700 | 315 | 726006 | 0.04 | 99.77 |
| 800 | 220 | 726226 | 0.03 | 99.80 |
| 900 | 175 | 726401 | 0.02 | 99.82 |
| 1000 | 135 | 726536 | 0.02 | 99.84 |
| 1100 | 130 | 726666 | 0.02 | 99.86 |
| 1200 | 82 | 726748 | 0.01 | 99.87 |
| 1300 | 74 | 726822 | 0.01 | 99.88 |
| 1400 | 61 | 726883 | 0.00 | 99.89 |
| 1500 | 53 | 726936 | 0.00 | 99.90 |
| 1600 | 67 | 727003 | 0.00 | 99.90 |
| 1700 | 49 | 727052 | 0.00 | 99.91 |
| 1800 | 50 | 727102 | 0.00 | 99.92 |
| 1900 | 32 | 727134 | 0.00 | 99.92 |
| 2000 | 34 | 727168 | 0.00 | 99.93 |
| 2100 | 33 | 727201 | 0.00 | 99.93 |
| 2200 | 32 | 727233 | 0.00 | 99.94 |
| 2300 | 34 | 727267 | 0.00 | 99.94 |
| 2400 | 25 | 727292 | 0.00 | 99.94 |
| 2500 | 30 | 727322 | 0.00 | 99.95 |
| 2600 | 13 | 727335 | 0.00 | 99.95 |
| 2700 | 30 | 727365 | 0.00 | 99.95 |
| 2800 | 13 | 727378 | 0.00 | 99.96 |
| 2900 | 15 | 727393 | 0.00 | 99.96 |
| 3000 | 17 | 727410 | 0.00 | 99.96 |
| 3100 | 17 | 727427 | 0.00 | 99.96 |
| 3200 | 13 | 727440 | 0.00 | 99.96 |
| 3300 | 13 | 727453 | 0.00 | 99.97 |
| 3400 | 18 | 727471 | 0.00 | 99.97 |
| 3500 | 12 | 727483 | 0.00 | 99.97 |
| 3600 | 9 | 727492 | 0.00 | 99.97 |
| 3700 | 13 | 727505 | 0.00 | 99.97 |
| 3800 | 14 | 727519 | 0.00 | 99.98 |
| 3900 | 10 | 727529 | 0.00 | 99.98 |
| 4000 | 13 | 727542 | 0.00 | 99.98 |
| 4100 | 10 | 727552 | 0.00 | 99.98 |
| 4200 | 7 | 727559 | 0.00 | 99.98 |
| 4300 | 8 | 727567 | 0.00 | 99.98 |
| 4400 | 3 | 727570 | 0.00 | 99.98 |
| 4500 | 9 | 727579 | 0.00 | 99.98 |
| 4600 | 3 | 727582 | 0.00 | 99.98 |
| 4700 | 7 | 727589 | 0.00 | 99.99 |
| 4800 | 2 | 727591 | 0.00 | 99.99 |
| 4900 | 2 | 727593 | 0.00 | 99.99 |
| 5000 | 2 | 727595 | 0.00 | 99.99 |
| 5100 | 101 | 727696 | 0.01 | 100.00 |

**Figure 3-2. Distribution of ASM HC2525 Concentrations for All Filtered I/M Tests**



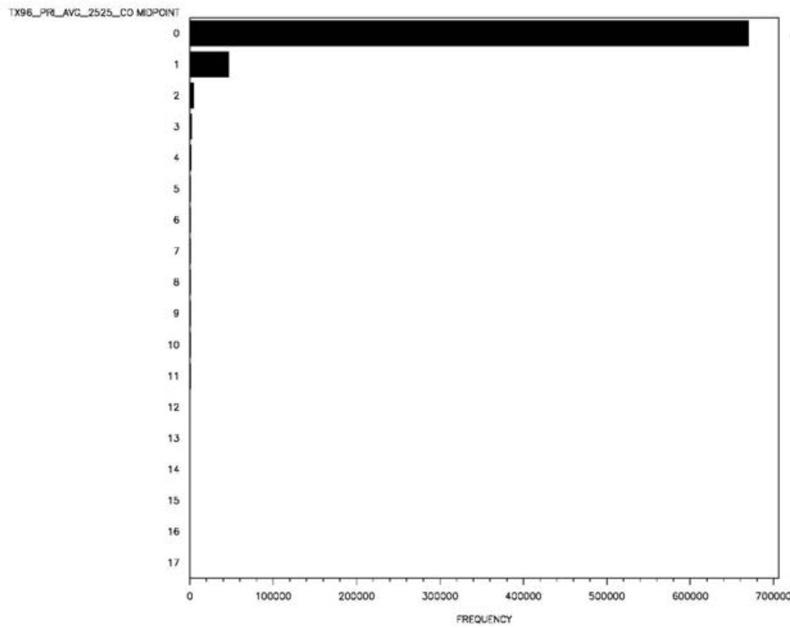

| TX96_PRI_AVG_2525_HC MIDPOINT | FREQ. | CUM. FREQ. | PCT. | CUM. PCT. |
|---|---|---|---|---|
| 100 | 697313 | 697313 | 95.82 | 95.82 |
| 200 | 21843 | 719156 | 3.00 | 98.83 |
| 300 | 4211 | 723367 | 0.58 | 99.41 |
| 400 | 1421 | 724788 | 0.20 | 99.60 |
| 500 | 699 | 725487 | 0.10 | 99.70 |
| 600 | 432 | 725919 | 0.06 | 99.76 |
| 700 | 274 | 726193 | 0.04 | 99.79 |
| 800 | 217 | 726410 | 0.03 | 99.82 |
| 900 | 152 | 726562 | 0.02 | 99.84 |
| 1000 | 120 | 726682 | 0.02 | 99.86 |
| 1100 | 100 | 726782 | 0.01 | 99.87 |
| 1200 | 85 | 726867 | 0.01 | 99.89 |
| 1300 | 71 | 726938 | 0.01 | 99.90 |
| 1400 | 68 | 727006 | 0.00 | 99.91 |
| 1500 | 48 | 727054 | 0.00 | 99.91 |
| 1600 | 46 | 727100 | 0.00 | 99.92 |
| 1700 | 39 | 727139 | 0.00 | 99.92 |
| 1800 | 34 | 727173 | 0.00 | 99.93 |
| 1900 | 38 | 727211 | 0.00 | 99.93 |
| 2000 | 34 | 727245 | 0.00 | 99.94 |
| 2100 | 26 | 727271 | 0.00 | 99.94 |
| 2200 | 32 | 727303 | 0.00 | 99.95 |
| 2300 | 23 | 727326 | 0.00 | 99.95 |
| 2400 | 19 | 727345 | 0.00 | 99.95 |
| 2500 | 37 | 727382 | 0.00 | 99.96 |
| 2600 | 30 | 727412 | 0.00 | 99.96 |
| 2700 | 13 | 727425 | 0.00 | 99.96 |
| 2800 | 12 | 727437 | 0.00 | 99.96 |
| 2900 | 10 | 727447 | 0.00 | 99.97 |
| 3000 | 11 | 727458 | 0.00 | 99.97 |
| 3100 | 12 | 727470 | 0.00 | 99.97 |
| 3200 | 14 | 727484 | 0.00 | 99.97 |
| 3300 | 9 | 727493 | 0.00 | 99.97 |
| 3400 | 6 | 727499 | 0.00 | 99.97 |
| 3500 | 10 | 727509 | 0.00 | 99.97 |
| 3600 | 9 | 727518 | 0.00 | 99.98 |
| 3700 | 7 | 727525 | 0.00 | 99.98 |
| 3800 | 13 | 727538 | 0.00 | 99.98 |
| 3900 | 12 | 727550 | 0.00 | 99.98 |
| 4000 | 11 | 727561 | 0.00 | 99.98 |
| 4100 | 7 | 727568 | 0.00 | 99.98 |
| 4200 | 8 | 727576 | 0.00 | 99.98 |
| 4300 | 4 | 727580 | 0.00 | 99.98 |
| 4400 | 2 | 727582 | 0.00 | 99.98 |
| 4500 | 9 | 727591 | 0.00 | 99.99 |
| 4600 | 3 | 727594 | 0.00 | 99.99 |
| 4700 | 4 | 727598 | 0.00 | 99.99 |
| 4800 | 5 | 727603 | 0.00 | 99.99 |
| 4900 | 3 | 727606 | 0.00 | 99.99 |
| 5000 | 2 | 727608 | 0.00 | 99.99 |
| 5100 | 88 | 727696 | 0.01 | 100.00 |

**Figure 3-3. Distribution of ASM CO5015 Concentrations for All Filtered I/M Tests**



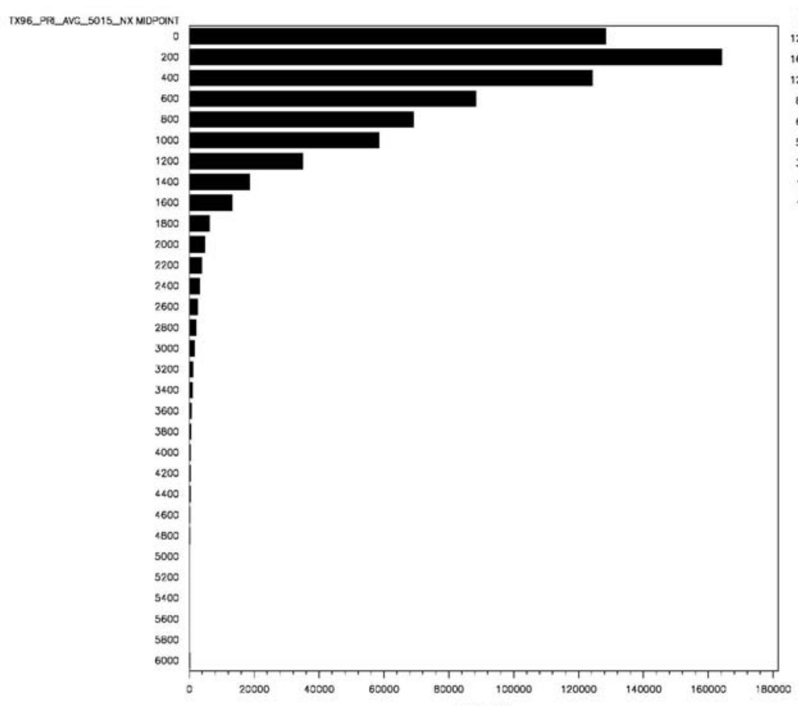

| TX96_PRI_AVG_5015_CO MIDPOINT | FREQ. | CUM. FREQ. | PCT. | CUM. PCT. |
|---|---|---|---|---|
| 0 | 644011 | 644011 | 88.50 | 88.50 |
| 1 | 71353 | 715364 | 9.81 | 98.31 |
| 2 | 4054 | 719418 | 0.56 | 98.86 |
| 3 | 1953 | 721371 | 0.27 | 99.13 |
| 4 | 1279 | 722650 | 0.18 | 99.31 |
| 5 | 1088 | 723738 | 0.15 | 99.46 |
| 6 | 837 | 724575 | 0.12 | 99.57 |
| 7 | 707 | 725282 | 0.10 | 99.67 |
| 8 | 585 | 725867 | 0.08 | 99.75 |
| 9 | 446 | 726313 | 0.06 | 99.81 |
| 10 | 608 | 726921 | 0.08 | 99.89 |
| 11 | 404 | 727325 | 0.06 | 99.95 |
| 12 | 194 | 727519 | 0.03 | 99.98 |
| 13 | 102 | 727621 | 0.01 | 99.99 |
| 14 | 29 | 727650 | 0.00 | 99.99 |
| 15 | 8 | 727658 | 0.00 | 99.99 |
| 16 | 7 | 727665 | 0.00 | 100.00 |
| 17 | 31 | 727696 | 0.00 | 100.00 |

## Figure 3-4. Distribution of ASM CO2525 Concentrations for All Filtered I/M Tests



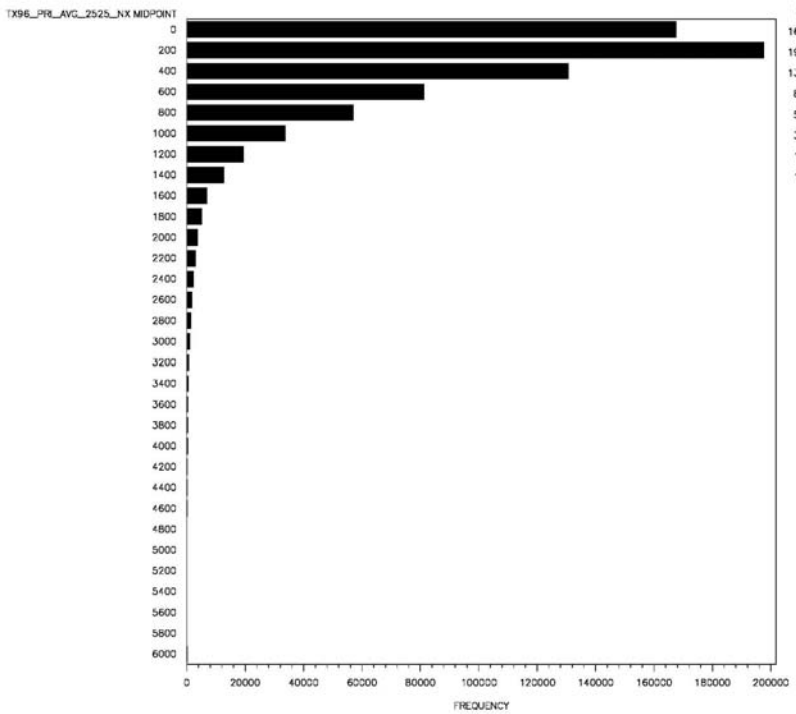

| TX96_PRI_AVG_2525_CO MIDPOINT | FREQ. | CUM. FREQ. | PCT. | CUM. PCT. |
|---|---|---|---|---|
| 0 | 669313 | 669313 | 91.98 | 91.98 |
| 1 | 46287 | 715600 | 6.36 | 98.34 |
| 2 | 4200 | 719800 | 0.58 | 98.91 |
| 3 | 1814 | 721614 | 0.25 | 99.16 |
| 4 | 1285 | 722899 | 0.18 | 99.34 |
| 5 | 947 | 723846 | 0.13 | 99.47 |
| 6 | 802 | 724648 | 0.11 | 99.58 |
| 7 | 632 | 725280 | 0.09 | 99.67 |
| 8 | 516 | 725796 | 0.07 | 99.74 |
| 9 | 479 | 726275 | 0.07 | 99.80 |
| 10 | 597 | 726872 | 0.08 | 99.89 |
| 11 | 415 | 727287 | 0.06 | 99.94 |
| 12 | 225 | 727512 | 0.03 | 99.97 |
| 13 | 92 | 727604 | 0.01 | 99.99 |
| 14 | 42 | 727646 | 0.00 | 99.99 |
| 15 | 11 | 727657 | 0.00 | 99.99 |
| 16 | 8 | 727665 | 0.00 | 100.00 |
| 17 | 31 | 727696 | 0.00 | 100.00 |

## Figure 3-5. Distribution of ASM $NO_x$ 5015 Concentrations for All Filtered I/M Tests



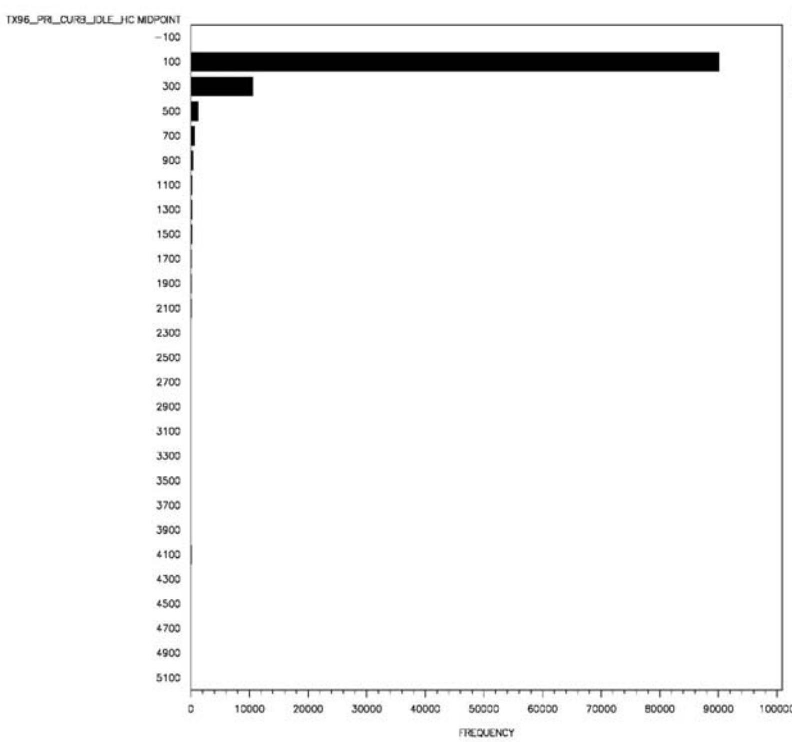

| TX96_PRI_AVG_5015_NX MIDPOINT | FREQ. | CUM. FREQ. | PCT. | CUM. PCT. |
|---|---|---|---|---|
| 0 | 128452 | 128452 | 17.65 | 17.65 |
| 200 | 164054 | 292506 | 22.54 | 40.20 |
| 400 | 124220 | 416726 | 17.07 | 57.27 |
| 600 | 88261 | 504987 | 12.13 | 69.40 |
| 800 | 69069 | 574056 | 9.49 | 78.89 |
| 1000 | 58548 | 632604 | 8.05 | 86.93 |
| 1200 | 34982 | 667586 | 4.81 | 91.74 |
| 1400 | 18590 | 686176 | 2.55 | 94.29 |
| 1600 | 13210 | 699386 | 1.82 | 96.11 |
| 1800 | 6141 | 705527 | 0.84 | 96.95 |
| 2000 | 4717 | 710244 | 0.65 | 97.60 |
| 2200 | 3736 | 713980 | 0.51 | 98.12 |
| 2400 | 3099 | 717079 | 0.43 | 98.54 |
| 2600 | 2549 | 719628 | 0.35 | 98.89 |
| 2800 | 2034 | 721662 | 0.28 | 99.17 |
| 3000 | 1526 | 723188 | 0.21 | 99.38 |
| 3200 | 1093 | 724281 | 0.15 | 99.53 |
| 3400 | 886 | 725167 | 0.12 | 99.65 |
| 3600 | 623 | 725790 | 0.09 | 99.74 |
| 3800 | 465 | 726255 | 0.06 | 99.80 |
| 4000 | 340 | 726595 | 0.05 | 99.85 |
| 4200 | 266 | 726861 | 0.04 | 99.89 |
| 4400 | 204 | 727065 | 0.03 | 99.91 |
| 4600 | 139 | 727204 | 0.02 | 99.93 |
| 4800 | 107 | 727311 | 0.01 | 99.95 |
| 5000 | 67 | 727378 | 0.01 | 99.96 |
| 5200 | 59 | 727437 | 0.01 | 99.96 |
| 5400 | 40 | 727477 | 0.01 | 99.97 |
| 5600 | 39 | 727516 | 0.01 | 99.98 |
| 5800 | 21 | 727537 | 0.00 | 99.98 |
| 6000 | 159 | 727696 | 0.02 | 100.00 |

## Figure 3-6. Distribution of ASM $NO_x$ 2525 Concentrations for All Filtered I/M Tests



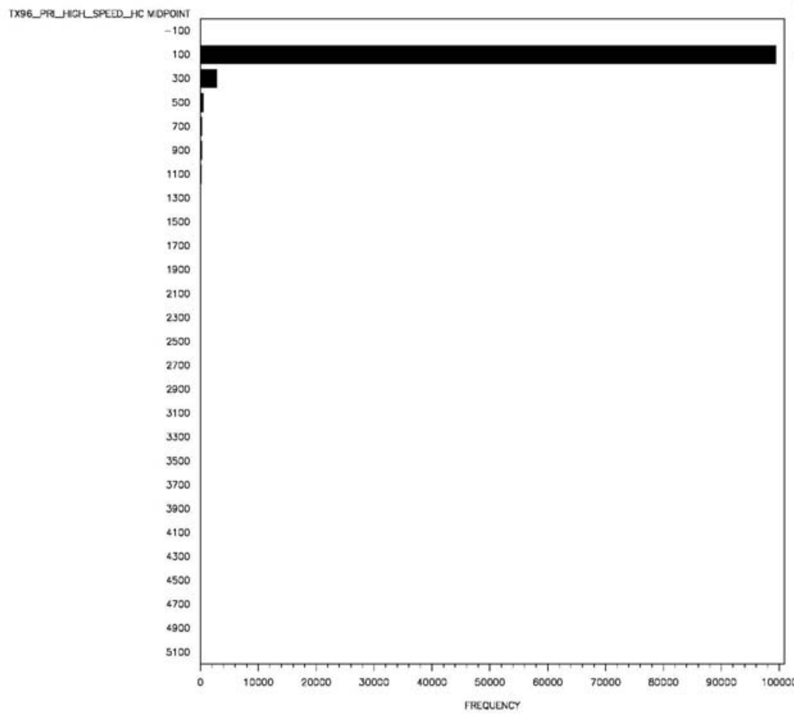

| TX96_PRI_AVG_2525_NX MIDPOINT | FREQ. | CUM. FREQ. | PCT. | CUM. PCT. |
|---|---|---|---|---|
| 0 | 167472 | 167472 | 23.01 | 23.01 |
| 200 | 197492 | 364964 | 27.14 | 50.15 |
| 400 | 130703 | 495667 | 17.96 | 68.11 |
| 600 | 81274 | 576941 | 11.17 | 79.28 |
| 800 | 56992 | 633933 | 7.83 | 87.12 |
| 1000 | 33733 | 667666 | 4.64 | 91.75 |
| 1200 | 19277 | 686943 | 2.65 | 94.40 |
| 1400 | 12688 | 699631 | 1.74 | 96.14 |
| 1600 | 6887 | 706518 | 0.95 | 97.09 |
| 1800 | 5112 | 711630 | 0.70 | 97.79 |
| 2000 | 3720 | 715350 | 0.51 | 98.30 |
| 2200 | 2973 | 718323 | 0.41 | 98.71 |
| 2400 | 2266 | 720589 | 0.31 | 99.02 |
| 2600 | 1690 | 722279 | 0.23 | 99.26 |
| 2800 | 1269 | 723548 | 0.17 | 99.43 |
| 3000 | 964 | 724512 | 0.13 | 99.56 |
| 3200 | 790 | 725302 | 0.11 | 99.67 |
| 3400 | 556 | 725858 | 0.08 | 99.75 |
| 3600 | 420 | 726278 | 0.06 | 99.81 |
| 3800 | 329 | 726607 | 0.05 | 99.85 |
| 4000 | 240 | 726847 | 0.03 | 99.88 |
| 4200 | 184 | 727031 | 0.03 | 99.91 |
| 4400 | 128 | 727159 | 0.02 | 99.93 |
| 4600 | 119 | 727278 | 0.02 | 99.94 |
| 4800 | 85 | 727363 | 0.01 | 99.95 |
| 5000 | 70 | 727433 | 0.01 | 99.96 |
| 5200 | 55 | 727488 | 0.01 | 99.97 |
| 5400 | 33 | 727521 | 0.00 | 99.98 |
| 5600 | 33 | 727554 | 0.00 | 99.98 |
| 5800 | 20 | 727574 | 0.00 | 99.98 |
| 6000 | 122 | 727696 | 0.02 | 100.00 |

## Figure 3-7. Distribution of TSI HC Curb Idle Concentrations for All Filtered I/M Tests



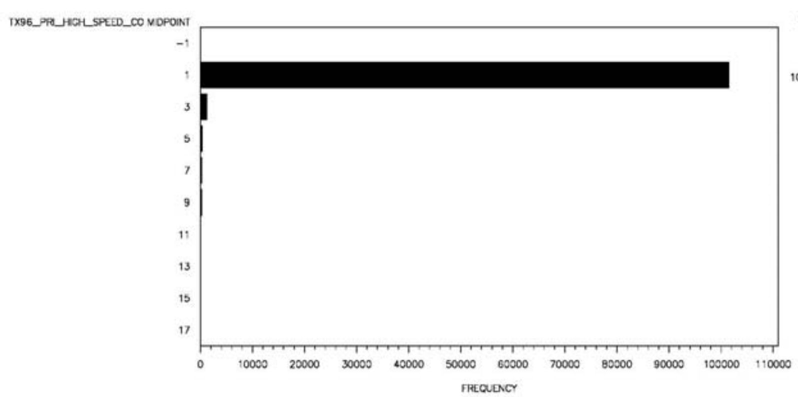

| TX96_PRI_CURB_IDLE_HC MIDPOINT | FREQ. | CUM. FREQ. | PCT. | CUM. PCT. |
|---|---|---|---|---|
| -100 | 0 | 0 | 0.00 | 0.00 |
| 100 | 90050 | 90050 | 86.94 | 86.94 |
| 300 | 10502 | 100552 | 10.14 | 97.08 |
| 500 | 1175 | 101727 | 1.13 | 98.22 |
| 700 | 571 | 102298 | 0.55 | 98.77 |
| 900 | 322 | 102620 | 0.31 | 99.08 |
| 1100 | 197 | 102817 | 0.19 | 99.27 |
| 1300 | 160 | 102977 | 0.15 | 99.42 |
| 1500 | 105 | 103082 | 0.10 | 99.52 |
| 1700 | 76 | 103158 | 0.07 | 99.60 |
| 1900 | 71 | 103229 | 0.07 | 99.67 |
| 2100 | 44 | 103273 | 0.04 | 99.71 |
| 2300 | 42 | 103315 | 0.04 | 99.75 |
| 2500 | 38 | 103353 | 0.04 | 99.79 |
| 2700 | 40 | 103393 | 0.04 | 99.83 |
| 2900 | 25 | 103418 | 0.02 | 99.85 |
| 3100 | 16 | 103434 | 0.02 | 99.86 |
| 3300 | 16 | 103450 | 0.02 | 99.88 |
| 3500 | 13 | 103463 | 0.01 | 99.89 |
| 3700 | 15 | 103478 | 0.01 | 99.91 |
| 3900 | 7 | 103485 | 0.00 | 99.91 |
| 4100 | 62 | 103547 | 0.06 | 99.97 |
| 4300 | 2 | 103549 | 0.00 | 99.98 |
| 4500 | 5 | 103554 | 0.00 | 99.98 |
| 4700 | 2 | 103556 | 0.00 | 99.98 |
| 4900 | 2 | 103558 | 0.00 | 99.98 |
| 5100 | 16 | 103574 | 0.02 | 100.00 |

**Figure 3-8. Distribution of TSI HC High Speed Concentrations for All Filtered I/M Tests**




| TX96_PRI_HIGH_SPEED_HC MIDPOINT | FREQ. | CUM. FREQ. | PCT. | CUM. PCT. |
|---|---|---|---|---|
| -100 | 0 | 0 | 0.00 | 0.00 |
| 100 | 99374 | 99374 | 95.94 | 95.94 |
| 300 | 2789 | 102163 | 2.69 | 98.64 |
| 500 | 469 | 102632 | 0.45 | 99.09 |
| 700 | 216 | 102848 | 0.21 | 99.30 |
| 900 | 152 | 103000 | 0.15 | 99.45 |
| 1100 | 119 | 103119 | 0.11 | 99.56 |
| 1300 | 71 | 103190 | 0.07 | 99.63 |
| 1500 | 50 | 103240 | 0.05 | 99.68 |
| 1700 | 57 | 103297 | 0.06 | 99.73 |
| 1900 | 47 | 103344 | 0.05 | 99.78 |
| 2100 | 36 | 103380 | 0.03 | 99.81 |
| 2300 | 26 | 103406 | 0.03 | 99.84 |
| 2500 | 24 | 103430 | 0.02 | 99.86 |
| 2700 | 17 | 103447 | 0.02 | 99.88 |
| 2900 | 9 | 103456 | 0.00 | 99.89 |
| 3100 | 8 | 103464 | 0.00 | 99.89 |
| 3300 | 11 | 103475 | 0.01 | 99.90 |
| 3500 | 11 | 103486 | 0.01 | 99.92 |
| 3700 | 6 | 103492 | 0.00 | 99.92 |
| 3900 | 5 | 103497 | 0.00 | 99.93 |
| 4100 | 52 | 103549 | 0.05 | 99.98 |
| 4300 | 4 | 103553 | 0.00 | 99.98 |
| 4500 | 2 | 103555 | 0.00 | 99.98 |
| 4700 | 1 | 103556 | 0.00 | 99.98 |
| 4900 | 1 | 103557 | 0.00 | 99.98 |
| 5100 | 17 | 103574 | 0.02 | 100.00 |

**Figure 3-9. Distribution of TSI CO Curb Idle Concentrations for All Filtered I/M Tests**




| TX96_PRI_HIGH_SPEED_CO MIDPOINT | FREQ. | CUM. FREQ. | PCT. | CUM. PCT. |
|---|---|---|---|---|
| -1 | 0 | 0 | 0.00 | 0.00 |
| 1 | 101469 | 101469 | 97.97 | 97.97 |
| 3 | 1207 | 102676 | 1.17 | 99.13 |
| 5 | 359 | 103035 | 0.35 | 99.48 |
| 7 | 193 | 103228 | 0.19 | 99.67 |
| 9 | 258 | 103486 | 0.25 | 99.92 |
| 11 | 39 | 103525 | 0.04 | 99.95 |
| 13 | 43 | 103568 | 0.04 | 99.99 |
| 15 | 5 | 103573 | 0.00 | 100.00 |
| 17 | 1 | 103574 | 0.00 | 100.00 |

**Figure 3-10. Distribution of TSI CO High Speed Concentrations for All Filtered I/M Tests**

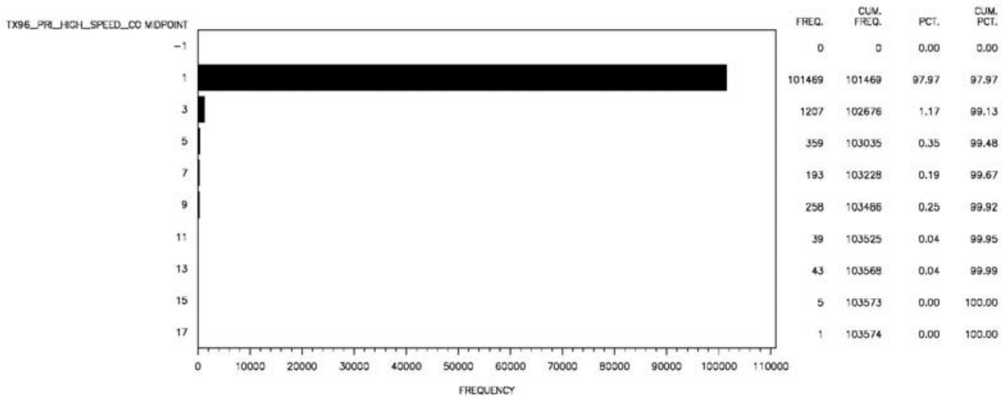


**Table 3-1. Distribution of Measured $CO_2$ Concentrations**

| Emission Test Type | Test Mode | Frequency | Percent of CO2 Readings | | |
|---|---|---|---|---|---|
| | | | CO2 < 6% | 6% < CO2 < 16% | CO2 > 16% |
| ASM | 5015 | 727,696 | 0.63 | 98.43 | 0.94 |
| | 2525 | 727,696 | 0.61 | 98.36 | 1.04 |
| TSI | Curb Idle | 103,574 | 0.63 | 98.57 | 0.80 |
| | Fast Idle | 103,574 | 0.37 | 98.77 | 0.86 |

1. The fraction of observations with both the license plate and the VIN missing was determined. 99.98% of the observations have neither VIN nor Plate missing. 0.02% of the observations have VIN present, but a missing Plate. These are the only two combinations present.
2. The validity of each 17-digit VIN was checked using the check digit of the VIN (valid on 1981 and newer VINS). Table 3-2 shows the counts of the various Check Digit results.

**Table 3-2. Distribution of Check Digit Codes on Unique 17-Digit VINs in the I/M Test Records**

| Check Digit Code | Description of Code | Frequency | Percent |
|---|---|---|---|
| BADCK | Invalid Check Digit (should be 0 to 9 or X) | 437 | 0.005 |
| CHAR | Either I, O, or Q (invalid characters) is in the VIN string | 1 | 0.0000 |
| ERROR | Check Digit does not agree with check digit calculation | 9,230 | .105 |
| OK | Check Digit agrees with check digit calculation | 8,750,175 | 99.89 |
| Total | | 8,759,843 | 100.00 |

1. Each license plate is generally associated with only a single VIN, except in the cases of vehicle sales where the seller keeps his/her plate (including vanity plates), or dealer plates which may be used with multiple vehicles. Table 3-3 below shows that 99.26% of the plates have a single VIN. The

0.70% of the plates with two or more VINs is expected due to the situations listed above.

**Table 3-3. Number of VINs per Plate**

| VIN Count | Frequency | Percent |
|---|---|---|
| 1 | 8,593,124 | 99.26 |
| 2 | 60,278 | 0.70 |
| 3 | 2,554 | 0.03 |
| 4 | 472 | 0.005 |
| 5 | 259 | 0.003 |
| >5 | 710 | 0.008 |
| Total | 8,657,397 | 100.00 |

## 3.2 Inspection Statistics: Number of Vehicles Inspected by Inspection Type

The goal of this element was to tabulate inspection types and failure rates of I/M eligible vehicles in each I/M program area. The TIMS data were used to make a simple count of various types of inspections performed (TSI, ASM, OBD) and the number of vehicles that received these inspections. This is an indication of the extent to which the Texas I/M program fleet was participating in the I/M program. Counts include only emissions inspections.

#### 3.2.1.1 Inspection Statistics

Table 3-4 shows the number of ASM, OBD, and TSI tests in each I/M program area performed during the evaluation period (January 1, 2012 through December 31, 2013).

**Table 3-4. Emissions Tests per I/M Program Areas**

| I/M Program Area | Emission Test Type | Counts | Percent |
|---|---|---|---|
| DFW | ASM | 391,074 | 5.04 |
| | OBD | 7,303,023 | 94.18 |
| | TSI | 60,389 | 0.78 |
| | Total | 7,754,486 | 100.0 |
| HGB | ASM | 336,622 | 4.80 |
| | OBD | 6,632,821 | 94.58 |
| | TSI | 43,185 | 0.62 |
| | Total | 7,012,628 | 100.0 |

Table 3-5 shows the number of vehicles receiving at least one I/M test during the evaluation period.

**Table 3-5. Number of Vehicles Receiving at least One Emissions Test**

| I/M Program Area | Emission Test Type | Counts | Percent |
|---|---|---|---|
| DFW | ASM | 249,207 | 5.36 |
| | OBD | 4,355,109 | 93.60 |
| | TSI | 48,785 | 1.05 |
| | Total | 4,653,101 | 100.0 |
| HGB | ASM | 217,439 | 5.18 |
| | OBD | 3,942,768 | 94.00 |
| | TSI | 34,409 | 0.82 |
| | Total | 4,194,646 | 100.0 |

Table 3-6 shows the number of passes and fails and the fail fraction along with the number of emissions tests (including ASM, OBD, and TSI) performed in each I/M Program Area.

**Table 3-6. Emission Test Pass/Fail Counts**

| I/M Program Area | Emission Test Type | Pass/Fail Status | Counts | Fail Percent |
|---|---|---|---|---|
| DFW | ASM | Fail | 44,175 | 11.30 |
| | | Pass | 346,899 | |
| | OBD | Fail | 288,446 | 3.95 |
| | | Pass | 7,014,573 | |
| | TSI | Fail | 3,960 | 6.56 |
| | | Pass | 56,429 | |
| HGB | ASM | Fail | 29,887 | 8.88 |
| | | Pass | 306,735 | |
| | OBD | Fail | 274,498 | 4.14 |
| | | Pass | 6,358,320 | |
| | TSI | Fail | 2,746 | 6.36 |
| | | Pass | 40,439 | |

ERG also looked at the emission test types within I/M cycles to determine whether emission test types changed mid-cycle. For about 99.96% of the I/M cycles the same emissions test type was performed throughout the duration of the cycle, where a cycle is defined as the sequence of tests undertaken by a particular vehicle between initial and final tests.

ERG then looked at test type by model year. Figures 3-11 and 3-12 show the distributions of numbers of vehicles by model year for each emission test type for the DFW and HGB I/M program areas, respectively. As would be expected, there is a noticeable transition between the 1995 and 1996 model year vehicles from tailpipe testing to OBD testing. This sudden change occurs because OBD tests are conducted on 1996 and newer model year vehicles while ASM tests are conducted on 1995 and older model vehicles. TSI tests are performed on vehicles such as those with all-wheel drive that cannot be tested on a dynamometer. The figures show that the TIMS contain a small number of apparent OBD inspections on pre-1996 vehicles. The reason for these observations is not known, but whatever the reason, the trend is very minor in this large TIMS dataset.

**Figure 3-11. Count of Emission Test Types by Model Year for DFW**

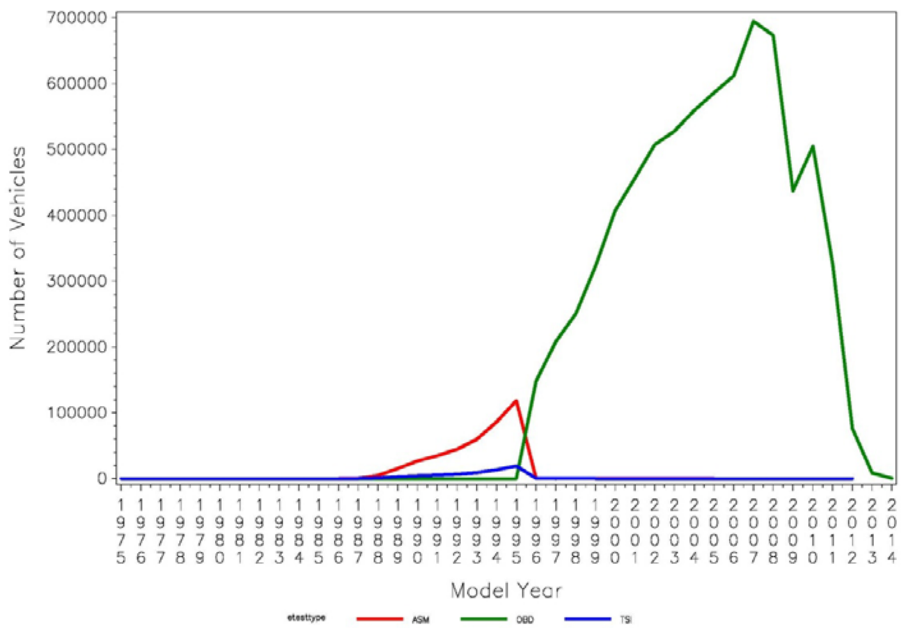
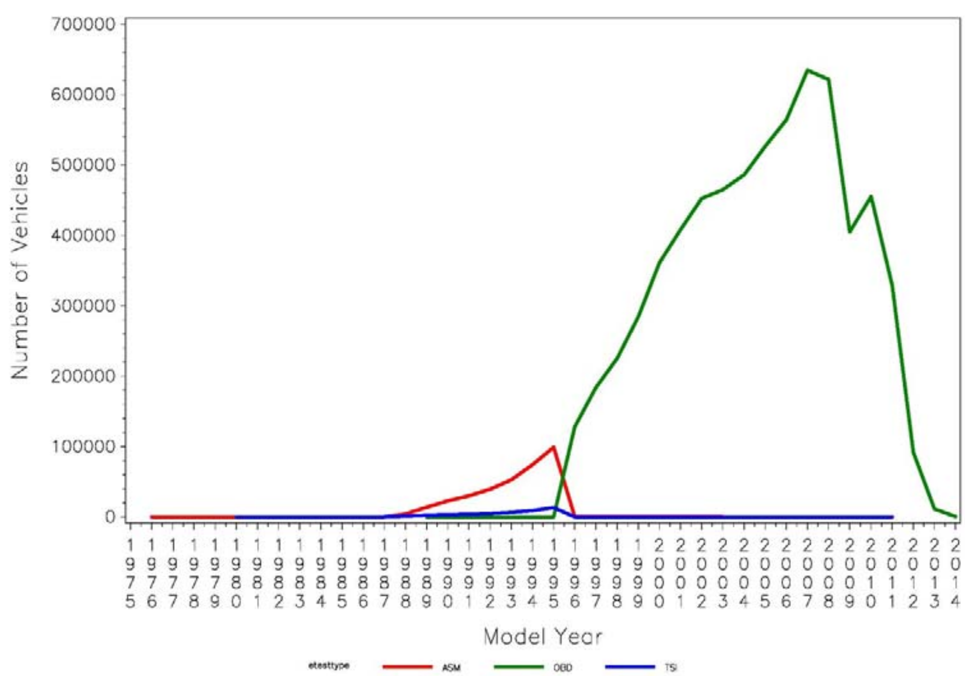



**Figure 3-12. Count of Emission Test Types by Model Year for HGB**



Figures 3-13 and 3-14 show the number of vehicles tested by month and by year for the DFW and HGB I/M program areas, respectively. The number of tests conducted each month is not the same from month to month, in both I/M areas for all years. In both Figures 3-13 and 3-14 the counts of vehicles tested begins in January 2012.

**Figure 3-13. Emission Test by Month for DFW**

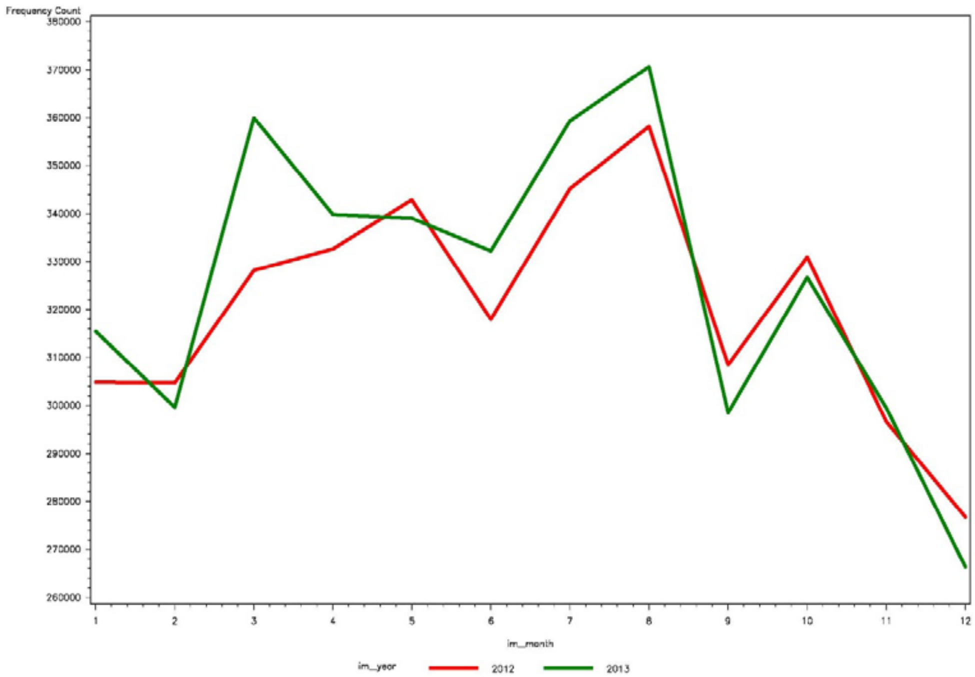
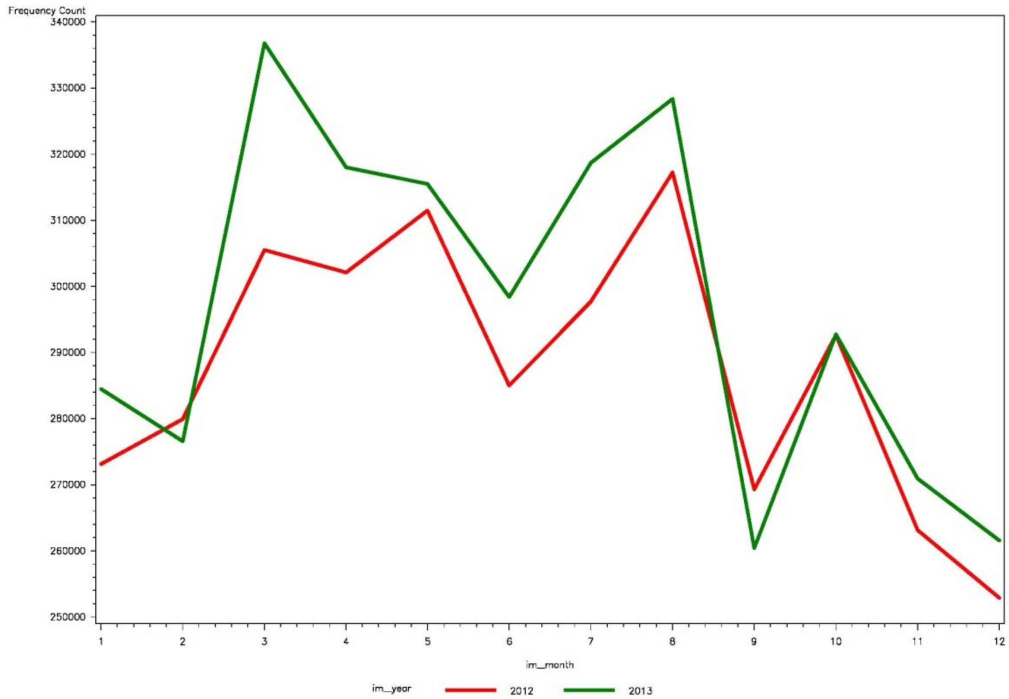


**Figure 3-14. Emission Test by Month for HGB**




## 3.3 Repeat I/M Failure Patterns

ERG examined the TIMS data to determine the patterns of repeat I/M failures. This illustrates the extent and properties of repairs related to the I/M program. TIMS data collected between January 1, 2012 and December 31, 2013 was used for this analysis. To distinguish amongst and handle partial and complete individual vehicle histories, ERG developed four I/M cycle categories:

1. Initial test (first time GroupID is encountered) occurred during the first three months of the dataset, but unsure whether it is a true initial test (i.e., the true initial test may have occurred prior to January 1, 2012) AND the Final test is a Certified[4] test.
2. Initial test (first time GroupID is encountered) occurred during the first three months of the dataset, but unsure whether it is a true Initial test AND the Final test is NOT a Certified test.
3. Initial test (either definition applies) occurs after the first three months of the dataset and assumed to be a true Initial test AND the Final test is a Certified test.

[4] In this report, the term Certified test is used to designate an I/M inspection in which the vehicle was issued a certificate, that is, a windshield sticker, for having completed and met the I/M program inspection requirements.

4. Initial test (either definition applies) occurs after the first three months of the dataset and assumed to be a true Initial test AND the Final test is NOT a Certified test.

Every vehicle that participates in the I/M program produces a brief history when it is inspected, repaired, and retested. Ideally, vehicles should be tested and pass if they are in proper working condition and if they are not, it is expected they would fail, be repaired, tested, and passed soon thereafter. If all vehicles in the inspected fleet had only one of these two possibilities, one could conclude that the accuracy of the I/M measurements and the efficacy of the repairs made to Texas vehicles were ideal. The actual test-repair sequences of real I/M programs were determined by an analysis of the TIMS data and, in general, produced many more possibilities than just the ideal two scenarios. For example, a sequence that is fail, fail, fail, pass might indicate that either the motorist is “shopping around” for a passing result, that the repairs done to the vehicle were inadequate, or that the emissions test was inaccurate.

Each vehicle was tested at an I/M station on one or more occasions. The TIMS does contain a variable that gives the type of test (Initial or Retest) and a variable that gives the result of the emissions test (Pass or Fail). However, for the purposes of determining failure patterns, ERG did not consider whether the test was designated by the TIMS as an initial or retest. For this analysis, the I/M sequences that were built by designating the first test to follow a certifying test as an initial test, and any test after that initial test, up to an including the certifying test, as a retest. Failed inspections were designated with an “F” and passes with a “P”.

For each unique GroupID, the designators were concatenated in chronological order to create a sequence that describes the failure pattern that each vehicle experienced during an I/M testing cycle. For example, for a vehicle that initially failed and then passed on a re-test, the test sequence would be “FP”. The frequency distribution of the resulting test sequences for completed I/M cycles (I/M Cycle Category = 3) is shown in Tables 3-7 and 3-8 for DFW and HGB, respectively.

**Table 3-7. Frequency Distribution of Test Sequences for DFW for I/M Cycle Category = 3**

| Test Sequence | Number of Vehicles | % of Vehicles |
|---|---|---|
| P | 6,231,915 | 96.0 |
| FP | 238,245 | 3.67 |
| PP | 11,770 | 0.2 |
| FFP | 8,456 | 0.1 |
| FFFP | 463 | 0.0 |
| FF | 308 | 0.0 |
| PFP | 290 | 0.0 |
| FPP | 181 | 0.0 |
| FFF | 91 | 0.0 |
| PPP | 62 | 0.0 |
| FFFFP | 32 | 0.0 |
| Other Sequences | 59 | 0.0 |
| Total | 6,491,872 | 100.0 |

**Table 3-8. Frequency Distribution of Test Sequences for HGB for I/M Cycle Category = 3**

| Test Sequence | Number of Vehicles | % of Vehicles |
|---|---|---|
| P | 5,614,406 | 95.9 |
| FP | 222,744 | 3.8 |
| PP | 11,777 | |
| FFP | 6,615 | |
| PFP | 274 | 0.0 |
| FF | 298 | 0.0 |
| FFFP | 264 | 0.0 |
| FPP | 135 | 0.0 |
| PPP | 116 | 0.0 |
| FFF | 66 | 0.0 |
| FFFFP | 19 | 0.0 |
| Other Sequences | 125 | 0.0 |
| Total | 5,856,839 | 100.0 |

In Tables 3-7 and 3-8, the top two rows, which represent the two "ideal" inspection sequences, comprise more than 99% of the total distribution, both in DFW and HGB. However, some of the other sequences raise questions, such as, why are some of the vehicles tested a second time after they pass initially, in either program area? One explanation could be that a vehicle goes to one station and passes its emissions test, but fails its safety test. Rather than returning to the same station, the vehicle goes to another station, but needs to be completely tested again even though it failed just the safety portion at its previous test.

About 15 less common sequences accounted for the remaining 0.4% of the tested fleets in DFW and HGB. Many of these remaining sequences seem to be unlikely, and could be the result of resale vehicles, unidentified covert audit vehicles, or possibly test classification errors instead of real situations. While it may be possible to reduce the occurrence of these unlikely test sequences, the problem is relatively uncommon.

Tables 3-7 and 3-8 showed the results for the third I/M cycle category separated into the HGB and DFW fleets. Tables 3-9 through 3-11 show the first, second, and fourth I/M cycle categories for the combined fleet.

The test sequences for the first I/M cycle category in Table 3-9 look very similar to the sequences in Tables 3-7 and 3-8. Many of these cycles are probably complete and certified cycles with the true initial tests occurring in the dataset, but uncertainty remains without examining the TIMS data prior to January 1, 2012. The test sequences for the second and fourth I/M Cycle Categories in Tables 3-10 and 3-11 consist of many more sequences that end in a Fail. As expected, these are not certified cycles. Approximately 75% of the sequences are either a single Fail or Fail-Fail. The remaining percentage of single, uncertified passes may be due to grouping errors. It is not possible to judge if these observations warrant further investigation at this point; therefore, the actual records for these sequences have been provided to the TCEQ.

**Table 3-9. Frequency Distribution of Test Sequences for I/M Cycle Category=1**

| Test Sequence | Vehicle Frequency | % of Vehicles |
|---|---|---|
| P | 1,646,001 | 95.2 |
| FP | 75,303 | 4.4 |
| PP | 3,791 | 0.2 |
| FFP | 2,843 | 0.2 |
| FFFP | 141 | 0.0 |
| PFP | 113 | 0.0 |
| Other Sequences | 319 | 0.0 |
| Total | 1,728,511 | 100.0 |

**Table 3-10. Frequency Distribution of Test Sequences for I/M Cycle Category=2**

| Test Sequence | Vehicle Frequency | % of Vehicles |
|---|---|---|
| F | 4,696 | 68.9 |
| P | 1,407 | 20.7 |
| FF | 293 | 4.3 |
| PP | 250 | 3.7 |
| FP | 82 | 1.2 |
| FFF | 28 | 0.4 |
| Other Sequences | 55 | 0.8 |
| Total | 6,811 | 100.0 |

**Table 3-11. Frequency Distribution of Test Sequences for I/M Cycle Category=4**

| Test Sequence | Vehicle Frequency | % of Vehicles |
|---|---|---|
| F | 54,316 | 73.8 |
| P | 15,217 | 20.7 |
| FF | 2,501 | 3.4 |
| PP | 603 | 0.8 |
| FP | 513 | 0.7 |
| PF | 122 | 0.2 |
| Other Sequences | 352 | 0.5 |
| Total | 73,624 | 100.0 |

## 3.4 Emissions Analyzer Data Quality

The goal of this task was to demonstrate the accuracy of the emissions inspection methods. The following four I/M analyzer checks were made using Texas TIMS data: Drift, Dilution Correction Factors, Gas Audits, and Lockouts.

### 3.4.1 Analyzer Drift

Texas I/M program emissions analyzers require 72-hour calibrations. The calibration is done using the analyzer to measure a bottled calibration gas mixture with a concentration that is known within a specified precision. Before a calibration is performed, a pre-calibration measurement on the calibration gas is made and recorded in the TIMS for HC, CO, $NO_x$, $O_2$, and $CO_2$ gases. The difference between the pre-calibration analyzer reading and the labeled concentration of the gas mixture is a direct measure of instrument drift. If the analyzer has not drifted since the last calibration, its readings for the calibration gas will be close to the bottle label value, and little calibration adjustment will be necessary. This fact can be used to develop an indicator of analyzer calibration stability. Analyzers that consistently retain calibrations can be expected to produce more accurate measures of vehicle emissions than those that drift greatly. If the difference between the bottle label value and the pre-calibration analyzer reading is very large, then it is presumed that some of the emissions measurements made during the previous 72 hours were less accurate than desirable.

#### 3.4.1.1 Calibration Procedures and Specifications

In each 72-hour calibration, the analyzer first records pre-calibration readings for HC, CO, $CO_2$, and $NO_x$ for zero, low-span, and mid-span bottle gases, and for $O_2$ with ambient air. The analyzer is then calibrated on the mid-span gases to within 1% of the bottle gas values. Next, the analyzer is tested on the low-span gases, and must fall within 2% of the bottle gas value. If the analyzer cannot be brought within specifications during the calibration, the instrument is automatically prohibited from performing any portion of any I/M test until it is successfully adjusted.

Table 3-12 shows the specified bottle gas values for the low-span and mid-span portions of the calibration. The bottled gases are permitted a 5% blend tolerance, which is also shown in the table. Finally, the table shows the specified accuracy of the analyzer for I/M inspections for each pollutant and gas level. These tolerances for I/M inspections are less stringent than the 1% mid-span and 2% low-span tolerances that are used for calibrations. The I/M inspection tolerances are applicable to this analysis of pre-calibration readings since the concern here is with whether analyzer drift affected I/M inspection results just prior to calibration. As an example from the table, the low-span HC bottle gas concentration is specified to be 200 ppm, but may range between 190 and 210 ppm. If a bottle gas labeled to contain 195 ppm HC were used for a calibration, the analyzer would be required to read between 189 and 201 ppm in order to meet the specification.

**Table 3-12. Calibration Span Gas Values and Tolerances**

| Gas | Specified Bottle Gas Concentration | Bottle Gas Blend Tolerance | Analyzer Tolerance for I/M Inspections |
|---|---|---|---|
| Zero Gas | | | |
| HC (ppm) | <1 | Not applicable for zero gases | ±4 |
| CO (%) | <0.01 | | ±0.02 |
| NOx (ppm) | <1 | | ±25 |
| CO2 (%) | <4.0 | | ±0.3 |
| O2 (%) | 20.7 | | ±1.04 |
| Low-Span Bottle Gas | | | |
| HC (ppm) | 200 | ±10 | ±6 |
| CO (%) | 0.5 | ±0.025 | ±0.02 |
| NOx (ppm) | 300 | ±15 | ±25 |
| CO2 (%) | 6.0 | ±0.3 | ±0.3 |

| Gas | Specified Bottle Gas Concentration | Bottle Gas Blend Tolerance | Analyzer Tolerance for I/M Inspections |
|---|---|---|---|
| Mid-Span Bottle Gas | | | |
| HC (ppm) | 3200 | ±160 | ±160 |
| CO (%) | 8.0 | ±0.4 | ±0.24 |
| NOx (ppm) | 3000 | ±150 | ±120 |
| CO2 (%) | 12.0 | ±0.6 | ±0.36 |

The actual concentrations of the bottle gases used in each calibration are recorded in the TIMS. More than 99.9% of calibration records include bottle gas label concentrations within the tolerances listed in Table 3-12. However, the remaining small fraction of records include some surprisingly high and low bottle gas values, such as about 7 records with zero percent or ppm for each of the low-span and mid-span concentrations. It is possible that the bottle gas concentration was entered incorrectly into the TIMS, or that the outlying values represent real bottle gas mixtures that were occasionally used. In either case, the calibration results are called into question when the analyzer reading is compared to out-of-specification bottle gas label values. To eliminate this issue in future calibration records, ERG recommends that the TCEQ restrict the inspector-entered bottle gas values to a range that corresponds to the specifications. Thus, the analyzer software would not allow a calibration to proceed unless reasonable bottle gas values were entered.

#### 3.4.1.2 Results

Span test calibration records (502,013 records) from the TIMS between January 1, 2012, and December 31, 2013, were available for this analysis. Records with a PEF result of "0" were deleted, since these records appeared to contain no calibration information, leaving 472,047 records in the dataset. Records for the Austin and El Paso areas were deleted from the dataset by deleting all analyzers where the NOx calibration readings were always zero, leaving 365,549 HGB/DFW records in the dataset. Finally, an additional 7 records in which the pre-calibration reading for each gas concentration was zero were deleted, leaving 365,542 records in the dataset. Although these records contained no span gas calibration readings, each did include a pass or fail result for the span gas calibration. Some of these records did contain dynamometer calibration information, and some contained a pass or fail result for the leak check; therefore, these might be records for calibration events that did not include a span gas calibration. However, if that is the case, the analyzer software should not have allowed a pass/fail result to be recorded for the span gas audit.

Figures 3-15 through 3-28 each show the distribution of the difference between the analyzer reading and the labeled value of the bottle gas, for one gas type/concentration level combination. For the zero level readings, the difference between zero and the recorded concentration is shown. The calibration records for $O_2$ have been divided into two separate groups for Figures 3-19 and 3-20. The pre-calibration value of $O_2$ should be 20.7%, corresponding to the $O_2$ content of ambient air. It was found that analyzers with manufacturer codes of SE, JB, and WW measured near 20.7% $O_2$ in more than 99% of calibrations, while analyzers with the manufacturer code ESP measured less than 3% $O_2$ in almost 50% of calibrations. It may be that ESP analyzers are designed to measure $O_2$ from bottle gas (perhaps the CO/HC bottle that contains zero $O_2$) during calibrations, instead of ambient air as specified. Since the tolerance for the analyzer is tighter at 0% $O_2$ than at 20.7% $O_2$, the two sets of readings are plotted separately.

All of the distributions show a clear peak at zero, indicating that many analyzers drift very little between 72-hour calibrations. For many of the figures, almost the entire range of readings fell within the tolerance for that gas type/concentration level.

**Figure 3-15. Distribution of Difference Between Zero and HC Pre-Calibration Reading**

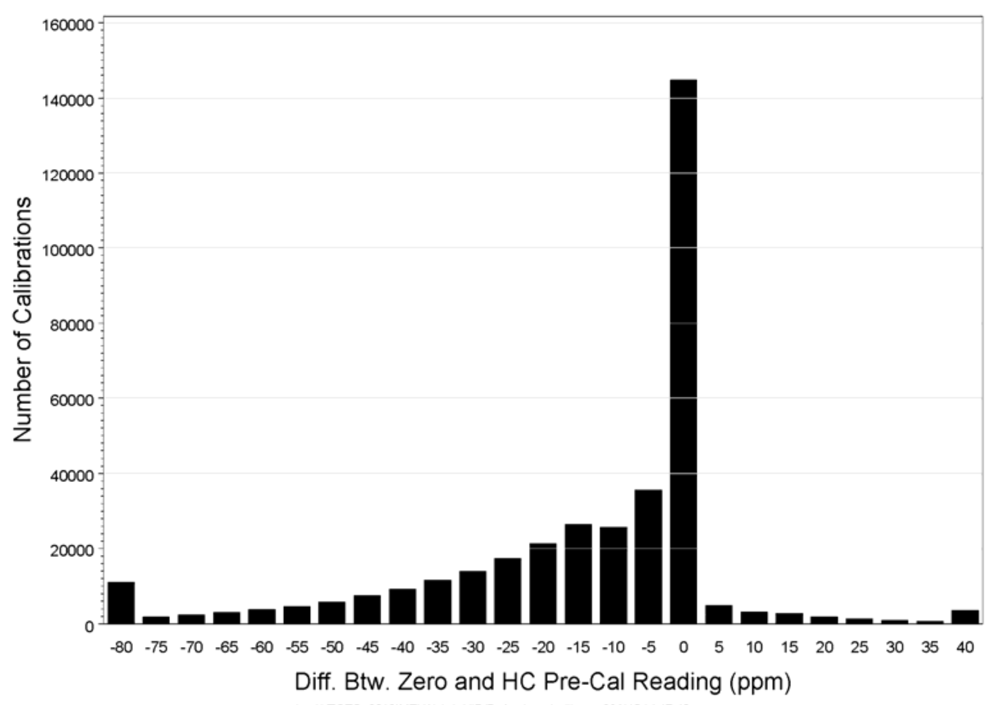


**Figure 3-16. Distribution of Difference Between Zero and CO Pre-Calibration Reading**

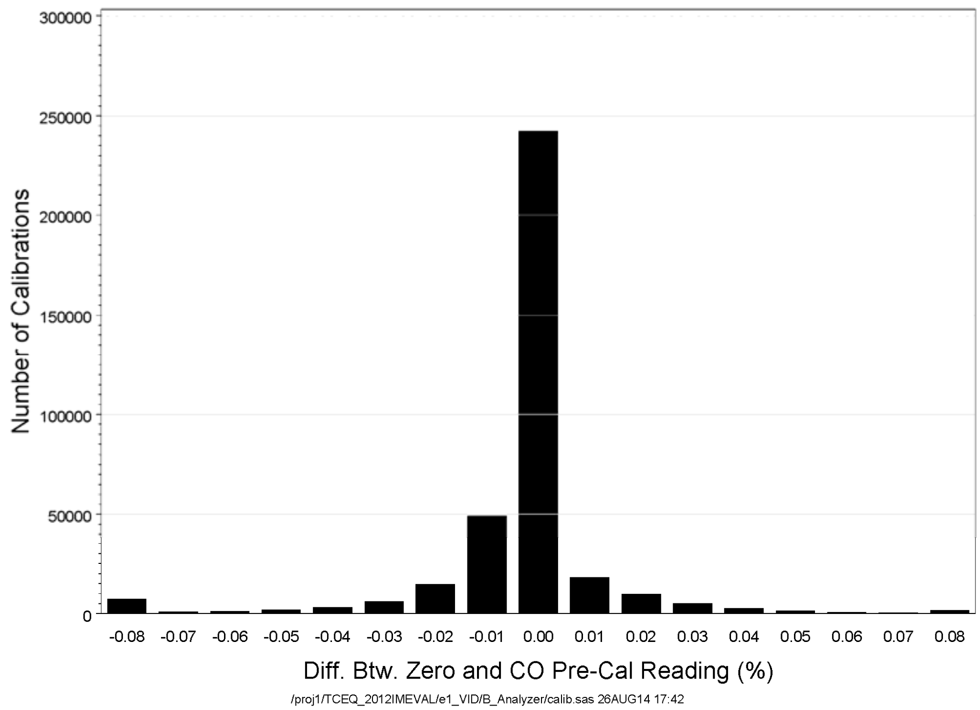



**Figure 3-17. Distribution of Difference Between Zero and $NO_x$ Pre-Calibration Reading**

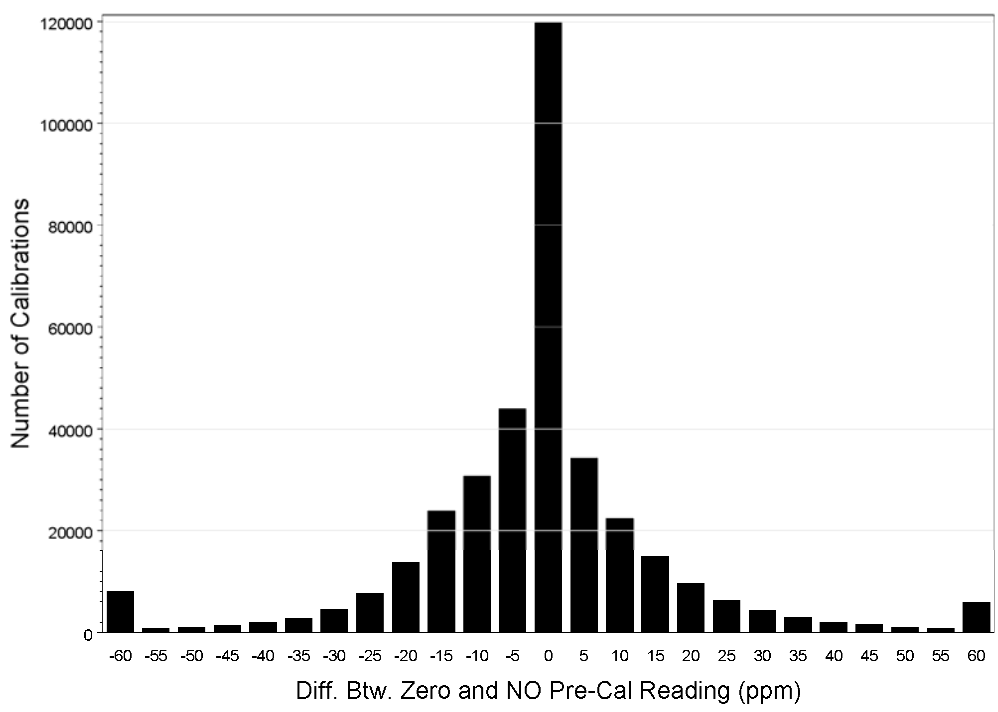


**Figure 3-18. Distribution of Difference Between Zero and $CO_2$ Pre-Calibration Reading**

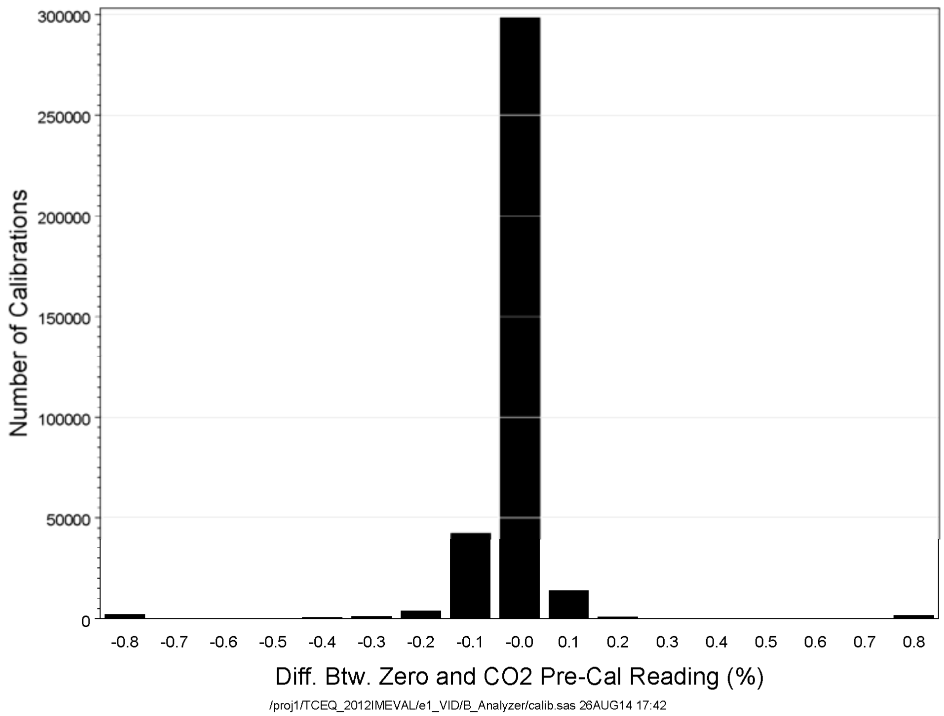



**Figure 3-19. Distribution of Difference Between Zero and $O_2$ Pre-Calibration Reading**

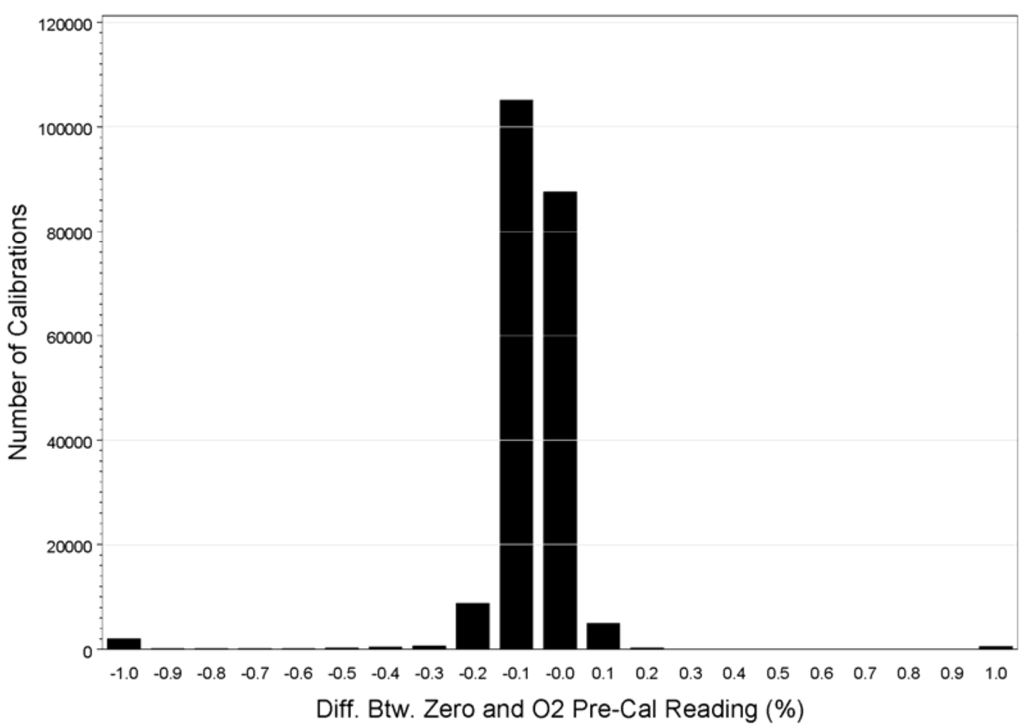


**Figure 3-20. Distribution of Difference Between 20.7% and $O_2$ Pre-Calibration Reading**

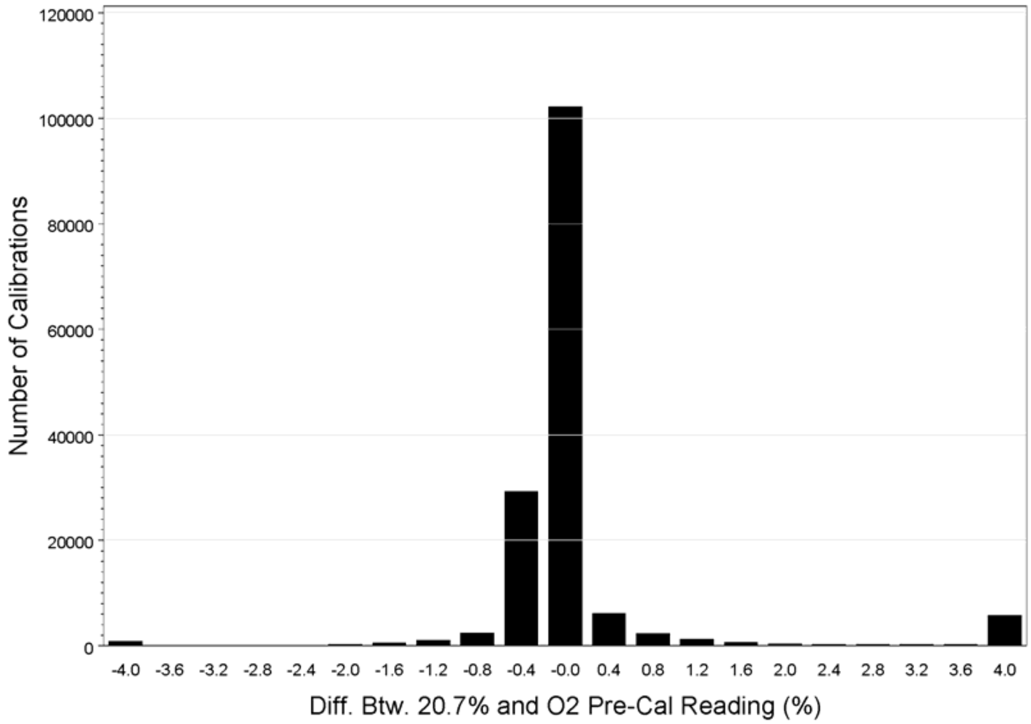



**Figure 3-21. Distribution of Difference Between Low-Span Bottle and HC Pre-Calibration Reading**

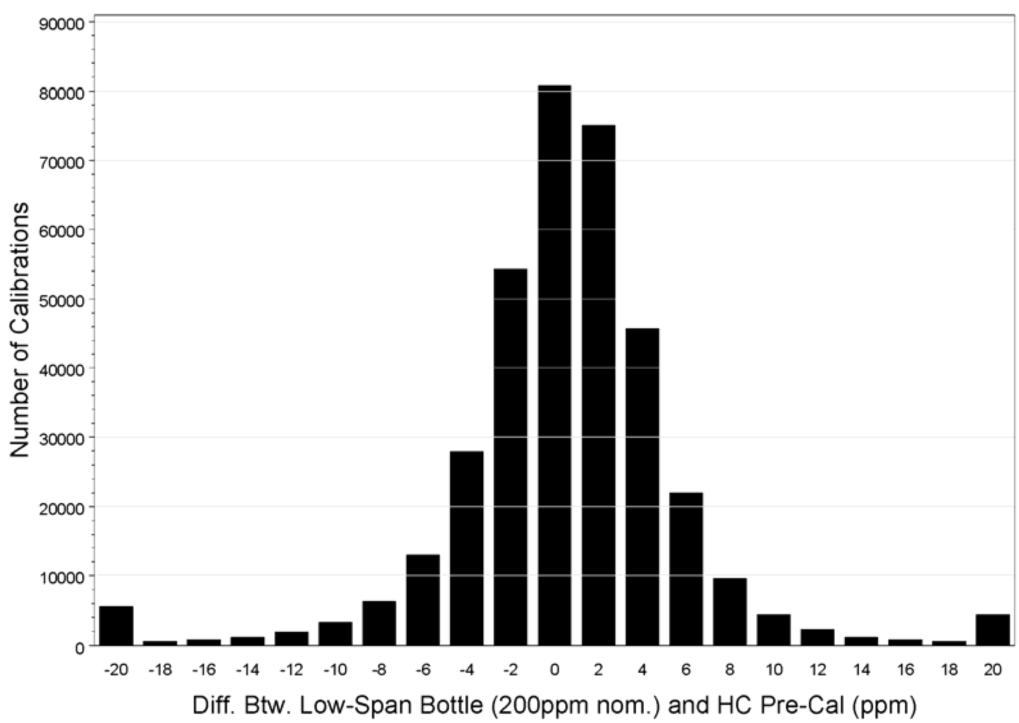


**Figure 3-22. Distribution of Difference Between Low-Span Bottle and CO Pre-Calibration Reading**

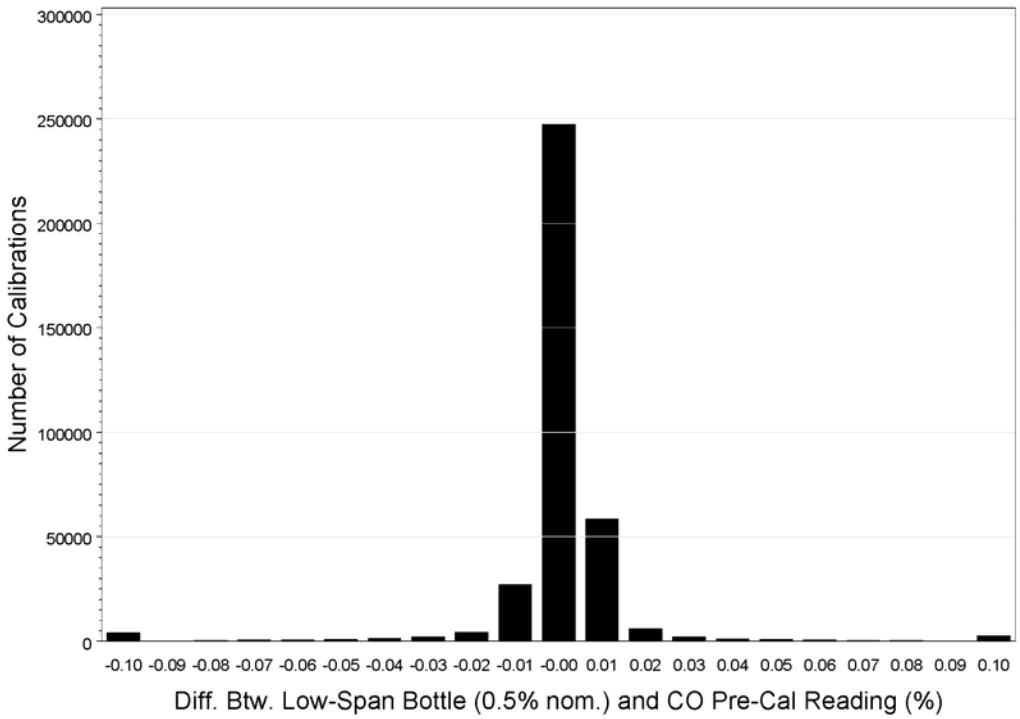



**Figure 3-23. Distribution of Difference Between Low-Span Bottle and $NO_x$ Pre-Calibration Reading**

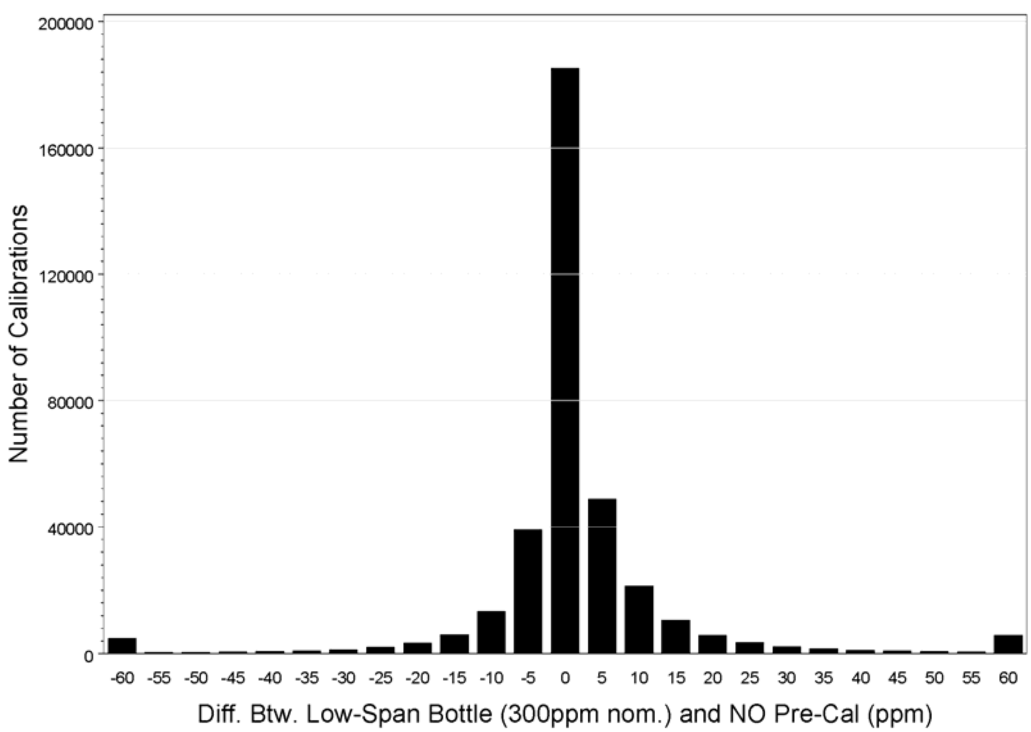


**Figure 3-24. Distribution of Difference Between Low-Span Bottle and $CO_2$ Pre-Calibration Reading**

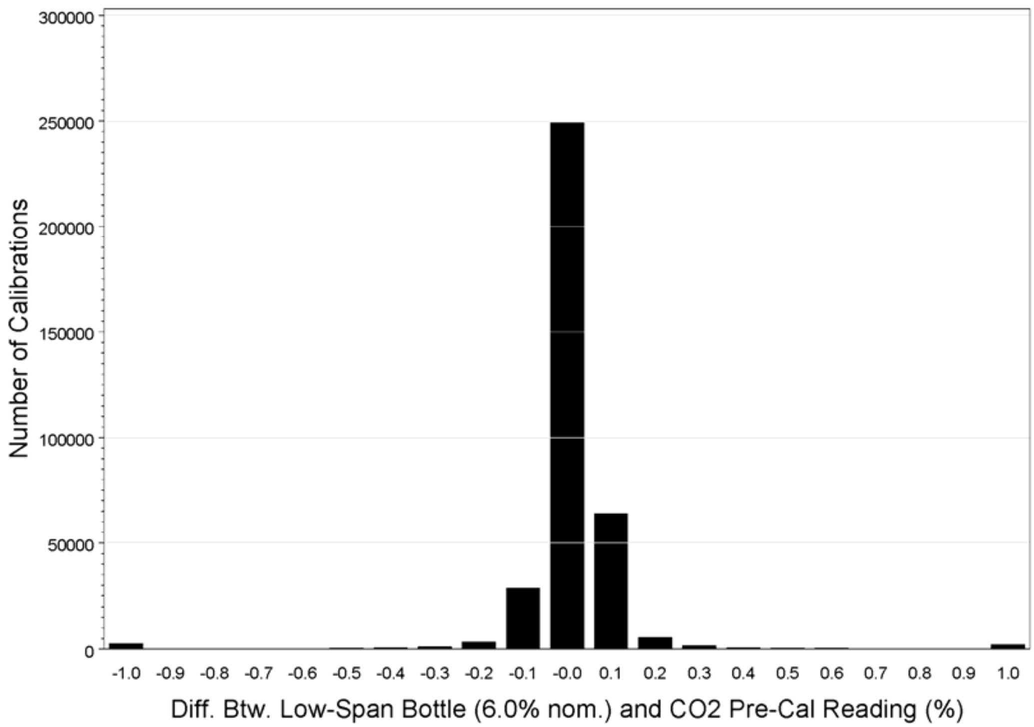



**Figure 3-25. Distribution of Difference Between Mid-Span Bottle and HC Pre-Calibration Reading**

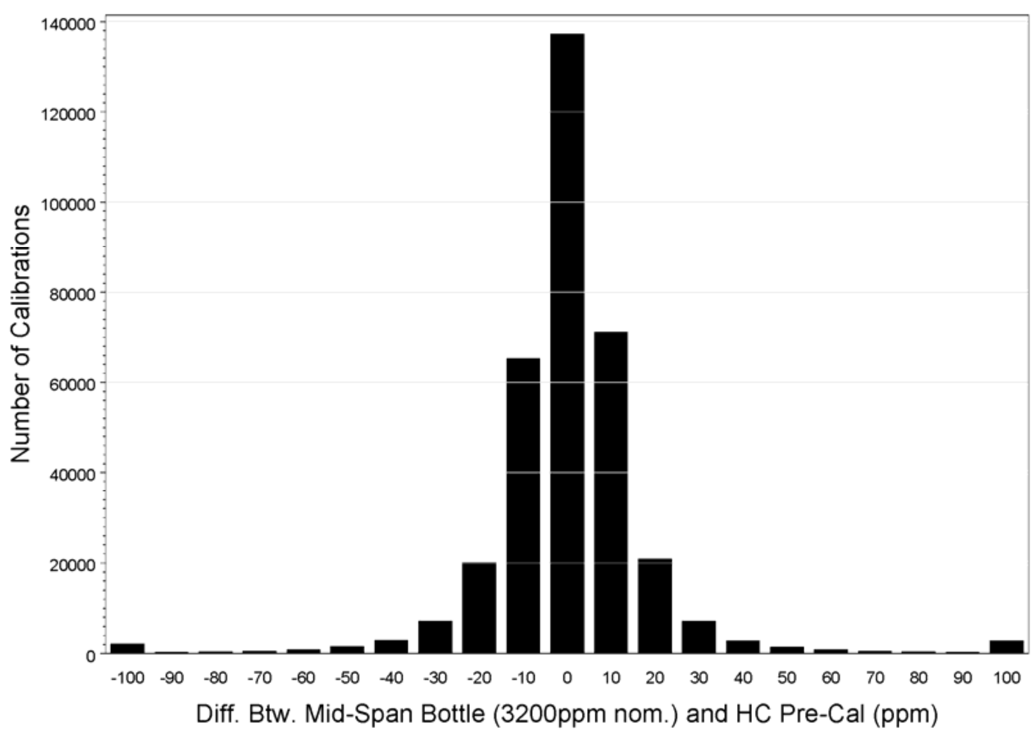


**Figure 3-26. Distribution of Difference Between Mid-Span Bottle and CO Pre-Calibration Reading**

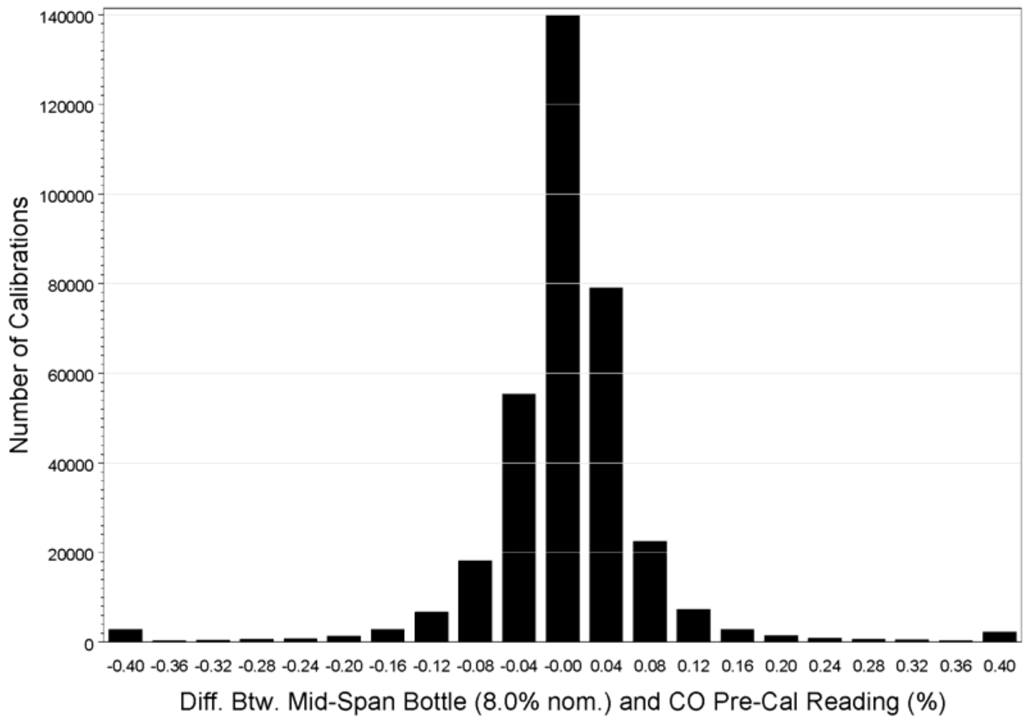



**Figure 3-27. Distribution of Difference Between Mid-Span Bottle and $NO_x$ Pre-Calibration Reading**

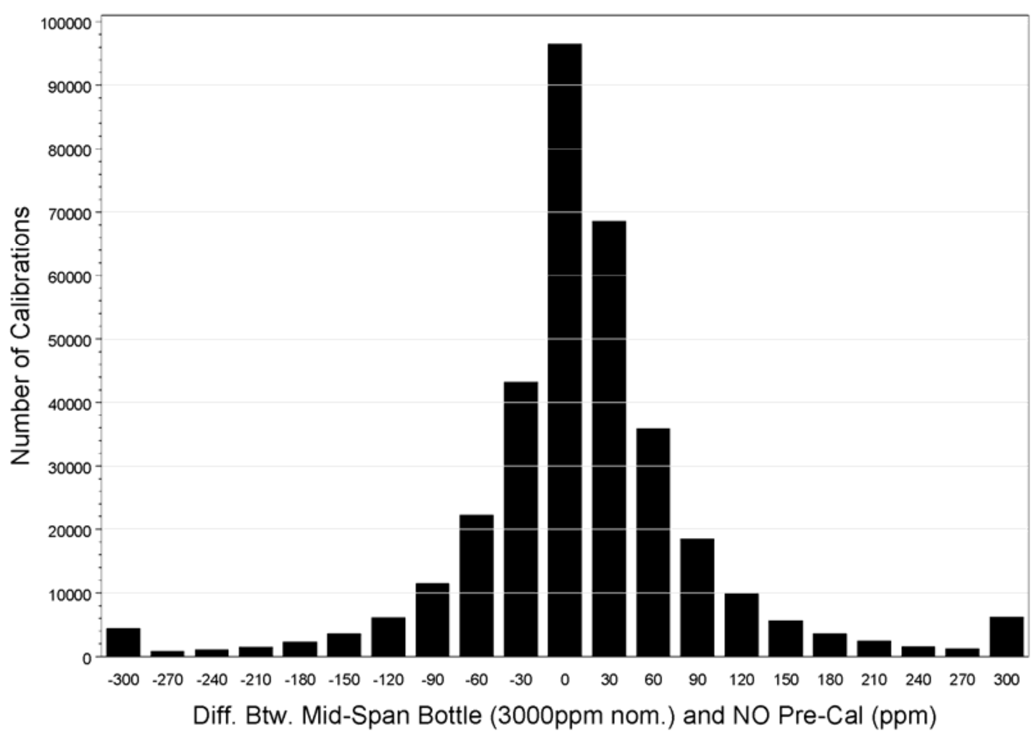


**Figure 3-28. Distribution of Difference Between Mid-Span Bottle and $CO_2$ Pre-Calibration Reading**

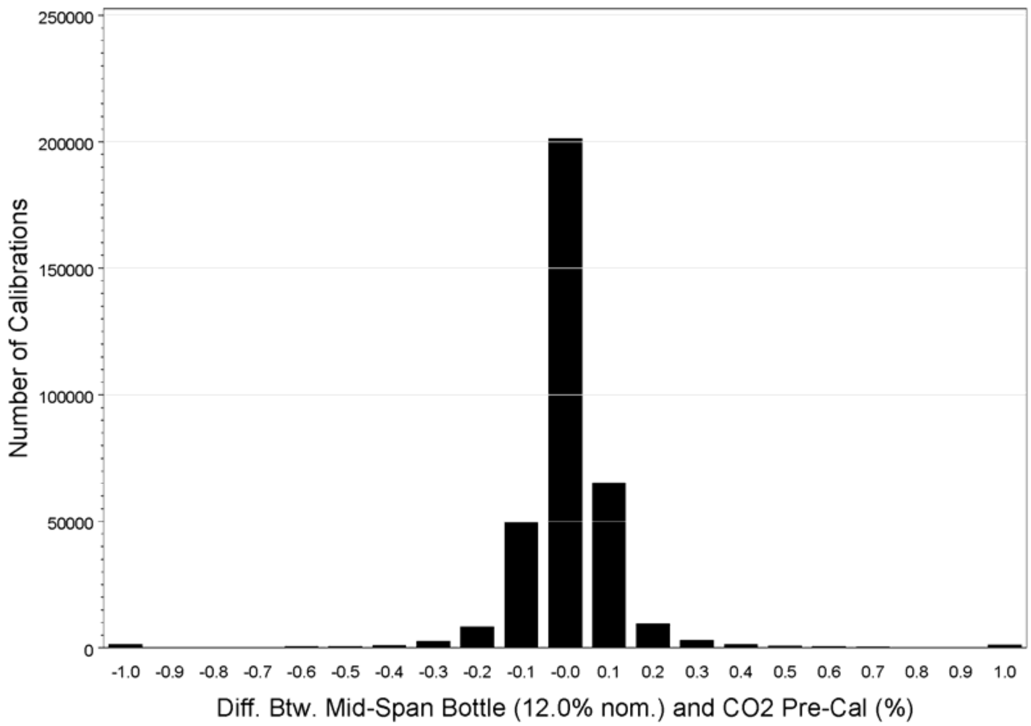



Table 3-13 shows the specified value and tolerance for each gas type/concentration level, the total number of pre-calibration records available at that level, the percent of records whose values fell within the tolerance bounds, and finally, the amount of difference from the specified value that would include 90% of calibration records (the $90^{th}$ percentile).

Note that the total record counts vary by concentration level in Table 3-13. About 365,000 records were available at the zero level, but only 361,000 records at the low-span level. This reduction is a result of calibration records with zero pre-calibration values but no low-span values. For a similar reason, there are only 347,000 records available at the mid-span level. It is important to record the pre-calibration readings so that analyzer drift can be tracked, but it appears that not all portions of the pre-calibration data are recorded at every calibration event.

For almost all gas type/concentration level combinations, more than 86% of pre-calibration records fell within the tolerance of the analyzer. The exception is the zero level HC, where only 46% of records were within tolerance (the wide distribution can be seen in Figure 3-15 as well). This indicates that results for more than 86% of I/M inspections performed just before the calibration can be expected to be within instrument tolerance (except for very low values of HC).

**Table 3-13. Number and Percent of Pre-Calibration Records Occurring Within Analyzer Tolerance**

| Gas | Specification | Total Number of Pre-Cal Records | Within Tolerance | | 90th Percentile |
|---|---|---|---|---|---|
| | | | N | % | |
| Zero Gas | | | | | |
| HC (ppm) | 0±4 | 365,541 | 167,041 | 45.7 | 47 |
| CO (%) | 0.00±0.02 | 365,541 | 333,403 | 91.2 | 0.02 |
| NOx (ppm) | 0±25 | 365,541 | 321,787 | 88.0 | 29 |
| CO2 (%) | 0.0±0.3 | 365,542 | 360,331 | 98.6 | 0.1 |
| O2 (%) | 0.0±0.1 | 211,403 | 197,550 | 93.4 | 0.1 |
| O2 (%) | 20.7±1.04 | 154,138 | 142,668 | 92.6 | 0.7 |
| Low-Span Gas | | | | | |
| HC (ppm) | 200±6 | 361,667 | 313,424 | 86.7 | 8 |
| CO (%) | 0.50±0.02 | 361,669 | 333,073 | 92.1 | 0.01 |
| NOx (ppm) | 300±25 | 361,050 | 337,028 | 93.3 | 18 |
| CO2 (%) | 6.0±0.3 | 361,638 | 352,973 | 97.6 | 0.1 |
| Mid-Span Gas | | | | | |
| HC (ppm) | 3200±160 | 346,966 | 344,173 | 99.2 | 24 |
| CO (%) | 8.00±0.24 | 347,002 | 338,134 | 97.4 | 0.1 |
| NOx (ppm) | 3000±150 | 346,655 | 305,734 | 88.2 | 134 |
| CO2 (%) | 12.00±0.36 | 347,000 | 338,859 | 97.7 | 0.1 |

### 3.4.2 Analyzer Dilution Correction Factors

For every ASM or TSI emissions test, a dilution correction factor based on the measured CO and $CO_2$ concentration is calculated. Dilution correction factors (DCFs) can also be calculated based on the measured $O_2$ concentration. The dilution correction factors from these two separate sources of tailpipe emissions should be within agreement with a relatively small tolerance. With those emissions tests where the DCFs are not in substantial agreement, there is question about the accuracy of the emissions test. The analysis does not indicate which emission is in error but indicates that something is wrong with the CO, $CO_2$, or $O_2$ measurements. Unless all three of these pollutants are in agreement with respect to their corresponding dilution correction factors, the HC, CO, and $NO_x$ measurements reported by the instrument are in question. [Section 4.2.1.3 of Reference 1]

The measurement of exhaust emissions concentrations can be confounded by the dilution of the exhaust gas by non-optimal probe placement, leaking exhaust systems, cylinder misfires, and excess oxygen from air pumps. The Texas I/M program analyzers quantify the degree of dilution for each ASM or TSI inspection using measured CO and $CO_2$ concentrations to calculate a DCF. For this analysis, the $CO/CO_2$ DCFs were recalculated for the ASM and TSI inspections in the TIMS.

The $CO/CO_2$ DCFs are the official dilution correction factors used for the emissions test; however, DCFs can also be calculated using the $O_2$ concentration measured at each emissions test. A comparison of $CO/CO_2$ DCFs with $O_2$ DCFs is just another way to check the emissions instruments. Therefore, ERG also calculated DCFs based on the measured $O_2$ concentration. The dilution corrections reported in the TIMS, the $CO/CO_2$ dilution corrections calculated by ERG, and the $O_2$ dilution corrections calculated by ERG should be in agreement with a relatively small tolerance. This analysis does not necessarily indicate which emission is in error, but does indicate that something is wrong with the CO, $CO_2$, or $O_2$ measurements. Unless all three of these pollutants are in agreement with respect to their corresponding dilution correction factors, the resulting HC, CO, and $NO_x$ measurements reported by the instrument are in question.

#### 3.4.2.1 Background

Assuming stoichiometric combustion of gasoline, an exhaust dilution correction factor can be estimated using a carbon mass-balance and the measurements of CO and $CO_2$. These constituents are measured in the non-dispersive infrared bench of the analyzer. The equations are based on the average composition of gasoline. First, define the variable x:

$$x = \frac{CO_2}{CO_2 + CO}$$

where $CO_2$ and CO values are in percent. Then the dilution factor, $DCFCO/CO_2$, is as follows:

$$DCF_{CO/CO2} = 100 \frac{x/(4.64 + 1.88x)}{CO_2}$$

If a fuel other than gasoline were used, the 4.64 constant would be different. However, only gasoline-fueled vehicles will be considered in this analysis.

In addition, many emissions analyzers also measure exhaust gas oxygen concentration with an electrochemical cell. Assuming an ambient air oxygen concentration of 20.9%, the exhaust oxygen measurement can also be used to estimate dilution in the exhaust. A dilution correction factor based on the measured oxygen concentration is:

$$dcf_{O_2} = \frac{20.9}{20.9 - O_2}$$

This relationship assumes that the tailpipe oxygen concentration for stoichiometric combustion and no air in-leakage is 0.0% $O_2$. Field measurements indicate that new vehicles with no exhaust system leaks and operating at stoichiometric air/fuel ratio have 0.0% tailpipe oxygen concentrations.

If CO, $CO_2$, and $O_2$ are measured correctly, the independent DCFs (CO/$CO_2$ and $O_2$) for each vehicle inspection should agree well with each other. Previous studies have indicated that the difference between the two DCFs should be no larger than about ±0.14 [Reference 1].

#### 3.4.2.2 Results

For this analysis, vehicle inspection records from the TIMS for vehicles tested in the Dallas/Fort Worth and the Houston/Galveston/Brazoria areas were used. Results for 881,683 inspections of gasoline-fueled vehicles that received either the ASM or the two-speed idle (TSI) test were available. Any records with flags that indicated the inspection had been aborted, timed out, or ended due to a dilution condition were deleted.

It was found that the TIMS variable indicating which inspection type was performed (ASM or TSI) was not always accurate. In a small number of cases, it indicated that an ASM inspection was performed, but the emissions concentration data in the record was for a TSI inspection, or vice-versa. Therefore the inspection type was determined by whether a record contained a non-zero, non-missing value for $CO_2$ for the ASM2525, ASM5015, low-idle TSI, or high-idle TSI. The presence of $CO_2$ indicates that combustion was taking place and being recorded. This resulted in a dataset with 773,685 records for the ASM2525 test condition, 773,766 records for the ASM5015 test condition, 107,728 records for the low-idle TSI inspection, and 107,833 records for the high-idle TSI inspection.

The CO/$CO_2$-based DCF and the $O_2$-based DCF were calculated for each inspection record, and then plotted against each other. Figure 3-29 shows a plot of the ASM2525 DCF based on CO/$CO_2$ versus the ASM2525 DCF based on $O_2$ for each ASM2525 test. Similar plots for ASM5015, low-idle TSI, and high-idle TSI results are shown in Figures 3-30, 3-31, and 3-32. In each plot, most of the points fall near the 1:1 line as expected, and the degree of scatter around the 1:1 line is relatively low. However, in addition to the points clustered on the 1:1 line, the two ASM plots also show a smaller horizontal ray (DCF $CO/CO_2 \approx 1$ while DCF$O_2$ increases) and a vertical ray (DCF $O_2 \approx 1$ while DCF $CO/CO_2$ increases). Points at a distance from the 1:1 line may represent analyzer sensors for CO, $CO_2$, or $O_2$ that are broken or out of calibration, data entry errors, or other anomalies. Some of the reasons for these out-of-line points will be discussed in further detail in the sub-sections which follow.

**Figure 3-29. Comparison of ASM2525 DCF $CO/CO_2$ and DCF $O_2$**

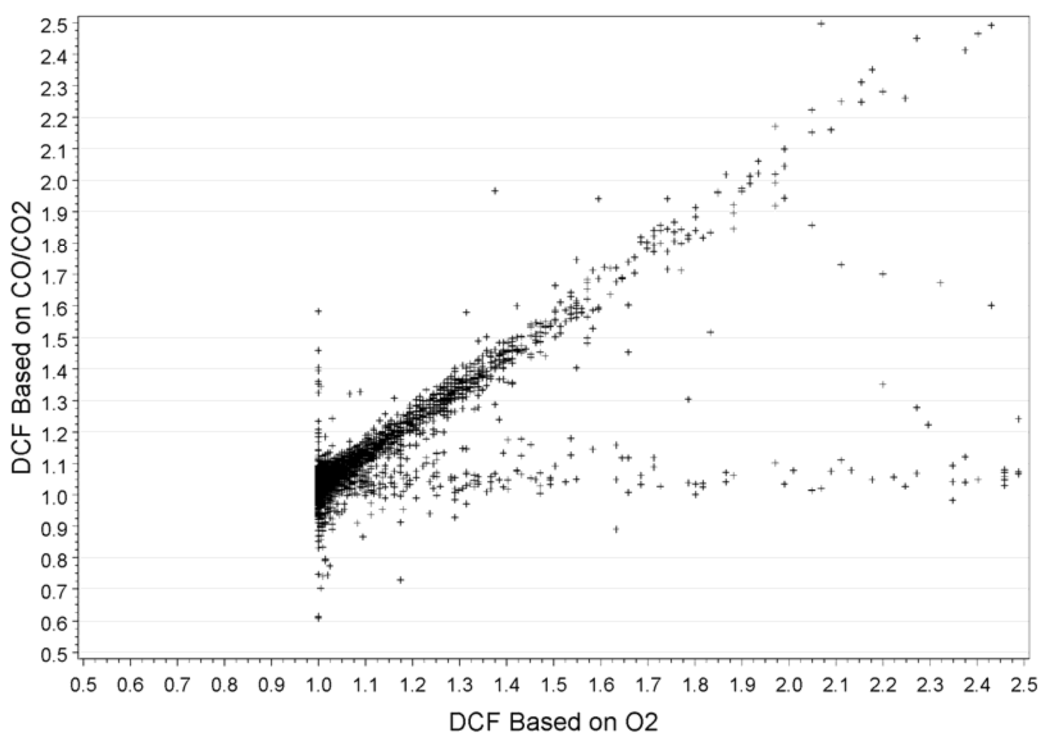


**Figure 3-30. Comparison of ASM5015 DCF CO/$CO_2$ and DCF $O_2$**

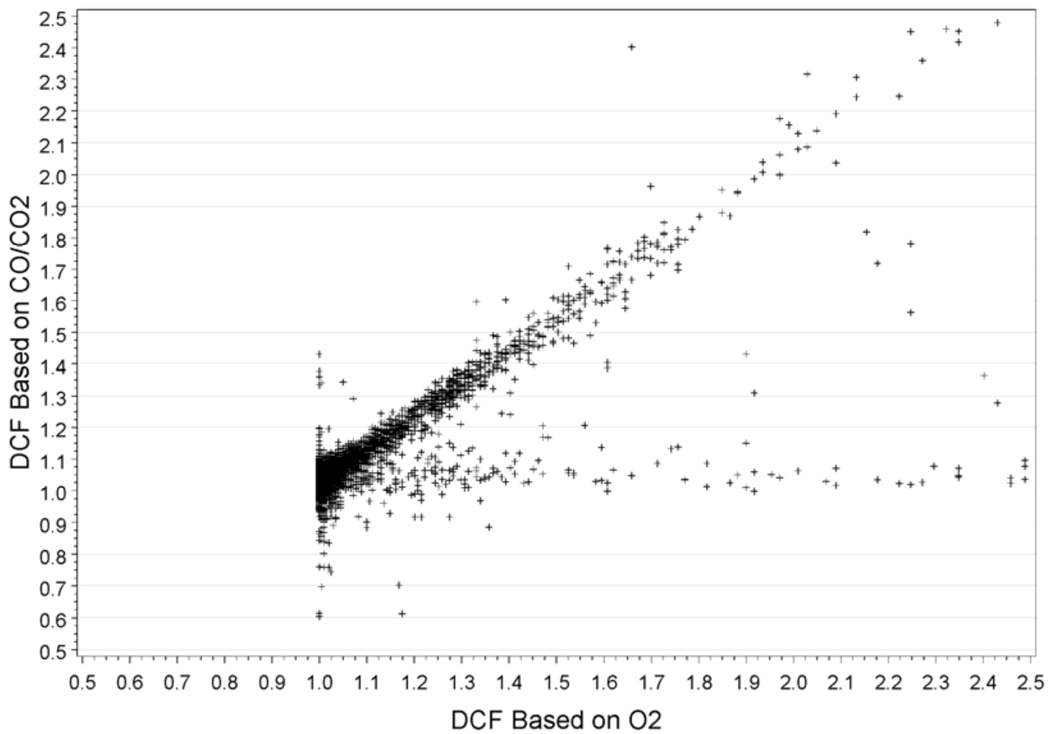



**Figure 3-31. Comparison of Low-Speed Idle TSI DCF CO/$CO_2$ and DCF $O_2$**

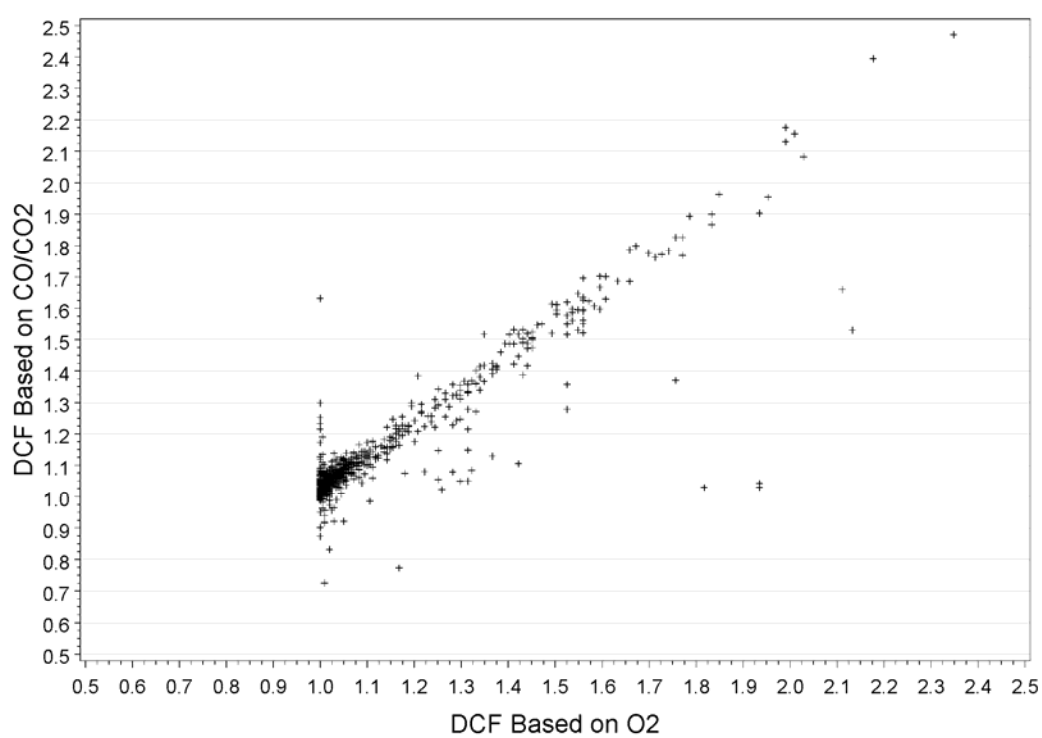
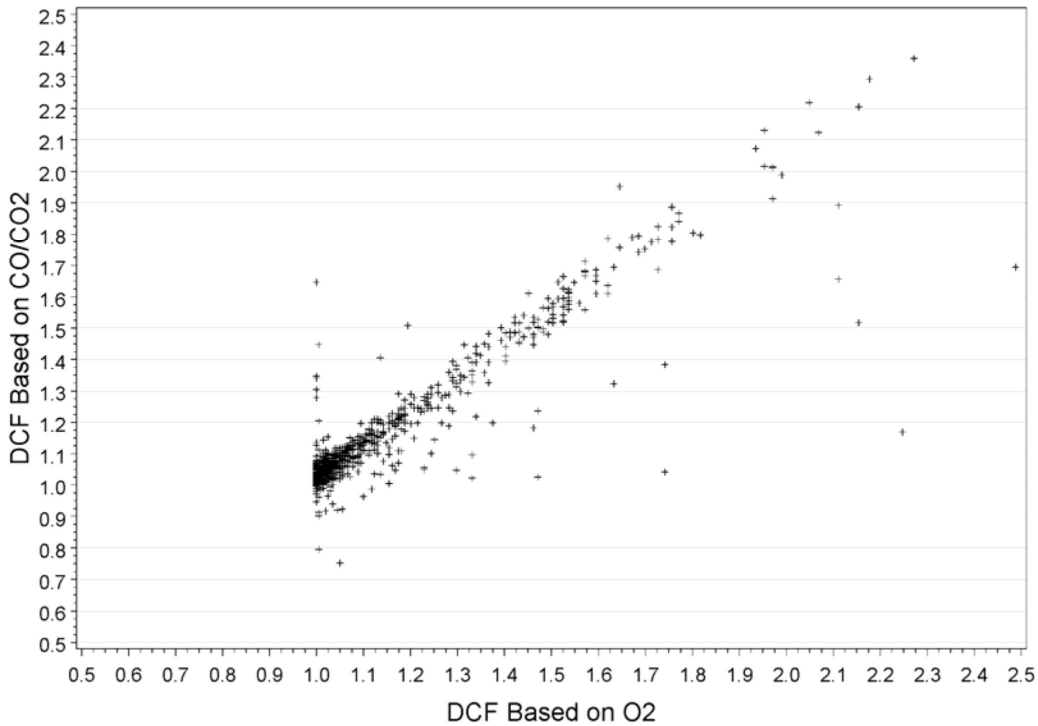


**Figure 3-32. Comparison of High-Speed Idle TSI DCF $CO/CO_2$ and DCF O2**




The information presented graphically in Figures 3-29 through 3-32 is quantified in Table 3-14. For each inspection record, the difference between the $CO/CO_2$-based DCF and the $O_2$-based DCF was calculated. The table shows the number and percentage of records that fall into six levels of DCF difference, for each type of inspection. As noted above, previous studies have found that this difference should be no more than about ±0.14. It can be seen from Table 3-14 that for the ASM inspection, 87% of records have a difference of less than 0.14. For the TSI inspection records, 83% have a difference of less than 0.14.

**Table 3-14. Distribution of Differences Between DCF$CO/CO_2$ and DCFO2**

| Test Type | <0.01 | 0.01-0.14 | 0.14-0.3 | 0.3-1.0 | 1-10 | >10 | Total |
|---|---|---|---|---|---|---|---|
| ASM2525 | 89,073<br>11.5% | 584,095<br>75.5% | 9,043<br>1.2% | 7,825<br>1.0% | 20,243<br>2.6% | 63,406<br>8.2% | 773,685<br>100.0% |
| ASM5015 | 100,895<br>13.0% | 571,077<br>73.8% | 8,984<br>1.2% | 8,115<br>1.0% | 20,524<br>2.7% | 64,171<br>8.3% | 773,766<br>100.0% |
| TSI Low | 10,558<br>9.8% | 79,060<br>73.4% | 2,633<br>2.4% | 1,530<br>1.4% | 2,890<br>2.7% | 11,057<br>10.3% | 107,728<br>100.0% |
| TSI High | 10,076<br>9.3% | 80,437<br>74.6% | 1,901<br>1.8% | 1,442<br>1.3% | 2,818<br>2.6% | 11,159<br>10.3% | 107,833<br>100.0% |

The TIMS contains a DCF based on $CO/CO_2$ for the ASM2525 and ASM5015 test cycles. The TIMS DCF $CO/CO_2$ was compared to the DCF $CO/CO_2$ calculated by ERG. Results are shown in Table 3-15. It was expected that agreement would be extremely close, since the same two emissions concentrations (CO and $CO_2$) were used for the TIMS calculation and the ERG calculation. It can be seen from Table 3-15 that agreement was very good; more than 99% of records had a difference of less than 0.14.

**Table 3-15. Distribution of Differences Between ERG DCF $CO/CO_2$ and TIMS DCF $CO/CO_2$**

| Test Type | <0.01 | 0.01-0.14 | 0.14-0.3 | 0.3-1.0 | 1-10 | >10 | Total |
|---|---|---|---|---|---|---|---|
| ASM2525 | 712,207<br>92.1% | 54,317<br>7.0% | 1,925<br>0.2% | 1,246<br>0.2% | 1,375<br>0.2% | 2,615<br>0.3% | 773,685<br>100.0% |
| ASM5015 | 702,703<br>90.8% | 63,338<br>8.2% | 2,038<br>0.3% | 1,388<br>0.2% | 1,580<br>0.2% | 2,719<br>0.4% | 773,766<br>100.0% |

The TIMS record for each inspection contains an identification number for the analyzer used to perform the inspection. The first two characters of the analyzer identification number indicate the manufacturer of the analyzer. The distribution of differences between the DCF $CO/CO_2$ and the DCF $O_2$ (both calculated by ERG, not from the TIMS) were compared by analyzer manufacturer, as shown in Table 3-16. The ESP and WW rates of differences of less 0.14 are near 94-97%, while the JB and SE rates of differences of less than 0.14 are very low (less than 14%). This is probably due to erroneous O2 concentrations for these manufacturer's analyzers, as discussed in the following section.

**Table 3-16. Distribution of Differences Between DCF $CO/CO_2$ and DCF $O_2$ by Analyzer Manufacturer, for ASM5015 Inspections**

| Analyzer Mfg. ID | <0.01 | 0.01-0.14 | 0.14-0.3 | 0.3-1.0 | 1-10 | >10 | Total |
|---|---|---|---|---|---|---|---|
| ESP | 76,664<br>16.6% | 358,101<br>77.4% | 4,831<br>1.0% | 3,909<br>0.8% | 7,367<br>1.6% | 11,809<br>2.6% | 76,664<br>16.6% |
| JB | 1<br>0.1% | 11<br>0.7% | 7<br>0.4% | 23<br>1.5% | 198<br>12.7% | 1,320<br>84.6% | 1<br>0.1% |
| SE | 822<br>1.1% | 9,268<br>12.2% | 1,137<br>1.5% | 2,886<br>3.8% | 12,215<br>16.0% | 49,862<br>65.4% | 822<br>1.1% |
| WW | 23,408<br>10.0% | 203,697<br>87.3% | 3,009<br>1.3% | 1,297<br>0.6% | 744<br>0.3% | 1,180<br>0.5% | 23,408<br>10.0% |

#### 3.4.2.3 O2 Emissions Concentration Anomalies

One factor that was found to cause problems with the DCF calculations was inaccuracy in the reported O2 emissions concentrations. The tailpipe oxygen concentration for stoichiometric combustion and no air in-leakage would be 0.0% O2, while the ambient air concentration of O2 is approximately 20.9%. The percent of otherwise-valid inspection records that included O2 concentrations greater than 20.5% is shown in Table 3-17, for each test condition. From the table, 6% of ASM and 8% of TSI records included suspicious O2 concentrations, with tailpipe exhaust O2 concentrations very close to or equal to ambient O2 concentrations. These will cause the O2-based DCF to have a very high (or undefined, when O2 equaled exactly 20.9%) value.

**Table 3-17. Number and Percent of Suspicious $O_2$ Concentrations by Test Mode**

| Test Type | O2 >20.5% | O2 <20.5% | Total |
|---|---|---|---|
| ASM2525 | 48,893<br>6.3% | 724,794<br>93.7% | 773,687<br>100.0% |
| ASM5015 | 49,377<br>6.4% | 724,391<br>93.6% | 773,768<br>100.0% |
| TSI Low | 9,056<br>8.4% | 98,679<br>91.6% | 107,735<br>100.0% |
| TSI High | 9,086<br>8.4% | 98,755<br>91.6% | 107,841<br>100.0% |

It was also found that the rate of suspicious $O_2$ concentrations was much higher for two of the analyzer manufacturers than for the other two, as shown in Table 3-18. The ESP and WW analyzers were responsible for 90% of inspection records, but only 19% of suspicious $O_2$ concentrations.

**Table 3-18. Number and Percent of Suspicious $O_2$ Concentrations ($O_2$ >20.5%), by Analyzer Manufacturer, for ASM5015**

| Analyzer Mfg. ID | O2 >20.5% | O2 <20.5% | Total |
|---|---|---|---|
| ESP | 8,383<br>1.8% | 454,300<br>98.2% | 462,683<br>100.0% |
| JB | 1,251<br>80.2% | 309<br>19.8% | 1,560<br>100.0% |
| SE | 38,769<br>50.9% | 37,421<br>49.1% | 76,190<br>100.0% |
| WW | 974<br>0.4% | 232,361<br>99.6% | 233,335<br>100.0% |

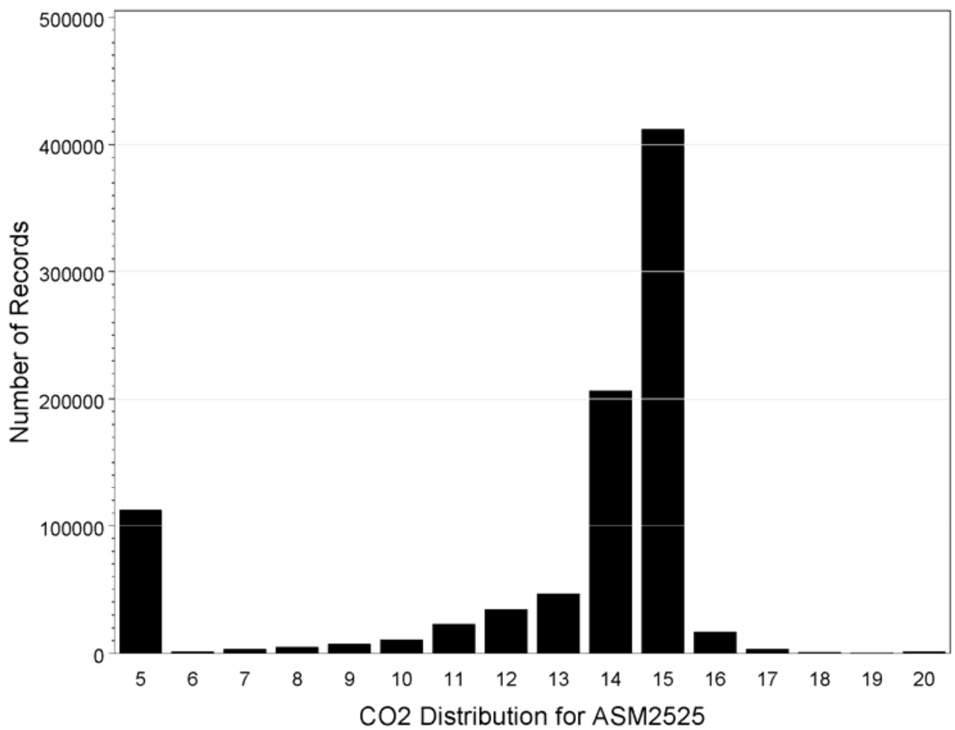
#### 3.4.2.4 CO2 Emissions Concentration Anomalies

Another factor that was found to cause problems with the DCF calculations was inaccuracy in the reported $CO_2$ emissions concentrations. The tailpipe carbon dioxide concentration for stoichiometric combustion and no air in-leakage should be 15.6% $CO_2$.

$CO_2$ values lower than 15.6% can occur because of air in-leakage or because some of the carbon is in the form of CO or HC. Any $CO_2$ values higher than 15.6% would be cause for suspicion.

The distribution of $CO_2$ values for the ASM2525 inspection is shown in Figure 3-33. It can be seen from the figure that the $CO_2$ values are concentrated around 15%, as expected. However, a small fraction of $CO_2$ values do exceed 16%, for 0.5% of ASM2525 inspection records. These records were investigated further.

**Figure 3-33. Distribution of CO2 Values for ASM 2525 Inspection**



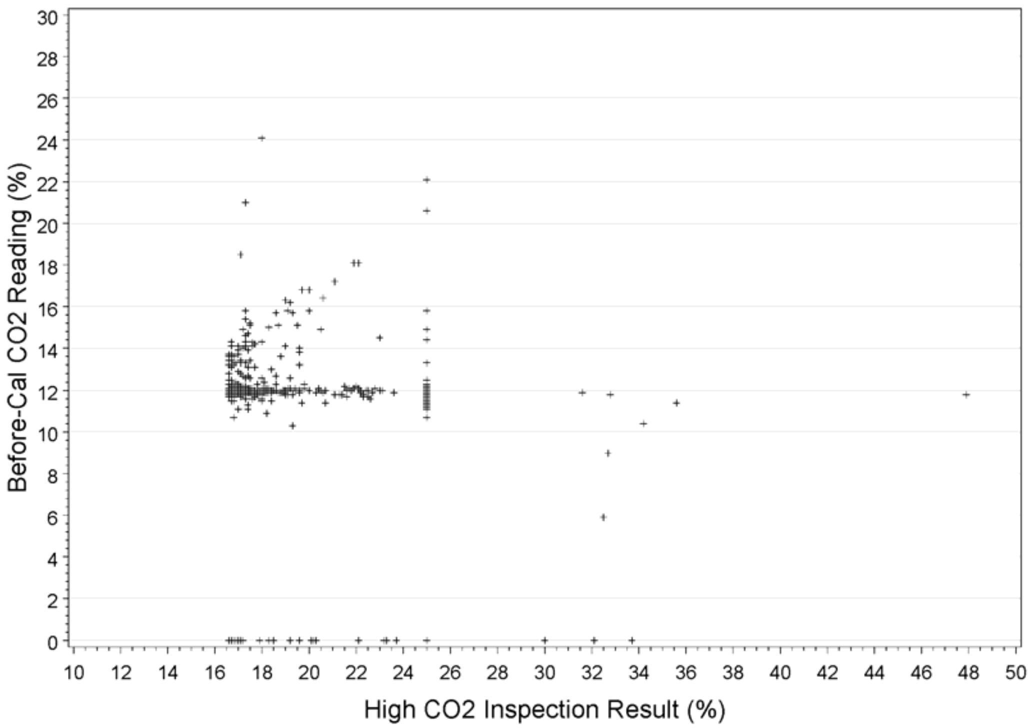

The rate of high $CO_2$ concentrations was found to vary slightly among the different analyzer manufacturers, as shown in Table 3-19, although the differences were not as pronounced as those found for the suspicious $O_2$ concentrations.

**Table 3-19. Number and Percent of Suspicious $CO_2$ Concentrations ($CO_2$ >16.5%), by Analyzer Manufacturer, for ASM 2525**

| Analyzer Mfg. ID | CO2 >16.5% | CO2 <16.5% | Total |
|---|---|---|---|
| ESP | 2,917<br>0.6% | 522,628<br>99.4% | 525,545<br>100.0% |
| JB | -<br>0.0% | 1,772<br>100.0% | 1,772<br>100.0% |
| SE | 290<br>0.3% | 88,384<br>99.7% | 88,674<br>100.0% |
| WW | 1,629<br>0.6% | 263,596<br>99.4% | 265,225<br>100.0% |

The high-$CO_2$ inspection records were matched to calibration records (described in Section 3.4.1) to find instances where the analyzer responsible for the high-$CO_2$ inspection record was calibrated within the following 24 hours. The mid-span pre-calibration $CO_2$ readings were then inspected to determine whether the high-$CO_2$ records could be attributed to out-of-calibration analyzers. In Figure 3-34, the pre-calibration $CO_2$ readings are plotted against the high $CO_2$ readings found in the inspection record dataset. The plot does not show a correlation between increasingly high-$CO_2$ inspection results and increasingly high pre-calibration $CO_2$ levels (which should be close to 12% for the mid-span bottle gas), so analyzer drift does not seem to be responsible for the high $CO_2$ results.

**Figure 3-34. High $CO_2$ Inspection Results Compared to $CO_2$ Pre-Calibration Readings**




One consequence of recording a $CO_2$ concentration greater than 15.6% is that the $CO/CO_2$-based dilution correction factor will be less than 1, indicating a "concentration" condition, rather than a dilution condition. Records with very high CO concentrations will also have a DCF of less than 1. In the TIMS, these DCFs are rounded up to 1; no DCFs of less than 1 are stored. However, just as a high DCF (greater than 1) can act as a flag for a problematic dilution condition, a low DCF (less than 1) can also provide a useful warning that inspection results may be suspect. The equation for the $O_2$-based DCFs does not allow the $O_2$ DCF to fall below 1. However, low $CO/CO_2$-based DCFs can be seen in Figures 3-29 through 3-32. For the ASM2525 inspection, 140 records (0.02% of total inspection records) have DCF $CO/CO_2$ between 0 and 0.55, and 9,258 records have DCF $CO/CO_2$ between 0.55 and 0.95 (1.1% of total inspection records).

#### 3.4.2.5 Extra Vertical and Horizontal Rays

It was noted above that Figures 3-29 and 3-30 with the $CO/CO_2$-based DCF plotted against the $O_2$-based DCF for ASM inspections, appear to contain three distinct "rays". The majority of points fall near the diagonal 1:1 line, but there is a substantial set of points near a horizontal line at DCF $CO/CO_2$ =1, and a smaller set of points near a vertical at DCF $O_2$=1. To investigate the reasons for the rays, the set of inspection records for the ASM2525 test was subdivided into four categories: points falling along each of the diagonal, horizontal rays, vertical rays, and other points that didn't fall neatly into any of the rays. The distributions of emissions concentrations for $O_2$, $CO_2$, and CO for records comprising the three rays were then compared, as shown in Figures 3-35 through 3-37.

Figure 3-35 shows that the horizontal ray is comprised of inspection records with high $O_2$ concentrations. Almost all of the records with $O_2$ concentrations greater than 4% fall on that ray. (The horizontal ray results from records with high DCF $O_2$ values and DCF $CO/CO_2$ values near 1.) A high $O_2$ concentration results in a high DCF $O_2$ value, and would seem to indicate a dilution condition (air entering the exhaust stream to add $O_2$ to the sample), but the DCF $CO/CO_2$ values remain around 1 in the horizontal ray, indicating that the CO and $CO_2$ emissions are not being diluted. Figures 3-36 and 3-37 show that the distributions of $CO_2$ and CO concentration for the horizontal ray are very similar to the distributions for the diagonal ray.

The figures show the opposite result for the vertical ray (comprised of records with high DCF $CO/CO_2$ and DCF $O_2$ near 1). Figure 3-35 shows that the $O_2$ concentration distribution for the vertical ray is similar to that of the diagonal ray. Figure 3-36 shows that the $CO_2$ concentration for records in the vertical ray was almost always less than 10%, instead of the 15% seen for the diagonal ray. Figure 3-37 shows that the CO concentration for records in the vertical and horizontal rays was similar to that of records in the diagonal ray.

Overall, Figures 3-35, 3-36, and 3-37 indicate the records in each ray were systematically different from the records in each other ray.

**Figure 3-35. Distribution of O2 Concentrations, by "Ray"**

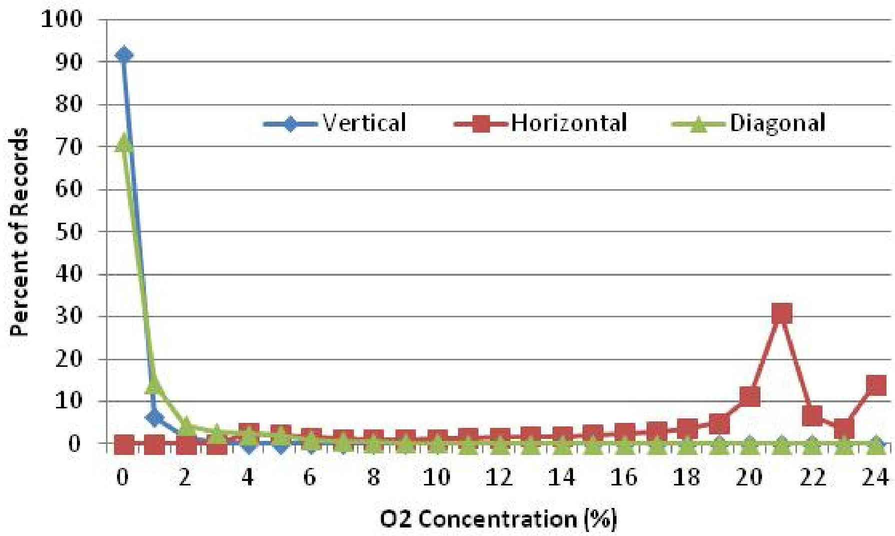



**Figure 3-36. Distribution of $CO_2$ Concentrations, by "Ray"**

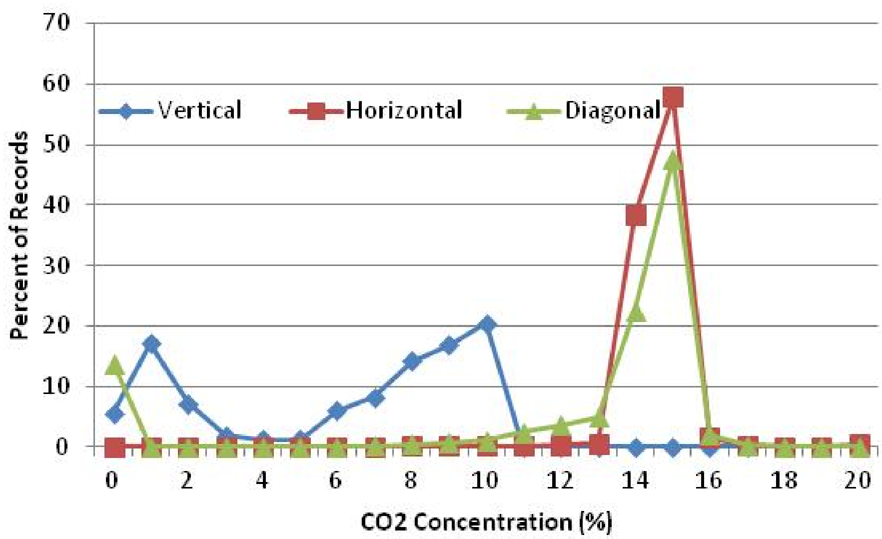
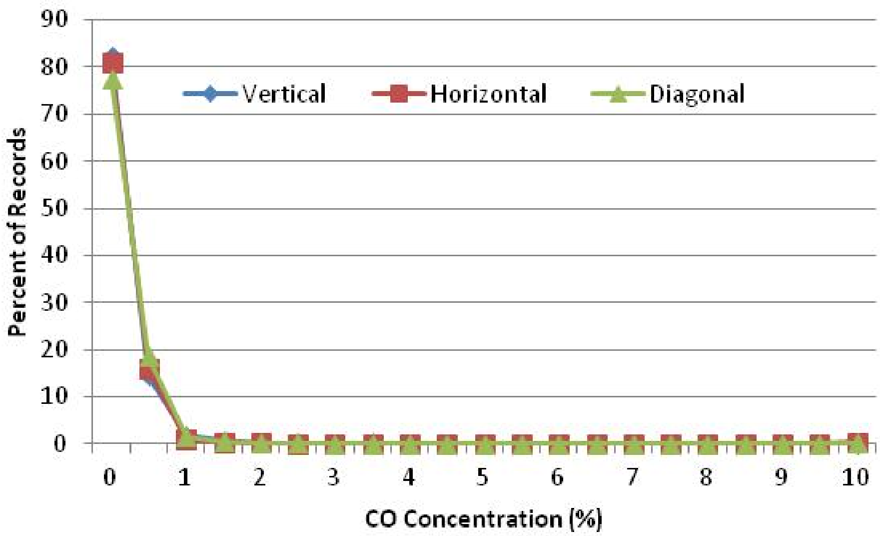


**Figure 3-37. Distribution of CO Concentrations, by "Ray"**




The distribution of records into each ray-group was tabulated by analyzer manufacturer, as shown in Table 3-20 below. As expected, the manufacturers represented by codes JB and SE contributed a large portion of the records for the horizontal ray. In Figure 3-35 it was seen that this ray includes most of the records with $O_2$ concentrations near 20.9% (ambient concentration), and in Table 3-18 it was seen that the JB and SE manufacturers contributed the majority of the records with the high $O_2$ concentrations. Table 3-20 also shows that the JB and SE analyzers were responsible for a greater proportion of the records in the "Other" column than were the ESP and WW analyzers. The "Other" group includes all records that didn't fall neatly into one of the rays; these records represent scatter in the data, rather than a systematic problem as represented by the vertical and horizontal rays. It is more difficult to see trends among the analyzer manufacturers for the vertical ray, since there were many fewer records in that ray.

**Table 3-20. Number and Percent of Records in Each Ray by Analyzer Manufacturer, for ASM2525**

| Analyzer Mfg. ID | Vertical | Horizontal | Diagonal | Other | Total |
|---|---|---|---|---|---|
| ESP | 263<br>0.1% | 15,214<br>2.9% | 498,466<br>94.8% | 11,870<br>2.3% | 525,813<br>100.0% |
| JB | 4<br>0.2% | 1,318<br>74.4% | 224<br>12.6% | 226<br>12.8% | 1,772<br>100.0% |
| SE | 96<br>0.1% | 47,860<br>54.0% | 22,823<br>25.7% | 17,909<br>20.2% | 88,688<br>100.0% |
| WW | 52<br>0.0% | 2,582<br>1.0% | 259,507<br>97.8% | 3,269<br>1.2% | 265,410<br>100.0% |

### 3.4.3 Analyzer Gas Audits

One component of a station equipment audit is the emissions analyzer gas audit. This audit is performed by independent auditors using bottled audit gases (independent of the station's calibration gases), and the gas is introduced by the auditor at the tailpipe sampling probe rather than simply at the analyzer inlet (as in a 72-hour analyzer calibration). This type of audit adds an additional level of certainty about instrument measurement accuracy, since it can identify problems with the probe and the sample transport line from the probe to the I/M analyzer. If the analyzer fails the gas audit, it must be repaired (if necessary) and successfully re-calibrated before it may be used for additional I/M inspections involving tailpipe measurements.

Bottled gases containing zero gas and blends of HC, CO, $NO_x$, and $CO_2$ at low and mid-span concentration levels are used in a gas audit. The analyzer specification requires that the measured pollutant concentrations fall within 5.5% of the labeled (actual) bottle gas value for the low and mid-span level gases in order to pass the gas audit. The nominal bottle gas concentrations for the low and mid-span gas audits are listed in Table 3-21 (these are the same as the nominal bottle gas values for low- and mid-span calibrations). Actual labeled bottle gas concentrations may vary up to 5% from the nominal values, so the labeled bottle gas values are recorded in the analyzer and transmitted to the TIMS for each audit.

**Table 3-21. Bottle Gas Concentrations for Low and Mid Span Audits**

| Gas | Low Span Nominal Concentration | Mid Span Nominal Concentration |
|---|---|---|
| HC (ppm) | 200 | 3,200 |
| CO (%) | 0.5 | 8.0 |
| NOx (ppm) | 300 | 3,000 |
| CO2 (%) | 6.0 | 12.0 |

The Texas SIP requires that each analyzer be audited at least twice per year. For the two-year dataset used for this analysis, this should result in an average of 4 audits per analyzer. A frequency distribution of the number of audits per analyzer is shown in Table 3-22. As can be seen from the table, many of the 2,142 analyzers received many more than four audits; in fact, about a quarter of the analyzers received eight or more audits. Many of the extra audits result from follow-up audits (re-audits) after an analyzer failed a portion of an initial audit. Additionally, the time differences between consecutive audits indicate that it is standard that analyzers be audited on a two- or three-month cycle, rather than the longer six-month cycle required as a minimum by the SIP.

**Table 3-22. Number of Gas Audits per Analyzer Over a Two-Year Period**

| Number of Audits | Number of Analyzers | Percent of Analyzers |
|---|---|---|
| 1 | 101 | 4.7% |
| 2 | 127 | 5.9% |
| 3 | 216 | 10.1% |
| 4 | 272 | 12.7% |
| 5 | 284 | 13.3% |
| 6 | 306 | 14.3% |
| 7 | 276 | 12.9% |
| 8 | 241 | 11.3% |
| More than 8 | 319 | 14.9% |
| Total | 2,142 | 100.0% |

The pass/fail results for the gas audit are based on whether or not the analyzer reads a pollutant concentration within 5.5% of the labeled bottle gas value:

$$\text{Difference (\%)} = 100 \times [(\text{Reading} - \text{Bottle Value}) / \text{Bottle Value}]$$

The distribution of percentage differences between readings and bottle gas values is shown in Figures 3-38 through 3-45 for CO, HC, $CO_2$, and $NO_x$, at the low- and mid-span levels. In almost all of the figures, the vast majority of readings fall between +/- 4% of the labeled gas values. The main exceptions were the low-span HC, with a somewhat wider spread, and the low- and mid-span $NO_x$, which were both biased toward low readings.

**Figure 3-38. Percent Difference Between Reading and Bottle Gas, Low-Span CO**

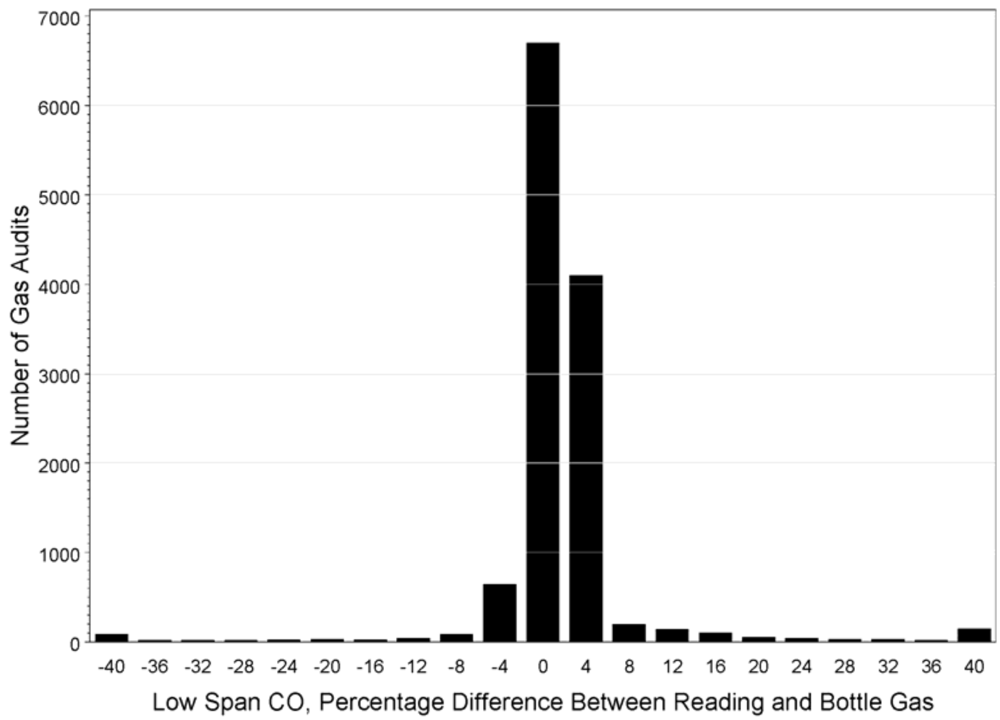



**Figure 3-39. Percent Difference Between Reading and Bottle Gas, Low-Span HC**

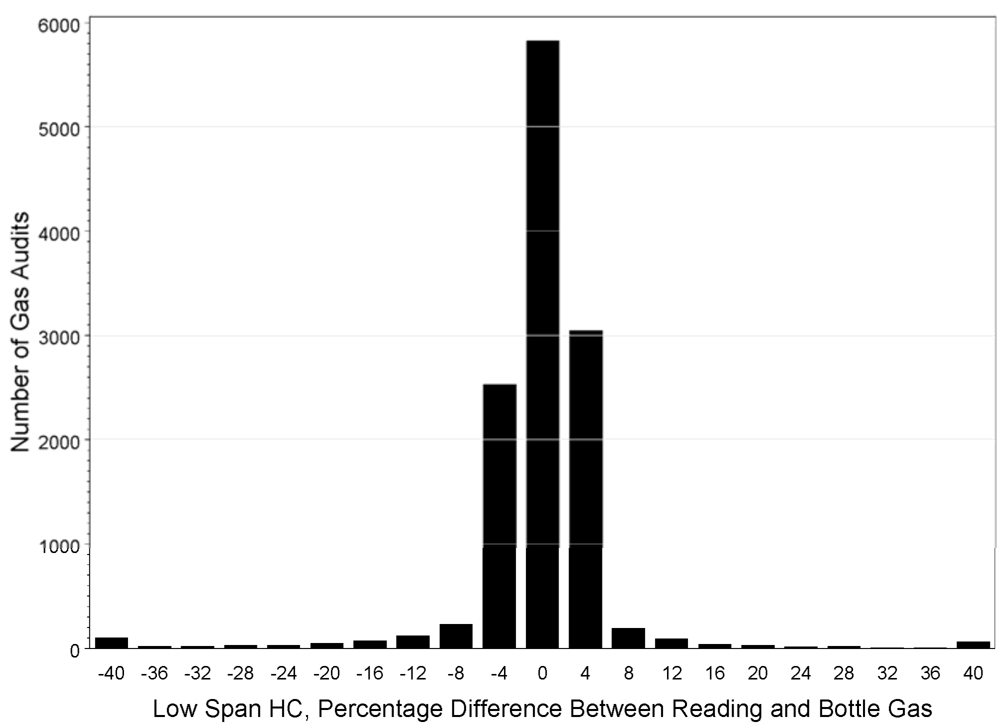


**Figure 3-40. Percent Difference Between Reading and Bottle Gas, Low-Span $CO_2$**

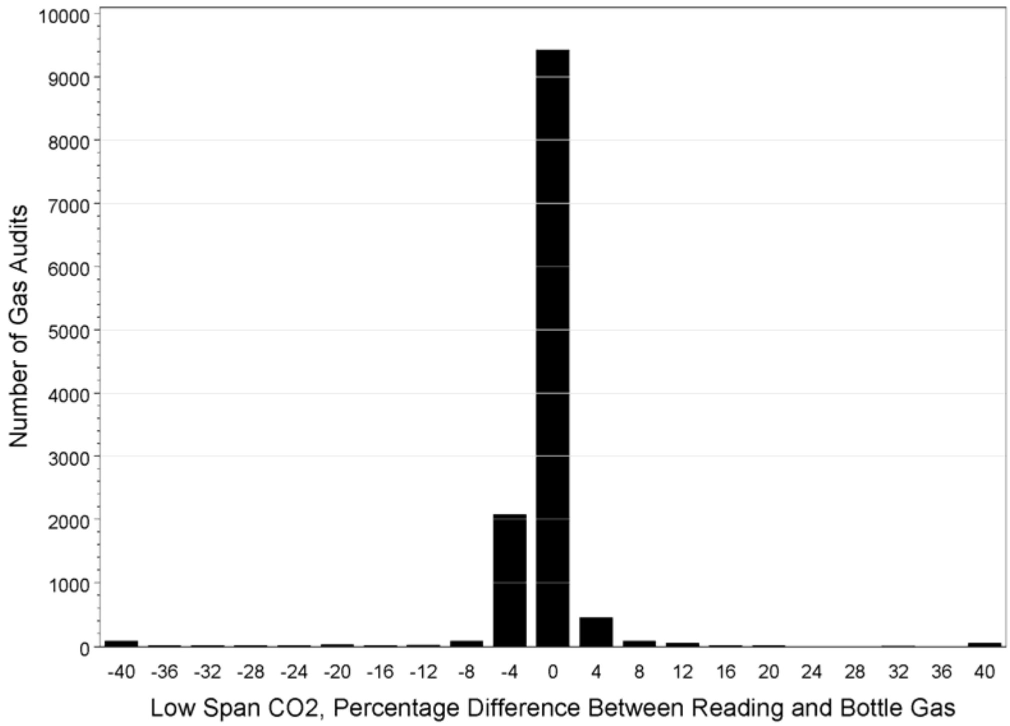



**Figure 3-41. Percent Difference Between Reading and Bottle Gas, Low-Span $NO_x$**

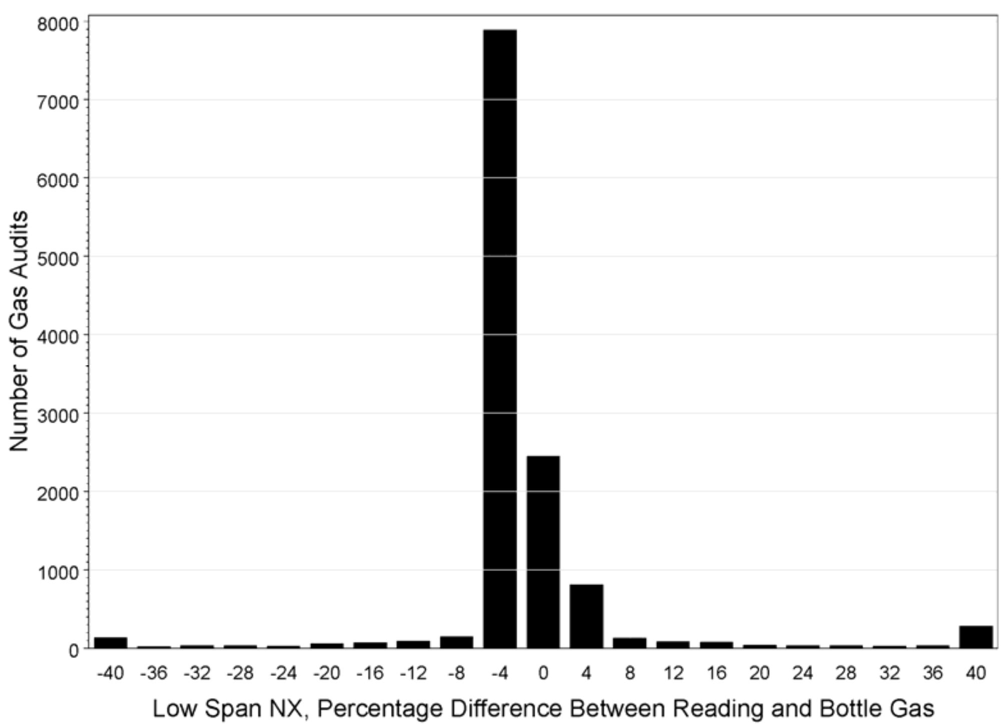


**Figure 3-42. Percent Difference Between Reading and Bottle Gas, Mid-Span CO**

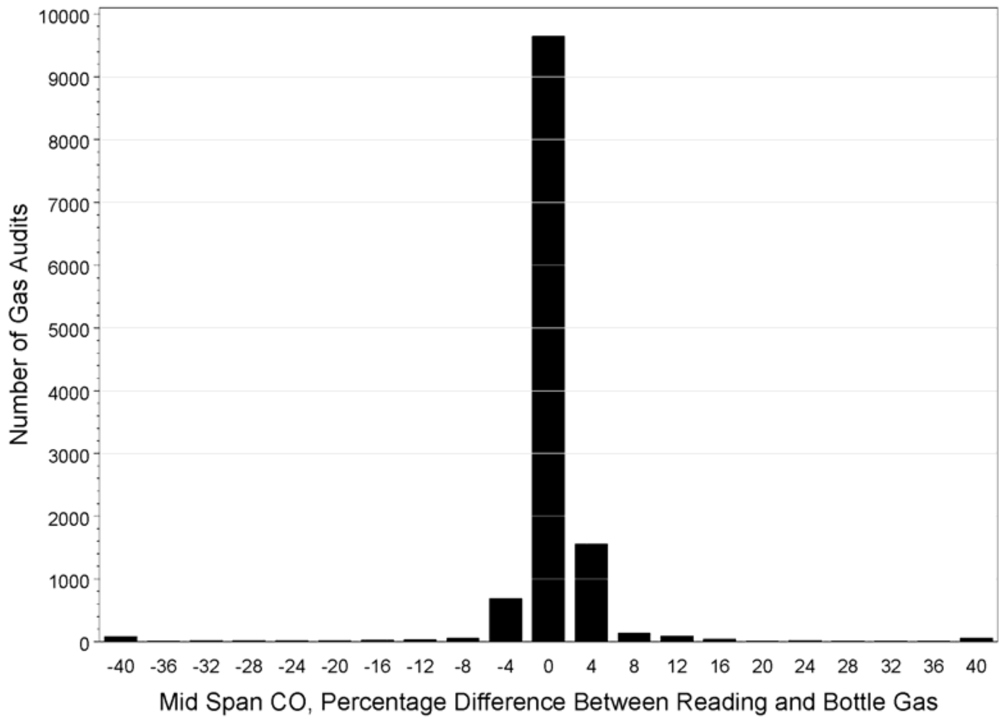



**Figure 3-43. Percent Difference Between Reading and Bottle Gas, Mid-Span HC**

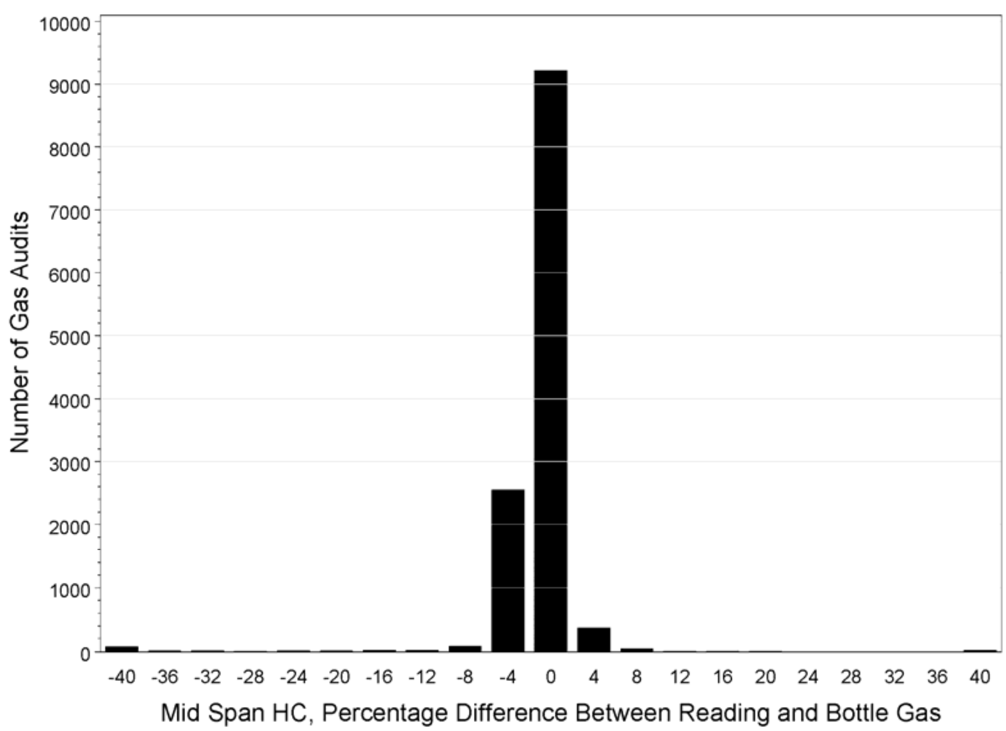


**Figure 3-44. Percent Difference Between Reading and Bottle Gas, Mid-Span $CO_2$**

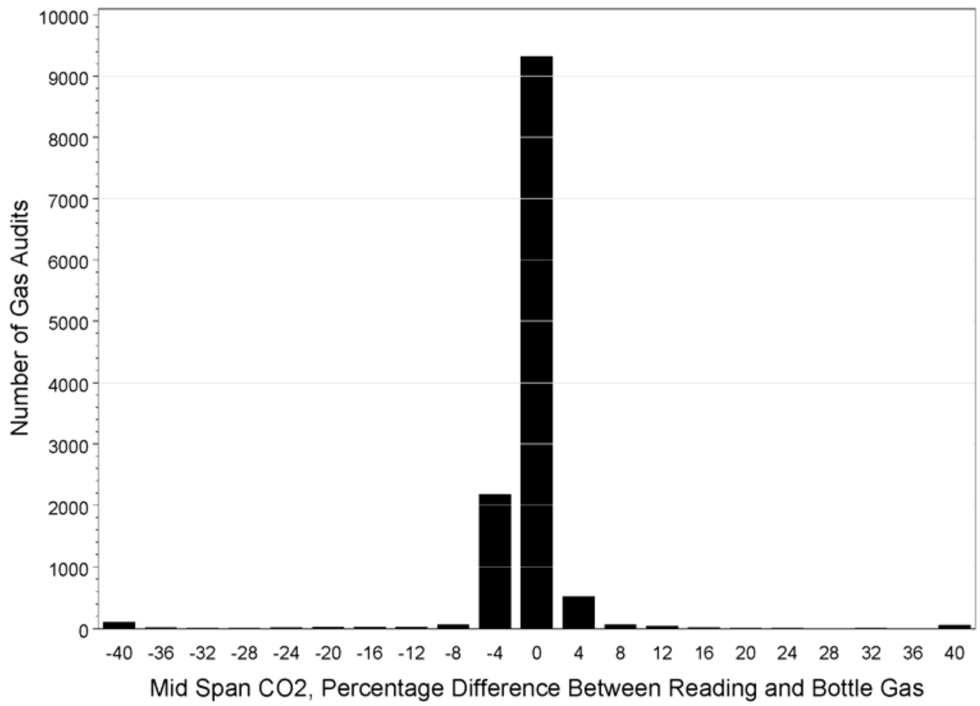



**Figure 3-45. Percent Difference Between Reading and Bottle Gas, Mid-Span $NO_x$**

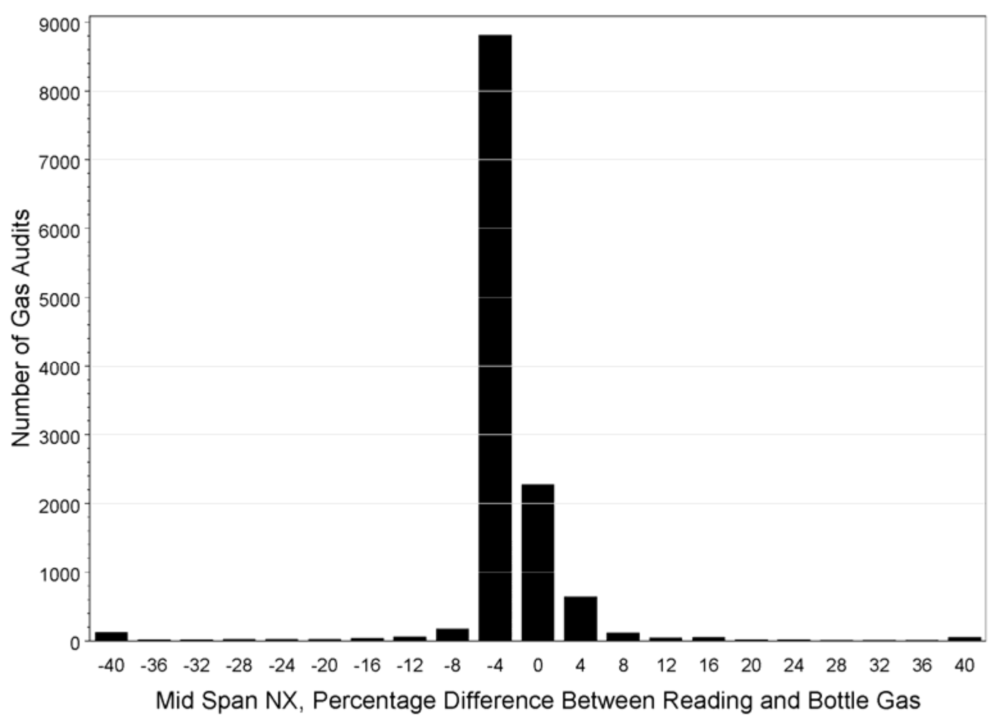


Table 3-23 shows pass/fail results for gas audits at the low- and mid- span levels. The table includes the pass/fail results that were recorded in the TIMS, as well pass/fail results calculated by ERG for this analysis (based on the labeled bottle gas value entered in the TIMS, the measured emissions concentration, and a 5.5% tolerance). It can be seen from Table 3-23 that the pass/fail results stored in the TIMS reconcile well with the pass/fail results ERG calculated from the measured span gas values. The largest discrepancies are 19 audits for which a failing result was calculated by ERG but a passing result was recorded in the TIMS. Almost all of those audits had one or more span gas measurements that were just slightly more than 5.5% different than the labeled bottle gas value, indicating that the discrepancy is probably caused by a slight difference in the rounding of results.

**Table 3-23. Span Gas Pass/Fail Results from TIMS Compared to Calculated Results**

| Calculated Results | TIMS Result | | | |
|---|---|---|---|---|
| | **Pass** | **Fail** | **No Result** | **Total** |
| Pass | 9,875 | 27 | 114 | 10,016 |
| Fail | 19 | 2,370 | 129 | 2,518 |
| Comb. Pass & Missing | 5 | 33 | 3 | 41 |
| Entirely Missing | 2 | 10 | - | 12 |
| Total | 9,901 | 2,440 | 243 | 12,587 |

The gas audit procedures specify that if an analyzer fails a gas audit, it must be locked out, repaired as necessary and calibrated in order to pass a re-audit. . The calibration data described in the section above was combined with the audit gas data to determine whether the calibrations were actually taking place after the failed audits. In 40% of cases, an analyzer that failed an audit was calibrated or re-audited and passed within the next 60 minutes. In an additional 11% of cases, the failing analyzer was calibrated or re-audited and passed within 24 hours, and another 37% of failing analyzers were calibrated or re-audited and passed within one week. The remaining 12% percent of failed audits took from one week up to three months to achieve a passing audit or successful calibration. It is possible that the audit found more serious problems with these analyzers, and they were taken off-line until an analyzer repair technician was able to undertake repairs on the analyzer.

### 3.4.4 Analyzer Lockouts

A Texas I/M gas analyzer or dynamometer is required to automatically lock itself out from performing I/M inspections if it is not successfully calibrated or verified on a regular basis. The calibration/verification requirements include:

1. Gas analyzers must be successfully calibrated and verified with BAR-97 calibration-blend gases at least every 72 hours, or they cannot be used for ASM or TSI inspections.
2. Gas analyzers must pass an internal leak check at least every 72 hours, or they cannot be used for ASM or TSI inspections.
3. Dynamometer calibrations must be successfully verified using a coast-down check at least every 72 hours, or they cannot be used for ASM inspections.
4. Analyzers that fail a gas audit (as a component of an overt station audit) must be successfully calibrated and pass a re-audit before being used for ASM or TSI inspections. This requirement is evaluated in the previous section.

Calibration records, dynamometer coast-down check records, leak check records, and vehicle inspection records were used to determine whether analyzer and dynamometer calibrations and checks were taking place as required, and whether un-calibrated/un-checked analyzers or dynamometers were in fact locked out until passing a calibration.

The regularity of the three types of 72-hour calibrations and checks (gas calibration, internal leak check, and dynamometer cost-down check) was investigated first. Each type of calibration/check was analyzed separately, since the different checks and calibrations were often performed at different times and recorded in separate records. It was not found to be meaningful to identify calibration/check lapses by simply calculating the time between passed calibrations and checks. The 72-hour deadline frequently fell on a Sunday, holiday, or other time that the station was not open, so the analyzer or dynamometer would legitimately remain un-calibrated/checked beyond 72 hours, until the station re-opened.

Instead, efforts were made to determine whether analyzers did lock themselves out from performing I/M inspections if more than 72 hours had passed since the previous successful calibration or check. To do this, the dataset of calibration and check records was added to the dataset of I/M inspection records. Only I/M inspection records for the HGB or DFW areas in calendar years 2012 or 2013 were used, and only if the inspection involved a TSI or ASM inspection (safety-only inspections or OBD tests were excluded). Then, for each gas analyzer, any I/M inspections having date/times more than 72 hours after the most recent analyzer gas calibration or dynamometer check were identified. These inspections should not have been allowed by the analyzer software; the analyzer should have been locked out from performing vehicle inspections until it passed a calibration.

The results for each type of calibration or check are shown in Table 3-24. For each calibration or check, the number of I/M inspections taking place while the analyzer should have been locked out is listed. This result is also presented as a percentage of the total number of I/M inspections performed. The total number of I/M inspections is lower for the dynamometer coast-down checks because TSI inspections do not require a dynamometer and are not included (i.e., TSI tests may be legitimately performed if a dynamometer is locked out). It can be seen from the table that although the percentage of inspections performed by analyzers that were overdue for a calibration or check was small compared to the total inspections performed, a relatively large number of emissions inspections appear to have been performed at times when the analyzers should have been locked out. Notably, 3% of ASM inspections were performed at times that the dynamometer should have been locked out, and 0.5% of ASM and TSI inspections were performed at times that the analyzer should have been locked out.

**Table 3-24. I/M Inspections More Than 72 Hours After Successful Calibration or Check**

| Calibration Type | I/M Inspections 72+ Hours After Passed Calibration or Check | I/M Inspections 72+ Hours After Passed Calibration Or Check (% of total inspections) | Total I/M Inspections |
|---|---|---|---|
| Span Gas Calibration | 4,876 | 0.51% | 953,297 |
| Leak Check | 798 | 0.08% | 953,297 |
| Dynamometer Check | 25,452 | 3.0% | 836,179 |

In order to determine why this was occurring, a review of the sequence of calibration/check records and vehicle inspection records for several different analyzers suggested that some analyzers that passed only one type of calibration or check (instead of all three) were still permitted to perform inspections. For example, passing a leak check would reset the 72-hour clock for each of the analyzer's gas calibration, leak check, and dynamometer coast-down check sequences, thereby allowing the analyzer to continue testing even though it had not passed a gas calibration or a dynamometer coast-down check in more than 72 hours.

The rate of inspections being performed while the analyzer should have been locked out was not the same for the different analyzer manufacturers, as shown in Table 3-25. The table shows that WW analyzers had a much higher overall rate of performing inspections while they should have been locked out, and that most of those were done while the dynamometer should have been locked out (not the analyzer).

**Table 3-25. I/M Inspections More Than 72 Hours After Successful Calibration or Check, by Analyzer Manufacturer**

| Analyzer ID | Inspections while not locked out | | ASM Inspections while dyno should be locked out / analyzer in compliance | | ASM & TSI Inspections while analyzer should be locked out / dyno in compliance | | ASM & TSI Inspections with combo of lockout for analyzer / dyno / leak check | | Total Inspections | |
|---|---|---|---|---|---|---|---|---|---|---|
| ESP | 562,112 | 99.6% | 28 | 0.0% | 1,860 | 0.3% | 516 | 0.1% | 564,516 | 100.0% |
| JB | 1,887 | 99.7% | 5 | 0.3% | - | 0.0% | 0 | 0.0% | 1,892 | 100.0% |
| SE | 94,556 | 99.4% | 179 | 0.2% | 201 | 0.2% | 150 | 0.2% | 95,086 | 100.0% |
| WW | 265,638 | 91.0% | 23,931 | 8.2% | 1,039 | 0.4% | 1,195 | 0.4% | 291,803 | 100.0% |
| Total for all analyzers | 924,193 | 96.9% | 24,143 | 2.5% | 3,100 | 0.3% | 1,861 | 0.2% | 953,297 | 100.0% |

## 3.5 OBD Inspection Analyzer Communication Performance

ERG analyzed TIMS OBD data to look for proper analyzer communication, as it is possible that certain models of analyzers cannot communicate with certain model year, make, and model vehicles. The objective of this task was to analyze TIMS data to determine if certain manufacturers of OBD inspection analyzers appear to have communication problems with certain makes, models, or model year vehicles, which would result in elevated fail to communicate rates for those vehicle groups.

For this task, ERG reviewed OBD inspection records to identify all tests with a result other than "P" in the "OBD2_DLC_RES" field of the test record. For these records, analysis was performed to identify the following:

- Rate of failure to communicate by analyzer manufacturer
- Rate of failure to communicate by vehicle make
- Rate of failure to communicate by vehicle model
- Rate of failure to communicate by vehicle model year

Results are presented for these four categories below.

48,806 of the 14,295,997 OBD test records (0.3%) had no information stored in the OBD communication result field. These records all had null values for ready result, fault code result, downloaded MIL status, and OBD pass/fail result. 28 OBD test records had vehicle model years earlier than 1996 or later than 2014. 437,031 records were for heavy-duty (HD) vehicles or vehicles of unknown GVWR. All these records were excluded from the following results, leaving 13,810,160 OBD records in the dataset.

**Communication Rates by Vehicle Model Year -** Table 3-26 provides a summary of communication rates by model year of vehicles tested in the program.

The "MODEL_YEAR" field from the vehicle test result tables was used to determine model year. Values and percentages shown in the table are listed by model year. For example, 271,953 OBD tests were conducted on model year 1996 vehicles, and only 2 of these had an OBD fail to communicate status. Overall, very low numbers were seen for "failure to communicate" test results and the overall "failure to communicate" rates were near zero. The overall program-wide communication rate between vehicles and analyzers is 99.97%.

## Table 3-26. OBD Communication Rates by Vehicle Model Year

| Model Year | DLC is Damaged, Inaccessible, or Cannot be Found | | Vehicle will not Communicate with Analyzer | | Vehicle Successfully Communicates with Analyzer | | Total Count of Tests by Model Yr |
|---|---|---|---|---|---|---|---|
| | Count | Percent | Count | Percent | Count | Percent | |
| 1996 | 239 | 0.09% | 2 | 0.00% | 271,712 | 99.91% | 271,953 |
| 1997 | 223 | 0.06% | - | 0.00% | 384,068 | 99.94% | 384,291 |
| 1998 | 240 | 0.05% | - | 0.00% | 470,758 | 99.95% | 470,998 |
| 1999 | 337 | 0.06% | 1 | 0.00% | 595,844 | 99.94% | 596,182 |
| 2000 | 382 | 0.05% | - | 0.00% | 755,404 | 99.95% | 755,786 |
| 2001 | 434 | 0.05% | 1 | 0.00% | 850,600 | 99.95% | 851,035 |
| 2002 | 401 | 0.04% | 1 | 0.00% | 952,370 | 99.96% | 952,772 |
| 2003 | 426 | 0.04% | 1 | 0.00% | 980,746 | 99.96% | 981,173 |
| 2004 | 463 | 0.04% | - | 0.00% | 1,037,322 | 99.96% | 1,037,785 |
| 2005 | 379 | 0.03% | - | 0.00% | 1,106,726 | 99.97% | 1,107,105 |
| 2006 | 432 | 0.04% | - | 0.00% | 1,166,496 | 99.96% | 1,166,928 |
| 2007 | 291 | 0.02% | 1 | 0.00% | 1,323,375 | 99.98% | 1,323,667 |
| 2008 | 189 | 0.01% | - | 0.00% | 1,283,956 | 99.99% | 1,284,145 |
| 2009 | 99 | 0.01% | - | 0.00% | 837,034 | 99.99% | 837,133 |
| 2010 | 61 | 0.01% | - | 0.00% | 958,164 | 99.99% | 958,225 |
| 2011 | 51 | 0.01% | - | 0.00% | 647,015 | 99.99% | 647,066 |
| 2012 | 26 | 0.02% | - | 0.00% | 164,008 | 99.98% | 164,034 |
| 2013 | 2 | 0.01% | - | 0.00% | 19,103 | 99.99% | 19,105 |
| 2014 | - | 0.00% | - | 0.00% | 756 | 100.00% | 756 |
| Total | 4,675 | 0.03% | 7 | 0.00% | 13,805,457 | 99.97% | 13,810,139 |

**Communication Rates by Equipment Manufacturer -** Table 3-27 provides results of communication rates among the various analyzer manufacturers.

Again, the percentages shown for the "damaged, inaccessible or cannot be found," the "will not communicate" and the "successfully communicates" columns pertain to all tests conducted by each type of analyzer (not percentage of all tests). The two rightmost columns provide counts of tests and percentages of tests by each analyzer manufacturer relative to the total number of tests. For the most part, the rate of communication problems was consistently low for each manufacturer.

**Table 3-27. OBD Communication Rates by Equipment Manufacturer**

| Equipment Manufacturer (EM) | DLC is Damaged, Inaccessible, or Cannot be Found | | Vehicle will not Communicate with Analyzer | | Vehicle Successfully Communicates with Analyzer | | Total Count of Tests by EM | % of Tests by EM |
|---|---|---|---|---|---|---|---|---|
| | Count | Percent | Count | Percent | Count | Percent | | |
| ESP | 3,388 | 0.00 | - | - | 9,134,888 | 1.00 | 9,138,276 | 66% |
| JB | - | - | - | - | 9,952 | 1.00 | 9,952 | 0% |
| SE | 541 | 0.00 | - | - | 1,017,300 | 1.00 | 1,017,841 | 7% |
| WW | - | - | - | - | 47 | 1.00 | 47 | 0% |
| Total | 746 | 0.00 | 7 | 0.00 | 3,643,290 | 1.00 | 3,644,043 | 26% |

**Communication Rates by Vehicle Make -** To assess communication rates by vehicle make, vehicle registration records were merged with vehicle test records by VIN. The "VEHMK" field from the registration database was reviewed, but found to have numerous inconsistencies and errors. Similarly, the "MAKE" field from the vehicle test result table was evaluated and also found to have a number of inconsistencies. To obtain a consistent "make" list, VINs from the emission test records were decoded using the ERG VIN Decoder, and the "make" output from this decoding process was merged with the vehicle test records and used for this evaluation. Records for which a make from the VIN Decoder was unavailable were excluded from this analysis. Makes that were represented by 100 or fewer vehicles were also removed from the table, since sample sizes would be too small to provide meaningful results.

Table 3-28 provides a summary of communication rates among the various vehicle makes. Except for a small number of very uncommon vehicle makes (Rolls Royce, Maserati) the incident rates for "damaged, inaccessible, or cannot be found" or "no communication" were very low.

## Table 3-28. OBD Communication Rates by Vehicle Make

| Vehicle Make | DLC is Damaged, Inaccessible, or Cannot be Found | | Vehicle will not Communicate with Analyzer | | Vehicle Successfully Communicates with Analyzer | | Total Count of Tests by Make | % of Overall Tests by Make |
|---|---|---|---|---|---|---|---|---|
| | Count | Percent | Count | Percent | Count | Percent | | |
| ACURA | 34 | 0.02% | - | 0.00% | 176,582 | 99.98% | 176,616 | 1.3% |
| ASTON MARTIN | 3 | 0.25% | - | 0.00% | 1,199 | 99.75% | 1,202 | 0.0% |
| AUDI | 14 | 0.02% | - | 0.00% | 57,553 | 99.98% | 57,567 | 0.4% |
| BENTLEY | - | 0.00% | - | 0.00% | 2,075 | 100.00% | 2,075 | 0.0% |
| BMW | 77 | 0.03% | 1 | 0.00% | 258,892 | 99.97% | 258,970 | 1.9% |
| BUICK | 52 | 0.03% | - | 0.00% | 161,833 | 99.97% | 161,885 | 1.2% |
| CADILLAC | 119 | 0.06% | - | 0.00% | 212,147 | 99.94% | 212,266 | 1.5% |
| CHEVROLET | 1,000 | 0.05% | 2 | 0.00% | 2,066,520 | 99.95% | 2,067,522 | 15.0% |
| CHRYSLER | 96 | 0.03% | - | 0.00% | 331,170 | 99.97% | 331,266 | 2.4% |
| DAEWOO | 4 | 0.20% | - | 0.00% | 1,968 | 99.80% | 1,972 | 0.0% |
| DATSUN | 29 | 0.03% | - | 0.00% | 86,332 | 99.97% | 86,361 | 0.6% |
| DODGE | 232 | 0.03% | 1 | 0.00% | 802,663 | 99.97% | 802,896 | 5.8% |
| EAGLE | 1 | 0.32% | - | 0.00% | 308 | 99.68% | 309 | 0.0% |
| FERRARI | 3 | 0.20% | - | 0.00% | 1,511 | 99.80% | 1,514 | 0.0% |
| FORD | 1,075 | 0.05% | - | 0.00% | 2,093,130 | 99.95% | 2,094,205 | 15.2% |
| FORD/MAZDA | 4 | 0.01% | - | 0.00% | 73,630 | 99.99% | 73,634 | 0.5% |
| GMC | 170 | 0.04% | 2 | 0.00% | 382,829 | 99.96% | 383,001 | 2.8% |
| HONDA | 172 | 0.01% | - | 0.00% | 1,163,462 | 99.99% | 1,163,634 | 8.5% |
| HUMMER | 4 | 0.02% | - | 0.00% | 19,448 | 99.98% | 19,452 | 0.1% |
| HYUNDAI | 71 | 0.03% | - | 0.00% | 263,348 | 99.97% | 263,419 | 1.9% |
| INFINITI | 19 | 0.01% | 1 | 0.00% | 146,640 | 99.99% | 146,660 | 1.1% |
| ISUZU | 24 | 0.06% | - | 0.00% | 38,156 | 99.94% | 38,180 | 0.3% |
| JAGUAR | 11 | 0.03% | - | 0.00% | 39,128 | 99.97% | 39,139 | 0.3% |
| JEEP | 77 | 0.02% | - | 0.00% | 309,485 | 99.98% | 309,562 | 2.2% |
| KIA | 40 | 0.02% | - | 0.00% | 219,878 | 99.98% | 219,918 | 1.6% |
| LAND ROVER | 5 | 0.01% | - | 0.00% | 35,661 | 99.99% | 35,666 | 0.3% |
| LEXUS | 40 | 0.01% | - | 0.00% | 403,120 | 99.99% | 403,160 | 2.9% |
| LINCOLN | 125 | 0.08% | - | 0.00% | 152,103 | 99.92% | 152,228 | 1.1% |
| LOTUS | - | 0.00% | - | 0.00% | 592 | 100.00% | 592 | 0.0% |
| MASERATI | 3 | 0.17% | - | 0.00% | 1,797 | 99.83% | 1,800 | 0.0% |
| MAZDA | 130 | 0.05% | - | 0.00% | 253,078 | 99.95% | 253,208 | 1.8% |
| MERCEDES | 44 | 0.02% | - | 0.00% | 252,881 | 99.98% | 252,925 | 1.8% |

| Vehicle Make | DLC is Damaged, Inaccessible, or Cannot be Found | | Vehicle will not Communicate with Analyzer | | Vehicle Successfully Communicates with Analyzer | | Total Count of Tests by Make | % of Overall Tests by Make |
|---|---|---|---|---|---|---|---|---|
| | Count | Percent | Count | Percent | Count | Percent | | |
| MERCURY | 49 | 0.03% | - | 0.00% | 146,341 | 99.97% | 146,390 | 1.1% |
| MINI | 4 | 0.01% | - | 0.00% | 30,031 | 99.99% | 30,035 | 0.2% |
| MITSUBISHI | 100 | 0.06% | - | 0.00% | 161,874 | 99.94% | 161,974 | 1.2% |
| NISSAN | 164 | 0.02% | - | 0.00% | 848,247 | 99.98% | 848,411 | 6.2% |
| OLDSMOBILE | 27 | 0.06% | - | 0.00% | 42,239 | 99.94% | 42,266 | 0.3% |
| PLYMOUTH | 9 | 0.04% | - | 0.00% | 20,109 | 99.96% | 20,118 | 0.1% |
| PONTIAC | 96 | 0.04% | - | 0.00% | 214,032 | 99.96% | 214,128 | 1.6% |
| PORSCHE | 4 | 0.01% | - | 0.00% | 29,723 | 99.99% | 29,727 | 0.2% |
| ROLLS ROYCE | 1 | 0.27% | - | 0.00% | 364 | 99.73% | 365 | 0.0% |
| SAAB | 6 | 0.04% | - | 0.00% | 15,194 | 99.96% | 15,200 | 0.1% |
| SATURN | 126 | 0.09% | - | 0.00% | 138,742 | 99.91% | 138,868 | 1.0% |
| SCION | 8 | 0.01% | - | 0.00% | 66,141 | 99.99% | 66,149 | 0.5% |
| SUBARU | 9 | 0.02% | - | 0.00% | 45,262 | 99.98% | 45,271 | 0.3% |
| SUZUKI | 24 | 0.05% | - | 0.00% | 44,630 | 99.95% | 44,654 | 0.3% |
| TOYOTA | 230 | 0.01% | - | 0.00% | 1,681,490 | 99.99% | 1,681,720 | 12.2% |
| VOLVO | 33 | 0.04% | - | 0.00% | 78,986 | 99.96% | 79,019 | 0.6% |
| VW | 76 | 0.04% | - | 0.00% | 192,391 | 99.96% | 192,467 | 1.4% |
| Total | 4,644 | 0.03% | 7 | 0.00% | 13,764,915 | 99.97% | 13,769,566 | 100.0% |

**Communication Rates by Vehicle Model -** To assess communication rates by vehicle models, the following model designation fields were reviewed:

- The "MODEL" field from the vehicle test result tables was seen to have a number of inconsistencies and errors. This could be because it is a manual keyboard entry, but there may be other data entry methods for this field.
- veh_modl (derived from the merged registration records) was also seen to have a number of inconsistencies and errors.
- The "MODEL_CD" field from the emission test records was based on table lookup values and therefore appeared to be a more consistent descriptor for the vehicle's model designation. The Texas analyzer specification reports this "model code" is "The NCIC model code or acceptable TCEQ code, otherwise left blank." In order to correlate this "model code" to an actual vehicle model, all vehicle emission test record VINS were decoded using ERG's VIN Decoder, and the vehicle "series" (i.e., model) resulting from this decoding process was merged into the test record. An output table correlating "series" with "model code" was then developed using the most frequently occurring series associated with each model code.

Table 3-29 lists communication rates for each vehicle model code. The series that is shown in the table was derived from the decoded VIN as described above. Records for which model code was missing were excluded from the table. Records for the more uncommon series, i.e. less than 100 inspection records, were also excluded.

It can be seen from the table that no model codes/vehicle series had "damaged, inaccessible, or cannot be found" or "no communication" rates that were greater than 1 percent.

## Table 3-29. OBD Communication Rates by Vehicle Model Code for Elevated Miscommunications

| Model Code | Series (Model) | DLC is Damaged, Inaccessible, or Cannot be Found | | Vehicle will not Communicate with Analyzer | | Vehicle Successfully Communicates with Analyzer | | Total Count of Tests by Model | % of Overall Tests by Model |
|---|---|---|---|---|---|---|---|---|---|
| | | Count | Percent | Count | Percent | Count | Percent | | |
| 88 | Delta 88 | | 0.00% | | 0.00% | 992 | 100.00% | 992 | 0.01% |
| 94 | Ram Pickup 1500 2WD | 23 | 0.03% | 1 | 0.00% | 91,705 | 99.97% | 91,729 | 0.85% |
| 98 | 98 Regency Elite | 1 | 0.96% | | 0.00% | 103 | 99.04% | 104 | 0.00% |
| 133 | F250 Super Duty 2WD | | 0.00% | | 0.00% | 1,329 | 100.00% | 1,329 | 0.01% |
| 180 | 1500 2WD | 2 | 0.07% | | 0.00% | 2,739 | 99.93% | 2,741 | 0.03% |
| 184 | Savanna 2500 2WD | | 0.00% | | 0.00% | 116 | 100.00% | 116 | 0.00% |
| 200 | Tracker 2WD | 1 | 0.02% | | 0.00% | 4,108 | 99.98% | 4,109 | 0.04% |
| 230 | SLK230 | | 0.00% | | 0.00% | 696 | 100.00% | 696 | 0.01% |
| 231 | Truck Regular Bed | 2 | 0.06% | | 0.00% | 3,279 | 99.94% | 3,281 | 0.03% |
| 240 | 240SX | | 0.00% | | 0.00% | 609 | 100.00% | 609 | 0.01% |
| 254 | Grand Cherokee Laredo 2WD | 10 | 0.03% | | 0.00% | 38,967 | 99.97% | 38,977 | 0.36% |
| 300 | ES300 | 25 | 0.03% | 1 | 0.00% | 94,350 | 99.97% | 94,376 | 0.88% |
| 320 | S320 | | 0.00% | | 0.00% | 467 | 100.00% | 467 | 0.00% |
| 400 | LS400 | 2 | 0.03% | | 0.00% | 6,965 | 99.97% | 6,967 | 0.06% |
| 420 | S420 | | 0.00% | | 0.00% | 237 | 100.00% | 237 | 0.00% |
| 500 | 528i | 3 | 0.01% | | 0.00% | 23,427 | 99.99% | 23,430 | 0.22% |
| 550 | 550 Maranello | 3 | 0.57% | | 0.00% | 522 | 99.43% | 525 | 0.00% |
| 600 | 650i | | 0.00% | | 0.00% | 2,507 | 100.00% | 2,507 | 0.02% |
| 626 | 626 | 14 | 0.08% | | 0.00% | 17,754 | 99.92% | 17,768 | 0.17% |
| 700 | 750Li | 1 | 0.01% | | 0.00% | 7,095 | 99.99% | 7,096 | 0.07% |
| 820 | 3500 Van 2WD | | 0.00% | | 0.00% | 135 | 100.00% | 135 | 0.00% |
| 850 | 850 | 4 | 0.31% | | 0.00% | 1,280 | 99.69% | 1,284 | 0.01% |
| 900 | 900S / 900CS | | 0.00% | | 0.00% | 436 | 100.00% | 436 | 0.00% |
| 911 | 911 | | 0.00% | | 0.00% | 366 | 100.00% | 366 | 0.00% |
| 960 | 960 | 5 | 0.63% | | 0.00% | 792 | 99.37% | 797 | 0.01% |
| 22C | CL | | 0.00% | | 0.00% | 377 | 100.00% | 377 | 0.00% |
| 23C | CL | | 0.00% | | 0.00% | 536 | 100.00% | 536 | 0.00% |
| 25T | TL | 1 | 0.19% | | 0.00% | 539 | 99.81% | 540 | 0.01% |
| 30C | CL | | 0.00% | | 0.00% | 919 | 100.00% | 919 | 0.01% |

| Model Code | Series (Model) | DLC is Damaged, Inaccessible, or Cannot be Found | | Vehicle will not Communicate with Analyzer | | Vehicle Successfully Communicates with Analyzer | | Total Count of Tests by Model | % of Overall Tests by Model |
|---|---|---|---|---|---|---|---|---|---|
| | | Count | Percent | Count | Percent | Count | Percent | | |
| 32T | TL | 2 | 0.03% | | 0.00% | 7,861 | 99.97% | 7,863 | 0.07% |
| 35R | RL | 1 | 0.04% | | 0.00% | 2,270 | 99.96% | 2,271 | 0.02% |
| 3GT | 3000 GT | 1 | 0.13% | | 0.00% | 763 | 99.87% | 764 | 0.01% |
| 4RN | 4Runner SR5 | 2 | 0.00% | | 0.00% | 41,398 | 100.00% | 41,400 | 0.38% |
| 85F | 850 | | 0.00% | | 0.00% | 717 | 100.00% | 717 | 0.01% |
| AA4 | A4/S4 | 8 | 0.05% | | 0.00% | 15,003 | 99.95% | 15,011 | 0.14% |
| AA6 | A6/S6 | 2 | 0.06% | | 0.00% | 3,168 | 99.94% | 3,170 | 0.03% |
| AA8 | A8 | | 0.00% | | 0.00% | 1,560 | 100.00% | 1,560 | 0.01% |
| ACC | Accord EX | 41 | 0.02% | | 0.00% | 196,173 | 99.98% | 196,214 | 1.82% |
| ACV | Achieva SL/SC | | 0.00% | | 0.00% | 722 | 100.00% | 722 | 0.01% |
| AER | Aerostar XLT Wagon | | 0.00% | | 0.00% | 728 | 100.00% | 728 | 0.01% |
| ALO | Alero Level II | 8 | 0.05% | | 0.00% | 15,477 | 99.95% | 15,485 | 0.14% |
| ALT | Altima | 48 | 0.02% | | 0.00% | 212,133 | 99.98% | 212,181 | 1.97% |
| AMG | Amigo/Rodeo 2WD | | 0.00% | | 0.00% | 349 | 100.00% | 349 | 0.00% |
| ARL | RL | 2 | 0.10% | | 0.00% | 1,904 | 99.90% | 1,906 | 0.02% |
| ARN | Arnage Red Label | | 0.00% | | 0.00% | 207 | 100.00% | 207 | 0.00% |
| AS4 | A4/S4 | 1 | 0.08% | | 0.00% | 1,195 | 99.92% | 1,196 | 0.01% |
| AS6 | A6/S6 | | 0.00% | | 0.00% | 123 | 100.00% | 123 | 0.00% |
| ASP | Aspen Limited 2WD | | 0.00% | | 0.00% | 2,489 | 100.00% | 2,489 | 0.02% |
| AST | Astro 2WD | 7 | 0.08% | | 0.00% | 8,900 | 99.92% | 8,907 | 0.08% |
| ATL | TL | | 0.00% | | 0.00% | 22,063 | 100.00% | 22,063 | 0.21% |
| AUR | Aurora | 1 | 0.04% | | 0.00% | 2,816 | 99.96% | 2,817 | 0.03% |
| AVA | Avalon | 18 | 0.03% | | 0.00% | 70,790 | 99.97% | 70,808 | 0.66% |
| AVN | Avenger SE | 2 | 0.03% | | 0.00% | 7,208 | 99.97% | 7,210 | 0.07% |
| B23 | Pickup (not Cab Plus 4WD) | | 0.00% | | 0.00% | 318 | 100.00% | 318 | 0.00% |
| BEE | New Beetle | 7 | 0.07% | | 0.00% | 9,982 | 99.93% | 9,989 | 0.09% |
| BER | Beretta | | 0.00% | | 0.00% | 196 | 100.00% | 196 | 0.00% |
| BLZ | S10 Blazer 2WD | 8 | 0.04% | | 0.00% | 20,983 | 99.96% | 20,991 | 0.20% |
| BON | Bonneville SE | 3 | 0.04% | | 0.00% | 7,522 | 99.96% | 7,525 | 0.07% |
| BOX | 986 Boxster | 1 | 0.02% | | 0.00% | 5,439 | 99.98% | 5,440 | 0.05% |
| BRO | Bronco 4WD | | 0.00% | | 0.00% | 285 | 100.00% | 285 | 0.00% |
| BRZ | Breeze | 1 | 0.05% | | 0.00% | 2,162 | 99.95% | 2,163 | 0.02% |
| BVD | Bravada 4WD | 1 | 0.11% | | 0.00% | 933 | 99.89% | 934 | 0.01% |

| Model Code | Series (Model) | DLC is Damaged, Inaccessible, or Cannot be Found | | Vehicle will not Communicate with Analyzer | | Vehicle Successfully Communicates with Analyzer | | Total Count of Tests by Model | % of Overall Tests by Model |
|---|---|---|---|---|---|---|---|---|---|
| | | Count | Percent | Count | Percent | Count | Percent | | |
| C10 | C1500 Pickup 2WD | | 0.00% | | 0.00% | 101 | 100.00% | 101 | 0.00% |
| C15 | C1500 Pickup 2WD | 79 | 0.03% | | 0.00% | 248,285 | 99.97% | 248,364 | 2.31% |
| C22 | C220 | | 0.00% | | 0.00% | 484 | 100.00% | 484 | 0.00% |
| C23 | C230 | 12 | 0.08% | | 0.00% | 14,487 | 99.92% | 14,499 | 0.13% |
| C25 | C2500 Pickup 2WD | 7 | 0.11% | | 0.00% | 6,477 | 99.89% | 6,484 | 0.06% |
| C28 | C280 | 1 | 0.02% | | 0.00% | 4,163 | 99.98% | 4,164 | 0.04% |
| C35 | C3500 Pickup 2WD | | 0.00% | | 0.00% | 1,244 | 100.00% | 1,244 | 0.01% |
| C70 | C70 | | 0.00% | | 0.00% | 2,903 | 100.00% | 2,903 | 0.03% |
| CAB | Cabrio Convertible | 4 | 0.23% | | 0.00% | 1,747 | 99.77% | 1,751 | 0.02% |
| CAM | Camry | 68 | 0.02% | | 0.00% | 387,753 | 99.98% | 387,821 | 3.60% |
| CAP | Caprice Classic | 3 | 0.30% | | 0.00% | 991 | 99.70% | 994 | 0.01% |
| CAR | 911 | 1 | 0.05% | | 0.00% | 2,078 | 99.95% | 2,079 | 0.02% |
| CAT | Catera | | 0.00% | | 0.00% | 1,664 | 100.00% | 1,664 | 0.02% |
| CAV | Cavalier | 33 | 0.05% | | 0.00% | 63,318 | 99.95% | 63,351 | 0.59% |
| CEN | Century Custom | 5 | 0.02% | | 0.00% | 29,202 | 99.98% | 29,207 | 0.27% |
| CHA | Charger (RWD) | 11 | 0.02% | | 0.00% | 51,344 | 99.98% | 51,355 | 0.48% |
| CHL | Challenger | | 0.00% | | 0.00% | 3,544 | 100.00% | 3,544 | 0.03% |
| CI1 | Civic del Sol | | 0.00% | | 0.00% | 345 | 100.00% | 345 | 0.00% |
| CIE | Cutlass Ciera SL | | 0.00% | | 0.00% | 436 | 100.00% | 436 | 0.00% |
| CIR | Cirrus LXi | 2 | 0.10% | | 0.00% | 2,099 | 99.90% | 2,101 | 0.02% |
| CIV | Civic LX | 51 | 0.02% | | 0.00% | 257,370 | 99.98% | 257,421 | 2.39% |
| CL3 | CLK320 | 1 | 0.06% | | 0.00% | 1,817 | 99.94% | 1,818 | 0.02% |
| CL4 | CLK430 | | 0.00% | | 0.00% | 2,149 | 100.00% | 2,149 | 0.02% |
| CL5 | CL500 | | 0.00% | | 0.00% | 493 | 100.00% | 493 | 0.00% |
| CNC | Concorde LX/LXi | 5 | 0.07% | | 0.00% | 7,049 | 99.93% | 7,054 | 0.07% |
| CNT | Contour LX/SE | 6 | 0.08% | | 0.00% | 7,360 | 99.92% | 7,366 | 0.07% |
| COA | Corolla/Matrix | 48 | 0.02% | | 0.00% | 263,043 | 99.98% | 263,091 | 2.44% |
| CON | Continental | 5 | 0.09% | | 0.00% | 5,330 | 99.91% | 5,335 | 0.05% |
| COU | Cougar | 9 | 0.11% | | 0.00% | 8,024 | 99.89% | 8,033 | 0.07% |
| CRS | Corsica | 1 | 0.14% | | 0.00% | 733 | 99.86% | 734 | 0.01% |
| CRV | CR-V | 2 | 0.00% | | 0.00% | 40,163 | 100.00% | 40,165 | 0.37% |
| CST | Celica | 1 | 0.01% | | 0.00% | 10,566 | 99.99% | 10,567 | 0.10% |
| CUT | Cutlass GL | 1 | 0.04% | | 0.00% | 2,568 | 99.96% | 2,569 | 0.02% |

| Model Code | Series (Model) | DLC is Damaged, Inaccessible, or Cannot be Found | | Vehicle will not Communicate with Analyzer | | Vehicle Successfully Communicates with Analyzer | | Total Count of Tests by Model | % of Overall Tests by Model |
|---|---|---|---|---|---|---|---|---|---|
| | | Count | Percent | Count | Percent | Count | Percent | | |
| CVC | Crown Victoria (Police) | 15 | 0.04% | | 0.00% | 38,328 | 99.96% | 38,343 | 0.36% |
| CVN | Caravan C/V FWD | 15 | 0.04% | | 0.00% | 38,857 | 99.96% | 38,872 | 0.36% |
| CVT | Corvette | 9 | 0.03% | | 0.00% | 34,444 | 99.97% | 34,453 | 0.32% |
| CW2 | E250 2WD | | 0.00% | | 0.00% | 270 | 100.00% | 270 | 0.00% |
| CW3 | E350 2WD | | 0.00% | | 0.00% | 176 | 100.00% | 176 | 0.00% |
| DAK | Dakota 2WD | 2 | 0.01% | | 0.00% | 15,984 | 99.99% | 15,986 | 0.15% |
| DEN | Yukon 4WD Luxury | | 0.00% | | 0.00% | 312 | 100.00% | 312 | 0.00% |
| DEV | DeVille | 21 | 0.05% | | 0.00% | 40,523 | 99.95% | 40,544 | 0.38% |
| DIA | Diamante LS | 7 | 0.16% | | 0.00% | 4,288 | 99.84% | 4,295 | 0.04% |
| DIS | Discovery Series II; Class E | | 0.00% | | 0.00% | 2,174 | 100.00% | 2,174 | 0.02% |
| DLT | Delta 88/88LS | 1 | 0.17% | | 0.00% | 588 | 99.83% | 589 | 0.01% |
| DUR | Durango SLT 2WD | 9 | 0.04% | | 0.00% | 21,369 | 99.96% | 21,378 | 0.20% |
| E32 | E320W | | 0.00% | | 0.00% | 18,106 | 100.00% | 18,106 | 0.17% |
| E42 | E420 | 1 | 0.09% | | 0.00% | 1,145 | 99.91% | 1,146 | 0.01% |
| E43 | E430W | | 0.00% | | 0.00% | 1,448 | 100.00% | 1,448 | 0.01% |
| E50 | E500W | | 0.00% | | 0.00% | 1,225 | 100.00% | 1,225 | 0.01% |
| E55 | E55AMG | | 0.00% | | 0.00% | 264 | 100.00% | 264 | 0.00% |
| EC2 | E250 2WD | 8 | 0.39% | | 0.00% | 2,043 | 99.61% | 2,051 | 0.02% |
| EC3 | E350 2WD | 2 | 0.22% | | 0.00% | 911 | 99.78% | 913 | 0.01% |
| ECH | Echo | 3 | 0.06% | | 0.00% | 4,912 | 99.94% | 4,915 | 0.05% |
| ECL | Eclipse GS | 28 | 0.10% | | 0.00% | 27,673 | 99.90% | 27,701 | 0.26% |
| ELD | Eldorado | 2 | 0.06% | | 0.00% | 3,359 | 99.94% | 3,361 | 0.03% |
| ELL | | 1 | 0.92% | | 0.00% | 108 | 99.08% | 109 | 0.00% |
| ELN | Elantra (XD) | 22 | 0.04% | | 0.00% | 49,998 | 99.96% | 50,020 | 0.46% |
| EPD | Expedition | 48 | 0.05% | | 0.00% | 87,477 | 99.95% | 87,525 | 0.81% |
| ES1 | Esteem | | 0.00% | | 0.00% | 389 | 100.00% | 389 | 0.00% |
| ESC | Escort SE | 16 | 0.05% | | 0.00% | 34,825 | 99.95% | 34,841 | 0.32% |
| EST | Esteem | | 0.00% | | 0.00% | 662 | 100.00% | 662 | 0.01% |
| EXC | Excursion Limited 2WD | 1 | 0.22% | | 0.00% | 463 | 99.78% | 464 | 0.00% |
| F15 | F150 2WD | 22 | 0.03% | | 0.00% | 76,560 | 99.97% | 76,582 | 0.71% |
| F25 | F250 Super Cab | 20 | 0.77% | | 0.00% | 2,581 | 99.23% | 2,601 | 0.02% |

| Model Code | Series (Model) | DLC is Damaged, Inaccessible, or Cannot be Found | | Vehicle will not Communicate with Analyzer | | Vehicle Successfully Communicates with Analyzer | | Total Count of Tests by Model | % of Overall Tests by Model |
|---|---|---|---|---|---|---|---|---|---|
| | | Count | Percent | Count | Percent | Count | Percent | | |
| F35 | 355 Spider | 3 | 0.77% | | 0.00% | 389 | 99.23% | 392 | 0.00% |
| FBD | Firebird | 5 | 0.05% | | 0.00% | 10,002 | 99.95% | 10,007 | 0.09% |
| FI1 | | | 0.00% | | 0.00% | 1,513 | 100.00% | 1,513 | 0.01% |
| FLE | Fleetwood | | 0.00% | | 0.00% | 443 | 100.00% | 443 | 0.00% |
| FOC | Focus ZX4 | 10 | 0.02% | | 0.00% | 45,357 | 99.98% | 45,367 | 0.42% |
| FOR | Forester | | 0.00% | | 0.00% | 2,543 | 100.00% | 2,543 | 0.02% |
| FRT | Frontier | 7 | 0.03% | | 0.00% | 25,688 | 99.97% | 25,695 | 0.24% |
| G15 | Express 1500 2WD | | 0.00% | | 0.00% | 292 | 100.00% | 292 | 0.00% |
| G20 | G20 | 3 | 0.08% | | 0.00% | 3,813 | 99.92% | 3,816 | 0.04% |
| G35 | G35 | | 0.00% | | 0.00% | 20,213 | 100.00% | 20,213 | 0.19% |
| GAL | Galant ES / GTZ / LS | 33 | 0.08% | | 0.00% | 42,545 | 99.92% | 42,578 | 0.40% |
| GCK | Grand Cherokee 2WD | 2 | 0.04% | | 0.00% | 5,359 | 99.96% | 5,361 | 0.05% |
| GOL | Golf / GTI / Jetta Wagon | 1 | 0.03% | | 0.00% | 3,892 | 99.97% | 3,893 | 0.04% |
| GRA | Grand Prix GT | 16 | 0.04% | | 0.00% | 44,332 | 99.96% | 44,348 | 0.41% |
| GRM | Grand Am SE1 | 23 | 0.06% | | 0.00% | 38,782 | 99.94% | 38,805 | 0.36% |
| GS3 | GS300-GS450 | 3 | 0.02% | | 0.00% | 18,058 | 99.98% | 18,061 | 0.17% |
| GS4 | GS400 | | 0.00% | | 0.00% | 1,786 | 100.00% | 1,786 | 0.02% |
| GT | Mustang GT | | 0.00% | | 0.00% | 228 | 100.00% | 228 | 0.00% |
| GTI | Jetta/Rabbit/GTI | 4 | 0.06% | | 0.00% | 6,298 | 99.94% | 6,302 | 0.06% |
| GTO | G T O | 1 | 0.03% | | 0.00% | 2,942 | 99.97% | 2,943 | 0.03% |
| GVT | Grand Vitara 2WD | 1 | 0.03% | | 0.00% | 3,095 | 99.97% | 3,096 | 0.03% |
| HOM | Sonoma Pickup 2WD | | 0.00% | | 0.00% | 117 | 100.00% | 117 | 0.00% |
| hom | Sonoma Pickup 2WD | | 0.00% | | 0.00% | 745 | 100.00% | 745 | 0.01% |
| HUM | Hummer H2 4WD | | 0.00% | | 0.00% | 205 | 100.00% | 205 | 0.00% |
| I30 | I30 | 5 | 0.04% | | 0.00% | 12,961 | 99.96% | 12,966 | 0.12% |
| IMP | Impala | 45 | 0.03% | | 0.00% | 156,560 | 99.97% | 156,605 | 1.46% |
| INT | Intrepid SE | 9 | 0.03% | | 0.00% | 26,039 | 99.97% | 26,048 | 0.24% |
| J30 | J30 | 1 | 0.09% | | 0.00% | 1,162 | 99.91% | 1,163 | 0.01% |
| JET | Jetta | 26 | 0.04% | | 0.00% | 69,591 | 99.96% | 69,617 | 0.65% |
| JMY | Jimmy 2WD | 2 | 0.07% | | 0.00% | 3,011 | 99.93% | 3,013 | 0.03% |
| L45 | LX450 | | 0.00% | | 0.00% | 224 | 100.00% | 224 | 0.00% |
| L47 | LX470 | 1 | 0.05% | | 0.00% | 2,091 | 99.95% | 2,092 | 0.02% |

| Model Code | Series (Model) | DLC is Damaged, Inaccessible, or Cannot be Found | | Vehicle will not Communicate with Analyzer | | Vehicle Successfully Communicates with Analyzer | | Total Count of Tests by Model | % of Overall Tests by Model |
|---|---|---|---|---|---|---|---|---|---|
| | | Count | Percent | Count | Percent | Count | Percent | | |
| LAN | Lancer ES | 11 | 0.06% | | 0.00% | 19,183 | 99.94% | 19,194 | 0.18% |
| LCR | Land Cruiser | | 0.00% | | 0.00% | 2,644 | 100.00% | 2,644 | 0.02% |
| LEG | Legacy/Outback | 2 | 0.03% | | 0.00% | 6,823 | 99.97% | 6,825 | 0.06% |
| LES | LeSabre Custom | 2 | 0.01% | | 0.00% | 13,836 | 99.99% | 13,838 | 0.13% |
| LHS | LHS | 2 | 0.09% | | 0.00% | 2,283 | 99.91% | 2,285 | 0.02% |
| LIM | Incomplete | | 0.00% | | 0.00% | 171 | 100.00% | 171 | 0.00% |
| LS6 | LS | 5 | 0.05% | | 0.00% | 9,459 | 99.95% | 9,464 | 0.09% |
| LSS | Delta 88LSS | | 0.00% | | 0.00% | 339 | 100.00% | 339 | 0.00% |
| LUM | Lumina LS | 6 | 0.04% | | 0.00% | 14,752 | 99.96% | 14,758 | 0.14% |
| M3 | M3 | 7 | 0.18% | | 0.00% | 3,906 | 99.82% | 3,913 | 0.04% |
| M5 | M5 | 1 | 0.07% | | 0.00% | 1,420 | 99.93% | 1,421 | 0.01% |
| M6 | | | 0.00% | | 0.00% | 695 | 100.00% | 695 | 0.01% |
| MAG | Magnum / Magnum SXT | 1 | 0.01% | | 0.00% | 7,746 | 99.99% | 7,747 | 0.07% |
| MAL | Malibu LS | 43 | 0.04% | | 0.00% | 121,043 | 99.96% | 121,086 | 1.13% |
| MAR | Grand Marquis LS | 3 | 0.01% | | 0.00% | 21,324 | 99.99% | 21,327 | 0.20% |
| MAU | Grand Marquis LS | | 0.00% | | 0.00% | 417 | 100.00% | 417 | 0.00% |
| MAX | Maxima | 30 | 0.03% | | 0.00% | 87,454 | 99.97% | 87,484 | 0.81% |
| MET | Geo Metro LSi | | 0.00% | | 0.00% | 1,599 | 100.00% | 1,599 | 0.01% |
| MGO | Montego Premier | 1 | 0.03% | | 0.00% | 3,182 | 99.97% | 3,183 | 0.03% |
| MIA | MX-5 Miata | 5 | 0.04% | | 0.00% | 11,959 | 99.96% | 11,964 | 0.11% |
| MIL | Millenia | 4 | 0.10% | | 0.00% | 4,143 | 99.90% | 4,147 | 0.04% |
| MIR | Mirage ES | 3 | 0.04% | | 0.00% | 7,829 | 99.96% | 7,832 | 0.07% |
| MK8 | Mark VIII | | 0.00% | | 0.00% | 262 | 100.00% | 262 | 0.00% |
| ML3 | ML320 | 2 | 0.08% | | 0.00% | 2,423 | 99.92% | 2,425 | 0.02% |
| ML4 | ML430 | | 0.00% | | 0.00% | 490 | 100.00% | 490 | 0.00% |
| MOC | Monte Carlo LS | 10 | 0.05% | | 0.00% | 19,908 | 99.95% | 19,918 | 0.19% |
| MON | Montero Sport 2WD | 3 | 0.04% | | 0.00% | 7,622 | 99.96% | 7,625 | 0.07% |
| MPV | MPV | 1 | 0.03% | | 0.00% | 3,661 | 99.97% | 3,662 | 0.03% |
| MR2 | MR2 Spyder | 2 | 0.12% | | 0.00% | 1,607 | 99.88% | 1,609 | 0.01% |
| MTA | Montana 2WD | 3 | 0.10% | | 0.00% | 2,950 | 99.90% | 2,953 | 0.03% |
| MTN | Mountaineer 2WD | | 0.00% | | 0.00% | 3,576 | 100.00% | 3,576 | 0.03% |
| MUS | Mustang | 31 | 0.02% | | 0.00% | 134,814 | 99.98% | 134,845 | 1.25% |
| MYS | Mystique GS | 1 | 0.05% | | 0.00% | 2,213 | 99.95% | 2,214 | 0.02% |

| Model Code | Series (Model) | DLC is Damaged, Inaccessible, or Cannot be Found | | Vehicle will not Communicate with Analyzer | | Vehicle Successfully Communicates with Analyzer | | Total Count of Tests by Model | % of Overall Tests by Model |
|---|---|---|---|---|---|---|---|---|---|
| | | Count | Percent | Count | Percent | Count | Percent | | |
| NAV | Navigator 2WD | 38 | 0.11% | | 0.00% | 34,075 | 99.89% | 34,113 | 0.32% |
| NEO | Neon SXT | 15 | 0.04% | | 0.00% | 37,060 | 99.96% | 37,075 | 0.34% |
| NSX | NSX | | 0.00% | | 0.00% | 213 | 100.00% | 213 | 0.00% |
| NUB | Nubira | 1 | 0.22% | | 0.00% | 455 | 99.78% | 456 | 0.00% |
| OAS | Trooper 4WD | | 0.00% | | 0.00% | 113 | 100.00% | 113 | 0.00% |
| ODY | Odyssey | 7 | 0.02% | | 0.00% | 34,260 | 99.98% | 34,267 | 0.32% |
| OTH | | 2,339 | 0.04% | 2 | 0.00% | 5,407,085 | 99.96% | 5,409,426 | 50.26% |
| PAS | Passat | 20 | 0.06% | | 0.00% | 33,739 | 99.94% | 33,759 | 0.31% |
| PAV | Park Avenue | 2 | 0.05% | | 0.00% | 3,742 | 99.95% | 3,744 | 0.03% |
| PRE | Prelude | 2 | 0.04% | | 0.00% | 5,108 | 99.96% | 5,110 | 0.05% |
| PRI | Prius | 6 | 0.02% | | 0.00% | 26,602 | 99.98% | 26,608 | 0.25% |
| PRO | ProtGgG | 15 | 0.07% | | 0.00% | 22,950 | 99.93% | 22,965 | 0.21% |
| PRV | Previa 2WD | | 0.00% | | 0.00% | 131 | 100.00% | 131 | 0.00% |
| PRW | Prowler | | 0.00% | | 0.00% | 196 | 100.00% | 196 | 0.00% |
| PTH | Pathfinder | 4 | 0.02% | | 0.00% | 16,833 | 99.98% | 16,837 | 0.16% |
| Q45 | Q45 | 2 | 0.05% | | 0.00% | 4,299 | 99.95% | 4,301 | 0.04% |
| QST | Quest | 1 | 0.01% | | 0.00% | 8,381 | 99.99% | 8,382 | 0.08% |
| QTO | A4/S4 | | 0.00% | | 0.00% | 3,235 | 100.00% | 3,235 | 0.03% |
| QUA | | 2 | 0.26% | | 0.00% | 776 | 99.74% | 778 | 0.01% |
| QX4 | QX4 (SUV) | 1 | 0.16% | | 0.00% | 615 | 99.84% | 616 | 0.01% |
| QXA | QX4 (SUV) | | 0.00% | | 0.00% | 1,993 | 100.00% | 1,993 | 0.02% |
| R25 | Ram Pickup 2500 2WD | | 0.00% | | 0.00% | 866 | 100.00% | 866 | 0.01% |
| RAB | Jetta/Rabbit/GTI | | 0.00% | | 0.00% | 3,347 | 100.00% | 3,347 | 0.03% |
| RAV | RAV4 | | 0.00% | | 0.00% | 26,802 | 100.00% | 26,802 | 0.25% |
| REG | Regal LS | 4 | 0.03% | | 0.00% | 13,128 | 99.97% | 13,132 | 0.12% |
| RIV | Riviera | | 0.00% | | 0.00% | 961 | 100.00% | 961 | 0.01% |
| RNG | Ranger 2WD | 7 | 0.03% | | 0.00% | 22,702 | 99.97% | 22,709 | 0.21% |
| ROA | RoadMaster ITT Limited | 1 | 0.17% | | 0.00% | 589 | 99.83% | 590 | 0.01% |
| ROD | Rodeo 2WD | 7 | 0.08% | | 0.00% | 8,560 | 99.92% | 8,567 | 0.08% |
| RRV | Range Rover HSE | 1 | 0.02% | | 0.00% | 6,306 | 99.98% | 6,307 | 0.06% |
| RST | Z3 | | 0.00% | | 0.00% | 191 | 100.00% | 191 | 0.00% |
| RX3 | RX300 | 1 | 0.01% | | 0.00% | 8,594 | 99.99% | 8,595 | 0.08% |

| Model Code | Series (Model) | DLC is Damaged, Inaccessible, or Cannot be Found | | Vehicle will not Communicate with Analyzer | | Vehicle Successfully Communicates with Analyzer | | Total Count of Tests by Model | % of Overall Tests by Model |
|---|---|---|---|---|---|---|---|---|---|
| | | Count | Percent | Count | Percent | Count | Percent | | |
| S10 | S10 Pickup 2WD | 8 | 0.05% | | 0.00% | 15,812 | 99.95% | 15,820 | 0.15% |
| S20 | S2000 | | 0.00% | | 0.00% | 3,138 | 100.00% | 3,138 | 0.03% |
| S30 | SC300 | | 0.00% | | 0.00% | 1,055 | 100.00% | 1,055 | 0.01% |
| S40 | S40 / V50 | 7 | 0.09% | | 0.00% | 7,911 | 99.91% | 7,918 | 0.07% |
| S70 | S70 / V70 | 8 | 0.16% | | 0.00% | 4,875 | 99.84% | 4,883 | 0.05% |
| S80 | S80 | | 0.00% | | 0.00% | 7,499 | 100.00% | 7,499 | 0.07% |
| S90 | S90 / V90 | 1 | 0.22% | | 0.00% | 449 | 99.78% | 450 | 0.00% |
| SAB | Sable GS | 5 | 0.03% | | 0.00% | 19,381 | 99.97% | 19,386 | 0.18% |
| SAF | Safari 2WD | | 0.00% | | 0.00% | 1,998 | 100.00% | 1,998 | 0.02% |
| SAV | Savanna 1500 2WD | 2 | 0.21% | | 0.00% | 962 | 99.79% | 964 | 0.01% |
| SC | SC2 / SL1 / SW1 | 16 | 0.17% | | 0.00% | 9,258 | 99.83% | 9,274 | 0.09% |
| SDK | Sidekick 4dr 4WD | | 0.00% | | 0.00% | 130 | 100.00% | 130 | 0.00% |
| SEB | Sebring LX | 21 | 0.05% | | 0.00% | 45,622 | 99.95% | 45,643 | 0.42% |
| SEN | Sentra | 23 | 0.03% | | 0.00% | 90,977 | 99.97% | 91,000 | 0.85% |
| SEP | Sephia/Spectra | 2 | 0.06% | | 0.00% | 3,169 | 99.94% | 3,171 | 0.03% |
| SEV | SLS | 7 | 0.11% | | 0.00% | 6,325 | 99.89% | 6,332 | 0.06% |
| SIL | Silhouette | | 0.00% | | 0.00% | 1,685 | 100.00% | 1,685 | 0.02% |
| SKY | Skylark | | 0.00% | | 0.00% | 829 | 100.00% | 829 | 0.01% |
| SL | SL2 / SW2 | 39 | 0.16% | | 0.00% | 23,703 | 99.84% | 23,742 | 0.22% |
| SL5 | SL500R | | 0.00% | | 0.00% | 3,778 | 100.00% | 3,778 | 0.04% |
| SL6 | SL600 Bi-T | | 0.00% | | 0.00% | 257 | 100.00% | 257 | 0.00% |
| SNA | Sienna LE | 1 | 0.00% | | 0.00% | 31,241 | 100.00% | 31,242 | 0.29% |
| SNF | Sunfire | 7 | 0.04% | | 0.00% | 16,642 | 99.96% | 16,649 | 0.15% |
| SOL | Solara | | 0.00% | | 0.00% | 332 | 100.00% | 332 | 0.00% |
| SON | Sonata | 16 | 0.02% | | 0.00% | 65,362 | 99.98% | 65,378 | 0.61% |
| SPT | Legacy/Outback | | 0.00% | | 0.00% | 7,194 | 100.00% | 7,194 | 0.07% |
| SSE | SL2 / SW2 | | 0.00% | | 0.00% | 260 | 100.00% | 260 | 0.00% |
| STA | Stratus SXT | 22 | 0.07% | | 0.00% | 32,021 | 99.93% | 32,043 | 0.30% |
| STS | STS | 3 | 0.09% | | 0.00% | 3,307 | 99.91% | 3,310 | 0.03% |
| SUB | C1500 Suburban 2WD | 5 | 0.03% | | 0.00% | 15,827 | 99.97% | 15,832 | 0.15% |
| SUP | Supra | | 0.00% | | 0.00% | 172 | 100.00% | 172 | 0.00% |
| SW | SL2 / SW2 | 1 | 0.08% | | 0.00% | 1,332 | 99.92% | 1,333 | 0.01% |
| SWI | Geo Prizm Lsi | | 0.00% | | 0.00% | 110 | 100.00% | 110 | 0.00% |

| Model Code | Series (Model) | DLC is Damaged, Inaccessible, or Cannot be Found | | Vehicle will not Communicate with Analyzer | | Vehicle Successfully Communicates with Analyzer | | Total Count of Tests by Model | % of Overall Tests by Model |
|---|---|---|---|---|---|---|---|---|---|
| | | Count | Percent | Count | Percent | Count | Percent | | |
| T10 | T100 XTRACAB 2WD | 2 | 0.16% | | 0.00% | 1,263 | 99.84% | 1,265 | 0.01% |
| TAC | Tacoma Deluxe | 2 | 0.00% | | 0.00% | 48,067 | 100.00% | 48,069 | 0.45% |
| TAH | Tahoe 2WD | 34 | 0.04% | | 0.00% | 80,569 | 99.96% | 80,603 | 0.75% |
| TAL | Talon ESi | 1 | 0.44% | | 0.00% | 226 | 99.56% | 227 | 0.00% |
| TAM | Formula / Trans Am | | 0.00% | | 0.00% | 177 | 100.00% | 177 | 0.00% |
| TAU | Taurus SE | 36 | 0.03% | | 0.00% | 120,484 | 99.97% | 120,520 | 1.12% |
| TC | Scion tC | 2 | 0.02% | | 0.00% | 10,740 | 99.98% | 10,742 | 0.10% |
| TER | Tercel | 2 | 0.09% | | 0.00% | 2,130 | 99.91% | 2,132 | 0.02% |
| THU | Thunderbird | 10 | 0.15% | | 0.00% | 6,812 | 99.85% | 6,822 | 0.06% |
| TIB | Tiburon | 4 | 0.04% | | 0.00% | 9,638 | 99.96% | 9,642 | 0.09% |
| TL | TL | 1 | 0.01% | | 0.00% | 10,621 | 99.99% | 10,622 | 0.10% |
| TOW | Town Car Signature | 57 | 0.08% | | 0.00% | 74,030 | 99.92% | 74,087 | 0.69% |
| TRA | Tracer LS | 1 | 0.07% | | 0.00% | 1,441 | 99.93% | 1,442 | 0.01% |
| TRP | Trooper 4WD | 1 | 0.05% | | 0.00% | 1,873 | 99.95% | 1,874 | 0.02% |
| TSP | Transport | | 0.00% | | 0.00% | 486 | 100.00% | 486 | 0.00% |
| TUN | Tundra SR5 | 2 | 0.00% | | 0.00% | 45,262 | 100.00% | 45,264 | 0.42% |
| V15 | Ram Pickup 2WD | 6 | 0.05% | | 0.00% | 12,589 | 99.95% | 12,595 | 0.12% |
| V25 | Ram Van/Wagon | | 0.00% | | 0.00% | 727 | 100.00% | 727 | 0.01% |
| V35 | Ram Wagon Bus | 1 | 0.89% | | 0.00% | 111 | 99.11% | 112 | 0.00% |
| V40 | S40 / V40 | 1 | 0.35% | | 0.00% | 288 | 99.65% | 289 | 0.00% |
| V70 | S70 / V70 | 3 | 0.12% | | 0.00% | 2,408 | 99.88% | 2,411 | 0.02% |
| VAN | Vandenplas LWB | 3 | 0.23% | | 0.00% | 1,317 | 99.77% | 1,320 | 0.01% |
| VEN | Venture 2WD Extended Van | 2 | 0.13% | | 0.00% | 1,554 | 99.87% | 1,556 | 0.01% |
| VGR | Villager Wagon | | 0.00% | | 0.00% | 2,273 | 100.00% | 2,273 | 0.02% |
| VIP | Viper SRT-10 | | 0.00% | | 0.00% | 1,206 | 100.00% | 1,206 | 0.01% |
| VIT | Vitara / Grand Vitara 2WD | 2 | 0.40% | | 0.00% | 503 | 99.60% | 505 | 0.00% |
| VOY | Voyager | 2 | 0.05% | | 0.00% | 4,423 | 99.95% | 4,425 | 0.04% |
| WIN | Windstar LX | 4 | 0.04% | | 0.00% | 11,416 | 99.96% | 11,420 | 0.11% |
| WRG | Wrangler 4WD | 6 | 0.02% | | 0.00% | 25,543 | 99.98% | 25,549 | 0.24% |
| XJ | | | 0.00% | | 0.00% | 211 | 100.00% | 211 | 0.00% |

| Model Code | Series (Model) | DLC is Damaged, Inaccessible, or Cannot be Found | | Vehicle will not Communicate with Analyzer | | Vehicle Successfully Communicates with Analyzer | | Total Count of Tests by Model | % of Overall Tests by Model |
|---|---|---|---|---|---|---|---|---|---|
| | | Count | Percent | Count | Percent | Count | Percent | | |
| XJ6 | XJ6 (USA) / Sovereign (Canada) | | 0.00% | | 0.00% | 877 | 100.00% | 877 | 0.01% |
| XJ8 | XJ | 1 | 0.02% | | 0.00% | 6,101 | 99.98% | 6,102 | 0.06% |
| XJR | XJR | 1 | 0.10% | | 0.00% | 965 | 99.90% | 966 | 0.01% |
| XJS | XJS | | 0.00% | | 0.00% | 102 | 100.00% | 102 | 0.00% |
| XK | XK / XKR | | 0.00% | | 0.00% | 988 | 100.00% | 988 | 0.01% |
| XK8 | XK8 / XKR | | 0.00% | | 0.00% | 816 | 100.00% | 816 | 0.01% |
| XPL | Explorer XL | 14 | 0.03% | | 0.00% | 45,911 | 99.97% | 45,925 | 0.43% |
| XTE | Xterra | | 0.00% | | 0.00% | 19,101 | 100.00% | 19,101 | 0.18% |
| XXX | Wrangler 4WD | 8 | 0.02% | | 0.00% | 33,232 | 99.98% | 33,240 | 0.31% |
| YUK | Yukon 2WD | 9 | 0.03% | | 0.00% | 30,152 | 99.97% | 30,161 | 0.28% |
| Z3 | Z3 | | 0.00% | | 0.00% | 2,000 | 100.00% | 2,000 | 0.02% |
| Z3C | Z3 | | 0.00% | | 0.00% | 437 | 100.00% | 437 | 0.00% |
| Z3R | Z3 | | 0.00% | | 0.00% | 428 | 100.00% | 428 | 0.00% |
| ZEP | Zephyr | | 0.00% | | 0.00% | 948 | 100.00% | 948 | 0.01% |
| | All Models | 4,139 | 0.04% | 4 | 0.00% | 10,757,815 | 99.96% | 10,761,958 | 100.00% |

## 3.6 TIMS Handling of OBD Codes

ERG analyzed TIMS OBD data to evaluate the accuracy of OBD data collected in the program. This is a process-based measure for inspection effectiveness. The handling of OBD readiness, pending trouble codes and communication failures varies among I/M programs. The objective of this task was to analyze OBD inspection records to ensure OBD test results are appropriate for various OBD test dispositions, such as a vehicle with too many OBD monitors "not ready," a vehicle with "pending" diagnostic trouble codes (DTCs), or a vehicle with which the OBD analyzer cannot communicate.

### Program Description and Results of Analysis

Proper handling of various OBD test scenarios is defined in Parts 85.2207 and 85.2222 of Title 40 of the Code of Federal Regulations and also in various OBD implementation guidance documents issued by the EPA. Appropriate responses to the various test scenarios are summarized here, and serve as the basis for analysis for this task. The dataset for this analysis included records for OBD inspections between 1 January 2012 and 31 December 2013. Records for inspections that were aborted were excluded from the dataset, as were records for which either the OBD result or the overall result was not "P" (pass) or "F" (fail). Because this analysis was performed with the goal of determining whether OBD inspection guidelines are enforced, only records for light-duty vehicles were used. Records for heavy-duty vehicles (>8500 lbs GVWR) for which the OBD test pass/fail results are not enforced and for vehicles with no GVWR given (because these might be heavy-duty vehicles) were also removed from the dataset, leaving 13,611,405 records in the dataset[5]. Finally, re-test inspections on OBD vehicles that included a safety or gas cap re-inspection, but did not include an OBD re-inspection (because the vehicle had passed OBD in a preceding inspection) were also excluded from the dataset, leaving 13,598,046 records in the dataset.

**Diagnostic Link Connector Communication Status** – According to federal guidelines, a diagnostic link connector (DLC) that is missing, tampered, or otherwise inoperable is a basis for failure, but the vehicle may be "rejected" for a DLC that is inaccessible or cannot be located. Failure to communicate with an OBD analyzer is also a basis for failure. To perform this analysis, the result stored in the "OBD2_DLC_RES" field was compared with that in the "OBD2_PF_FLAG" field. No test results with a "D"

5 HD vehicles were identified using the tx96_type field equal to 1 and the tx96_gvw_actual field being greater than zero but less than 8,501.

(damaged), “N” (connected but will not communicate), “L” (inspector cannot find DLC), or “I” (DLC is inaccessible) in the “OBD2_DLC_RES” should have a “P” in the “OBD2_PF_FLAG”. Results of this analysis are shown in Table 3-30.

**Table 3-30. Comparison of DLC Communication Status with Overall OBD Test Results**

| DLC Communication Status | Overall OBD Test Results | |
|---|---|---|
| | Fail | Pass |
| “D” (damaged) | 2,497 | - |
| “I” (DLC is inaccessible) | 970 | 1 |
| “L” (inspector cannot find DLC) | 955 | 36 |
| Total count of “D”, “I”, “L”, and “N” Tests | 4,422 | 42 |
| “P” (communication successful) | 591,862 | 13,001,720 |
| Total | 596,284 | 13,001,762 |

As can be seen in the table, 42 test records have a DLC communication status of “D”, “I”, or “L”, yet have an OBD test result of “pass”. For these records, it was noted that no result was given for monitor readiness (which should have been a “pass” in order to pass the OBD inspection). Additionally, no fields indicate that a fallback tailpipe inspection was performed for those records. It is not clear what led to the passing result for those records. In conclusion, the DLC fail to communicate was enforced on most, but not all, OBD tests conducted on light-duty vehicles during the period of evaluation.

Because successful communication with the inspection analyzer is critical for all other OBD results, the OBD records with OBD2_DLC_RES results other than “P” were removed from the dataset for the other analyses that comprise the remainder of this section. This left 13,593,582 records in the dataset.

Agreement between OBD test result and overall test result – A vehicle that fails the OBD inspection should fail the overall inspection, excluding any test exceptions such as converting to a backup tailpipe test.

To determine if OBD failures are properly enforced, that is, reflected in the overall inspection disposition, a query was performed to quantify the number of vehicles that failed the OBD portion of the test (“F” in the “OBD2_PF_FL” field) but passed the overall OBD test (“P” in the “OVERALL_RESULTS” field). Table 3-31 shows that only 9 tests were recorded with a “fail” in the OBD portion of the test but a “pass” for the overall test. Additional analysis was performed to determine the source of this apparent discrepancy. Only one of these records contained a passing result for the tailpipe inspection, suggesting this test may have been converted to a tailpipe test. For the remaining 10 records, no explanation for the overall passing result could be found. This is a very small fraction of the total number of inspections performed; more than 99.99% of OBD inspections have agreement between the OBD result and the overall test result.

**Table 3-31. Comparison of OBD Test Result with Overall Test Result**

| Result of OBD Test | Overall Test Result | | | | Total | |
|---|---|---|---|---|---|---|
| | Fail | | Pass | | | |
| Fail | 591,853 | 100.00% | 9 | 0.00% | 591,862 | 4.35% |
| Pass | 266,532 | 2.05% | 12,735,188 | 97.95% | 13,001,720 | 95.65% |
| Total | 858,385 | 6.31% | 12,735,197 | 93.69% | 13,593,582 | 100.00% |

**Inspector-Entered Malfunction Indicator Light (MIL) bulb check -** This is also referred to as the Key On / Engine Off (KOEO) check. The inspector turns the vehicle's ignition key to the "on" position, but does not start the vehicle, in order to illuminate the MIL. Results are manually entered into the analyzer (via keyboard) by the inspector. If the MIL does not illuminate, the vehicle should fail the OBD portion of the inspection.

To perform this analysis, the results for the inspector keyboard-entered MIL bulb check ("OBD2_MIL_CHECK" field of the test record) were compared with results of the overall OBD test result ("OBD2_PF_FLAG" field), to ensure that a MIL bulb check failure always results in an OBD test failure. The "OBD2_MIL_CHECK" results are "Y" or "K", which is a pass (yes, the MIL did illuminate or keyless ignition), and "N", which is a fail (no, the MIL did not illuminate). 59 records were found where a KOEO MIL result of "N" (fail) did not receive a failing OBD result. The results are presented in Table 3-32 below.

**Table 3-32. Comparison of KOEO MIL Bulb Check Result with Overall OBD Test Result**

| Result of KOEO MIL Bulb Check | Overall OBD Test Result | | Total |
|---|---|---|---|
| | Fail | Pass | |
| N (fail) | 17,751 | 59 | 17,810 |
| K (pass) | 3,272 | 199,125 | 202,397 |
| Y (pass) | 570,839 | 12,802,536 | 13,373,375 |
| Total | 574,111 | 13,001,661 | 13,593,582 |

Inspector-Entered Engine-Running MIL Illumination Status – The key-on engine running result manually entered by the inspector is a basis for failure. No vehicle with an "F" in the "OBD2_MIL_ON_RUN" field should have a "P" in the "OBD2_PF_FLAG" field of the OBD test record. The "OBD2_MIL_ON_RUN" results are "Y", which is a pass (Y = MIL turned off after the vehicle was started) or “N”, which is a fail (N = MIL stayed illuminated after the vehicle was started). Table 3-33 shows that the MIL Illumination Status appears to be enforced as a condition for OBD failure: no inspections were recorded with a MIL Illumination status of “N” and an overall OBD result of “P”. However, since the Key On Engine Running MIL Illumination Status is manually entered by the inspector, accuracy of this entry is not automatically enforced by the analyzer.

**Table 3-33. Comparison of Inspector-Entered MIL Illumination Status (Engine Running) with Overall OBD Test Result**

| Result of MIL Illumination Status | Overall OBD Test Result | | Total |
|---|---|---|---|
| | Fail | Pass | |
| N (Fail) | 56,330 | - | 56,330 |
| Y (Pass) | 535530 | 13,001,722 | 13,537,252 |
| Total | 591862 | 13,001,722 | 13,593,582 |

**MIL commanded on** – A vehicle with the MIL commanded on and with stored emissions-related DTCs should fail the OBD inspection, regardless of readiness status. Manufacturer-specific (non-generic) DTCs are ignored in this pass/fail determination. To perform this analysis, all OBD test records were reviewed to determine the overall OBD pass/fail status in comparison with the downloaded MIL command status results. Specifically, any vehicle with “F” in the “OBD2_MIL_STATUS” should also have “F” in the “OBD2_PF_FLAG” field (if DTCs are present). Table 3-34 provides the results of this review.

**Table 3-34. Comparison of Downloaded MIL Command Status with Overall OBD Test Result**

| Result of Downloaded MIL Status | Overall OBD Test Result | | | | Total | |
|---|---|---|---|---|---|---|
| | Fail | | Pass | | | |
| Fail | 179,425 | 30.3% | 40,252 | 0.3% | 219,677 | 1.6% |
| Pass | 412,437 | 69.7% | 12,961,468 | 99.7% | 13,373,905 | 98.4% |
| Total | 591,862 | 100.0% | 13,001,720 | 100.0% | 13,593,582 | 100.0% |

From Table 3-34, it can be seen that 40,252 test records (0.3% of all OBD “pass” test records) have a MIL commanded on status yet receive an overall OBD pass result. However, 40,250 of these tests had no stored DTCs, in which case it is appropriate to pass the test. The two remaining inspections had either one or three DTCs stored, and both should have resulted in a failed OBD result. In conclusion, the downloaded OBD

MIL command status was enforced for almost all OBD tests conducted on light-duty vehicles (< 8500 lbs. GVWR) with stored DTCs during the period of evaluation.

**Readiness Evaluation** – Federal guidelines recommend two or fewer unset non-continuous monitors be allowed for 1996-2000 vehicles, and only one (or none) unset non-continuous monitors be allowed for 2001 and newer vehicles. Vehicles with higher counts of unset non-continuous monitors should not receive a pass result. They should be failed or rejected on the basis of the OBD system's readiness status. However, certain vehicles that are designated as "transitional vehicles" are permitted to receive a tailpipe inspection if they are found to be not ready based on non-continuous monitor status at the time of an OBD inspection. To prevent any confusion of the results, these vehicles were excluded from this analysis of readiness. 12,000 records with transitional vehicles were excluded, leaving 13,581,582 records in the dataset for this analysis.

To perform this analysis, the OBD readiness status of test records was compared on a model-year basis to evaluate conformance with the readiness guidelines. Vehicles of model years 1996-2000 with three or more "not ready" non-continuous monitors should have an OBD readiness failure ("F" in the "OBD2_READY_RES" field of the test record), and an OBD test result of fail ("F" in the "OBD2_PF_FLAG" field of the test record). Vehicles with two or fewer "not ready" non-continuous monitors should have an OBD readiness result of pass ("P" in the "OBD2_READY_RES" of the test record). 2001 and newer vehicles with two or more "not ready" non-continuous monitors should have an OBD readiness failure ("F" in the "OBD2_READY_RES" of the test record), and an OBD test record result of fail ("F" in the "OBD2_PF_FLAG" field of the test record), while 2001 and newer vehicles with one or fewer "not ready" non-continuous monitors should have an OBD readiness result of pass ("P" in the "OBD2_READY_RES" field of the test record).

Table 3-35 compares OBD readiness status with the number of unset monitors for all OBD tests. Only non-continuous and "enabled" monitors are presented in this comparison.

**Table 3-35. Unset Monitors Vs. Test Readiness Status for Inspections**

| Count of Unset Non-Continuous Monitors | Counts of Tests of Vehicles Model Year 1996 through 2000 | | Counts of Tests of Vehicles Model Year 2001 and newer | |
|---|---|---|---|---|
| | OBD "Not Ready" | OBD "Ready" | OBD "Not Ready" | OBD "Ready" |
| 0 | 17 | 1,716,777 | 91 | 9,710,937 |
| 1 | 2 | 448,145 | 14 | 1,075,031 |
| 2 | 4 | 195,805 | 141,541 | 7,291 |
| 3 | 46,346 | - | 93,370 | 1 |
| 4 | 32,049 | - | 63,829 | - |
| 5 | 20,261 | - | 27,713 | - |
| 6 | 784 | - | 1,574 | - |
| Total Count | 99,463 | 2,360,727 | 328,132 | 10,793,260 |

Results in Table 3-35 show that a small number of tests (a total of 108) appear to have received an OBD "not ready" status despite having no unset monitors. Also, 7,291 vehicles of model year 2001 or newer with two unset readiness monitors still received a readiness result of "pass". Almost all of these occurred during a short period between January and April of 2012. These were limited to inspections performed by two analyzer manufacturers, and were probably limited in duration as a result of having been fixed by software updates.

**Readiness Evaluation** - Comparison of readiness result with overall pass/fail result – The pass/fail disposition of the readiness result field of the test record was compared with the overall OBD test disposition to see of any vehicles with a "not ready" status (as determined automatically by the analyzer) received an overall OBD test result of "pass". To perform this analysis, the "OBD2_READY_RES" field was compared to the "OBD2_PF_FLAG" fields in the analyzer OBD test records. Note that certain vehicles that are designated as "transitional vehicles" are permitted to receive a tailpipe inspection if they are found to be not ready (based on non-continuous monitor status) at the time of an OBD inspection. To prevent any confusion of the results, these vehicles were excluded from this analysis of readiness. 12,000 records with transitional vehicles were excluded, leaving 13,581,582 records in the dataset for this analysis. The results are shown in Table 3-36.

**Table 3-36. Comparison of Readiness Status Field with Overall OBD Test Result**

| Readiness Status Check | Overall OBD Test Result | | | | Total | |
|---|---|---|---|---|---|---|
| | Fail | | Pass | | | |
| Fail (Not Ready) | 427,466 | 72.3% | 129 | 0.0% | 427,595 | 3.1% |
| Pass (Ready) | 163,501 | 27.7% | 12,990,486 | 100.0% | 13,153,987 | 96.9% |
| Total | 590,967 | 100.0% | 12,990,615 | 100.0% | 13,581,582 | 100.0% |

As can be seen in Table 3-36, only 129 of the vehicles with a "not ready" status received an overall "pass" result for the OBD portion of the test. This indicates that the OBD readiness status (as determined by the analyzer and stored in the OBD2_READY_RES" field of the test record) was almost always enforced for OBD tests performed during the period of evaluation.

# 4.0 Repair

ERG used two years of Texas TIMS data to analyze repair activities in order to demonstrate the extent and effectiveness of repairs directed by the I/M program. This task will cover process-based measures for repair effectiveness.

## 4.1 Number and Types of Repairs

ERG performed analysis on the number and types of repairs for the two years of I/M data. The inspectors at I/M stations have an opportunity to enter vehicle repair information into the inspection analyzer prior to conducting an emissions retest. A simple count of the number of repairs entered and stored in the TIMS database and a distribution of the repair types suggests the I/M program is causing repairs to be performed. As for repairs reported for the TCEQ's Low Income and Repair Assistance, Retrofit, and Accelerated Vehicle Retirement Program (LIRAP), since the repairs reported are documented on paper and not electronically, LIRAP repairs are not included in this analysis but will be described generally.

In an effort to determine the number and types of repairs performed as a result of the Texas I/M program, two sets of data were analyzed: the Texas TIMS repair data collected as described above and detailed repair information collected from The Texas Department of Public Safety (DPS) Recognized Emissions Repair Facilities (RERF) program.

#### 4.1.1.1 General I/M Repairs

The TIMS database, provided by the TCEQ for this analysis, contained a large number of repair entries, but relatively little detail on the nature of repairs performed. The five repair categories listed in the TIMS, along with the corresponding number of performed repairs, are presented in Table 4-1 by model year group. Compared to 2012 results, the number of reported repairs dropped from 291,611 to 230,138. Comparing Table 3-6 test totals from the DFW and HGB areas between 2012 and 2014 results shows total OBD, ASM, and TSI fails dropped from 706,684 fails in the 2012 report versus 643,712 fails in this report (62,972 fewer fails), which is roughly equivalent to the drop in reported repairs between the 2012 and 2014 reports.

## Table 4-1. Repairs Listed in the TIMS

| Repair Type | Model Year | Number of Repairs | % of Repair Type | % of Total |
|---|---|---|---|---|
| Fuel System | pre-1980 | 0 | 0.00 | 0.00 |
| | 1980-1989 | 379 | 0.83 | 0.16 |
| | 1990-1999 | 14,142 | 31.09 | 6.15 |
| | post-2000 | 30,973 | 68.08 | 13.46 |
| | Total | 45,494 | 100.00 | 19.77 |
| Ignition / Electrical system | pre-1980 | 1 | 0.00 | 0.00 |
| | 1980-1989 | 318 | 1.43 | 0.14 |
| | 1990-1999 | 9,182 | 41.41 | 3.99 |
| | post-2000 | 12,675 | 57.16 | 5.51 |
| | Total | 22,176 | 100.00 | 9.64 |
| Emissions system | pre-1980 | 0 | 0.00 | 0.00 |
| | 1980-1989 | 977 | 1.48 | 0.42 |
| | 1990-1999 | 29,696 | 44.84 | 12.90 |
| | post-2000 | 35,551 | 53.68 | 15.45 |
| | Total | 66,224 | 100.00 | 28.78 |
| Engine Mechanical | pre-1980 | | 0.00 | 0.00 |
| | 1980-1989 | 34 | 0.80 | 0.01 |
| | 1990-1999 | 1,572 | 36.87 | 0.68 |
| | post-2000 | 2,658 | 62.34 | 1.15 |
| | Total | 4,264 | 100.00 | 1.85 |
| Miscellaneous | pre-1980 | 0 | 0.00 | 0.00 |
| | 1980-1989 | 806 | 0.88 | 0.35 |
| | 1990-1999 | 30,109 | 32.73 | 13.08 |
| | post-2000 | 61,065 | 66.39 | 26.53 |
| | Total | 91,980 | 100.00 | 39.97 |
| | Grand Total | 230,138 | | 100.00 |

### RERF Repairs

Relative to the TIMS, the separate RERF dataset obtained from DPS contains more comprehensive information about the nature of repairs performed. However, repairs made at RERFs only make up a fraction of overall repairs made throughout the I/M areas statewide. Nonetheless, the distribution of repairs performed at RERFs serves to illustrate the wide variety of repairs undertaken as a result of the Texas I/M program. Table 4-2 shows counts of repairs reported by stations participating in the RERF program.

## Table 4-2. Repairs Performed at RERF Stations

| Repair Type | Defective, Not Repaired | Repaired | % Repaired | Total Vehicles with This Defect | Defect % of Total |
|---|---|---|---|---|---|
| AIS | 0 | 15 | 100.0 | 15 | 0.37 |
| Battery/Charging System | 0 | 12 | 100.0 | 12 | 0.30 |
| CAT | 5 | 378 | 98.7 | 383 | 9.51 |
| Camshaft | 0 | 26 | 100.0 | 26 | 0.65 |
| Cylinder Head | 3 | 19 | 86.4 | 22 | 0.55 |
| EGR | 3 | 345 | 99.1 | 348 | 8.64 |
| EVAP | 4 | 339 | 98.8 | 343 | 8.51 |
| Emissions System | 1 | 104 | 99.0 | 105 | 2.61 |
| Eng. Cooling | 3 | 113 | 97.4 | 116 | 2.88 |
| Engine Block | 2 | 4 | 66.7 | 6 | 0.15 |
| Engine Crankcase Oil | 1 | 4 | 80.0 | 5 | 0.12 |
| Engine Exhaust | 0 | 14 | 100.0 | 14 | 0.35 |
| Engine Mechanical | 0 | 33 | 100.0 | 33 | 0.82 |
| Final Drive Ratio | 0 | 4 | 100.0 | 4 | 0.10 |
| Fuel Filter | 1 | 82 | 98.8 | 83 | 2.06 |
| Fuel Pump | 0 | 38 | 100.0 | 38 | 0.94 |
| Fuel System | 2 | 100 | 98.0 | 102 | 2.53 |
| Ignition/Electrical System | 1 | 67 | 98.5 | 68 | 1.69 |
| Injectors | 0 | 308 | 100.0 | 308 | 7.64 |
| Miscellaneous | 13 | 211 | 94.2 | 224 | 5.56 |
| O2 Sensor | 2 | 440 | 99.5 | 442 | 10.97 |
| Other | 0 | 1 | 100.0 | 1 | 0.02 |
| PCM | 2 | 58 | 96.7 | 60 | 1.49 |
| PCV | 0 | 71 | 100.0 | 71 | 1.76 |
| Spark Plug Wires | 2 | 171 | 98.8 | 173 | 4.29 |
| Spark Plugs | 1 | 283 | 99.6 | 284 | 7.05 |
| Spark Timing | 0 | 120 | 100.0 | 120 | 2.98 |
| TAC | 0 | 11 | 100.0 | 11 | 0.27 |
| Thermostat | 0 | 3 | 100.0 | 3 | 0.07 |
| Throttle Body | 1 | 146 | 99.3 | 147 | 3.65 |
| Trans/Final Drive | 7 | 58 | 89.2 | 65 | 1.61 |
| Valves (Mechanical) | 6 | 28 | 82.4 | 34 | 0.84 |
| Valves (Oil Seals) | 0 | 13 | 100.0 | 13 | 0.32 |
| Vehicle Fluids | 259 | 91 | 26.0 | 350 | 8.69 |
| Grand Total | 319 | 3,710 | 92.1 | 4,029 | 100.00 |

### Drive a Clean Machine

Texas has put in place a program to financially assist low income individuals with replacing vehicles that fail emissions testing. It is called the AirCheckTexas Drive a Clean Machine (DACM) and it is for qualified owners of vehicles that have failed the emissions test or whose vehicles are gasoline powered and 10 years old or older. The program was originally created under the Low Income Vehicle Repair Assistance, Retrofit and Accelerated Retirement Program (LIRAP); however, the program is now known as DACM as the result of further legislative amendments passed in 2007.

The DACM program provides financial assistance toward repair or, retirement and replacements of vehicles. This program is a financial assistance program for qualified owners of vehicles that fail an emissions test or they own a gasoline-powered vehicle ten years old or older. To qualify for the DACM program, a vehicle owner's net family income cannot exceed 300% of the federal poverty level, which varies by family unit size. The vehicle must pass the safety portion of the DPS motor-vehicle safety and emissions inspection, and driven under its own power to the inspection station must have failed an emissions test, must be currently registered in and has been registered in a program county for at least 12 of the 15 months preceding the application for assistance.

The repair assistance provides a voucher worth up to $600 for emissions-related repairs or retrofits performed at a participating DPS RERF. The retirement and replacement assistance offers a $3,000 voucher towards the purchase of a vehicle, current model year or up to three model years old, $3,000 voucher for a truck, current model year or up to two model years old or $3,500 for a replacement vehicle of the current model year or the previous three model years if the vehicle is a hybrid vehicle, electric vehicle, natural gas vehicle, or is in a class or category of vehicles that has been certified to meet federal Tier 2, Bin 3 or cleaner Bin certification under 40 Code of Federal Regulations §86.1811-04, as published in the February 10, 2000, *Federal Register* (65 FR 6698).

The replacement vehicle must have an odometer reading of not more than 70,000 miles and a sales price of $35,000 or less, for a car, current model year or up to three model years old; a sales price of $35,000 or less, for a truck, current model year or up to two model years old; or a sales price of $45,000 or less for a hybrid vehicle, electric vehicle, natural gas vehicle or a vehicle certified to meet or exceed federal Tier 2, Bin 3 or cleaner certification of the current model year or up to three model years old and have a gross vehicle weight rating less than 10,000 pounds.

For the period covering December 1, 2011 through November 30, 2013, 9,784 vehicle repairs were done at RERF stations under the DACM program, with 8,098 being made in the DFW and HGB programs. In the 2012 report there were 14,483 repairs with 13,554 done in the DFW and HGB areas. In the 2009 Report, this figure was 7,181, with 6,741 done in the DFW and HGB programs. In the 2006 Report there were 9,649 DACM driven repairs.

## 4.2 Emissions Changes Associated with Repair

One way to measure the effectiveness of the Texas I/M program is to assess emissions from vehicles both before and after repairs and to calculate the average emissions change produced by different repair types. Different types of repairs tend to produce characteristic changes in emissions.

In the discussion below, the average emissions and the emissions changes produced by repairs during the evaluation period in the Texas I/M program with similar quantities from the 2012 Report are compared.

#### 4.2.1.1 Emissions Changes as a Result of Repair

The average emissions of all vehicles in the current 2014 I/M analysis that received repairs are shown in Table 4-3b. Both ASM 5015 and ASM 2525 test results are presented. Average emissions for both inspections prior to and following repair cycles are shown, along with the average change between the two. The corresponding change in emissions for the vehicles in the 2012 Report are shown by the values in Table 4-3a. The average emissions before and after repair in the current analysis are considerably lower than the corresponding values in the previous 2012 Report. However, the percent emission changes for HC and CO for the time periods are quite close. The average emissions change in the 2012 Report for HC, CO, and $NO_x$, was -67%, -82%, and -70%, respectively. In the current analysis, the emissions change for HC, CO, and $NO_x$, respectively was -67%, -81%, and -70%.

Tables 4-4a and 4-5a present the same types of emissions averages as those shown in Table 4-3a, but they are stratified by inspection year and model year group, respectively. These tables show that when stratifying by either inspection year or model year, emissions of HC, CO, and $NO_x$ all decrease with increasing year, for both the ASM 5015 and ASM 2525 tests.

Table 4-6 presents the most common repair slates (groups of common types of repairs) in the TIMS data, as originally presented and discussed in Table 4-1 above. Average before and after repair emissions levels were calculated for each repair category to determine the emissions effects of different combinations of repair types.

As shown in Table 4-6 for the ASM2525 mode, seven combinations of the five repair categories dominate the repair slates used in Texas. As before, it is seen that average emissions before and after repairs are lower in the current 2014 Texas dataset than in the previous 2012 dataset. A similar finding will be seen in Section 5.1.

## Table 4-3. Average Emissions Before and After Repairs

a) Previous 2012 Report

| ASM Mode | N | HC (ppm) | | | | CO (%) | | | | NOx (ppm) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Before Repair | After Repair | Change | | Before Repair | After Repair | Change | | Before Repair | After Repair | Change | |
| | | | | Conc. | (%) | | | Conc. | (%) | | | Conc. | (%) |
| | | | | | | | | | | | | | |
| 5015 | 216,528 | 38 | 15 | -23 | -60% | 0.25 | 0.05 | -0.20 | -79% | 328 | 111 | -217 | -66% |
| 2525 | 216,528 | 33 | 11 | -22 | -67% | 0.24 | 0.04 | -0.20 | -82% | 293 | 89 | -204 | -70% |

b) Current Report

| ASM Mode | N | HC (ppm) | | | | CO (%) | | | | NOx (ppm) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Before Repair | After Repair | Change | | Before Repair | After Repair | Change | | Before Repair | After Repair | Change | |
| | | | | Conc. | (%) | | | Conc. | (%) | | | Conc. | (%) |
| | | | | | | | | | | | | | |
| 5015 | 193,288 | 28 | 11 | -17 | -61% | 0.18 | 0.04 | -0.14 | -78% | 244 | 81 | -163 | -67% |
| 2525 | 193,288 | 25 | 8 | -16 | -67% | 0.17 | 0.03 | -0.13 | -81% | 218 | 65 | -153 | -70% |

## Table 4-4. Average Emissions Before and After Repairs by Inspection Year

a) Previous 2012 Report

| Inspection Year | ASM Mode | N | HC (ppm) Before Repair | HC (ppm) After Repair | HC Change Conc. | HC Change (%) | CO (%) Before Repair | CO (%) After Repair | CO Change Conc. | CO Change (%) | NOx (ppm) Before Repair | NOx (ppm) After Repair | NOx Change Conc. | NOx Change (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | |
| 2010 | 5015 | 125,491 | 38 | 15 | -23 | -61% | 0.25 | 0.05 | -0.20 | -79% | 341 | 115 | -226 | -66% |
| 2011 | 5015 | 114,001 | 36 | 14 | -21 | -60% | 0.23 | 0.05 | -0.18 | -78% | 311 | 107 | -204 | -66% |
| 2010 | 2525 | 125,491 | 34 | 11 | -23 | -67% | 0.25 | 0.04 | -0.21 | -82% | 305 | 92 | -212 | -70% |
| 2011 | 2525 | 114,001 | 32 | 11 | -21 | -67% | 0.23 | 0.04 | -0.18 | -81% | 278 | 86 | -192 | -69% |
| b) Current Report | | | | | | | | | | | | | | |
| 2012 | 5015 | 99,871 | 30 | 12 | -18 | -60% | 0.19 | 0.04 | -0.15 | -79% | 262 | 87 | -175 | -67% |
| 2013 | 5015 | 93,414 | 26 | 10 | -16 | -61% | 0.16 | 0.04 | -0.13 | -78% | 224 | 74 | -150 | -67% |
| 2012 | 2525 | 99,871 | 26 | 9 | -18 | -67% | 0.18 | 0.03 | -0.15 | -81% | 235 | 70 | -165 | -70% |
| 2013 | 2525 | 93,414 | 23 | 8 | -15 | -67% | 0.15 | 0.03 | -0.12 | -80% | 200 | 60 | -140 | -70% |

## Table 4-5. Average Emissions Before and After Repairs by Model Year Group

a) Previous 2012 Report

| Model Year | ASM Mode | N | ASM2525 HC (ppm) | | | | ASM2525 CO (%) | | | | ASM2525 NOx (ppm) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Before Repair | After Repair | Change | | Before Repair | After Repair | Change | | Before Repair | After Repair | Change | |
| | | | | | Conc. | (%) | | | Conc. | (%) | | | Conc. | (%) |
| 1980-1989 | 5015 | 5,997 | 204 | 73 | -131 | -64% | 1.52 | 0.29 | -1.22 | -81% | 1,281 | 508 | -773 | -60% |
| 1990-1999 | 5015 | 93,065 | 74 | 30 | -44 | -60% | 0.48 | 0.10 | -0.38 | -79% | 681 | 226 | -455 | -67% |
| post-2000 | 5015 | 117,466 | 0 | 0 | 0 | N/A | 0.00 | 0.00 | 0.00 | N/A | 0 | 0 | 0 | N/A |
| 1980-1989 | 2525 | 5,997 | 187 | 58 | -129 | -69% | 1.53 | 0.26 | -1.27 | -83% | 1,133 | 416 | -717 | -63% |
| 1990-1999 | 2525 | 93,065 | 66 | 22 | -44 | -66% | 0.47 | 0.09 | -0.38 | -81% | 609 | 181 | -428 | -70% |
| post-2000 | 2525 | 117,466 | 0 | 0 | 0 | -N/A | 0.00 | 0.00 | 0.00 | N/A | 0 | 0 | 0 | N/A |

b) Current Report

| Model Year | ASM Mode | N | HC (ppm) | | | | CO (%) | | | | NOx (ppm) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Before Repair | After Repair | Change | | Before Repair | After Repair | Change | | Before Repair | After Repair | Change | |
| | | | | | Conc. | (%) | | | Conc. | (%) | | | Conc. | (%) |
| 1980-1989 | 5015 | 1,759 | 195 | 75 | -121 | -62% | 1.33 | 0.28 | -1.04 | -79% | 1,275 | 503 | -772 | -61% |
| 1990-1999 | 5015 | 68,364 | 74 | 29 | -45 | -61% | 0.46 | 0.10 | -0.36 | -78% | 657 | 215 | -442 | -67% |
| post-2000 | 5015 | 123,165 | 0 | 0 | 0 | N/A | 0.00 | 0.00 | 0.00 | N/A | 0 | 0 | 0 | N/A |
| 1980-1989 | 2525 | 2,525 | 1,759 | 182 | 59 | -123 | -67% | 1.28 | 0.25 | -1.03 | -81% | 1,145 | 411 | -734 |
| 1990-1999 | 2525 | 2,525 | 68,364 | 65 | 22 | -43 | -67% | 0.44 | 0.08 | -0.35 | -81% | 587 | 173 | -413 |
| post-2000 | 2525 | 2,525 | 123,165 | 0 | 0 | N/A | -100% | 0.00 | 0.00 | N/A | -100% | 0 | 0 | N/A |

## Table 4-6. Average Emissions Before and After Repairs by Repair Category and Model Year Group

### a) Previous 2012 Report

| Repair Category | Model Year | ASM Mode | N | HC (ppm) | | | | CO (%) | | | | NOx (ppm) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Change | | | | Change | | | | Change | |
| | | | | Before Repair | After Repair | Conc. | (%) | Before Repair | After Repair | Conc. | (%) | Before Repair | After Repair | Conc. | (%) |
| Miscellaneous | 1980-1989 | 5015 | 1,610 | 198 | 83 | -116 | -58% | 1.56 | 0.33 | -1.23 | -79% | 1,233 | 519 | -714 | -58% |
| Engine Mechanical | 1980-1989 | 5015 | 95 | 241 | 78 | -163 | -68% | 1.50 | 0.28 | -1.23 | -82% | 1,105 | 405 | -700 | -63% |
| Emissions System | 1980-1989 | 5015 | 2,366 | 187 | 69 | -118 | -63% | 1.27 | 0.25 | -1.02 | -80% | 1,517 | 516 | -1002 | -66% |
| Emissions System & Misc | 1980-1989 | 5015 | 122 | 239 | 86 | -153 | -64% | 1.50 | 0.50 | -1.00 | -66% | 1,410 | 634 | -775 | -55% |
| Ignition/ Electrical System | 1980-1989 | 5015 | 820 | 252 | 67 | -185 | -73% | 1.72 | 0.26 | -1.46 | -85% | 924 | 463 | -461 | -50% |
| Fuel System | 1980-1989 | 5015 | 685 | 193 | 71 | -122 | -63% | 1.88 | 0.31 | -1.57 | -84% | 1,094 | 500 | -594 | -54% |
| Fuel System & Emissions System | 1980-1989 | 5015 | 56 | 130 | 72 | -58 | -45% | 1.00 | 0.25 | -0.76 | -75% | 1,430 | 717 | -713 | -50% |
| Miscellaneous | 1990-1999 | 5015 | 30,273 | 60 | 26 | -34 | -57% | 0.39 | 0.10 | -0.29 | -75% | 517 | 186 | -331 | -64% |
| Engine Mechanical | 1990-1999 | 5015 | 1,555 | 73 | 26 | -47 | -65% | 0.45 | 0.09 | -0.36 | -80% | 597 | 185 | -412 | -69% |
| Emissions System | 1990-1999 | 5015 | 33,226 | 81 | 34 | -47 | -58% | 0.49 | 0.10 | -0.38 | -78% | 904 | 266 | -637 | -71% |
| Emissions System & Misc | 1990-1999 | 5015 | 1,378 | 106 | 50 | -56 | -53% | 0.64 | 0.17 | -0.48 | -74% | 1,214 | 424 | -790 | -65% |
| Ignition/Electrical System | 1990-1999 | 5015 | 9,926 | 104 | 32 | -72 | -69% | 0.67 | 0.11 | -0.56 | -83% | 606 | 231 | -376 | -62% |
| Fuel System | 1990-1999 | 5015 | 13,891 | 56 | 22 | -33 | -60% | 0.42 | 0.08 | -0.34 | -80% | 455 | 175 | -281 | -62% |
| Fuel System & Emissions System | 1990-1999 | 5015 | 690 | 102 | 47 | -56 | -54% | 0.71 | 0.14 | -0.56 | -80% | 1,058 | 370 | -688 | -65% |
| Miscellaneous | post-2000 | 5015 | 50244 | 0.009 | 0 | -0.01 | -100% | 0.00 | 0.00 | 0.00 | -100% | 0 | 0 | 0 | -100% |
| Engine Mechanical | post-2000 | 5015 | 1944 | 0.000 | 0 | 0.00 | N/A | 0.00 | 0.00 | 0.00 | N/A | 0 | 0 | 0 | N/A |
| Emissions System | post-2000 | 5015 | 30512 | 0.002 | 0 | 0.00 | N/A | 0.00 | 0.00 | 0.00 | N/A | 0 | 0 | 0 | N/A |
| Emissions System & Misc | post-2000 | 5015 | 679 | 0.044 | 0 | -0.04 | N/A | 0.00 | 0.00 | 0.00 | N/A | 0 | 0 | 0 | N/A |
| Ignition/Electrical | post-2000 | 5015 | 9,788 | 0.014 | 0 | -0.01 | N/A | 0.00 | 0.00 | 0.00 | N/A | 4 | 0 | -4 | N/A |

| Repair Category | Model Year | ASM Mode | N | HC (ppm) | | | | CO (%) | | | | NOx (ppm) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Change | | | | Change | | | | Change | |
| | | | | Before Repair | After Repair | Conc. | (%) | Before Repair | After Repair | Conc. | (%) | Before Repair | After Repair | Conc. | (%) |
| System | | | | | | | | | | | | | | | |
| Fuel System | post-2000 | 5015 | 22,548 | 0.025 | 0 | -0.02 | N/A | 0.00 | 0.00 | 0.00 | N/A | 0 | 0 | 0 | N/A |
| Fuel System & Emissions System | post-2000 | 5015 | 412 | 0 | 0 | 0.00 | N/A | 0.00 | 0.00 | 0.00 | N/A | 0 | 0 | 0 | N/A |
| Miscellaneous | 1980-1989 | 2525 | 1,610 | 186 | 67 | -119 | -64% | 1.56 | 0.29 | -1.27 | -82% | 1,082 | 427 | -655 | -61% |
| Engine Mechanical | 1980-1989 | 2525 | 95 | 196 | 54 | -142 | -72% | 1.40 | 0.25 | -1.16 | -82% | 1,027 | 300 | -727 | -71% |
| Emissions System | 1980-1989 | 2525 | 2,366 | 168 | 53 | -115 | -68% | 1.30 | 0.22 | -1.08 | -83% | 1,341 | 418 | -923 | -69% |
| Emissions System & Misc | 1980-1989 | 2525 | 122 | 242 | 67 | -174 | -72% | 1.68 | 0.46 | -1.22 | -73% | 1,243 | 515 | -728 | -59% |
| Ignition/Electrical System | 1980-1989 | 2525 | 820 | 224 | 53 | -171 | -76% | 1.72 | 0.24 | -1.48 | -86% | 814 | 385 | -429 | -53% |
| Fuel System | 1980-1989 | 2525 | 685 | 181 | 55 | -125 | -69% | 1.86 | 0.27 | -1.59 | -85% | 977 | 416 | -561 | -57% |
| Fuel System & Emissions System | 1980-1989 | 2525 | 56 | 161 | 56 | -105 | -65% | 1.26 | 0.26 | -1.00 | -80% | 1,322 | 521 | -802 | -61% |
| Miscellaneous | 1990-1999 | 2525 | 30,273 | 54 | 19 | -34 | -64% | 0.38 | 0.08 | -0.29 | -78% | 460 | 150 | -310 | -67% |
| Engine Mechanical | 1990-1999 | 2525 | 1,555 | 64 | 18 | -46 | -72% | 0.43 | 0.07 | -0.36 | -84% | 530 | 138 | -392 | -74% |
| Emissions System | 1990-1999 | 2525 | 33,226 | 71 | 24 | -46 | -65% | 0.47 | 0.09 | -0.38 | -81% | 811 | 211 | -600 | -74% |
| Emissions System & Misc | 1990-1999 | 2525 | 1,378 | 95 | 39 | -56 | -59% | 0.62 | 0.14 | -0.48 | -78% | 1,072 | 348 | -725 | -68% |
| Ignition/Electrical System | 1990-1999 | 2525 | 9,926 | 92 | 24 | -68 | -74% | 0.67 | 0.10 | -0.57 | -85% | 537 | 183 | -355 | -66% |
| Fuel System | 1990-1999 | 2525 | 13,891 | 51 | 17 | -34 | -67% | 0.42 | 0.07 | -0.35 | -83% | 406 | 143 | -263 | -65% |
| Fuel System & Emissions System | 1990-1999 | 2525 | 690 | 94 | 34 | -60 | -64% | 0.70 | 0.12 | -0.58 | -83% | 957 | 305 | -653 | -68% |
| Miscellaneous | post-2000 | 2525 | 50,244 | 0 | 0 | 0 | N/A | 0.00 | 0.00 | 0.00 | N/A | 0 | 0 | 0 | N/A |
| Engine Mechanical | post-2000 | 2525 | 1,944 | 0 | 0 | 0 | N/A | 0.00 | 0.00 | 0.00 | N/A | 0 | 0 | 0 | N/A |
| Emissions System | post-2000 | 2525 | 30,512 | 0 | 0 | 0 | N/A | 0.00 | 0.00 | 0.00 | N/A | 0 | 0 | 0 | N/A |
| Emissions System & Misc | post-2000 | 2525 | 679 | 0 | 0 | 0 | N/A | 0.00 | 0.00 | 0.00 | N/A | 3 | 0 | -3 | N/A |

| Repair Category | Model Year | ASM Mode | N | HC (ppm) | | | | CO (%) | | | | NOx (ppm) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Change | | | | Change | | | | Change | |
| | | | | Before Repair | After Repair | Conc. | (%) | Before Repair | After Repair | Conc. | (%) | Before Repair | After Repair | Conc. | (%) |
| Ignition/Electrical System | post-2000 | 2525 | 9,788 | 0 | 0 | 0 | N/A | 0.00 | 0.00 | 0.00 | N/A | 0 | 0 | 0 | N/A |
| Fuel System | post-2000 | 2525 | 22,548 | 0 | 0 | 0 | N/A | 0.00 | 0.00 | 0.00 | N/A | 0 | 0 | 0 | N/A |
| Fuel System & Emissions System | post-2000 | 2525 | 412 | 0 | 0 | 0 | N/A | 0.00 | 0.00 | 0.00 | N/A | 0 | 0 | 0 | N/A |

## b) Current Report

| Repair Category | Mode l Year | ASM Mode | N | HC (ppm) Before Repair | HC (ppm) After Repair | HC (ppm) Change Conc. | HC (ppm) Change (%) | CO (%) Before Repair | CO (%) After Repair | CO (%) Change Conc. | CO (%) Change (%) | NOx (ppm) Before Repair | NOx (ppm) After Repair | NOx (ppm) Change Conc. | NOx (ppm) Change (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Miscellaneous | 1980-1989 | 5015 | 468 | 207 | 75 | -132 | -64% | 1.22 | 0.30 | -0.92 | -76% | 1,215 | 528 | -686 | -57% |
| Engine Mechanical | 1980-1989 | 5015 | 20 | 187 | 66 | -121 | -65% | 1.92 | 0.23 | -1.69 | -88% | 1,278 | 424 | -855 | -67% |
| Emissions System | 1980-1989 | 5015 | 717 | 167 | 69 | -98 | -59% | 1.21 | 0.23 | -0.98 | -81% | 1,536 | 514 | -1022 | -67% |
| Emissions System & Misc | 1980-1989 | 5015 | 28 | 392 | 73 | -320 | -81% | 1.20 | 0.28 | -0.92 | -77% | 1,313 | 416 | -897 | -68% |
| Ignition/Electric al System | 1980-1989 | 5015 | 215 | 262 | 77 | -185 | -70% | 1.47 | 0.37 | -1.11 | -75% | 856 | 467 | -389 | -45% |
| Fuel System | 1980-1989 | 5015 | 246 | 182 | 90 | -92 | -50% | 1.63 | 0.28 | -1.35 | -83% | 1,011 | 483 | -528 | -52% |
| Fuel System & Emissions System | 1980-1989 | 5015 | 18 | 173 | 105 | -68 | -39% | 2.46 | 1.18 | -1.27 | -52% | 1,352 | 439 | -913 | -68% |
| Miscellaneous | 1990-1999 | 5015 | 22,356 | 62 | 27 | -36 | -57% | 0.40 | 0.10 | -0.30 | -75% | 510 | 182 | -328 | -64% |
| Engine Mechanical | 1990-1999 | 5015 | 1,200 | 80 | 24 | -55 | -69% | 0.43 | 0.07 | -0.36 | -83% | 542 | 158 | -384 | -71% |
| Emissions System | 1990-1999 | 5015 | 23,691 | 82 | 33 | -49 | -59% | 0.49 | 0.11 | -0.38 | -78% | 903 | 263 | -641 | -71% |
| Emissions System & Misc | 1990-1999 | 5015 | 898 | 107 | 47 | -61 | -56% | 0.79 | 0.16 | -0.63 | -80% | 1,168 | 404 | -764 | -65% |
| Ignition/Electric al System | 1990-1999 | 5015 | 7,255 | 99 | 31 | -68 | -69% | 0.59 | 0.11 | -0.48 | -81% | 557 | 208 | -349 | -63% |
| Fuel System | 1990-1999 | 5015 | 11,049 | 55 | 21 | -34 | -62% | 0.38 | 0.07 | -0.31 | -81% | 418 | 158 | -261 | -62% |
| Fuel System & Emissions System | 1990-1999 | 5015 | 461 | 125 | 49 | -76 | -61% | 0.87 | 0.20 | -0.67 | -77% | 1,017 | 338 | -679 | -67% |

| Repair Category | Model Year | ASM Mode | N | HC (ppm) | | | | CO (%) | | | | NOx (ppm) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Before Repair | After Repair | Change | | Before Repair | After Repair | Change | | Before Repair | After Repair | Change | |
| | | | | | | Conc. | (%) | | | Conc. | (%) | | | Conc. | (%) |
| Miscellaneous | post-2000 | 5015 | 51,151 | 0.000 | 0 | 0.00 | N/A | 0.00 | 0.00 | 0.00 | N/A | 0 | 0 | 0 | N/A |
| Engine Mechanical | post-2000 | 5015 | 2,219 | 0.156 | 0 | -0.16 | N/A | 0.00 | 0.00 | 0.00 | N/A | 1 | 0 | -1 | N/A |
| Emissions System | post-2000 | 5015 | 30,679 | 0.005 | 0 | 0.00 | N/A | 0.00 | 0.00 | 0.00 | N/A | 0 | 0 | 0 | N/A |
| Emissions System & Misc | post-2000 | 5015 | 557 | 0.000 | 0 | 0.00 | N/A | 0.00 | 0.00 | 0.00 | N/A | 0 | 0 | 0 | N/A |
| Ignition/Electrical System | post-2000 | 5015 | 10,765 | 0.000 | 0 | 0.00 | N/A | 0.00 | 0.00 | 0.00 | N/A | 0 | 0 | 0 | N/A |
| Fuel System | post-2000 | 5015 | 26,205 | 0.029 | 0 | -0.03 | N/A | 0.00 | 0.00 | 0.00 | N/A | 0 | 0 | 0 | N/A |
| Fuel System & Emissions System | post-2000 | 5015 | 351 | 0 | 0 | 0.00 | N/A | 0.00 | 0.00 | 0.00 | N/A | 0 | 0 | 0 | N/A |
| Miscellaneous | 1980-1989 | 2525 | 468 | 191 | 61 | -129 | -68% | 1.15 | 0.26 | -0.89 | -77% | 1,078 | 443 | -635 | -59% |
| Engine Mechanical | 1980-1989 | 2525 | 20 | 258 | 60 | -198 | -77% | 2.64 | 0.21 | -2.42 | -92% | 1,080 | 375 | -705 | -65% |
| Emissions System | 1980-1989 | 2525 | 717 | 161 | 52 | -108 | -67% | 1.11 | 0.20 | -0.91 | -82% | 1,392 | 410 | -981 | -71% |
| Emissions System & Misc | 1980-1989 | 2525 | 28 | 376 | 52 | -324 | -86% | 1.08 | 0.27 | -0.80 | -75% | 1,222 | 278 | -944 | -77% |
| Ignition/Electrical System | 1980-1989 | 2525 | 215 | 218 | 62 | -155 | -71% | 1.36 | 0.30 | -1.05 | -78% | 818 | 377 | -441 | -54% |
| Fuel System | 1980-1989 | 2525 | 246 | 170 | 74 | -97 | -57% | 1.63 | 0.27 | -1.36 | -83% | 895 | 415 | -480 | -54% |
| Fuel System & Emissions System | 1980-1989 | 2525 | 18 | 186 | 82 | -104 | -56% | 3.51 | 1.07 | -2.44 | -70% | 1,102 | 269 | -832 | -76% |
| Miscellaneous | 1990-1999 | 2525 | 22,356 | 55 | 20 | -34 | -63% | 0.37 | 0.08 | -0.29 | -78% | 455 | 151 | -305 | -67% |

| Repair Category | Model Year | ASM Mode | N | HC (ppm) | | | | CO (%) | | | | NOx (ppm) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Before Repair | After Repair | Change | | Before Repair | After Repair | Change | | Before Repair | After Repair | Change | |
| | | | | | | Conc. | (%) | | | Conc. | (%) | | | Conc. | (%) |
| Engine Mechanical | 1990-1999 | 2525 | 1,200 | 60 | 17 | -43 | -72% | 0.43 | 0.06 | -0.37 | -86% | 474 | 120 | -354 | -75% |
| Emissions System | 1990-1999 | 2525 | 23,691 | 72 | 24 | -48 | -67% | 0.47 | 0.09 | -0.38 | -81% | 806 | 208 | -598 | -74% |
| Emissions System & Misc | 1990-1999 | 2525 | 898 | 97 | 36 | -61 | -63% | 0.74 | 0.15 | -0.59 | -79% | 1,034 | 314 | -720 | -70% |
| Ignition/Electrical System | 1990-1999 | 2525 | 7,255 | 85 | 23 | -62 | -73% | 0.54 | 0.09 | -0.44 | -83% | 498 | 166 | -333 | -67% |
| Fuel System | 1990-1999 | 2525 | 11,049 | 48 | 16 | -33 | -67% | 0.37 | 0.06 | -0.31 | -83% | 374 | 129 | -245 | -65% |
| Fuel System & Emissions System | 1990-1999 | 2525 | 461 | 103 | 37 | -66 | -64% | 0.73 | 0.15 | -0.58 | -79% | 933 | 274 | -660 | -71% |
| Miscellaneous | post-2000 | 2525 | 51,151 | 0 | 0 | 0 | N/A | 0.00 | 0.00 | 0.00 | N/A | 0 | 0 | 0 | N/A |
| Engine Mechanical | post-2000 | 2525 | 2,219 | 0 | 0 | 0 | N/A | 0.00 | 0.00 | 0.00 | N/A | 1 | 0 | -1 | N/A |
| Emissions System | post-2000 | 2525 | 30,679 | 0 | 0 | 0 | N/A | 0.00 | 0.00 | 0.00 | N/A | 0 | 0 | 0 | N/A |
| Emissions System & Misc | post-2000 | 2525 | 557 | 0 | 0 | 0 | N/A | 0.00 | 0.00 | 0.00 | N/A | 0 | 0 | 0 | N/A |
| Ignition/Electrical System | post-2000 | 2525 | 10,765 | 0 | 0 | 0 | N/A | 0.00 | 0.00 | 0.00 | N/A | 0 | 0 | 0 | N/A |
| Fuel System | post-2000 | 2525 | 26,205 | 0 | 0 | 0 | N/A | 0.00 | 0.00 | 0.00 | N/A | 0 | 0 | 0 | N/A |
| Fuel System & Emissions System | post-2000 | 2525 | 351 | 0 | 0 | 0 | N/A | 0.00 | 0.00 | 0.00 | N/A! | 0 | 0 | 0 | N/A |

#### 4.2.1.2 Issues with the Repair Data in the TIMS and RERF Datasets

There are several issues with the repair data contained in both the TIMS and RERF datasets that make analysis difficult. Future changes in the way data is collected and stored may alleviate many of these issues. These issues are described below and are very similar to those listed in previous reports.

TIMS Dataset – The repair data in the TIMS is entered by the inspector performing the inspection; however, the motorist often does not bring the vehicle repair form for the reinspection and this leads to the inspector leaving this information blank. Usually, most repair entries in the TIMS are made by inspectors that either work in the same facility where the reinspection takes place or made the repairs themselves.

The TIMS repair data includes only five different repair types, and these types are too general to permit a detailed analysis of the data. These types include fuel system, ignition/electrical system, emissions system, engine mechanical, and miscellaneous. As listed in Table 4-1, "miscellaneous" repairs make up almost 40% of the reported repairs. The addition of more detailed repair types during the collection of data would allow for more specificity in analysis. Previously, the Texas I/M program did have a more detailed list of repair types. However, because the TCEQ believed that a large fraction of inspectors did not fill out the repair list correctly, the TCEQ adopted the simpler list which was used during this evaluation period. Accuracy and completeness of repair data is a common issue in I/M programs which attempt to collect repair data.

It is recommended that Texas consider increasing the number of repair categories in the analyzer software, and eliminating the "Miscellaneous" category since that does not provide any useful information. The repair choices that inspectors see and choose from should be only those that apply to the technology of the vehicle being inspected.

Another problem, described in the costs section below, exists in the reported values of repair costs. A large number of repairs with a cost of $0 exists in the dataset, along with some extremely high (greater than $2,000) costs as well. The source of these errors is not clear, but the erroneous costs make it difficult to comprehensively assess costs across the entire dataset.

**RERF Dataset** – The RERF data is obtained by the DPS from the repair shops using a repair summary sheet form that is different than the vehicle repair form a motorist gets when their vehicle fails an inspection. DPS often receives these forms via fax. Once received by DPS, this information is entered into the RERF database and is used to calculate repair effectiveness ratings for each facility in the program.

The RERF dataset, while very specific with respect to the type of repair performed, lacks cost information for each individual repair performed. Repair costs are only reported as a total of all repairs performed each time a particular vehicle reports to a RERF.

It should also be noted that while the RERF dataset contains extensive vehicle, facility, and cost information, no emissions data from I/M testing is available in it.

## 4.3 Overall Success of Repairs to Vehicles Failing OBD

The objective of this task was to determine whether vehicles failing the OBD inspection are being properly repaired. ERG performed an analysis of the TIMS data for OBD failures and the presence of an illuminated MIL and diagnostic trouble codes followed by a OBD pass (MIL commanded off and no DTCs) as an indicator that the I/M program is resulting in OBD repairs. In this analysis, it is assumed that an OBD fail result followed by an OBD pass result is due to vehicle repairs, although it's possible that some of the OBD fails followed by an OBD pass could result from intermittent problems, self-correcting problems (such as a loose gas cap that's tightened on a vehicle refuel) or an OBD problem that is masked by unset readiness monitors (i.e., through a battery disconnect) on a subsequent passing retest. This "masking" issue is analyzed in Section 4.4 of this report. This analysis is analogous to the tailpipe emissions changes observed with repairs in Section 4.2.

Since OBD test pass/fail results are not enforced on heavy-duty vehicles (vehicles over 8500 lbs GVWR), Class 2 vehicles were excluded from this analysis. This left a dataset of 13,790,603 OBD inspection records available for the analysis.

### Analysis and Results

For this task, ERG analyzed vehicle inspection records to identify tests with OBD failures, and then determine how many of those failures were subsequently corrected. To exclude initial test failures associated with readiness, test failures due to OBD/analyzer communication problems, and OBD tests failures converted to ASM tests, very specific definitions of OBD "fail" and "pass" were created. An OBD test failure was defined to be any test record with one or more stored DTCs, coinciding with the

OBD MIL command status of “on,” an OBD test disposition of “fail,” and an overall test disposition of “fail.” A passing result for an OBD test was defined as a downloaded OBD MIL commanded status of “off” and an OBD test disposition of “pass”. These definitions were needed in order to fully control the analysis of MIL status, but they did leave some inspections that did not qualify as either a full “fail” or a full “pass” (i.e., OBD test was passed but overall I/M test was failed, etc). These tests for which the OBD test was passed but the overall I/M test was failed were excluded from this analysis.

Next, all individual vehicle I/M cycles that contained at least one failed OBD test were identified. I/M cycles were defined to be a single test, or a series of tests, performed on a vehicle until the vehicle passed the overall inspection and received a certificate or until the vehicle received a waiver and a certificate (or until December 31, 2013, the end of the evaluation period). Thus, if a vehicle failed the initial OBD test, the I/M cycle for that vehicle would be the initial failure, and any and all subsequent tests, until the vehicle passed its inspection and received a certificate, until a waiver and certificate were granted, or until the end of the evaluation period. Once the vehicle was issued a certificate, its next test (most likely for the following year’s I/M inspection) would be a new I/M cycle. Any I/M cycles that began on or after October 1, 2013, were excluded from the analysis, since it would be possible that cycles starting so near the end of the date range of the dataset could have included additional re-inspections after December 31, 2013, and there would be no information for those inspections. Using these criteria, the dataset contained 11,447,874 I/M cycles that started before October 1, 2013.

After grouping by I/M cycle for vehicles with OBD failures (as previously defined), 145,195 I/M cycles were seen to include at least one failed OBD test. Of these cycles, 123,785 (85.3%) had a final OBD test disposition of “pass,” which for purposes of this analysis was defined as a test with a downloaded MIL status of “pass” (MIL commanded off) and an OBD test disposition of “pass.” The remaining 21,410 vehicles never passed a subsequent OBD test; for these vehicles it was learned that 16,416 of them received the initial failing result but did not ever report for a re-inspection. Additional re-inspections may have occurred after December 31 2013, which would increase the overall “repaired” numbers. Additionally, 520 of these vehicles received waivers.

It should be noted that the two allowed unset monitors could mask existing malfunctions in some of these repaired outcomes. The influence of this masking will be explored in Section 4.4.

## 4.4 Success of Repairs to Specific Emission Control Systems Failing OBD

For this analysis, diagnostic trouble codes were categorized based on the type of system they monitored, and using this categorization, ERG performed an analysis of repairs based on component categories, in order to determine if the program was resulting in effective emission control system repairs.

Analysis was performed on vehicles with DTC failures associated with oxygen sensors, exhaust gas recirculation systems, secondary air injection systems, catalyst efficiency, and evaporative emissions control system components.

### Analysis and Results

This task was performed as a continuation of the analysis in Section 4.3. It uses combinations of vehicles and I/M cycles defined in that section. However, for this task, failure modes were assigned based on the diagnostic trouble codes (DTCs) contained in the failed test records. In addition to analysis of test records with evaporative system failures, analyses were also performed to identify and quantify repairs for the following types of OBD failures listed below.  A list of DTCs that were included in each of these groups is given in Appendix A.

- Codes pertaining to insufficient oxygen sensor (O2 sensor) performance
- Codes pertaining to exhaust gas recirculation (EGR system) malfunctions
- Codes pertaining to secondary air injection system (AI system) malfunctions
- Codes pertaining to insufficient catalytic converter (catalyst) performance

These four additional categories of codes were included with this analysis because the “readiness status” of these systems, as well as the evaporative system, are specifically monitored by non-continuous monitors, and therefore the extent to which malfunctions may be masked by unset readiness monitors during a retest (which could result in a false pass) can be quantified. In this analysis, the extent of this potential masking is quantified along with the overall repair rates (as indicated by a fail test followed by a pass test).

For each of the failure categories, a failed inspection is defined as any inspection that contains at least one test record with stored DTCs, a downloaded OBD MIL commanded status of “on,” an OBD test disposition of “fail,” and an overall test disposition of “fail.” Passed inspections were those which had a final test in that I/M cycle with a downloaded MIL status of “pass” (not commanded on) and an OBD test disposition of “pass.”

To quantify the upper limit to which readiness may be masking unrepaired malfunctions during OBD retests, the following distinctions of “repaired” vehicles were made:

Total Repaired – This is the count of all vehicles that had at least one fail test with the final test classified as repaired. No regard is given to which (if any) monitors remain unset.

Repaired with Unset Monitors – This is the count of all “repaired” vehicles that have an unset monitor that may be masking the failure mode seen in the initial fail test. For example, if a vehicle fails for an evaporative system malfunction, then the evaporative system monitor is unset on the final “pass” test for this vehicle, thereby possibly masking an unrepaired evaporative system malfunction. Once this monitor becomes “ready”, any unrepaired malfunction would result in a stored evaporative system DTC and MIL re-illumination.

Confirmed Repaired – These are the vehicles whose monitors for which the initial failure occurred are “ready” in the final test, indicating that specific type of failure is not being masked by an “not-ready” monitor. Therefore, there is much higher confidence that these “confirmed repaired” vehicles are indeed properly repaired.

During this analysis of readiness status, some vehicles that failed for a certain system (e.g., EGR) were found to have a “not monitored” status for that monitored system (e.g., EGR not monitored). This is likely due to erroneous readiness status retrieved from certain vehicles and stored in that vehicle’s test record. Since by definition this is impossible (a system with a stored code must be monitored), this subset of results was classified as “ready.”

With regard to criteria used for categorizing “pass” and “fail” tests, it should also be noted that pending DTCs (also referred to as “soft” DTCs) are trouble codes that are insufficient for illuminating the MIL, generally because the number of successive repeat failures necessary for MIL illumination has not occurred. In accordance with the EPA guidance, vehicles are not failed for pending DTCs (stored DTCs but no MIL illumination) in the Texas program. Results from this repair analysis follows that strategy, and therefore only defines tests with MIL illumination and stored DTCs as "fail" tests, and only considers MIL illumination (without regard to stored DTCs) in determining whether a vehicle is successfully repaired.

Finally, it should be kept in mind that when reviewing repair analysis results, a failed OBD test record could contain more than one DTC. In Texas, up to 10 DTCs may be stored in the test record, and all stored DTCs were used for this analysis. Therefore, some vehicles will be included in more than one set of results. For example, repair results for vehicles with both oxygen sensor DTCs and catalytic converter DTCs will be included in both the oxygen sensor repair analysis and the catalytic converter repair analysis. Because of the inter-dependence of the various systems (e.g., an oxygen sensor failure may lead to a future catalytic converter failure), distinctions were not made regarding the number or types of DTCs in the original fail records. Rather, vehicles were categorized as "repaired" when the MIL was extinguished and the analyzer assigned an overall OBD pass result, regardless of the number or type of DTCs seen in the initial test failure.

Table 4-7 provides a summary of vehicle repairs (as indicated by OBD fails followed by OBD passes) performed over the period of evaluation. Since this analysis was performed on I/M data collected between January 1, 2012 through December 31, 2013, it is possible that some of the un-repaired vehicles were repaired in 2014. This would increase the "repaired" counts from the numbers shown in this table.

**Table 4-7. System Specific Repair Analysis for Vehicles**

| Type of Failure (DTC Category) | Total Vehicles Failed (with Indicated Failure Mode DTCs) | Total Repaired Vehicles (MIL Off) | | Repaired Vehicles with Failure Mode Monitors Not Yet Set | | Confirmed Repairs (Failure Mode Monitors Set) | |
|---|---|---|---|---|---|---|---|
| Evap System | 36,571 | 31,754 | 86.8% | 14,867 | 40.7% | 16,886 | 46.2% |
| O2 Sensor | 24,478 | 20,235 | 82.7% | 535 | 2.2% | 19,700 | 80.5% |
| EGR System | 15,982 | 13,182 | 82.5% | 1,320 | 8.3% | 11,862 | 74.2% |
| AI System | 2,184 | 1,761 | 80.6% | 268 | 12.3% | 1,493 | 68.4% |
| Catalyst | 30,688 | 25,721 | 83.8% | 4,960 | 16.2% | 20,761 | 67.7% |

As previously indicated, many vehicles were failed with more than one DTC. Therefore, results from some vehicles may be included in more than one category in

Table 4-7. Also, only categories directly monitored with non-continuous monitors are tabulated in Table 4-7. Other failure categories for which readiness status would be more difficult to assess are excluded from the table. Table 4-7 indicates that readiness status may be masking 2% to 41% of vehicles that pass OBD retests based on MIL status with these types of failures. I/M program modifications that would require confirmation of specific failure-mode monitors being set to "ready" would likely reduce the extent of potential false passes but at the expense of a potential increase in motorist inconvenience, especially for difficult to set monitors. ERG is not aware of any programs where this is currently performed.

A comparison was also made between OBD evaporative system results and gas cap test results, on a by-test basis, for all OBD tests conducted during the period of evaluation. Table 4-8 presents a summary of these results.

**Table 4-8. Comparison of OBD Evaporative Emission Control System Test Results with Gas Cap Test Results**

| **OBD Evap System Test Results** | **Gas Cap Test Result** | | | | **Total** | |
|---|---|---|---|---|---|---|
| | **Pass** | | **Fail** | | | |
| Pass | 13,316,694 | 98.3% | 76,130 | 0.6% | 13,392,824 | 98.9 |
| Fail | 148,912 | 1.1% | 3,148 | 0.02% | 152,060 | 1.1% |
| Total | 13,465,606 | 99.4% | 79,278 | 0.6% | 13,544,884 | 100.0% |

As can be seen from this table, approximately 0.9% of the tests had failed the OBD portion of the test with evaporative system DTCs, and gas cap failures were seen in 0.6% of the tests. The OBD evaporative system monitoring is designed to be a more comprehensive test since it assesses the integrity of the entire control system, but the OBD evaporative fail rate may be lowered in part by unset evaporative system readiness monitors. Evaporative systems generally require a fairly complex series of vehicle operating conditions before this monitor is set. Although most vehicles passed both tests, very few vehicles (0.02%) failed both tests. Allowable pressure decay limits may contribute to differences in fail rates of the two tests and the lack of overlap between the two tests.

## 4.5 Average Repair Costs

Both the TIMS and the RERF datasets contain costs for I/M program repairs. For both datasets, repair costs are manually entered. This information was analyzed to provide a rough estimate of the cost of vehicle repairs as a result of the I/M program.

### 4.5.1 TIMS Data

In order to estimate repair costs based on type of repair, repair categories were developed for each vehicle for a given I/M cycle. A repair category is a concatenation of the set of repair types performed in a repair event. In the TIMS data, the five different repairs types listed in Table 4-1 were combined to produce the seven most common repair categories, which account for approximately 98.8% of all vehicle and I/M cycle combinations. These categories are presented in Table 4-9.

Almost one-half (49.6%) of the repair costs in the TIMS were recorded as $0. There are several possible reasons for this, including inaccurate repair data entry during a vehicle reinspection, motorists performing their own repairs, lack of repair data available during a vehicle reinspection, or vehicles receiving a retest without receiving repairs. Because of the large number of repair records affected, no attempt was made to correct the costs as part of this analysis. Nonetheless, the existence of so many repair costs with a value of $0 significantly affected the average and median repair values calculated. Table 4-9 presents the number of records with a cost of $0 by repair category. It was observed that about 20-40 % of all categories listed contained $0 repair costs, but fuel system and miscellaneous repairs contained a much higher percentage (about 56.4% and 65.4%, respectively). All of these percentages are markedly higher than those observed in previous TIMS data analyses.

It was also noted than many of the repair costs listed in the TIMS data seemed to be unusually large; many records were in excess of $2000, with some as high as $100,000. It is suspected that these repair costs reflect invalid data entry by inspectors during vehicle reinspections. Figure 4-1 presents a histogram of repairs that cost more than $2000.

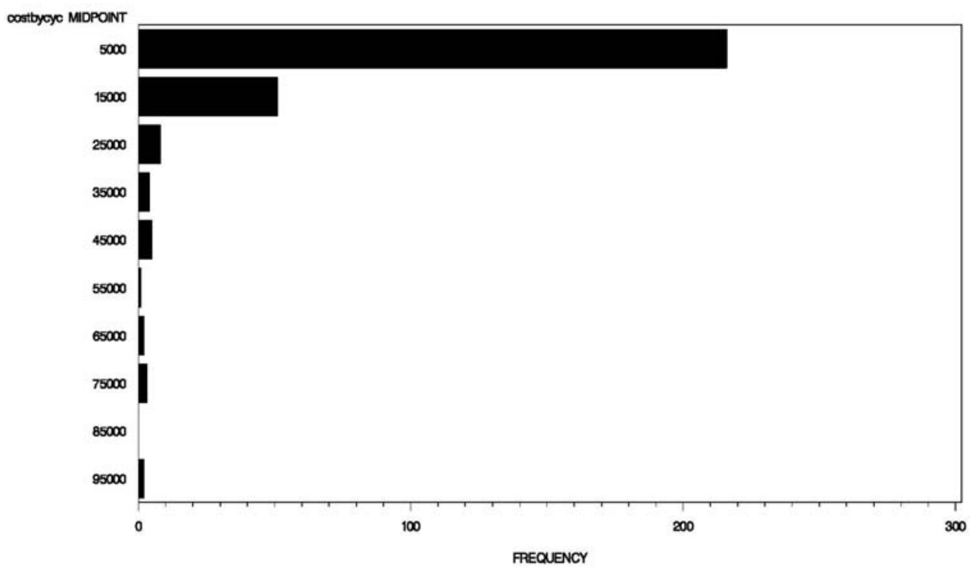
**Table 4-9. TIMS Records with a Repair Cost of $0, by Category**

| Repair Category | Cost > 0 | Cost = Zero | Total | % of Cost = 0 |
|---|---|---|---|---|
| Fuel System and Emissions System | 594 | 463 | 1,057 | 43.80 |
| Emissions System & Miscellaneous | 1,195 | 297 | 1,492 | 19.91 |
| Engine Mechanical | 2,576 | 1,253 | 3,829 | 32.72 |
| Ignition / Electrical System | 14,740 | 5,673 | 20,413 | 27.79 |
| Fuel System | 18,294 | 23,695 | 41,989 | 56.43 |
| Miscellaneous | 29,392 | 55,450 | 84,842 | 65.36 |
| Emissions System | 41,258 | 19,491 | 60,749 | 32.08 |
| Total (of Selected Repair Slates) | 10,8049 | 106,322 | 214,371 | 49.60 |

Table 4-10 presents median and mean repair costs for each of the repair types specified in the TIMS. Mean and median are calculated twice – once including the $0 and >$2000 repair costs found in the dataset (unedited), and once without (edited). According to the unedited dataset, vehicle owners performed 216,893 repairs while spending approximately $22.4 million. According to the edited dataset, which leaves out $0 cost and greater than 2,000 cost observations, vehicle owners performed 109,831 repairs while spending almost $20.0 million.

Figures 4-2 and 4-3 present mean repair costs by inspection year and model year, for both the unedited and edited TIMS datasets. There is a significant amount of variability in the unedited data when compared to the edited data. As shown by these plots, repair costs as a whole have not increased from year to year. Due to the limited control in repair data entry and the large number of suspect values in the TIMS repair data, these results may be significantly different from true repair costs in the Texas I/M program.

**Figure 4-1. Repairs with Cost Greater than $2000**




| costbycyc MIDPOINT | FREQ. | CUM. FREQ. | PCT. | CUM. PCT. |
|---|---|---|---|---|
| 5000 | 216 | 216 | 73.97 | 73.97 |
| 15000 | 51 | 267 | 17.47 | 91.44 |
| 25000 | 8 | 275 | 2.74 | 94.18 |
| 35000 | 4 | 279 | 1.37 | 95.55 |
| 45000 | 5 | 284 | 1.71 | 97.26 |
| 55000 | 1 | 285 | 0.34 | 97.60 |
| 65000 | 2 | 287 | 0.68 | 98.29 |
| 75000 | 3 | 290 | 1.03 | 99.32 |
| 85000 | 0 | 290 | 0.00 | 99.32 |
| 95000 | 2 | 292 | 0.68 | 100.00 |

## Table 4-10. Average Repair Costs

| Year of Inspection | Repair Category | Original Dataset | | | Costs Between $0 and $2000 | | |
|---|---|---|---|---|---|---|---|
| | | Number of Repairs | Median Repair Cost | Mean Repair Cost | Number of Repairs | Median Repair Cost | Mean Repair Cost |
| 2012 | Fuel System and Emissions System | 462 | $180 | $298 | 367 | $235 | $311 |
| 2012 | Emissions System & Miscellaneous | 850 | $150 | $281 | 688 | $185 | $241 |
| 2012 | Engine Mechanical | 1,943 | $120 | $223 | 1,289 | $200 | $284 |
| 2012 | Ignition / Electrical System | 10,869 | $90 | $144 | 7,738 | $125 | $178 |
| 2012 | Fuel System | 21,753 | $0 | $73 | 9,513 | $100 | $149 |
| 2012 | Miscellaneous | 33,090 | $120 | $182 | 15,313 | $40 | $92 |
| 2012 | Emissions System | 44,649 | $0 | $35 | 22,441 | $185 | $248 |
| 2013 | Fuel System and Emissions System | 370 | $150 | $237 | 273 | $220 | $296 |
| 2013 | Emissions System & Miscellaneous | 642 | $150 | $366 | 500 | $190 | $265 |
| 2013 | Engine Mechanical | 1,885 | $100 | $223 | 1,245 | $187 | $274 |
| 2013 | Ignition / Electrical System | 9,544 | $100 | $147 | 6,979 | $125 | $178 |
| 2013 | Fuel System | 20,233 | $0 | $76 | 8,727 | $90 | $150 |
| 2013 | Miscellaneous | 27,655 | $120 | $188 | 14,025 | $40 | $92 |
| 2013 | Emissions System | 40,191 | $0 | $37 | 18,709 | $180 | $250 |

**Figure 4-2. Mean Repair Costs by Model Year and Inspection Year (Unedited Dataset)**

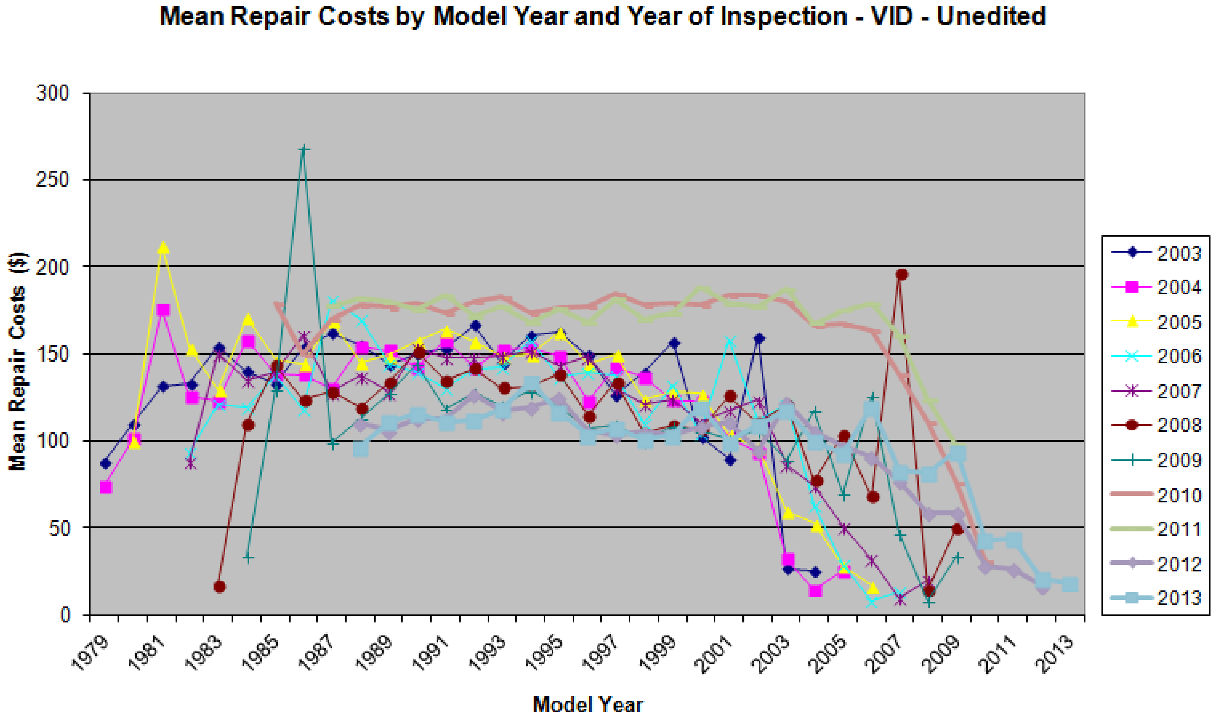
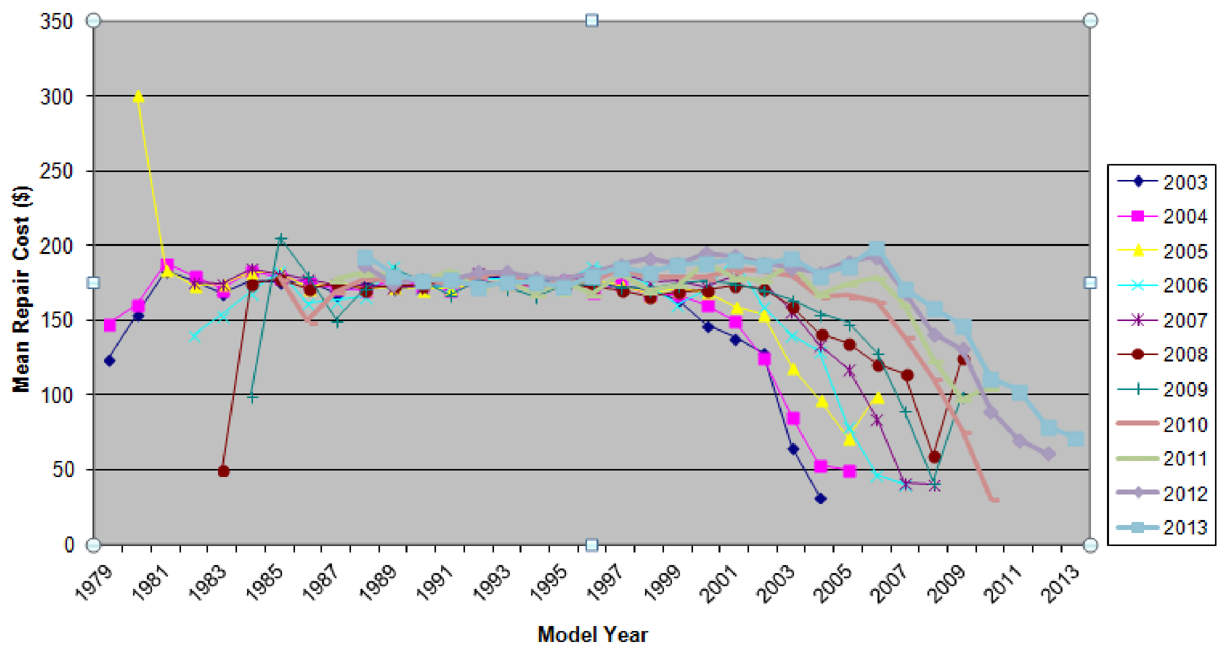



**Figure 4-3. Mean Repair Costs by Model Year and Inspection Year (Edited Dataset)**



Figures 4-4 and 4-5 present the percentile distribution of repair costs for the most common TIMS repair categories, for both the unedited and edited datasets. The unedited data contains repairs with an average cost of $0 for all repair slates, but miscellaneous repairs costing $0 extend close to the 70th percentile, considerably more than the other categories.

For both datasets, the range of average costs was most limited for miscellaneous repairs, while the greatest variation in average costs was visible in repairs performed on both the fuel and emissions systems.

**Figure 4-4. Distribution of Repair Costs by Category (Unedited Dataset)**

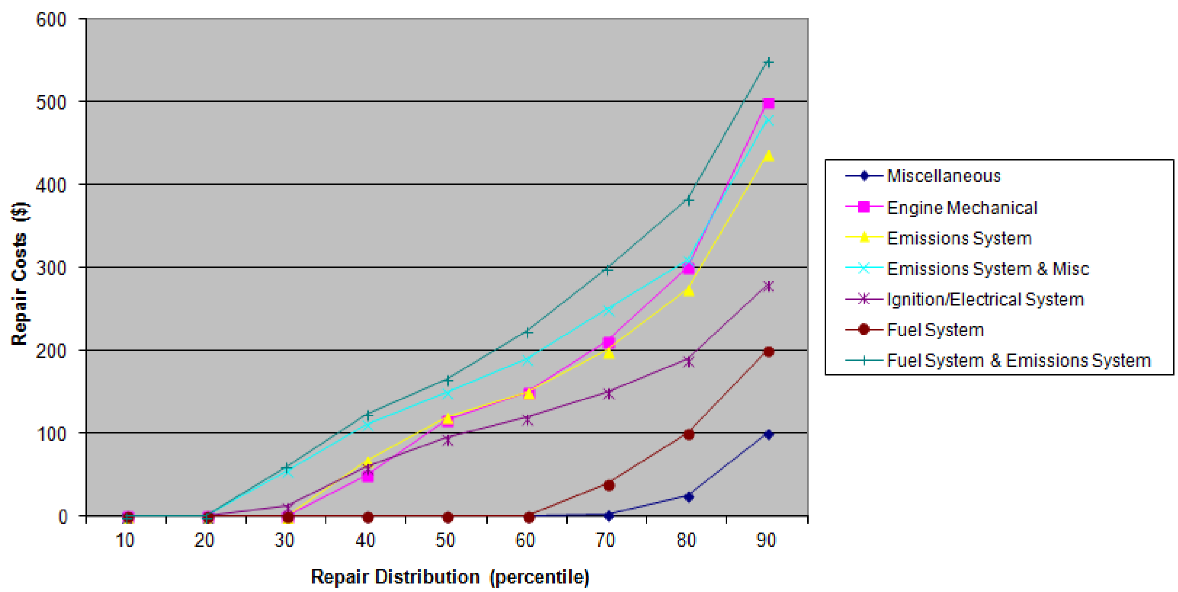
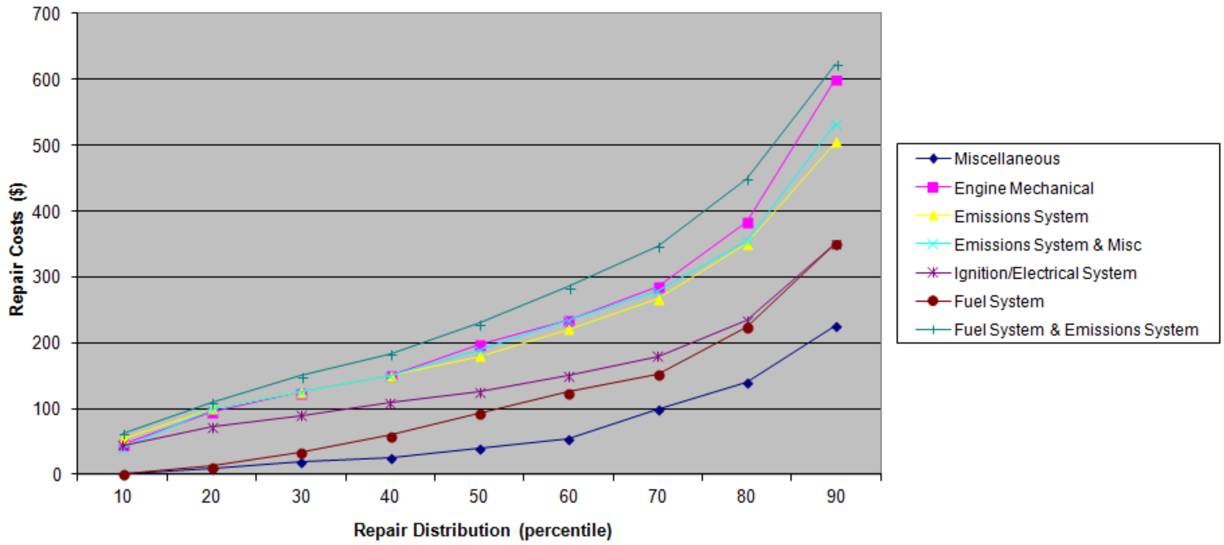


**Figure 4-5. Distribution of Repair Costs by Category (Edited Dataset)**




### 4.5.2 RERF Data

Analysis of the RERF data indicates vehicle owners spent over $3.7 million on 5,154 repairs at RERFs, resulting in mean and median repair costs of $630 and $750, respectively. These results were obtained from data collected from repair summary data submitted to DPS by repair shops participating in the recognized repair facility program.

In order to estimate repair costs based on type of repair, repair categories (referred to as repair slates) were developed for each vehicle for a given I/M cycle. As with the TIMS data analysis, a repair category is a concatenation of the set of repair types performed in a repair event. In the RERF data, the different repair types listed in Table 4-2 were combined to produce the thirteen most common repair slates. To simplify the aggregation of individual repairs into meaningful repair slates, some repairs were combined into a single “sub-category”. The most common repair categories observed are presented in Table 4-11.

**Table 4-11. Common RERF Repair Categories**

| Repair Category | Frequency | Percent |
|---|---|---|
| Catalyst & EGR | 15 | 0.47 |
| Transmission | 20 | 0.63 |
| Ignition/Electrical System | 23 | 0.73 |
| Injection System & Catalyst | 23 | 0.73 |
| PCM | 30 | 0.95 |
| O2 Sensor & Catalyst | 34 | 1.08 |

| **Repair Category** | **Frequency** | **Percent** |
|---|---|---|
| Fuel System | 35 | 1.11 |
| Emissions System | 39 | 1.23 |
| O2 Sensor | 69 | 2.18 |
| EGR | 76 | 2.41 |
| Evap System | 78 | 2.47 |
| Catalyst | 144 | 4.56 |
| Other Repair Slates | 2,574 | 81.46 |

Table 4-12 presents median and mean repair costs for each of the repair slates developed using data in the RERF dataset. Note that PCM mean repair costs are extraordinarily high due to an outlier.

**Table 4-12. RERF Repair Category Average Costs**

| **Year of Inspection** | **Repair Category** | **Number of Repairs** | **Median Repair Cost** | **Mean Repair Cost** |
|---|---|---|---|---|
| 2012 | Catalyst | 119 | $638 | $698 |
| 2012 | Catalyst & EGR | 9 | $635 | $734 |
| 2012 | EGR | 50 | $510 | $484 |
| 2012 | Emissions System | 33 | $534 | $481 |
| 2012 | Evap System | 61 | $483 | $452 |
| 2012 | Fuel System | 24 | $521 | $442 |
| 2012 | Ignition/Electrical System | 20 | $615 | $546 |
| 2012 | Injection System & Catalyst | 20 | $630 | $638 |
| 2012 | O2 Sensor | 57 | $575 | $485 |
| 2012 | O2 Sensor & Catalyst | 25 | $661 | $730 |
| 2012 | Other Repair Slates | 1,151 | $630 | $648 |
| 2012 | PCM | 24 | $652 | $17,846 |
| 2012 | Transmission | 17 | $631 | $1,010 |
| 2013 | Catalyst | 17 | $700 | $786 |
| 2013 | Catalyst & EGR | 2 | $532 | $532 |
| 2013 | EGR | 11 | $472 | $447 |
| 2013 | Emissions System | 4 | $243 | $343 |
| 2013 | Evap System | 12 | $350 | $408 |
| 2013 | Fuel System | 8 | $585 | $532 |
| 2013 | Ignition/Electrical System | 1 | $566 | $566 |
| 2013 | Injection System & Catalyst | 3 | $610 | $631 |
| 2013 | O2 Sensor | 10 | $345 | $360 |
| 2013 | O2 Sensor & Catalyst | 7 | $628 | $673 |
| 2013 | Other Repair Slates | 883 | $630 | $654 |
| 2013 | PCM | 5 | $189 | $308 |
| 2013 | Transmission | 3 | $625 | $639 |

Figure 4-6 presents mean repair costs by inspection year and model year, for the RERF TIMS dataset. Average repair costs tend to fall in the $400 - $650 range, which is significantly higher than the $150 - $175 range seen in the TIMS data. Note that this data has been corrected for a spike of approximately $4,150 average repair costs for 1999 model year vehicles in the 2012 inspection year. The median value of $630 was used instead. Also, note that inspection year 2013 repair costs are quite a bit more "noisy" than other years.

**Figure 4-6. Mean Repair Costs by Model Year and Inspection Year – RERF**

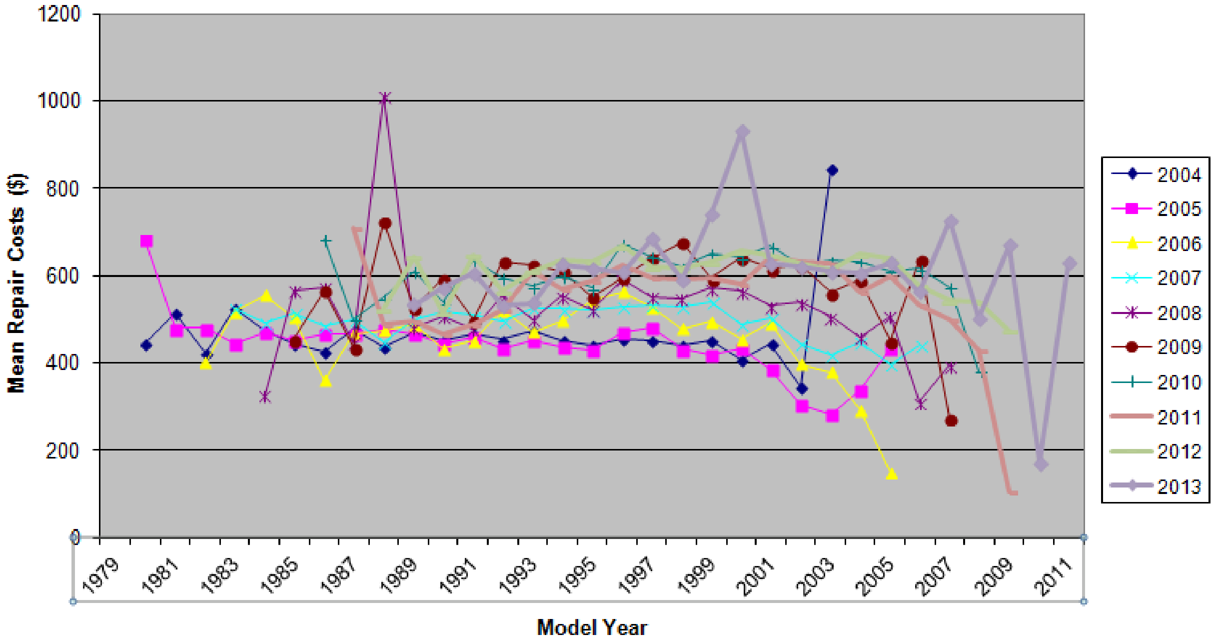
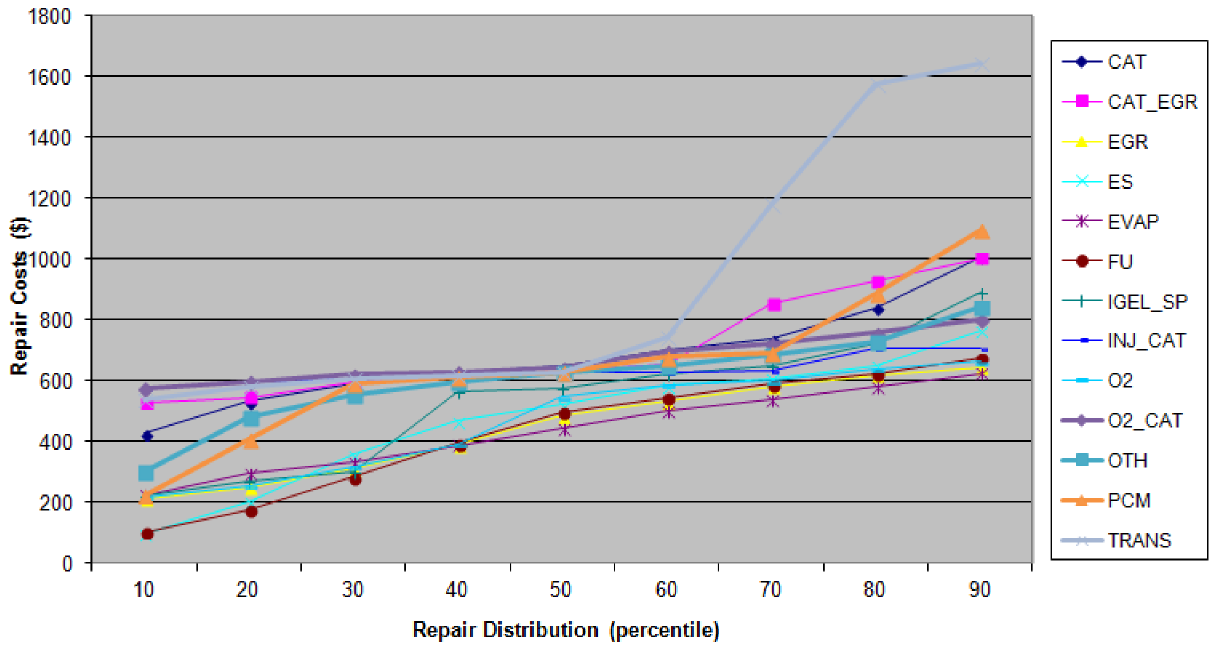



Figure 4-7 presents the percentile distribution of repair costs for the most common RERF repair slates. Transmission repair costs are a clear outlier here, and may be attributable to the outlier model 1999 costs mentioned above.

**Figure 4-7. Distribution of Repair Costs by Category - RERF.**




There is a large difference in the TIMS vs. RERF average repair cost data. As noted, obtaining accurate repair data is difficult and this certainly contributes to the problem. However, another explanation may be that the repair costs for RERF stations is higher than average repair stations since these stations voluntarily participate in the RERF program and, therefore, are more likely to make repairs that are more technically challenging and, more expensive. It is also possible that the inspection technicians are less likely to enter accurate repair cost data because unlike the RERF technicians they have no first-hand knowledge of the repair and the RERF technicians realize that repair cost data is used to rank their facility and this motivates them to be more conscientious in filling out the repair form.

# 5.0 Estimates of I/M Benefits

The Annual Benefit is the size of the fleet's "saw tooth" emissions profile that occurs during each cycle as the vehicles in the fleet are repeatedly inspected and repaired. The saw tooth is produced for each vehicle by the annual change in emissions downward from I/M-induced repair and then upward from emissions degradation during the long period before the next I/M cycle. The analyses presented in Sections 5.1 and 5.2 are annual benefits based on the TIMS data alone (Section 5.1) or pairing the TIMS data with remote sensing (RS) data (Section 5.2).

## 5.1 Estimate of Annual I/M Benefit from TIMS Data

ERG used two years of the TIMS data to calculate the Annual Benefit of the I/M program. Although using TIMS or in-program data is often done for estimating the Annual I/M Benefit, the approach has at least two inherent problems, which are described below. In spite of these problems, the TIMS data was used to estimate the Annual I/M Benefit because it is relatively easy to do.

The first problem is a consequence of using the fast-pass ASM algorithm in the I/M program. When the vehicle passes the final test of its annual I/M sequence, the ASM test is a fast-pass test instead of a full-duration ASM test. It is known from analysis of ASM data that fast-pass ASM values tend to be higher than the emissions values that are ultimately achieved using a full-duration ASM test. Therefore, the change in emissions caused by the repair is underestimated when fast-pass tests from the end of the I/M sequence are used for estimating program benefits. ERG has built models that attempt to predict full-duration ASM test values from fast-pass ASM values. While models can be built, there remains a large amount of uncertainty in the predicted full-duration ASM value. Therefore, the TIMS ASM test values have not been corrected for fast passes. Accordingly, the calculated benefit of I/M-induced repairs tends to underestimate the program's true emissions reduction.

The other source of bias is produced by regression toward the mean. Because of the emissions variability of the ASM measurements, vehicles that fail the ASM test tend to have a positive random error component in their measured ASM emissions values. This means that the calculated average difference between the before-repair test value and the after-repair test value for the dataset will almost always show a decrease even if the repairs produced no real emissions benefit. For this analysis, there was no correction made for this regression-toward-the-mean effect. Accordingly, regression toward the mean tends to overestimate the calculated benefit of I/M-induced repairs.

The TIMS contains emissions measurements obtained from a vehicle when it first is inspected for its annual inspection and emissions measurements after it has been repaired and meets the Texas I/M requirements. The difference between these two emissions can be expected to represent the improvement in emissions as a result of the repairs. The sum of all of these emissions changes for all vehicles that received repairs are an estimate of the Annual I/M Benefit using in-program data. Note that this difference is measured by the difference in emissions before and after the I/M inspection. Therefore, it represents the change in emissions concentration only at the inspection event. It does not measure the increase in emissions caused by emissions degradation between annual inspection cycles.

Four I/M sequence categories were considered in this analysis. All the various failure patterns described in Section 3.3 were combined into these four categories for the purposes of calculating the Annual I/M Benefit. The I/M sequence categories are as follows:

- Single Pass (1P) – A vehicle completes its annual I/M requirement with a pass on the first inspection.
- Single Fail (1F) – A vehicle receives a single inspection, and it is a fail. The dataset does not contain any evidence that the vehicle returns or any information that it may have been waivered.
- Initial Fail, then Final Fail (FF) – A vehicle fails its first annual emissions inspection and then, perhaps after a series of repairs and re-inspections, fails its last annual inspection. Waivers are flagged separately, but are not removed from these calculations.
- Initial Fail, then Final Pass (FP) – A vehicle fails its first annual emissions inspection and then ultimately passes its last annual inspection to meet the I/M requirements.

The largest numbers of sequences in the evaluation period were 1Ps since most vehicles pass their initial ASM inspection each year. 1Ps make up about 94.6% of all sequences. The FP sequences are the next most common and make up about 4.6% of all sequences. The 1F and FF sequences are less common and make up 0.5% and 0.04% of the sequences. Since vehicles with 1P and 1F sequences are tested only initially (because there is only one test), the final emissions values equal the initial emissions values.

Consequently, vehicles with 1P and 1F sequences do not contribute to the calculated Annual I/M Benefit. The vehicles with FF sequences do have different values for the initial and final average emissions; however, the values are not greatly different, which is probably because repairs to these vehicles were not entirely successful.

ERG calculated the average emission values using completed I/M cycles and presented the results in various ways. Tables 5-1 and 5-2 document the average emission concentration values for ASM and TSI tests, respectively, in both the DFW and HGB I/M program areas during this evaluation period (2014 report covering 2012 and 2013 program years). The values also show the measured average change in emissions concentrations at the inspection events. In the last row of each table it can be seen that ASM HC decreased 12 to 16%, ASM CO decreased 25 to 29%, ASM $NO_x$ decreased 15 to 17%, TSI HC decreased 18 to 20%, and TSI CO decreased 21 to 25%. As described above, these changes are confounded by the effects of the fast-pass algorithm (which tends to underestimate the program's emission reduction) and by regression toward the mean (which tends to overestimate the program's emission reduction). These averages include all four of the I/M sequence categories of 1P, 1F, FF and FP, but the focus of the analysis below is on the 1P and FP categories as they constitute the great majority of the data.

The second block of data in each of Tables 5-1 and 5-2 shows the emissions averages for the two I/M program areas categorized by the two major I/M sequence categories, 1P and FP. These two categories make up over 98% of the I/M sequences in the datasets. The table shows that, of course, for the 1P category the change in emissions is 0% since these vehicles simply initially pass. However, for the FP category, the ASM measurements and TSI measurements show large emissions decreases from 62 to 88%. These are emission reductions of the vehicles that were failing when they entered the sequence, were repaired, and left the sequence as passing vehicles. Thus, these vehicles are the source of the Annual I/M Benefit. The apparent changes in the emissions concentrations as a result of repair are substantial for the FP sequences. The remaining blocks of data in the tables show that the emissions average concentrations and emissions reductions for DFW and HGB have approximately the same values.

Another observation that can be made from the data in Tables 5-1 and 5-2 is that the final concentrations of the FP vehicles are comparable to, but slightly larger than, the final concentrations of the 1P vehicles. This seems to indicate that vehicles that fail initially can be repaired to produce large emissions reductions, but as a group, they cannot be repaired to emission levels as low as vehicles that initially pass. One of the factors that complicate this comparison is that the technologies of the 1P vehicles and FP vehicles are probably quite different. Tables 5-3 and 5-4 contain these same values from the 2012 Report (covering 2010 and 2011 program years) and are included here as a point of reference. Tables 5-5 and 5-6 contain these same values from the 2009 report (covering 2007 and 2008 program years), and tables 5-7 and 5-9 contain these same values from the 2006 report (covering 2004 and 2005 program years). In general, the emission percent reduction values were largest in the 2006 Report, and slightly larger in the 2009 report than in the 2012 report. The new results in this current report are very similar to the 2012 results, or slightly lower for some pollutants. It is possible this could be because the I/M program has been effectively encouraging owners to maintain their vehicles over the years, but has possibly reached a plateau in the achievement of additional reductions. However, additional analyses would be needed to verify that this is indeed the cause for this observation.

**Table 5-1. 2014 Report Annual I/M Benefit Using TIMS Data for ASM Emissions**

| **ASM HC (ppm)** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | **5015** | | | **2525** | | |
| **Area** | **Seq.** | **Count** | **Initial** | **Final** | **% Change** | **Initial** | **Final** | **% Change** |
| DFW | 1P | 312,423 | 65.4 | 65.4 | 0.0% | 42.4 | 42.4 | 0.0% |
| | FP | 32,878 | 162.8 | 63.6 | -60.9% | 143.0 | 46.6 | -67.4% |
| | 1P+FP | 352,673 | 77.3 | 68.3 | -11.7% | 54.6 | 45.9 | -16.0% |
| HGB | 1P | 281,083 | 61.6 | 61.6 | 0.0% | 40.5 | 40.5 | 0.0% |
| | FP | 23,765 | 170.0 | 60.8 | -64.3% | 150.8 | 44.2 | -70.7% |
| | 1P+FP | 309,856 | 71.9 | 63.7 | -11.4% | 51.0 | 43.0 | -15.6% |
| DFW & HGB | 1P | 593,506 | 63.6 | 63.6 | 0.0% | 41.5 | 41.5 | 0.0% |
| | FP | 56,643 | 165.9 | 62.4 | -62.4% | 146.3 | 45.6 | -68.9% |
| | 1P+FP | 662,529 | 74.8 | 66.2 | -11.5% | 52.9 | 44.5 | -15.9% |
| **ASM CO (%)** | | | | | | | | |
| DFW | 1P | 312,423 | 0.20 | 0.20 | 0.0% | 0.15 | 0.15 | 0.0% |
| | FP | 32,878 | 1.02 | 0.20 | -80.1% | 0.96 | 0.16 | -82.8% |
| | 1P+FP | 352,673 | 0.30 | 0.23 | -24.8% | 0.25 | 0.17 | -29.7% |
| HGB | 1P | 281,083 | 0.19 | 0.19 | 0.0% | 0.14 | 0.14 | 0.0% |
| | FP | 23,765 | 1.07 | 0.19 | -82.7% | 1.03 | 0.15 | -85.1% |
| | 1P+FP | 309,856 | 0.27 | 0.21 | -24.3% | 0.23 | 0.16 | -28.9% |
| DFW & HGB | 1P | 593,506 | 0.20 | 0.20 | 0.0% | 0.15 | 0.15 | 0.0% |
| | FP | 56,643 | 1.04 | 0.20 | -81.2% | 0.99 | 0.16 | -83.8% |
| | 1P+FP | 662,529 | 0.29 | 0.22 | -24.6% | 0.24 | 0.17 | -29.3% |
| **ASM NOx (ppm)** | | | | | | | | |
| DFW | 1P | 312,423 | 473 | 473 | 0.0% | 355 | 355 | 0.0% |
| | FP | 32,878 | 1485 | 492 | -66.9% | 1320 | 397 | -70.0% |
| | 1P+FP | 352,673 | 586 | 495 | -15.5% | 463 | 379 | -18.2% |
| HGB | 1P | 281,083 | 443 | 443 | 0.0% | 336 | 336 | 0.0% |
| | FP | 23,765 | 1422 | 455 | -68.0% | 1278 | 360 | -71.8% |
| | 1P+FP | 309,856 | 530 | 457 | -13.7% | 419 | 350 | -16.4% |
| DFW & HGB | 1P | 593,506 | 459 | 459 | 0.0% | 346 | 346 | 0.0% |

| ASM HC (ppm) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 5015 | | | 2525 | | |
| Area | Seq. | Count | Initial | Final | % Change | Initial | Final | % Change |
| | FP | 56,643 | 1459 | 476 | -67.3% | 1303 | 381 | -70.7% |
| | 1P+FP | 662,529 | 560 | 477 | -14.7% | 443 | 366 | -17.4% |

## Table 5-2. 2014 Report Annual I/M Benefit Using TIMS Data for TSI Emissions

| TSI HC (ppm) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Curb | | | High | | |
| Area | Seq. | Count | Initial | Final | % Change | Initial | Final | % Change |
| DFW | 1P | 51,466 | 79.8 | 79.8 | 0.0% | 42.6 | 42.6 | 0.0% |
| | FP | 4,680 | 534.3 | 93.6 | -82.5% | 337.6 | 54.6 | -83.8% |
| | 1P+FP | 56,888 | 107.8 | 88.6 | -17.9% | 61.3 | 49.1 | -19.9% |
| HGB | 1P | 37,458 | 78.8 | 78.8 | 0.0% | 42.3 | 42.3 | 0.0% |
| | FP | 2,734 | 562.0 | 89.5 | -84.1% | 323.1 | 51.7 | -84.0% |
| | 1P+FP | 40,687 | 106.8 | 86.5 | -19.0% | 58.6 | 47.1 | -19.6% |
| DFW & HGB | 1P | 88,924 | 79.4 | 79.4 | 0.0% | 42.5 | 42.5 | 0.0% |
| | FP | 7,414 | 545.8 | 92.1 | -83.1% | 331.6 | 53.5 | -83.9% |
| | 1P+FP | 97,575 | 107.4 | 87.7 | -18.3% | 60.2 | 48.3 | -19.8% |
| **TSI CO (%)** | | | | | | | | |
| DFW | 1P | 51,466 | 0.19 | 0.19 | 0.0% | 0.21 | 0.21 | 0.0% |
| | FP | 4,680 | 1.87 | 0.24 | -87.3% | 1.61 | 0.25 | -84.7% |
| | 1P+FP | 56,888 | 0.29 | 0.22 | -24.5% | 0.29 | 0.23 | -20.5% |
| HGB | 1P | 37,458 | 0.20 | 0.20 | 0.0% | 0.21 | 0.21 | 0.0% |
| | FP | 2,734 | 2.11 | 0.24 | -88.5% | 1.68 | 0.24 | -85.7% |
| | 1P+FP | 40,687 | 0.30 | 0.22 | -26.7% | 0.29 | 0.23 | -21.5% |
| DFW & HGB | 1P | 88,924 | 0.19 | 0.19 | 0.0% | 0.21 | 0.21 | 0.0% |
| | FP | 7,414 | 1.97 | 0.24 | -87.9% | 1.64 | 0.24 | -85.1% |
| | 1P+FP | 97,575 | 0.30 | 0.22 | -25.4% | 0.29 | 0.23 | -20.9% |

## Table 5-3. 2012 Report Annual I/M Benefit Using TIMS Data for ASM Emissions

| ASM HC (ppm) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 5015 | | | 2525 | | |
| Area | Seq. | Count | Initial | Final | % Change | Initial | Final | % Change |
| DFW | 1P | 477,748 | 64.76 | 64.76 | 0.00 | 42.10 | 42.10 | 0.00 |
| | FP | 51,133 | 166.90 | 62.92 | -62.30 | 146.87 | 45.91 | -68.74 |
| | 1P+FP | 540,337 | 77.43 | 67.79 | -12.45 | 54.91 | 45.57 | -17.02 |
| HGB | 1P | 409,231 | 61.98 | 61.98 | 0.00 | 40.79 | 40.79 | 0.00 |
| | FP | 38,895 | 161.94 | 60.12 | -62.88 | 144.67 | 43.59 | -69.87 |
| | 1P+FP | 457,187 | 72.97 | 64.44 | -11.69 | 52.07 | 43.62 | -16.24 |
| DFW & HGB | 1P | 886,979 | 63.48 | 63.48 | 0.00 | 41.49 | 41.49 | 0.00 |
| | FP | 90,028 | 164.75 | 61.71 | -62.54 | 145.91 | 44.91 | -69.22 |
| | 1P+FP | 997,524 | 75.38 | 66.26 | -12.11 | 53.61 | 44.67 | -16.67 |
| **ASM CO (%)** | | | | | | | | |
| DFW | 1P | 477,748 | 0.203 | 0.203 | 0.00 | 0.147 | 0.147 | 0.00 |
| | FP | 51,133 | 1.060 | 0.204 | -80.78 | 1.036 | 0.165 | -84.05 |
| | 1P+FP | 540,337 | 0.305 | 0.226 | -26.03 | 0.253 | 0.172 | -31.93 |
| HGB | 1P | 409,231 | 0.193 | 0.193 | 0.00 | 0.145 | 0.145 | 0.00 |
| | FP | 38,895 | 1.106 | 0.188 | -82.98 | 1.080 | 0.156 | -85.55 |

| ASM HC (ppm) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | **5015** | | | **2525** | | |
| **Area** | **Seq.** | **Count** | **Initial** | **Final** | **% Change** | **Initial** | **Final** | **% Change** |
| | 1P+FP | 457,187 | 0.289 | 0.212 | -26.57 | 0.244 | 0.167 | -31.69 |
| DFW & HGB | 1P | 886,979 | 0.198 | 0.198 | 0.00 | 0.146 | 0.146 | 0.00 |
| | FP | 90,028 | 1.080 | 0.197 | -81.75 | 1.055 | 0.161 | -84.72 |
| | 1P+FP | 997,524 | 0.298 | 0.219 | -26.27 | 0.249 | 0.170 | -31.82 |
| ASM NOx (ppm) | | | | | | | | |
| DFW | 1P | 477,748 | 472.77 | 472.77 | 0.00 | 355.73 | 355.73 | 0.00 |
| | FP | 51,133 | 1467.22 | 491.20 | -66.52 | 1,306.02 | 393.42 | -69.88 |
| | 1P+FP | 540,337 | 584.82 | 494.10 | -15.51 | 462.93 | 378.18 | -18.31 |
| HGB | 1P | 409,231 | 461.37 | 461.37 | 0.00 | 351.51 | 351.51 | 0.00 |
| | FP | 38,895 | 1441.50 | 472.61 | -67.21 | 1,292.90 | 378.06 | -70.76 |
| | 1P+FP | 457,187 | 559.31 | 477.93 | -14.55 | 445.48 | 368.69 | -17.24 |
| DFW & HGB | 1P | 886,979 | 467.51 | 467.51 | 0.00 | 353.78 | 353.78 | 0.00 |
| | FP | 90,028 | 1456.08 | 483.17 | -66.82 | 1,300.34 | 386.78 | -70.26 |
| | 1P+FP | 997,524 | 573.13 | 486.69 | -15.08 | 454.93 | 373.83 | -17.83 |

### Table 5-4. 2012 Report Annual I/M Benefit Using TIMS Data for TSI Emissions

| TSI HC (ppm) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | **Curb** | | | **High** | | |
| **Area** | **Seq.** | **Count** | **Initial** | **Final** | **% Change** | **Initial** | **Final** | **% Change** |
| DFW | 1P | 65,371 | 81.65 | 81.65 | 0.00 | 43.76 | 43.76 | 0.00 |
| | FP | 6,137 | 544.39 | 93.74 | -82.78 | 325.24 | 54.17 | -83.34 |
| | 1P+FP | 72,472 | 111.86 | 90.28 | -19.29 | 62.35 | 49.37 | -20.82 |
| HGB | 1P | 50,582 | 79.34 | 79.34 | 0.00 | 43.07 | 43.07 | 0.00 |
| | FP | 3,845 | 560.32 | 90.86 | -83.78 | 332.93 | 52.79 | -84.14 |
| | 1P+FP | 55,123 | 109.45 | 87.73 | -19.84 | 61.04 | 48.18 | -21.06 |
| DFW & HGB | 1P | 115,953 | 80.64 | 80.64 | 0.00 | 43.46 | 43.46 | 0.00 |
| | FP | 9,982 | 551.21 | 92.64 | -83.19 | 328.53 | 53.64 | -83.67 |
| | 1P+FP | 127,595 | 110.81 | 89.18 | -19.52 | 61.78 | 48.86 | -20.92 |
| **TSI CO (%)** | | | | | | | | |
| DFW | 1P | 65,371 | 0.203 | 0.203 | 0.00 | 0.217 | 0.217 | 0.00 |
| | FP | 6,137 | 2.028 | 0.254 | -87.47 | 1.678 | 0.263 | -84.31 |
| | 1P+FP | 72,472 | 0.320 | 0.235 | -26.47 | 0.310 | 0.242 | -21.73 |
| HGB | 1P | 50,582 | 0.205 | 0.205 | 0.00 | 0.214 | 0.214 | 0.00 |
| | FP | 3,845 | 2.061 | 0.263 | -87.24 | 1.699 | 0.252 | -85.18 |
| | 1P+FP | 55,123 | 0.316 | 0.233 | -26.36 | 0.303 | 0.236 | -22.22 |
| DFW & HGB | 1P | 115,953 | 0.204 | 0.204 | 0.00 | 0.215 | 0.215 | 0.00 |
| | FP | 9,982 | 2.042 | 0.258 | -87.38 | 1.687 | 0.259 | -84.66 |
| | 1P+FP | 127,595 | 0.319 | 0.234 | -26.42 | 0.307 | 0.239 | -21.93 |

## Table 5-5. 2009 Report Annual I/M Benefit Using TIMS Data for ASM Emissions

| ASM HC (ppm) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 5015 | | | 2525 | | |
| **Area** | **Seq.** | **Count** | **Initial** | **Final** | **% Change** | **Initial** | **Final** | **% Change** |
| DFW | 1P | 1,242,445 | 65.63 | 64.63 | 1.52% | 40.52 | 40.52 | 0.00% |
| | FP | 114,413 | 179.68 | 65.49 | 63.55% | 155.22 | 46.44 | 70.08% |
| | 1P+FP | 1,356,858 | 74.33 | 64.70 | 12.95% | 50.19 | 41.02 | 18.28% |
| HGB | 1P | 100,998 | 64.94 | 64.94 | 0.00% | 41.30 | 41.30 | 0.00% |
| | FP | 92,806 | 181.38 | 66.04 | 63.59% | 156.80 | 46.73 | 70.20% |
| | 1P+FP | 1,093,804 | 74.82 | 65.03 | 13.08% | 51.10 | 41.76 | 18.27% |
| DFW & HGB | 1P | 2,243,443 | 64.77 | 64.77 | 0.00% | 40.87 | 40.87 | 0.00% |
| | FP | 207,219 | 180.44 | 65.73 | 63.57% | 155.93 | 46.57 | 70.13% |
| | 1P+FP | 2,450,662 | 74.55 | 64.85 | 13.01% | 50.60 | 41.35 | 18.28% |
| **ASM CO (%)** | | | | | | | | |
| DFW | 1P | 1,242,445 | 0.195 | 0.195 | 0.00% | 0.132 | 0.132 | 0.00% |
| | FP | 114,413 | 1.114 | 0.205 | 81.55% | 1.047 | 0.160 | 84.76% |
| | 1P+FP | 1,356,858 | 0.272 | 0.196 | 28.13% | 0.209 | 0.134 | 35.77% |
| HGB | 1P | 100,998 | 0.192 | 0.192 | 0.00% | 0.133 | 0.133 | 0.00% |
| | FP | 92,806 | 1.106 | 0.201 | 81.86% | 1.043 | 0.158 | 84.88% |
| | 1P+FP | 1,093,804 | 0.269 | 0.193 | 28.51% | 0.210 | 0.135 | 35.75% |
| DFW & HGB | 1P | 2,243,443 | 0.193 | 0.193 | 0.00% | 0.132 | 0.132 | 0.00% |
| | FP | 207,219 | 1.110 | 0.203 | 81.69% | 1.045 | 0.159 | 84.81% |
| | 1P+FP | 2,450,662 | 0.271 | 0.194 | 28.30% | 0.210 | 0.135 | 35.76% |
| **ASM NOx (ppm)** | | | | | | | | |
| DFW | 1P | 1,242,445 | 434.52 | 434.52 | 0.00% | 307.34 | 307.34 | 0.00% |
| | FP | 114,413 | 1297.32 | 462.90 | 64.32% | 1,088.42 | 351.34 | 67.72% |
| | 1P+FP | 1,356,858 | 507.27 | 436.91 | 13.87% | 373.20 | 311.05 | 16.65% |
| HGB | 1P | 100,998 | 432.88 | 432.88 | 0.00% | 311.56 | 311.56 | 0.00% |
| | FP | 92,806 | 1261.82 | 463.48 | 63.27% | 1061.95 | 352.96 | 66.76% |
| | 1P+FP | 1,093,804 | 503.21 | 435.47 | 13.46% | 375.23 | 315.07 | 16.03% |
| DFW & HGB | 1P | 2,243,443 | 433.79 | 433.79 | 0.00% | 309.22 | 309.22 | 0.00% |
| | FP | 207,219 | 1281.42 | 463.16 | 63.86% | 1076.56 | 352.07 | 67.30% |
| | 1P+FP | 2,450,662 | 505.46 | 436.27 | 13.69% | 374.11 | 312.85 | 16.38% |

## Table 5-6. 2009 Report Annual I/M Benefit Using TIMS Data for TSI Emissions

| TSI HC (ppm) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Curb | | | High | | |
| **Area** | **Seq.** | **Count** | **Initial** | **Final** | **% Change** | **Initial** | **Final** | **% Change** |
| DFW | 1P | 164,392 | 67.303 | 67.303 | 0.00% | 35.737 | 35.737 | 0.00% |
| | FP | 12,806 | 472.859 | 85.459 | 81.93% | 266.783 | 47.949 | 82.03% |
| | 1P+FP | 177,198 | 96.612 | 68.615 | 28.98% | 52.434 | 36.620 | 30.16% |
| HGB | 1P | 133,775 | 66.152 | 66.152 | 0.00% | 35.501 | 35.501 | 0.00% |
| | FP | 9,633 | 452.337 | 83.524 | 81.54% | 263.543 | 47.361 | 82.03% |
| | 1P+FP | 143,408 | 92.093 | 67.319 | 26.90% | 50.819 | 36.298 | 28.57% |
| DFW & HGB | 1P | 298,167 | 66.787 | 66.787 | 0.00% | 35.631 | 35.631 | 0.00% |
| | FP | 22,439 | 464.049 | 84.628 | 81.76% | 265.392 | 47.697 | 82.03% |
| | 1P+FP | 320,606 | 94.591 | 68.035 | 28.07% | 51.712 | 36.476 | 29.46% |
| **TSI CO (%)** | | | | | | | | |
| DFW | 1P | 164,392 | 0.180 | 0.180 | 0.00% | 0.175 | 0.175 | 0.00% |
| | FP | 12,806 | 1.677 | 0.274 | 83.65% | 1.269 | 0.246 | 80.59% |
| | 1P+FP | 177,198 | 0.288 | 0.187 | 35.21% | 0.254 | 0.180 | 29.07% |
| HGB | 1P | 133,775 | 0.183 | 0.183 | 0.00% | 0.173 | 0.173 | 0.00% |
| | FP | 9,633 | 1.699 | 0.269 | 84.19% | 1.261 | 0.236 | 81.29% |
| | 1P+FP | 143,408 | 0.284 | 0.188 | 33.77% | 0.246 | 0.177 | 28.02% |
| DFW & HGB | 1P | 298,167 | 0.181 | 0.181 | 0.00% | 0.174 | 0.174 | 0.00% |
| | FP | 22,439 | 1.686 | 0.272 | 83.88% | 1.266 | 0.242 | 80.89% |
| | 1P+FP | 320,606 | 0.286 | 0.187 | 34.57% | 0.250 | 0.179 | 28.61% |

## Table 5-7a. 2006 Report Annual I/M Benefit Using TIMS Data for ASM Emissions

| I/M Program Area | I/M Sequence Category | Sequence Count | ASM HC (ppm) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 5015 | | | 2525 | | |
| | | | Initial | Final | Change (%) | Initial | Final | Change (%) |
| DFW + HGB | 1P + FP | 4,043,021 | 82.6 | 68.1 | -18% | 55.9 | 42.6 | -24% |
| DFW + HGB | 1P | 3,634,897 | 68.0 | 67.8 | 0% | 41.9 | 41.7 | 0% |
| | FP | 408,124 | 212.7 | 70.2 | -67% | 181.1 | 49.9 | -72% |
| DFW | 1P + FP | 2,214,458 | 81.9 | 68.0 | -17% | 55.1 | 42.3 | -23% |
| HGB | 1P + FP | 1,828,563 | 83.4 | 68.1 | -18% | 56.9 | 42.9 | -25% |
| DFW | 1P | 1,998,674 | 68.0 | 67.8 | 0% | 41.6 | 41.6 | 0% |
| | FP | 215,784 | 211.2 | 69.6 | -67% | 179.9 | 49.5 | -72% |
| HGB | 1P | 1,636,223 | 68.0 | 67.8 | 0% | 42.1 | 42.0 | 0% |
| | FP | 192,340 | 214.3 | 70.9 | -67% | 182.4 | 50.3 | -72% |

## Table 5-7b. 2006 Report Annual I/M Benefit Using TIMS Data for ASM Emissions

| I/M Program Area | I/M Sequence Category | Sequence Count | ASM CO (%) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 5015 | | | 2525 | | |
| | | | Initial | Final | Change (%) | Initial | Final | Change (%) |
| DFW + HGB | 1P + FP | 4,043,021 | 0.300 | 0.199 | -34% | 0.237 | 0.139 | -41% |
| DFW + HGB | 1P | 3,634,897 | 0.199 | 0.198 | 0% | 0.137 | 0.136 | 0% |
| | FP | 408,124 | 1.200 | 0.204 | -83% | 1.134 | 0.162 | -86% |
| DFW | 1P + FP | 2,214,458 | 0.3 | 0.2 | -33% | 0.2 | 0.1 | -40% |
| HGB | 1P + FP | 1,828,563 | 0.3 | 0.2 | -35% | 0.2 | 0.1 | -43% |
| DFW | 1P | 1,998,674 | 0.205 | 0.204 | 0% | 0.140 | 0.139 | 0% |
| | FP | 215,784 | 1.225 | 0.213 | -83% | 1.158 | 0.170 | -85% |
| HGB | 1P | 1,636,223 | 0.192 | 0.191 | 0% | 0.133 | 0.133 | 0% |
| | FP | 192,340 | 1.171 | 0.194 | -83% | 1.107 | 0.153 | -86% |

## Table 5-7c. 2006 Report Annual I/M Benefit Using TIMS Data for ASM Emissions

| I/M Program Area | I/M Sequence Category | Sequence Count | ASM NOx (ppm) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 5015 | | | 2525 | | |
| | | | Initial | Final | Change (%) | Initial | Final | Change (%) |
| DFW + HGB | 1P + FP | 4,043,021 | 553.2 | 463.8 | -16% | 429.0 | 348.0 | -19% |
| DFW + HGB | 1P | 3,634,897 | 461.6 | 460.2 | 0% | 343.9 | 342.8 | 0% |
| | FP | 408,124 | 1,368.4 | 495.9 | -64% | 1,186.6 | 394.3 | -67% |
| DFW | 1P + FP | 2,214,458 | 550.3 | 464.1 | -16% | 424.3 | 346.5 | -18% |
| HGB | 1P + FP | 1,828,563 | 556.6 | 463.4 | -17% | 434.6 | 349.9 | -20% |
| DFW | 1P | 1,998,674 | 461.9 | 460.8 | 0% | 342.3 | 341.4 | 0% |
| | FP | 215,784 | 1,369.0 | 494.8 | -64% | 1,184.4 | 393.2 | -67% |
| HGB | 1P | 1,636,223 | 461.3 | 459.4 | 0% | 346.0 | 344.5 | 0% |
| | FP | 192,340 | 1,367.7 | 497.1 | -64% | 1,189.0 | 395.5 | -67% |

## Table 5-8. 2006 Report Annual I/M Benefit Using TIMS Data for TSI Emissions

| I/M Program Area | I/M Sequence Category | Sequence Count | TSI HC (ppm) | | | | | | TSI CO (%) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Curb Idle | | | High Idle | | | Curb Idle | | | High Idle | | |
| | | | Initial | Final | Change (%) | Initial | Final | Change (%) | Initial | Final | Change (%) | Initial | Final | Change (%) |
| DFW + HGB | 1P + FP | 421,937 | 121.6 | 76.5 | -37% | 65.8 | 40.8 | -38% | 0.37 | 0.22 | -39% | 0.31 | 0.20 | -33% |
| DFW + HGB | 1P | 386,985 | 75.3 | 75.1 | 0% | 39.9 | 39.8 | 0% | 0.21 | 0.21 | 0% | 0.20 | 0.20 | 0% |
| | FP | 34,952 | 634.2 | 92.1 | -85% | 352.2 | 51.6 | -85% | 2.04 | 0.32 | -84% | 1.49 | 0.27 | -82% |
| DFW | 1P + FP | 211,413 | 122.8 | 77.1 | -37% | 64.1 | 39.5 | -38% | 0.38 | 0.23 | -38% | 0.31 | 0.21 | -32% |
| HGB | 1P + FP | 210,524 | 120.4 | 75.8 | -37% | 67.5 | 42.1 | -38% | 0.35 | 0.21 | -40% | 0.30 | 0.19 | -35% |
| DFW | 1P | 194,331 | 75.8 | 75.6 | 0% | 38.6 | 38.5 | 0% | 0.23 | 0.22 | 0% | 0.21 | 0.21 | 0% |
| | FP | 17,082 | 657.5 | 94.5 | -86% | 354.2 | 50.5 | -86% | 2.13 | 0.35 | -83% | 1.53 | 0.30 | -81% |
| HGB | 1P | 192,654 | 74.8 | 74.5 | 0% | 41.3 | 41.1 | 0% | 0.20 | 0.20 | 0% | 0.19 | 0.19 | 0% |
| | FP | 17,870 | 611.9 | 89.7 | -85% | 350.3 | 52.5 | -85% | 1.95 | 0.29 | -85% | 1.46 | 0.25 | -83% |

## 5.2 Estimate of the Annual I/M Benefit from Paired I/M and RS Data

The Annual Benefit is the size of the fleet's "saw tooth" emissions profile that occurs during each cycle as the vehicles in the fleet are repeatedly inspected and repaired. The saw tooth is produced for each vehicle by the annual change in emissions downward from I/M-induced repair and then upward from emissions degradation during the period before the next I/M cycle. The analysis presented in this section estimates annual benefits based on pairing the TIMS data with RS data.

Although the effect of the I/M program is to reduce emissions by repairing vehicles that fail an emissions test, these vehicles will then likely have increasing emissions until their next I/M test. This is also true for passing vehicles. RS data allows this slow increase in emissions to be observed as it can be seen that initially passing vehicles (95% of the fleet) go through the I/M program and their emissions gradually increase each year. This is often called emission creep. Eventually, when their emissions have increased over the years to a high enough level, the I/M cutpoint is tripped and repairs are done. During all of those previous years the emissions of the initially passing vehicles have been allowed to increase unchecked. More-stringent cutpoints should help reduce the number of vehicles that are allowed to go through the I/M program unchecked as their emissions profile deteriorates. However, more-stringent cutpoints would also cause an increase in the number of vehicles failed when the vehicles have no problem that can be identified. And it must be remembered that increasing cutpoint stringency is only possible with tailpipe testing, not OBD.

ERG used RS data taken in the I/M areas to determine the Annual I/M Benefit produced by the I/M program. This was done by pairing RS data with the TIMS inspection data by vehicle, and comparing the before-I/M and after-I/M RS levels.

A vehicle can be measured by RS at any time before or after its annual I/M inspection. By aligning all of the RS measurements with respect to the time of I/M repair, the average of the RS measurements will reveal the change in emissions produced by the I/M program and the rate of emissions degradation between I/M inspections. However, it is important to understand that the set of vehicles with RS measurements before the I/M inspection does not contain the same vehicles as those with RS measurements after the I/M inspection. Because of the large emissions variability of emissions measurements, the average RS emissions versus time before and after I/M inspection will have a considerable amount of variability even when millions of RS observations are used. Nevertheless, the calculation provides an estimate of the benefits of the I/M program that is independent of the I/M program itself.

Preparation of RS Data – In this task, the RS data were collected in the Houston/Galveston/Brazoria (HGB) area and the Dallas/Fort Worth (DFW) area to evaluate the Annual I/M Benefit. The goal was to use the RS data already being collected by the Texas Department of Public Safety (DPS) as an independent means of measuring the benefit.

The RS data provided by DPS started out with about 2.4 million records, collected from January 1, 2012, through December 31, 2013. In previous years of performing this type of analysis, some records with no license plate were included in the dataset and were deleted. However, all of this year's records contained the license plate.

This analysis evaluates the inspection and maintenance programs in the HGB and DFW areas. The RS records were collected in all I/M areas within the state of Texas including the El Paso, Williamson, and Travis counties. Therefore, only RS data collected in HGB and DFW were kept in the dataset. This left 1.6 million remaining RS records: 0.6 million records collected in the HGB area and 1.0 million records collected in the DFW area.

The RS records provided to ERG did not contain any information about the vehicle except the license plate number. For the Comprehensive Method [Reference 2] calculations, it is important to determine the fleet characteristics of the vehicles measured by RS in the I/M area. Therefore, it was important to determine the vehicle characteristics such as age, technology, and odometer. The potential sources of this information were the registration data, the I/M data, and the ERG VIN decoder. The records from the I/M program do contain odometer and other vehicle characteristics information; however, there are no I/M records for vehicles registered outside the I/M areas. The registration data contained vehicle make and model year but did not contain odometer, vehicle technology information, or vehicle odometer information. Because of this, the vehicle odometer could not be used in the comparison of fleet characteristics. In the 2006 performance of this analysis, the ERG VIN decoder was used to provide the vehicle characteristics information which included vehicle make, model year, type (car or truck), metering, and emission control systems. However, in the 2009 Report, limiting the RS dataset to only those records that had a successful match to a VIN-decoder result dropped the number of RS records from 6.2 million to 3.5 million records – a significant reduction. Also, in the 2006 analysis, the vehicle technology information that comes exclusively from the VIN decoder did not get used in the final analysis procedure. The only stratification variable was the vehicle model year, which is available from the registration records. Therefore, for the current analysis, it was decided not to use the VIN decoder results to obtain additional vehicle information.

The RS records provided to ERG by DPS were already checked for validity by the RS data collection contractor. Therefore, there was no check made for the validity of the values within each of the RS data fields. However, the vehicle specific power (VSP) for each vehicle using the RS speed, acceleration, and the slope at the RS site was calculated. The slope for the RS site was not included in the RS data. These data were provided separately by DPS. Once the sites and slopes were matched to the RS records and the VSP calculations were done, a VSP filter was applied. Any records with a VSP outside the range of 5-25 kilowatt per ton were removed from the dataset. This left 1.1 million remaining records: 670,000 records in the DFW and 390,000 records in the HGB area.

The calculation of the Annual I/M Benefit was done using the Comprehensive Method outlined by the EPA. [Section 6.2 of Reference 2] In this method, RS data taken in the I/M area is paired with I/M inspections by vehicle.

ERG calculated the time between the RS reading and the I/M test and placed each observation into a month bin – for example, 1 month before the initial test, 2 months before the initial test, 3 months before initial, 1 month after the final test, 2 months after the final test, 3 months after final, etc. Any RS readings that occurred within the I/M cycle, that is, between the initial test and the final test, were removed from the analysis, because for these mid-cycle observations it was not possible to determine the state of repair of the vehicle at the time of the RS measurement.

ERG also created a variable to describe the sequence of I/M inspection results for each vehicle inspected. There were four I/M sequence categories outlined in the EPA's description of the Comprehensive Method calculations: 1) vehicles that passed their initial I/M tests (1P), 2) vehicles that failed their initial I/M test and then eventually passed (FP), 3) vehicles that failed their I/M test and did not come back for another test (1F), and 4) vehicles that failed their I/M test and failed all other subsequent I/M tests (FF).

The average RS concentrations for HC, CO, and $NO_x$ by month bin, by I/M sequence category, and also by model year group were examined. Because the Texas I/M program is an annual program, the plots were limited to only the RS matches that happened up to 6 months before and 6 months after the I/M test. The HC, CO, and $NO_x$ plots for the entire dataset are shown in Figures 5-1 through 5-3 for the HGB area and in Figures 5-4 through 5-6 for the DFW area. These figures show the RS averages (indicated by the dots) and the uncertainties associated with these averages at a 95% confidence level (indicated by the lines).

**Figure 5-1. Average RS HC Versus Month from the I/M Test RS Readings from the HGB Area**

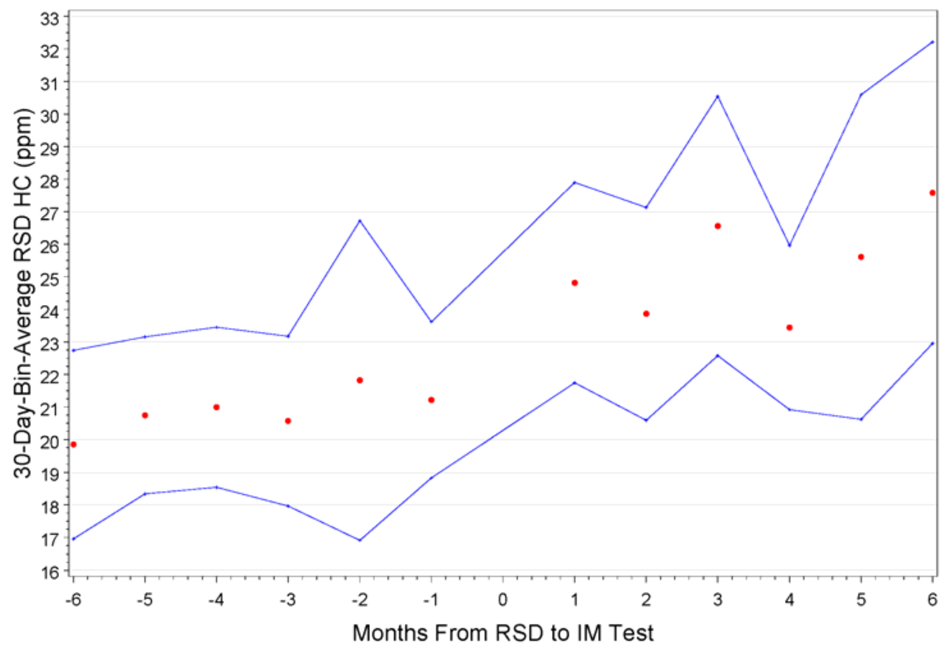


**Figure 5-2. Average RS CO Versus Month from the I/M Test RS Readings from the HGB Area**

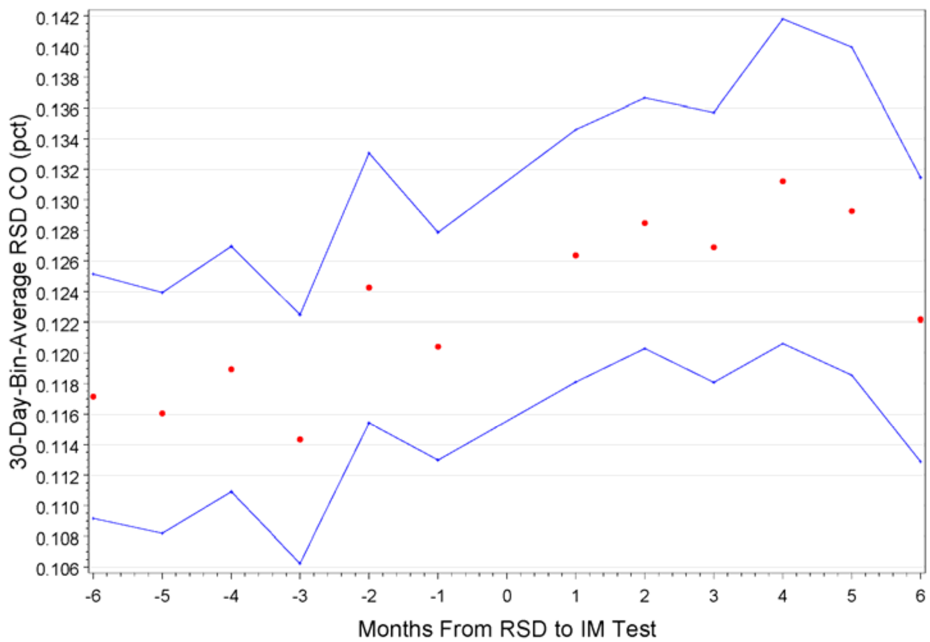



**Figure 5-3. Average RS $NO_x$ Versus Month from the I/M Test RS Readings from the HGB Area**

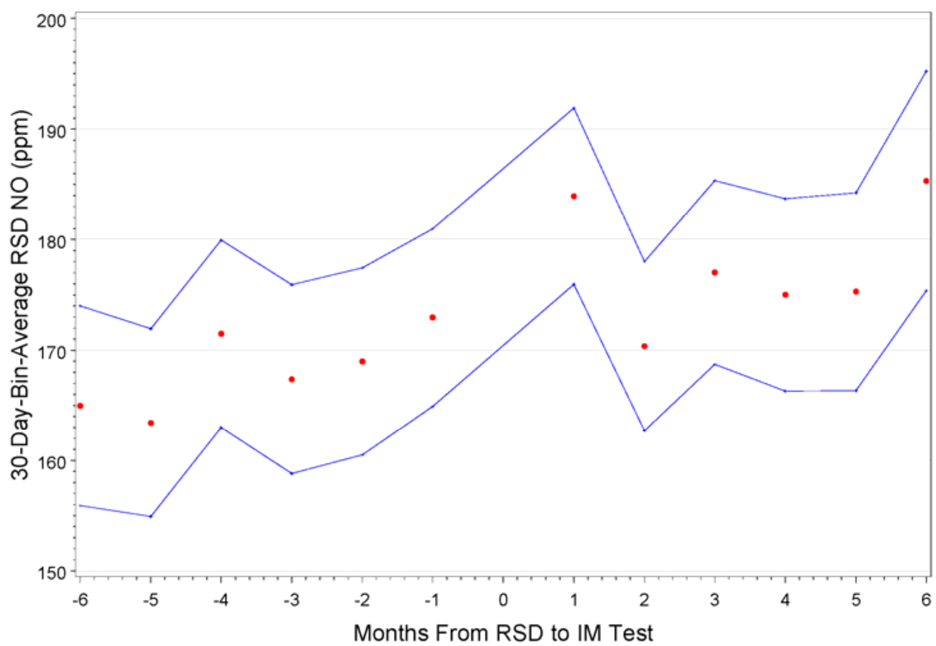


**Figure 5-4. Average RS HC Versus Month from the I/M Test RS Readings from the DFW Area**

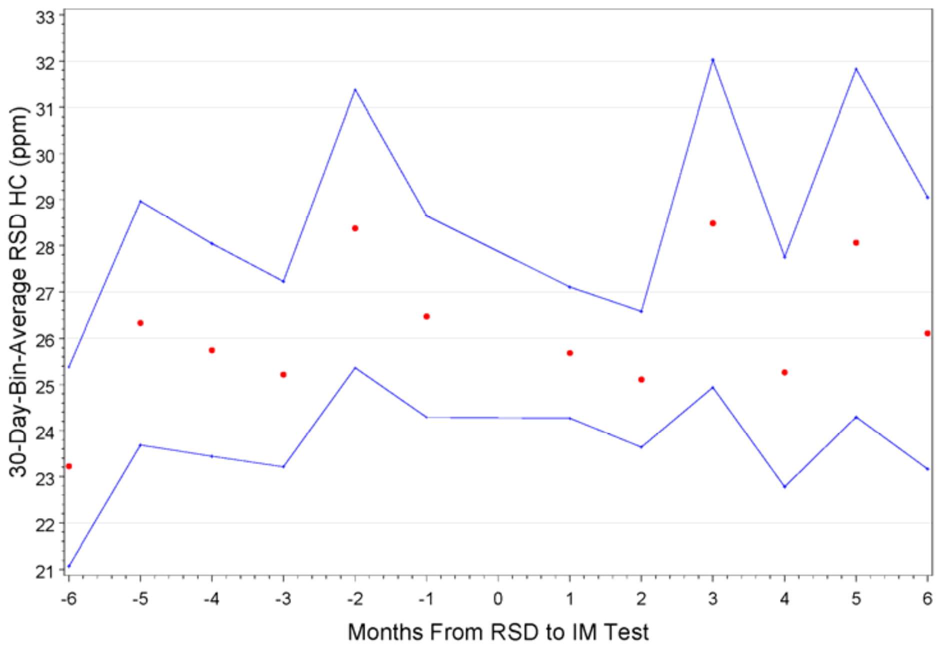



**Figure 5-5. Average RS CO Versus Month from the I/M Test RS Readings from the DFW Area**

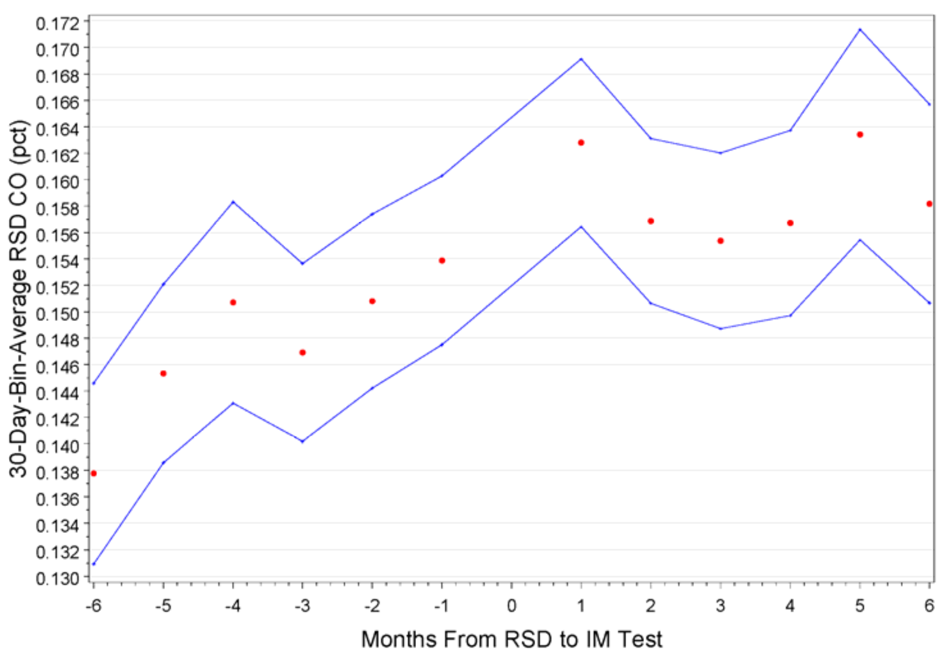
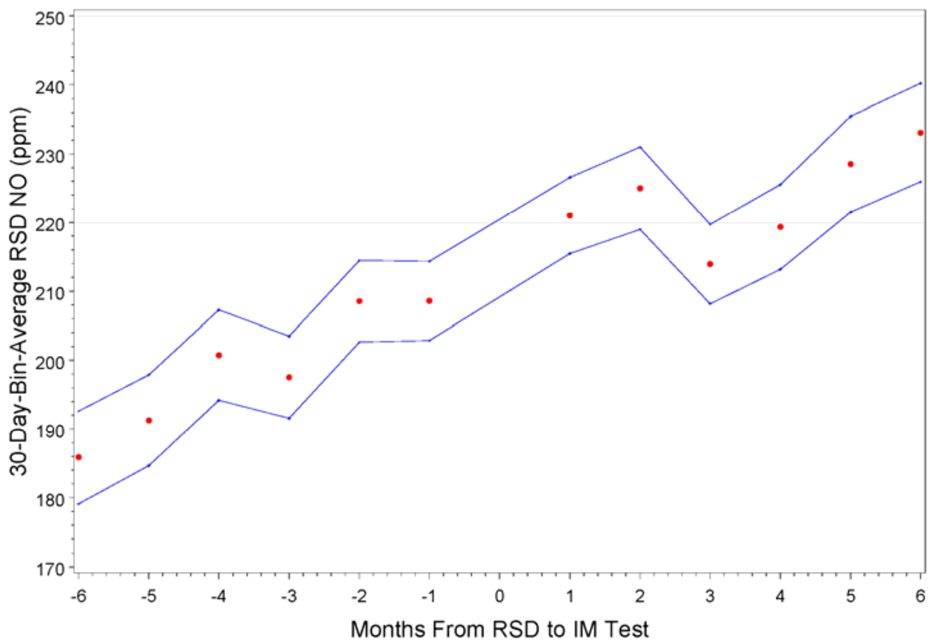


**Figure 5-6. Average RS $NO_x$ Versus Month from the I/M Test RS Readings from the DFW Area**




These figures above do not show a drop in the average RS emissions from before to after I/M. However, when the plots are done on a dataset that has been stratified by the I/M sequence category, some I/M benefits start to become evident. Table 5-9 shows the number of records in the RS-matched-with-I/M dataset (for both HGB and DFW) that fall into each I/M sequence category. The table clearly demonstrates that the 1P and FP I/M sequence categories dominate the I/M program. At this point, the separate effects of the 1P and FP categories are examined.

**Table 5-9. Number of Vehicles in Each I/M Sequence Category for the Dataset of RS Events Matched with I/M Tests**

| I/M Sequence Category | HGB | | DFW | |
|---|---|---|---|---|
| | Number of Vehicles | Percent | Number of Vehicles | Percent |
| Pass Initial (1P) | 190,780 | 96.3% | 332,662 | 96.3% |
| Fail Initial (1F) | 0 | 0.0% | 1 | 0.0% |
| Fail Initial, Fail Final (FF) | 9 | 0.0% | 17 | 0.0% |
| Fail Initial, Pass Final (FP) | 6,823 | 3.4% | 11,965 | 3.5% |
| Other Misc. Sequences | 438 | 0.2% | 690 | 0.2% |
| Total | 198,050 | 100.0% | 345,335 | 100.0% |

The plots of mean RS concentrations versus time from I/M inspection were repeated, this time separately for the 1P and FP categories. Figures 5-7, 5-9, and 5-11 show the time trend of the monthly average RS HC, CO, and $NO_x$ for the HGB area for vehicles that passed initially (1P). Below these figures are Figures 5-8, 5-10, and 5-12 for the corresponding vehicles that failed initially and then ultimately passed (FP).

The 1P plots, which describe 96.3% of the vehicles in the HGB area, show small emission increases from the month before to the month after the I/M test. There is no evidence of a decrease in emissions in the two months before the I/M inspection that could be attributed to pre-inspection repairs. If anything, the long term time trend is generally upward, which may be attributed to the general long term emissions deterioration of these vehicles.

The FP plots, which describe 3.4% of the vehicles in the HGB area, show downward jogs in the emissions at the time of the I/M inspection, or just following the inspection. Examining the overall trend of each plot shows that downward jogs at the I/M inspection interrupts the generally upward trend of emissions deterioration, which is what the I/M program is designed to do.

Grouping vehicles of all I/M sequence categories results in a slightly increasing trend from before to after I/M as was seen in Figures 5-1, 5-2, and 5-3. This is because while the FP vehicles show substantial emissions decreases, they make up only 3.4% of the HGB fleet. An additional 96.3% of the fleet is made up of 1P vehicles that have slight emissions increases, as an expected result of general long term degradation. There was no discernible difference in the plots for the emissions in the DFW area; therefore, they were not included here to conserve space.

**Figure 5-7. Average RS HC vs. Month After the I/M Test for HGB Vehicles with I/M Sequence Category = 1P**

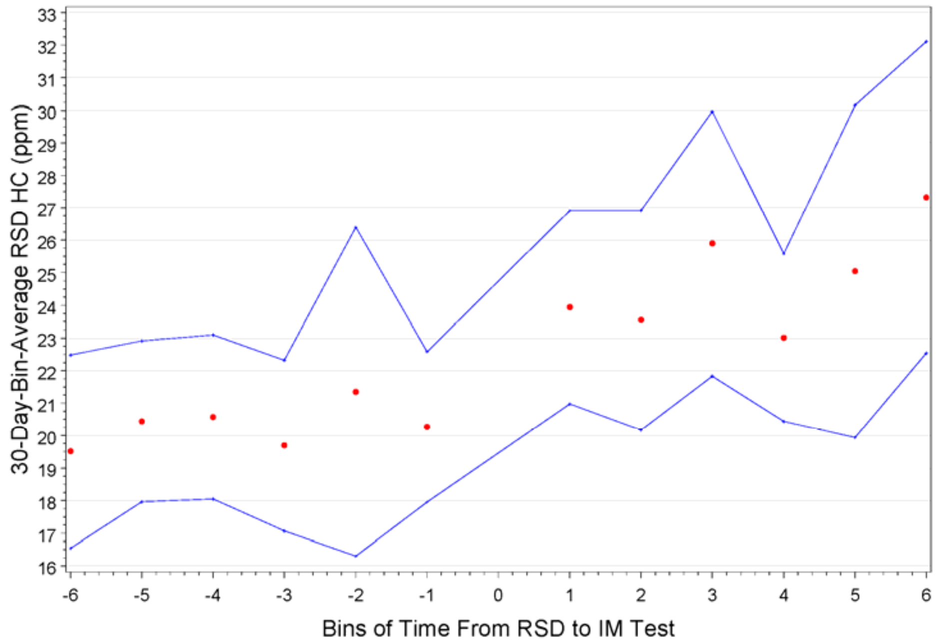



**Figure 5-8. Average RS HC vs. Month After the I/M Test for HGB Vehicles with I/M Sequence Category = FP**

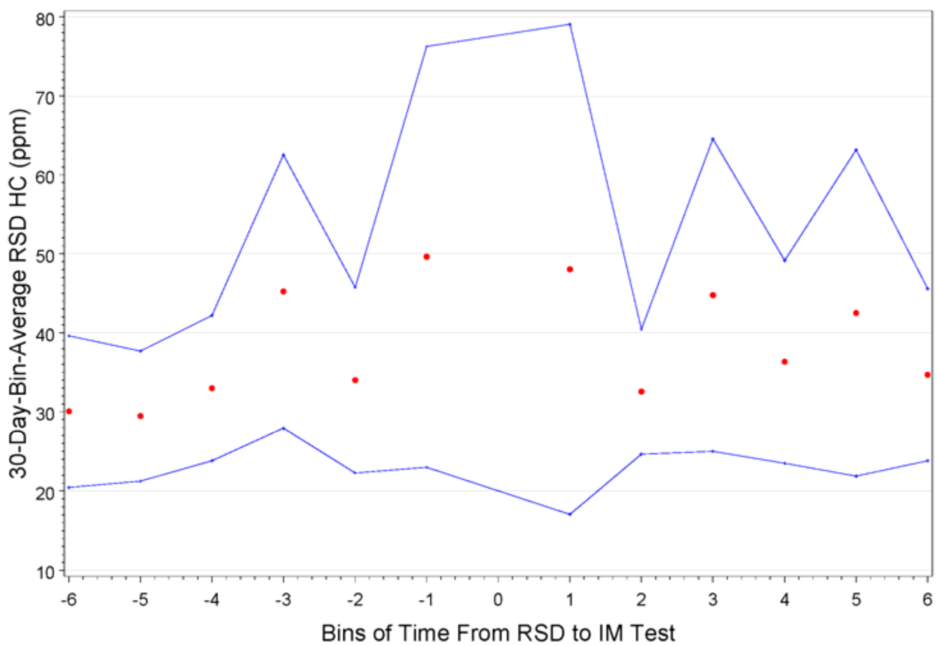


**Figure 5-9. Average RS CO vs. Month After the I/M Test for HGB Vehicles with I/M Sequence Category = 1P**

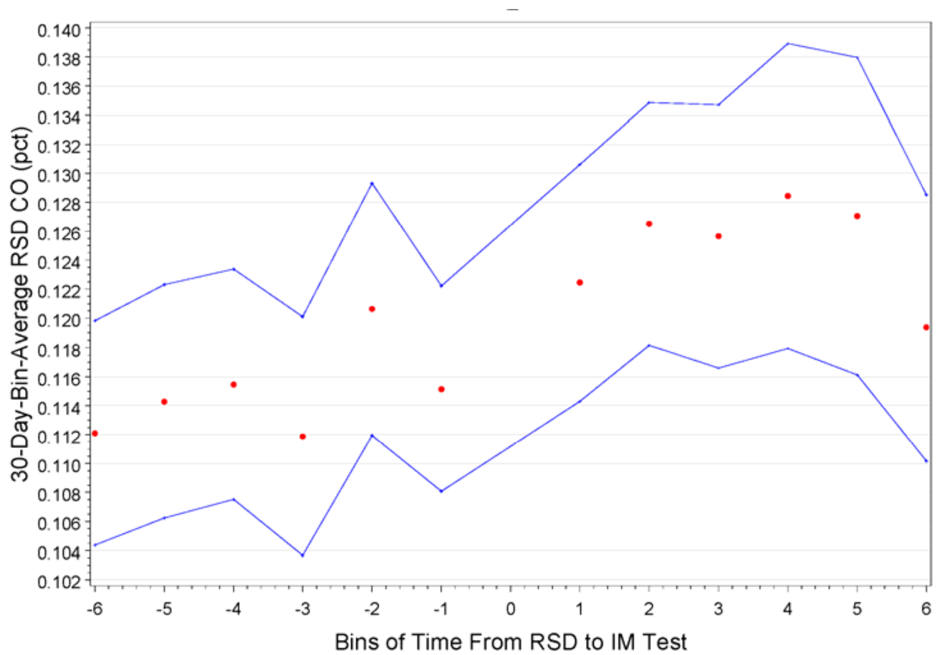



**Figure 5-10. Average RS CO vs. Month After the I/M Test for HGB Vehicles with I/M Sequence Category = FP**

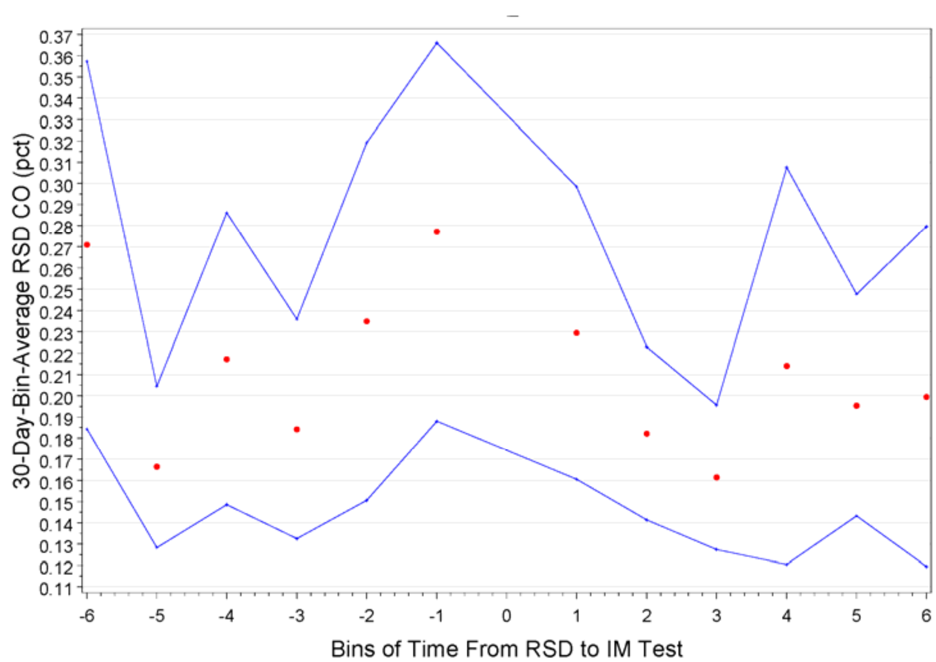


**Figure 5-11. Average RS $NO_x$ vs. Month After the I/M Test for HGB Vehicles with I/M Sequence Category = 1P**

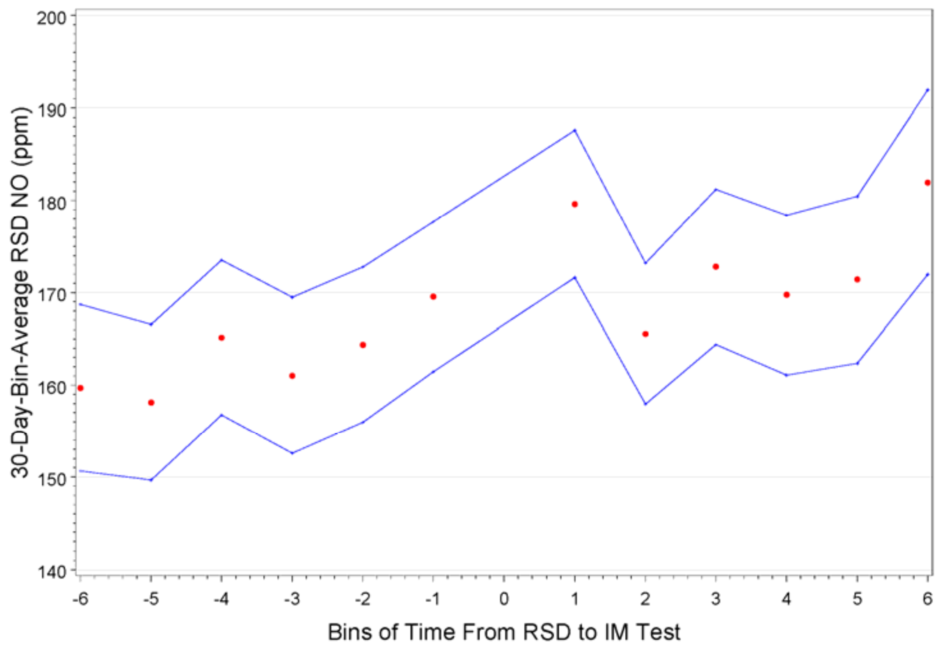
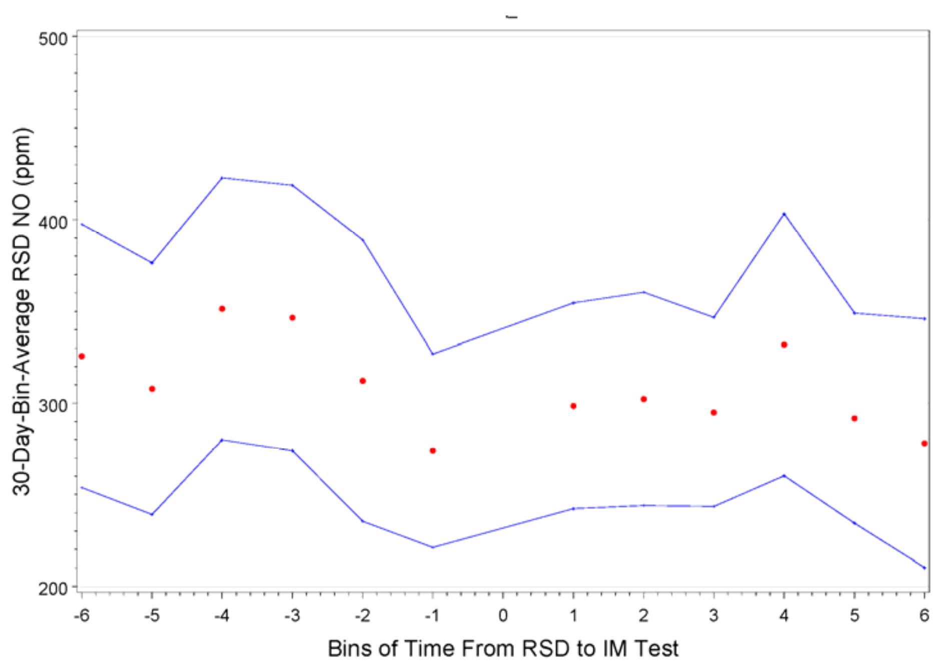



**Figure 5-12. Average RS $NO_x$ vs. Month After the I/M Test fro HGB Vehicles with I/M Sequence Category = FP**




To quantify the Annual I/M Benefit, the month bins were combined to obtain a single average RS concentration before the I/M test and another average RS concentration after the I/M test. The before bin consists of all RS measurements that happened between 31 and 90 days prior to the initial I/M test. The RS measurements that happened from 1 to 30 days prior to the I/M test were not included in the bin to minimize the effect of pre-inspection repairs on the before average. This binning methodology was suggested by the EPA in the documentation for the Comprehensive Method. The after bin contains all RS tests that happened between 1 and 90 days following the final I/M test.

The calculations for the before and after I/M RS averages were done for the entire RS matched I/M dataset for each of the two major I/M sequence categories, FP and 1P, and averages were calculated separately by model year group. At the beginning of this analysis, when the fleet characteristics of the I/M fleet were compared to the fleet characteristics of the set of vehicles with RS measurements matched to I/Ms, the RS-matched fleet was found to contain a larger percentage of new vehicles. Therefore, each of the I/M category bins were also separated by model year group. The benefit for each model year group could be weighted by the percentage of vehicles in each model year group in the I/M fleet to translate the benefits observed in the RS-matched fleet to the I/M fleet.

These before and after I/M average RS measurements for the FP vehicles and the 1P vehicles were plotted for both the HGB and DFW areas in Figures 5-13 through 5-24. Each plot contains a separate line for each of four model year groups, with the before I/M RS measurement on the left and the after I/M RS measurement on the right. The lines highlight the differences between these RS averages and the error bars show the 95% confidence level uncertainties for the respective averages. The plots for FP vehicles in Figures 5-13 to 5-18 show that in most cases the emissions of FP vehicles decrease; however, in many cases the decrease is not statistically significant – even with over 10,000 RS observations in the FP category. The plots for 1P vehicles in Figures 5-19 to 5-24 show that in some cases the emissions of 1P vehicles increase across the I/M inspections; however, in many cases the increase is not statistically significant even with around 300,000 RS observations in the 1P category.

**Figure 5-13. Average RS HC by Model Year Group Before and After I/M Test for HGB Vehicles with I/M Sequence Category = FP**

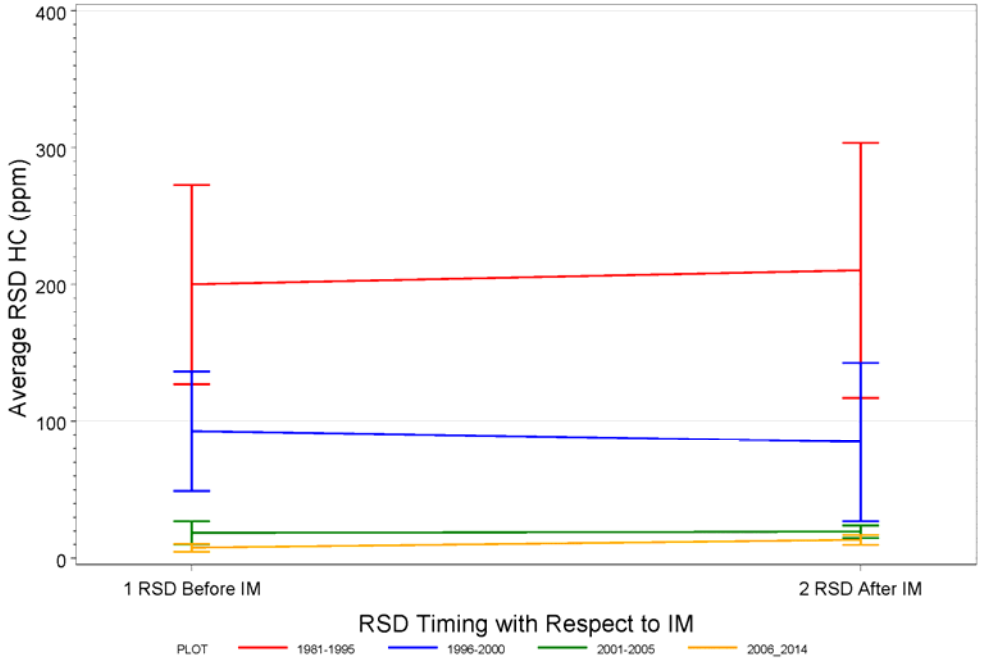



**Figure 5-14. Average RS HC by Model Year Group Before and After I/M Test for DFW Vehicles with I/M Sequence Category = FP**

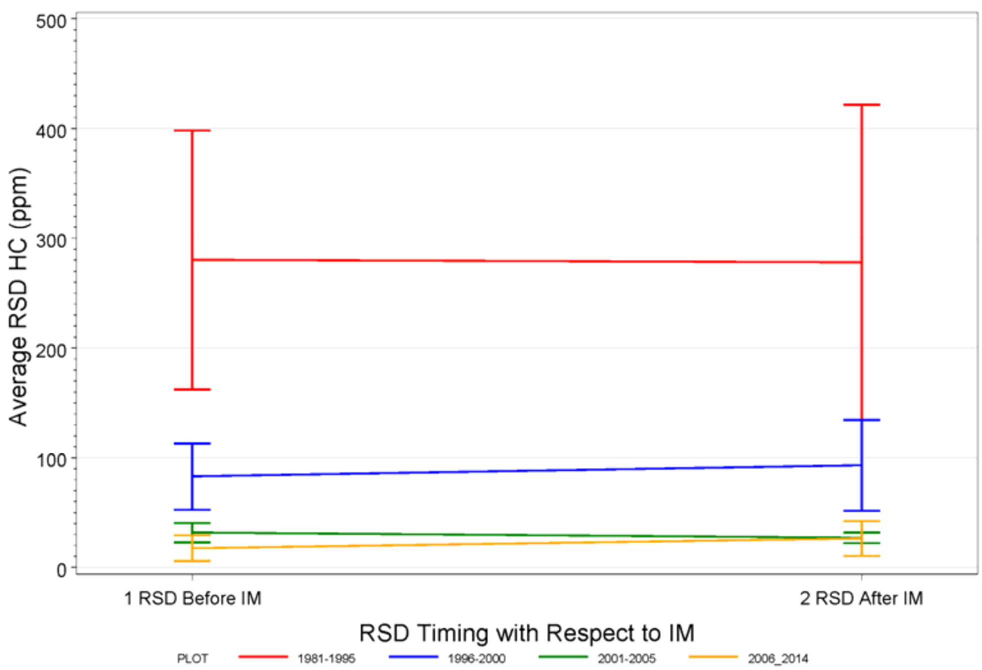


**Figure 5-15. Average RS CO by Model Year Group Before and After I/M Test for HGB Vehicles with I/M Sequence Category = FP**

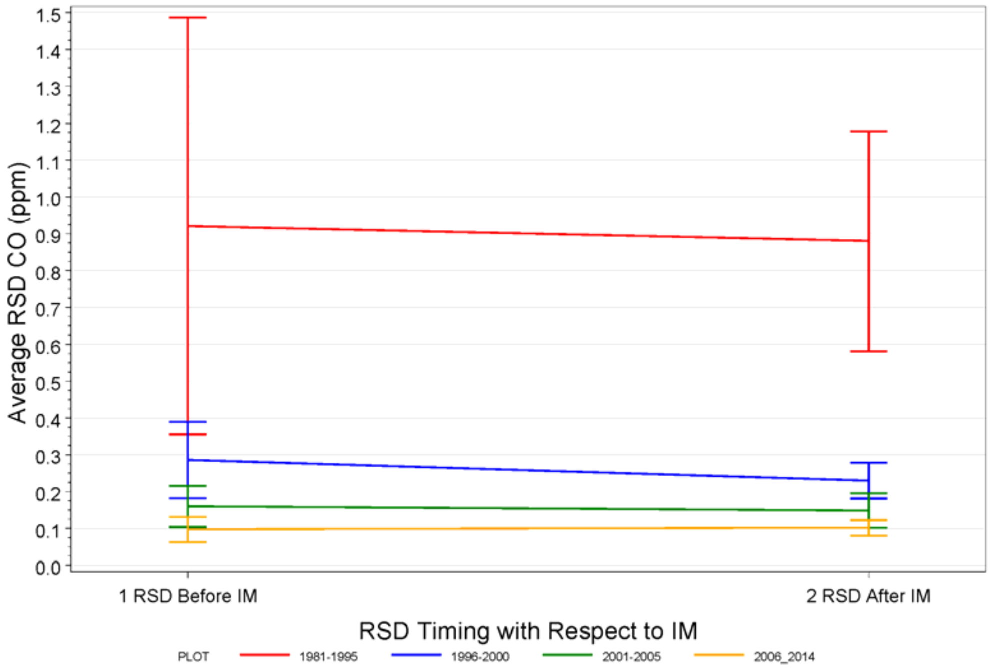



**Figure 5-16. Average RS CO by Model Year Group Before and After I/M Test for DFW Vehicles with I/M Sequence Category = FP**

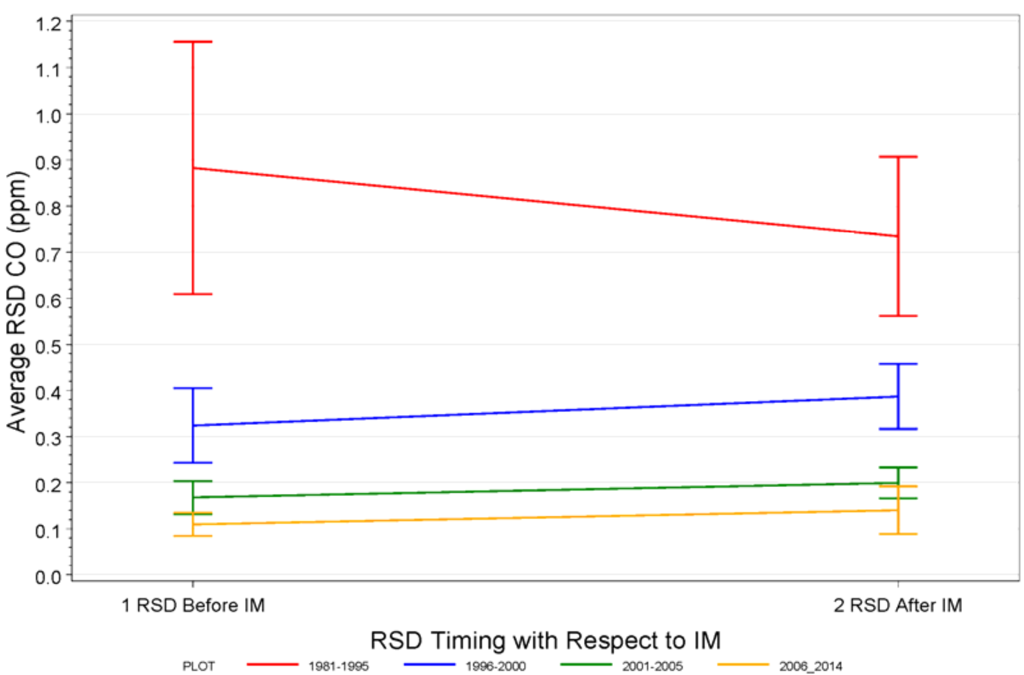


**Figure 5-17. Average RS $NO_x$ by Model Year Group Before and After I/M Test for HGB Vehicles with I/M Sequence Category = FP**

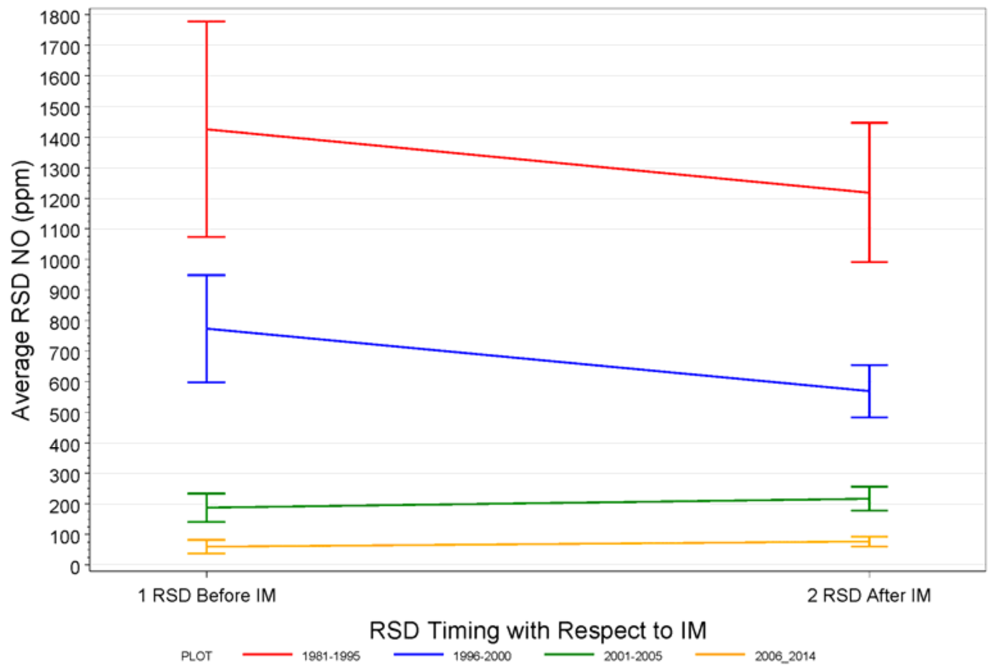



**Figure 5-18. Average RS $NO_x$ by Model Year Group Before and After I/M Test for DFW Vehicles with I/M Sequence Category = FP**

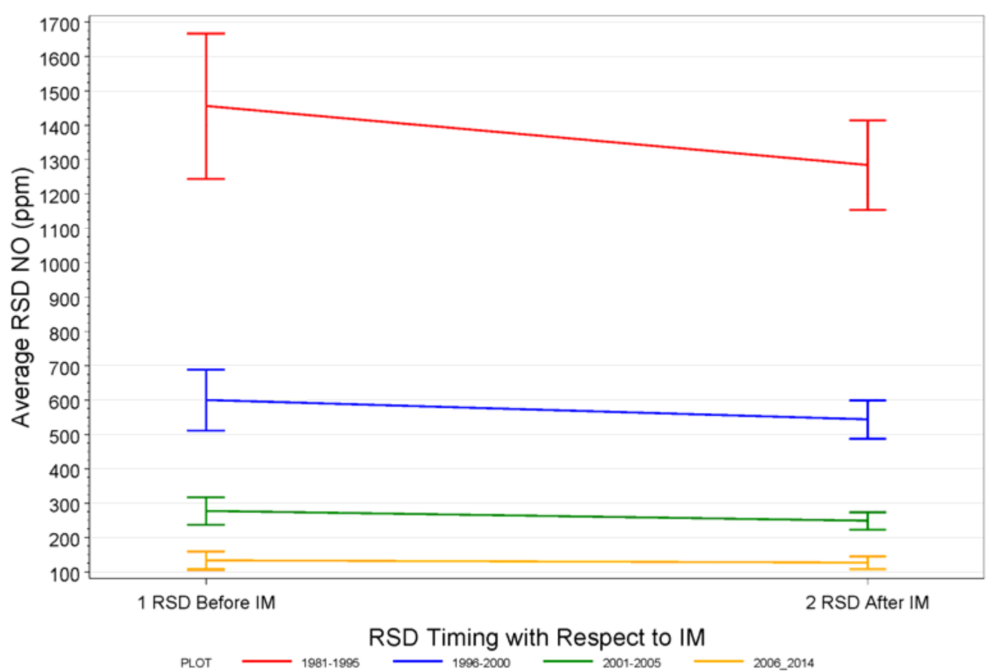


**Figure 5-19. Average RS HC by Model Year Group Before and After I/M Test for HGB Vehicles with I/M Sequence Category = 1P**

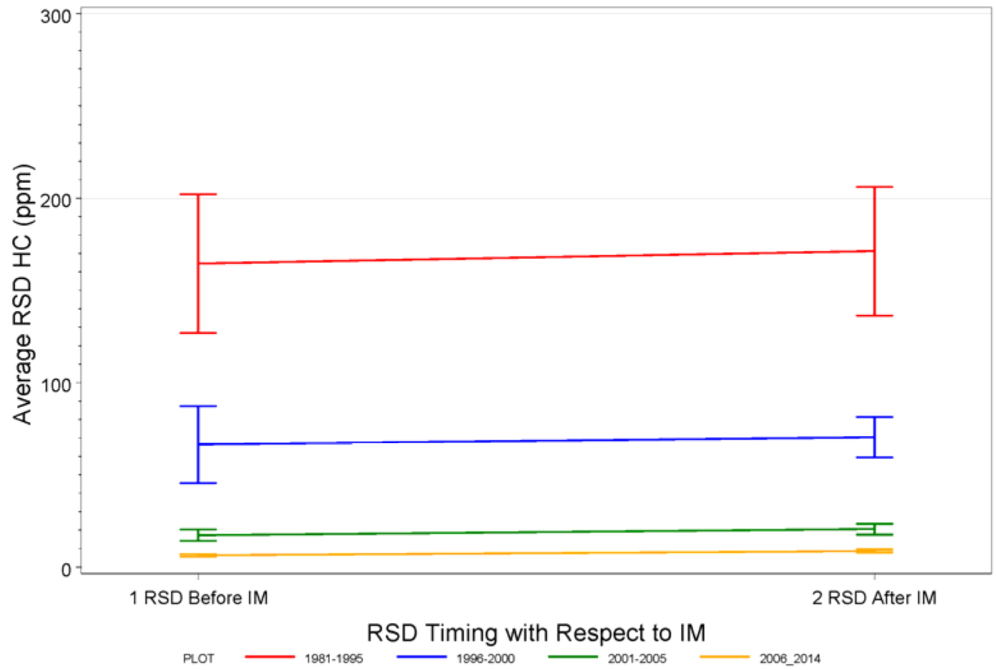



**Figure 5-20. Average RS HC by Model Year Group Before and After I/M Test for DFW Vehicles with I/M Sequence Category = 1P**

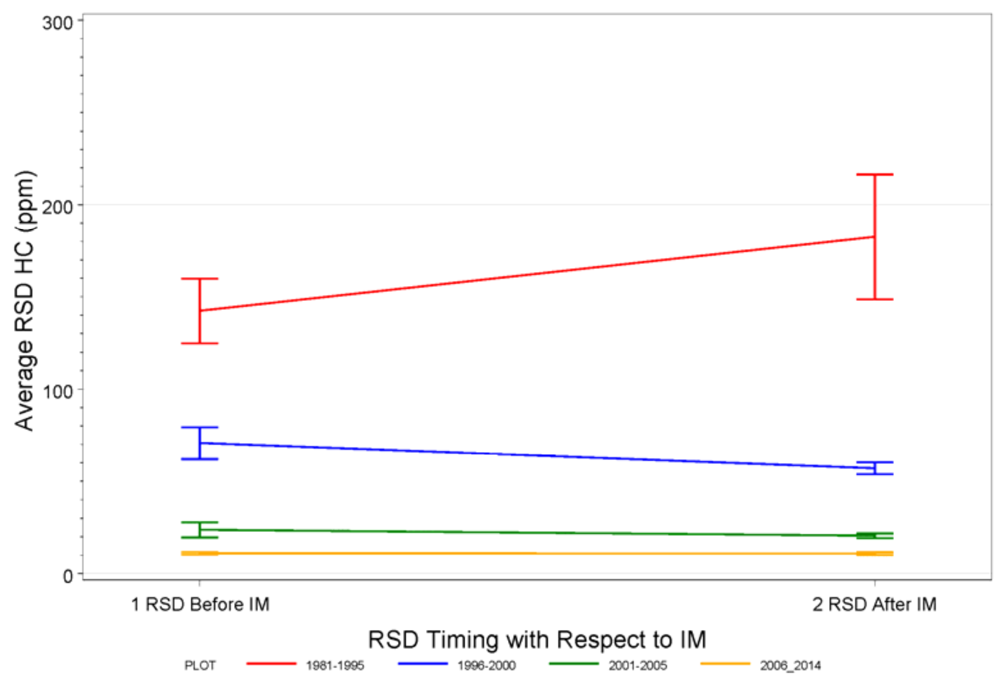


**Figure 5-21. Average RS CO by Model Year Group Before and After I/M Test for HGB Vehicles with I/M Sequence Category = 1P**

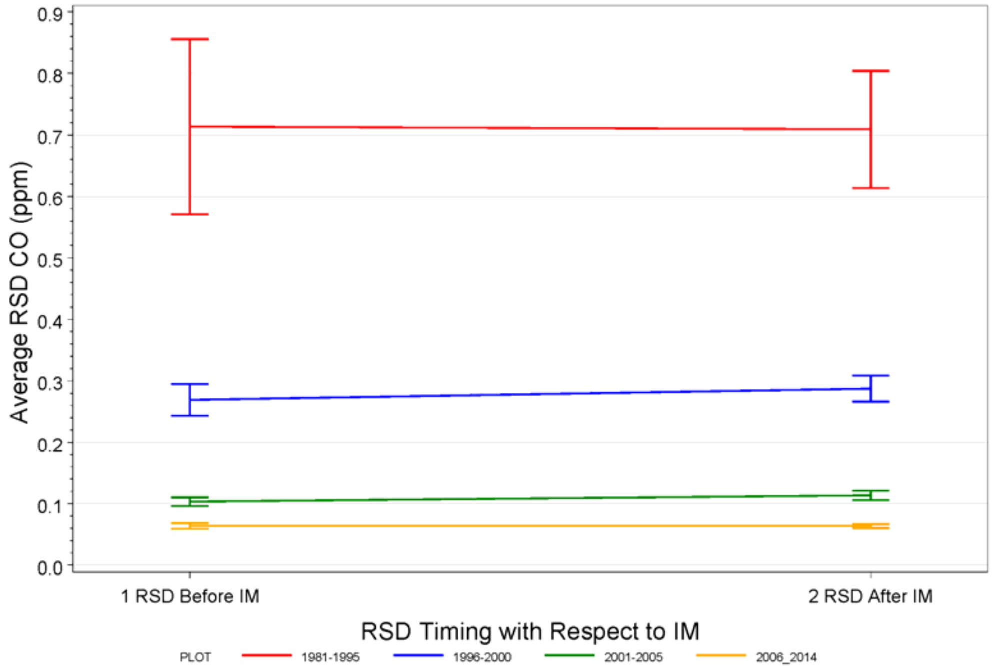



**Figure 5-22. Average RS CO by Model Year Group Before and After I/M Test for DFW Vehicles with I/M Sequence Category = 1P**

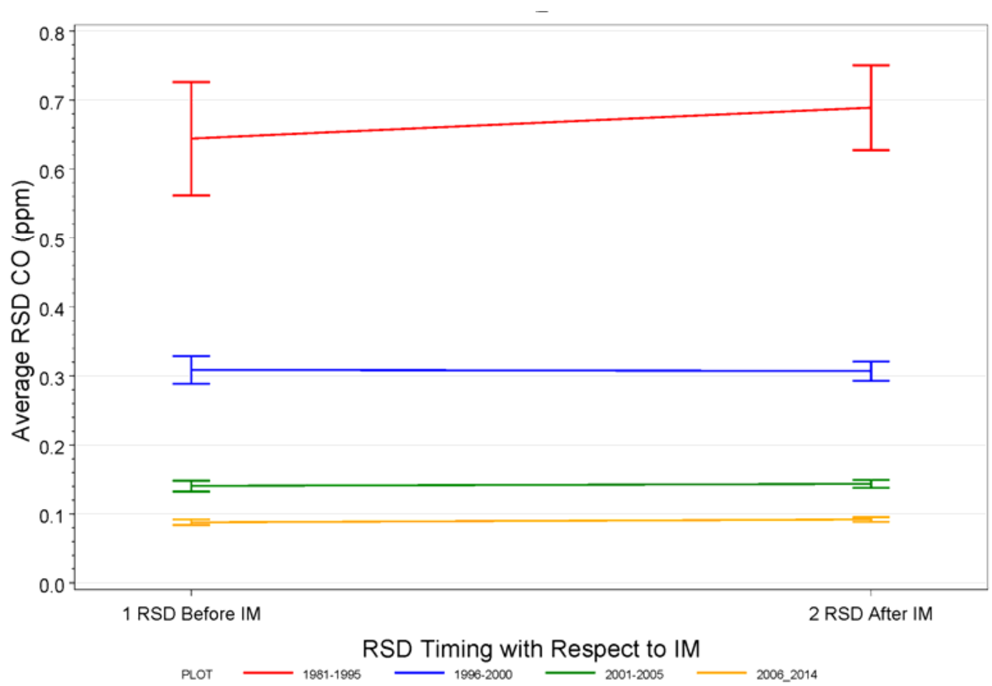


**Figure 5-23. Average RS $NO_x$ by Model Year Group Before and After I/M Test for HGB Vehicles with I/M Sequence Category = 1P**

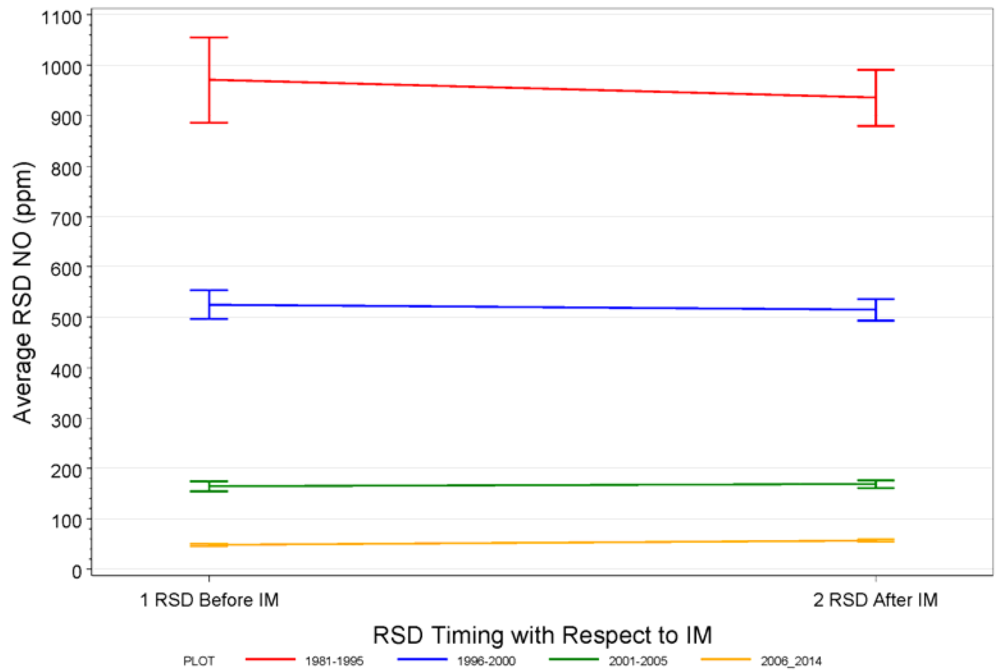
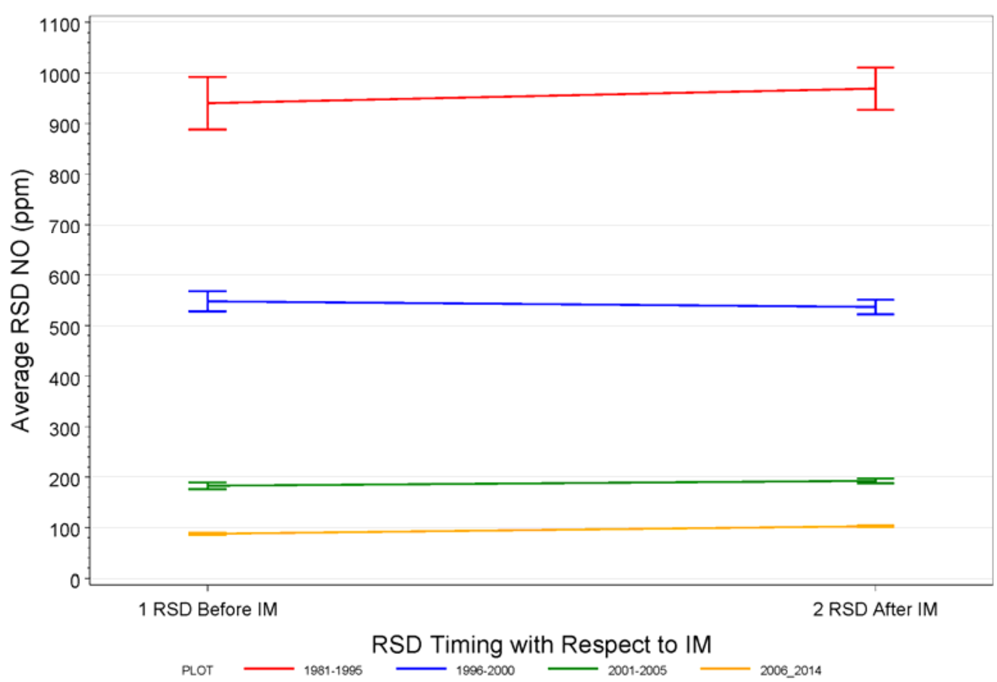



**Figure 5-24. Average RS $NO_x$ by Model Year Group Before and After I/M Test for DFW Vehicles with I/M Sequence Category = 1P**



The RS average concentrations shown in the figures above are summarized in Tables 5-10 and 5-11. The values in Table 5-10 show that for vehicles that failed and then passed, HC emissions remained fairly constant, while CO and NOx levels were somewhat reduced from before to after the I/M inspection. Changes were largest for the oldest model year groups. Table 5-11 shows that for 1P vehicles, there was generally a slight increase in emissions levels from before to after the I/M inspection. However, looking back at Figures 5-13 through 5-24, it can be seen that the changes are almost always within the errors bars, and therefore, not statistically significant.

**Table 5-10. RS Averages Before and After an I/M Test for HGB and DFW for I/M Sequence Category = FP**

| **Houston Galveston Brazoria (HGB) Area** | | | | | | |
|---|---|---|---|---|---|---|
| | **RS HC (ppm)** | | **RS CO (%)** | | **RS NOx (ppm)** | |
| **MY Group** | **Before I/M** | **After I/M** | **Before I/M** | **After I/M** | **Before I/M** | **After I/M** |
| 1981-1995 | 200 | 210 | 0.92 | 0.88 | 1,425 | 1,219 |
| 1996-2000 | 93 | 85 | 0.29 | 0.23 | 773 | 569 |
| 2001-2005 | 19 | 19 | 0.16 | 0.15 | 187 | 216 |
| 2006-2014 | 8 | 13 | 0.10 | 0.10 | 60 | 77 |
| Dallas Fort Worth (DFW) Area | | | | | | |
| | **RS HC (ppm)** | | **RS CO (%)** | | **RS NOx (ppm)** | |
| **MY Group** | **Before I/M** | **After I/M** | **Before I/M** | **After I/M** | **Before I/M** | **After I/M** |
| 1981-1995 | 280 | 278 | 0.88 | 0.73 | 1,455 | 1,284 |
| 1996-2000 | 83 | 93 | 0.32 | 0.39 | 600 | 544 |
| 2001-2005 | 32 | 27 | 0.17 | 0.20 | 277 | 248 |
| 2006-2010 | 18 | 26 | 0.11 | 0.14 | 133 | 126 |

**Table 5-11. RS Averages Before and After an I/M Test for HGB and DFW for I/M Sequence Category = 1P**

| **Houston Galveston Brazoria (HGB) Area** | | | | | | |
|---|---|---|---|---|---|---|
| | **RS HC (ppm)** | | **RS CO (%)** | | **RS NOx (ppm)** | |
| **MY Group** | **Before I/M** | **After I/M** | **Before I/M** | **After I/M** | **Before I/M** | **After I/M** |
| 1981-1995 | 165 | 171 | 0.71 | 0.71 | 971 | 935 |
| 1996-2000 | 66 | 70 | 0.27 | 0.29 | 524 | 514 |
| 2001-2005 | 17 | 20 | 0.10 | 0.11 | 164 | 169 |
| 2006-2014 | 6 | 9 | 0.06 | 0.06 | 48 | 57 |
| **Dallas Fort Worth (DFW) Area** | | | | | | |
| | **RS HC (ppm)** | | **RS CO (%)** | | **RS NOx (ppm)** | |
| **MY Group** | **Before I/M** | **After I/M** | **Before I/M** | **After I/M** | **Before I/M** | **After I/M** |
| 1981-1995 | 142 | 183 | 0.64 | 0.69 | 940 | 969 |
| 1996-2000 | 71 | 57 | 0.31 | 0.31 | 548 | 537 |
| 2001-2005 | 24 | 20 | 0.14 | 0.14 | 183 | 192 |
| 2006-2014 | 11 | 11 | 0.09 | 0.09 | 87 | 102 |

The results in Tables 5-10 and 5-11 show the difference in average RS concentrations between before and after I/M observations, for different model year groups. To calculate the net overall effect on emissions of the I/M program, these results must be combined. Because RS measurements are primarily taken on freeway on-ramps, the average vehicle that is observed by RS is somewhat newer that the average vehicle in the I/M fleet. This difference is shown in Table 5-12, which contains the distribution of vehicles among the model year groups for the RS measurements -matched-to-I/M fleet, and for the I/M fleet. The fact that this difference exists, i.e. that the RS measurements -matched-to-I/M fleet is somewhat newer than the I/M fleet, should be kept in mind when considering overall fleet results.

**Table 5-12. Model Year Distributions for RS-Matched-to-I/M Fleet and I/M Tested Fleet**

| Model Year Group | Dallas Fort Worth (DFW) Area | | | | Houston Galveston Brazoria (HGB) Area | | | |
|---|---|---|---|---|---|---|---|---|
| | RS-Matched-to-I/M Fleet | | I/M Tested Fleet | | RS-Matched-to-I/M Fleet | | I/M Tested Fleet | |
| | Number | % | Number | % | Number | % | Number | % |
| 1981-1995 | 9,788 | 2.8% | 337,434 | 5.2% | 5,379 | 2.7% | 289,807 | 4.9% |
| 1996-2000 | 45,750 | 13.2% | 1,082,269 | 16.7% | 24,297 | 12.3% | 950,544 | 16.2% |
| 2001-2005 | 113,432 | 32.8% | 2,170,792 | 33.4% | 61,957 | 31.3% | 1,916,417 | 32.7% |
| 2006-2014 | 176,365 | 51.1% | 2,900,949 | 44.7% | 106,417 | 53.7% | 2,699,599 | 46.1% |
| Total | 345,335 | 100.0% | 6,491,444 | 100.0% | 198,050 | 100.0% | 5,856,367 | 100.0% |

The overall fleet results for the annual I/M benefit are shown in Table 5-13. The first block of data shows a very slight increase in the RS averages from before to after an I/M test for the entire RS matched I/M fleet. However, as discussed above, the RS averages do drop for the vehicles that do actually receive a failing test and then a repair to pass the final I/M test. This suggests that the I/M program is causing an I/M benefit for those vehicles even though the emissions do not drop for the entire dataset. It is very possible that in the absence of the I/M program, annual fleet emissions would increase by much larger amounts.

**Table 5-13. RS Average Concentrations to Evaluate the Annual I/M Benefit**

| I/M Program Area | I/M Sequence Category | RS wrt IM | Number of Obs | RS HC (ppm) Mean | RS HC (ppm) Upper CLM | RS HC (ppm) Lower CLM | RS HC (ppm) Change (%) | RS CO (%) Mean | RS CO (%) Upper CLM | RS CO (%) Lower CLM | RS CO (%) Change (%) | RS NOx (ppm) Mean | RS NOx (ppm) Upper CLM | RS NOx (ppm) Lower CLM | RS NOx (ppm) Change (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DFW + HGB | 1P + FP | Before | 56,836 | 24.9 | 23.4 | 26.5 | | 0.139 | 0.135 | 0.143 | | 191 | 188 | 195 | |
| | | After | 90,924 | 25.9 | 24.8 | 27.0 | 3.9% | 0.148 | 0.145 | 0.151 | 6.3% | 205 | 202 | 208 | 7.2% |
| DFW + HGB | 1P | Before | 54,955 | 24.0 | 22.4 | 25.6 | | 0.136 | 0.132 | 0.140 | | 185 | 182 | 189 | |
| | | After | 87,624 | 24.8 | 23.7 | 25.9 | 3.4% | 0.144 | 0.141 | 0.147 | 6.1% | 200 | 197 | 203 | 8.0% |
| | FP | Before | 1,876 | 51.6 | 42.3 | 61.0 | | 0.228 | 0.201 | 0.256 | | 371 | 341 | 400 | |
| | | After | 3,297 | 55.2 | 43.7 | 66.6 | 6.9% | 0.242 | 0.220 | 0.264 | 6.0% | 342 | 323 | 361 | -7.7% |
| DFW | 1P + FP | Before | 37,564 | 26.8 | 25.0 | 28.7 | | 0.149 | 0.144 | 0.154 | | 203 | 199 | 207 | |
| | | After | 59,169 | 26.4 | 25.1 | 27.7 | -1.7% | 0.159 | 0.155 | 0.162 | 6.4% | 220 | 217 | 223 | 8.3% |
| HGB | 1P + FP | Before | 19,272 | 21.2 | 18.4 | 24.0 | | 0.119 | 0.113 | 0.125 | | 168 | 162 | 174 | |
| | | After | 31,755 | 25.0 | 23.1 | 27.0 | 18.1% | 0.127 | 0.122 | 0.132 | 6.6% | 177 | 173 | 182 | 5.4% |
| DFW | 1P | Before | 36,313 | 25.8 | 23.9 | 27.6 | | 0.146 | 0.141 | 0.151 | | 197 | 193 | 201 | |
| | | After | 56,999 | 25.0 | 23.8 | 26.2 | -3.0% | 0.154 | 0.151 | 0.158 | 5.9% | 215 | 211 | 218 | 9.1% |
| | FP | Before | 1,247 | 57.6 | 44.6 | 70.5 | | 0.239 | 0.204 | 0.273 | | 391 | 355 | 427 | |
| | | After | 2,168 | 62.1 | 46.1 | 78.1 | 7.9% | 0.268 | 0.238 | 0.298 | 12.2% | 365 | 341 | 389 | -6.7% |
| HGB | 1P | Before | 18,642 | 20.5 | 17.7 | 23.4 | | 0.116 | 0.110 | 0.122 | | 163 | 157 | 169 | |
| | | After | 30,625 | 24.4 | 22.4 | 26.4 | 18.9% | 0.125 | 0.120 | 0.130 | 7.3% | 173 | 168 | 177 | 6.2% |
| | FP | Before | 629 | 39.9 | 29.2 | 50.5 | | 0.208 | 0.160 | 0.257 | | 330 | 277 | 383 | |
| | | After | 1,129 | 41.9 | 28.9 | 55.0 | 5.1% | 0.193 | 0.163 | 0.223 | -7.3% | 299 | 266 | 331 | -9.5% |

## 6.0 Measures for Evaluating Station Performance

For an I/M program to function as designed, it is critical that each I/M inspection station follow the procedures and regulations that have been created to ensure that inspections are consistently performed properly. In this section, data from the TIMS database are used to explore a range of ways in which individual I/M stations and inspectors may be circumventing procedures or regulations – in other words, cheating. The offenses can be broken into two different levels: 1) errors of commission: intentional breaking of rules to manipulate inspection results, and 2) errors of omission: failure to routinely follow regulated procedures. The specific actions that will be investigated here include:

- Errors of Commission:
  - — OBD Fraud Checks (Section 6.1)
    - ▪ VIN from vehicle doesn't match OBD-downloaded VIN (6.1.1)
    - ▪ Powertrain Control Module (PCM), Parameter ID (PID), VIN, and/or readiness status changes between inspections (6.1.2)
  - — Tailpipe Inspection Manipulation (Section 6.2)
    - ▪ Clean-piping: a passing retest follows a failed inspection within only a few minutes (6.2.1)
    - ▪ Switching vehicle from ASM to TSI in order to pass inspection (6.2.2)
    - ▪ Switching from LD (<8,500 GVWR) to HD (>8,500 GVWR) in order to pass inspection (6.2.3)
    - ▪ Stations with a very high or very low ASM or OBD fail rate (6.2.4)
- Errors of Omission:
  - — Use of analyzers of less-than-optimal functionality (Section 6.3)
- Performing inspections on analyzers with a high degree of drift (6.3.1)
- Performing inspections right before failing a span gas audit (6.3.2)
- Performing only one of the four calibrations that are required every 72-hours, instead of all four (6.3.3)
  - — Data entry issues (Section 6.4)
- Consistently entering repair type as "Misc" (6.4.1)
- Consistently entering repair cost as $0 (6.4.2)

- VIN Check digit errors (6.4.3)
- Anomalous inspection sequences (other than 1P or FP) (6.4.4)

  — Anomalous test results (Section 6.5)
- ASM or TSI Inspection results with greater than 16% $CO_2$ (6.5.1)
- ASM or TSI Inspection results with greater than 20.5% $O_2$ (6.5.2)
- ASM or TSI inspections with high DCF values (6.5.3)

Obviously, many stations will have the occasional inspection where the analyzer had drifted just before a calibration, or the VIN was accidentally entered incorrectly and didn't match the downloaded OBD VIN, etc. However, the goal of this section is to identify those stations where these events are frequent, suggesting that their occurrence is not accidental and these events are much more common than at other stations.

A percentile rank was assigned to each station for its performance on each bullet the above list. Using a ranking of the stations for each measure permits the comparison of one measure to another measure even if the two have different types of results. The final results were a compilation of the ranks for each station on each of the measures of errors of commission and each of the measures of omission. These compiled ranks are discussed in Section 6.6.

A short list of inspection stations that are operated by the state was provided by the DPS. These stations were excluded from all of the analysis in this section, as they tended to exhibit a substantially different range of results than the majority of stations, skewing the distribution of the results. These stations were: 1G25792, 4G25799, 2G34721, 1G34843, 6G20541, 6G36011, and 2G25739.

## 6.1 OBD Data Checks for Evidence of Station Fraud

"Clean-piping" is a term used to describe a type of vehicle emissions test fraud in which an inspector substitutes a vehicle with passing emission rates in place of a vehicle with high emission rates in order to achieve a pass record for the high-emitting vehicle. Historically, this has been identified through the use of covert audits, notifications by motorists, and analysis of vehicle emission result trends. For a vehicle receiving an OBD inspection, the analogous practice is typically referred to as "clean-scanning," where a vehicle with no MIL illumination is substituted in place of a vehicle with MIL illumination and stored DTCs in an attempt to receive a passing test result. Although identification of emission results trends is not possible with OBD tests, information downloaded from the OBD system during an inspection may be used to identify possible clean-scanning activities.

### 6.1.1 Comparison of Inspector-Entered VIN to Vehicle-Downloaded OBD VIN

For OBD vehicles, a comparison of the inspector-entered VIN against the vehicle-downloaded VIN via the OBD connection can help verify that all OBD inspections are performed on the correct vehicle. Both the inspector-entered VIN and the vehicle-downloaded VIN are recorded in each vehicle inspection record of the Texas TIMS.

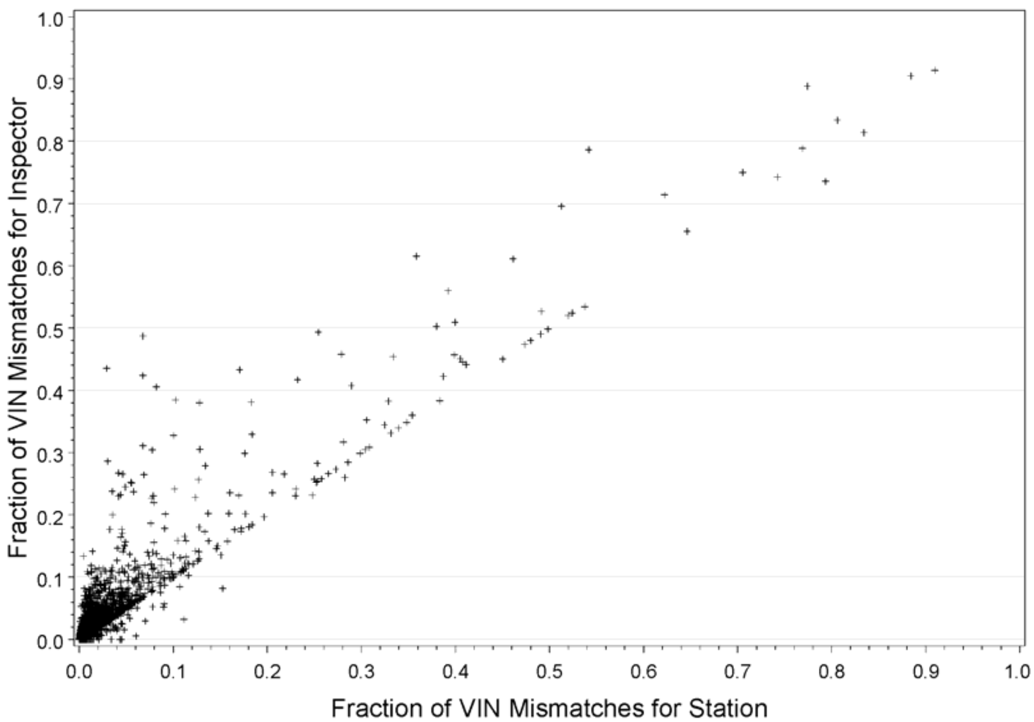
For this analysis, all test records where no OBD VIN was present were excluded. This reduced the dataset from 14,245,459 records to 9,170,097 records. For each of these remaining records, the OBD-downloaded VINs were compared with VINs entered (either via keyboard or barcode scan) during the vehicle inspection. Approximately 1.4% of these records (142,861 records) were found to have VIN to VIN discrepancies. Manual investigation of these records showed a number of the OBD VINs or entered VINs were invalid (for example, the VINs were less than 17 characters in length, or contained characters that are not allowed in a VIN), and some mismatches were also due to VIN errors in the vehicle test record. An investigation of the VIN discrepancies, shown in Table 6-1, revealed that vehicles from the early years of OBD (1996-1999) had very high rates of discrepancies, with as many as 87.6% of vehicle records containing a discrepancy. Rates were very low for the later model years, in part due to federal requirements for the OBD system to provide the OBD VIN on model year 2005 and newer vehicles. However, it should be noted that the vehicles that benefit from clean-scanning are those that fail an inspection and that group would likely be dominated by the early model-year vehicles, rather than the newer vehicles.

**Table 6-1. Rates of OBD-Downloaded and Inspector-Entered VIN Discrepancies, by Model Year**

| Model Year | Number of OBD Inspections with VIN Mismatch | Percent of OBD Inspections with VIN Mismatch | Total Inspections |
|---|---|---|---|
| 1996 | 2,828 | 87.6% | 3,229 |
| 1997 | 3,741 | 84.5% | 4,427 |
| 1998 | 4,156 | 82.6% | 5,031 |
| 1999 | 5,439 | 70.3% | 7,738 |
| 2000 | 12,200 | 12.5% | 97,406 |
| 2001 | 14,140 | 4.5% | 311,137 |
| 2002 | 15,248 | 3.9% | 394,832 |
| 2003 | 15,080 | 3.3% | 463,747 |
| 2004 | 14,481 | 2.5% | 590,926 |
| 2005 | 10,808 | 1.1% | 1,020,479 |
| 2006 | 8,117 | 0.7% | 1,105,649 |
| 2007 | 6,933 | 0.5% | 1,280,908 |
| 2008 | 5,200 | 0.4% | 1,267,032 |
| 2009 | 2,813 | 0.3% | 832,051 |
| 2010 | 2,770 | 0.3% | 956,043 |
| 2011 | 2,039 | 0.3% | 645,846 |
| 2012 | 743 | 0.5% | 164,483 |
| 2013 | 125 | 0.7% | 19,133 |

The rate at which VIN discrepancies were recorded was calculated for each station that performed OBD inspections, and for each inspector. These are compared graphically in Figure 6-1. The horizontal axis shows the fraction of OBD inspections that contained a VIN discrepancy for each station, while the vertical axis shows the fraction of OBD inspections with a VIN discrepancy for each inspector. To reduce errors due to small sample size, stations or inspectors that performed fewer than 100 inspections were excluded from the plot. The large cluster of points at the bottom left corner of the plot includes most stations and inspections: these had a near-zero rate of VIN discrepancies. The points closer to 1 on the horizontal or vertical axis indicate stations or inspectors that almost always produced OBD records with a VIN discrepancy. These very-high rates could in part result from practices other than clean-scanning, such as sloppy data entry when the VIN is manually entered, or vehicles with an invalid OBD VIN (earlier model years or PCM replacements).

**Figure 6-1. Rates of OBD-Downloaded and Inspector-Entered VIN Discrepancies, by Station and Inspector**




One additional factor that was calculated for each station was the number of times the same VIN was downloaded in different OBD inspections. If clean-scanning is taking place, there is a good chance that the "clean" vehicle would be used repeatedly and its VIN would be downloaded numerous times, whereas VIN typos would vary with each inspection. This turned out to be a revealing investigation, as it was found that some stations did OBD inspections on the same downloaded-VIN hundreds of times.

These VIN mismatch findings were condensed into a rank for each station, based on the fraction of inspections that revealed a disagreement between the entered VIN and the downloaded VIN. Stations that performed fewer than 100 OBD inspections over the two year period were again excluded from the results, due to the possibility of spurious results from the small sample size. As an example of the findings, the VIN mismatch rates for the 10 worst offending stations are listed below in Table 6-2. The table shows the rate at which there was a disagreement between the entered VIN and the downloaded OBD VIN, out of all inspections at that station that included a 17-digit VIN in both fields. The table also shows the maximum number of times a single VIN was tested at each station.

**Table 6-2. Stations with Highest Rates of OBD and Entered VIN Mismatches**

| Station ID | Percent of Inspections Where VIN Did Not Match | Total Number of Inspections Performed at Station | Maximum Number of Tests on a Single VIN | Percentile Rank for Station |
|---|---|---|---|---|
| **Ten worst stations:** | | | | |
| 1P42911 | 91.0% | 356 | 291 | 100.0 |
| 1P42971 | 88.4% | 302 | 104 | 100.0 |
| 1P42868 | 83.4% | 157 | 86 | 100.0 |
| 2P44652 | 80.6% | 258 | 209 | 99.9 |
| 1P42579 | 79.4% | 223 | 174 | 99.9 |
| 2P39821 | 77.4% | 2,249 | 290 | 99.9 |
| 1P43202 | 76.9% | 368 | 192 | 99.9 |
| 1P44505 | 74.2% | 198 | 145 | 99.8 |
| 1P44114 | 70.5% | 129 | 41 | 99.8 |
| 1P43059 | 64.7% | 348 | 33 | 99.8 |

### 6.1.2 Comparison of Vehicle-Specific Information between the First Test and Subsequent Tests

The purpose of this analysis was to compare OBD-downloaded information for a given vehicle on its first inspection, to OBD-downloaded information on retests of that same vehicle. Certain types of OBD information may be combined to create unique "electronic profiles" for each vehicle, and the electronic profile should be the same at the initial inspection and at subsequent inspections. If the electronic profile changes from one inspection to the next, inspection fraud may be suspected. For this analysis, only those vehicle inspection cycles that included an initial test and at least one retest were used, and only records where monitor readiness values were non-missing were used, reducing the dataset from 14,245,459OBD inspections to 1,592,273 inspections. This includes 760,506 initial inspections, and 831,767 retests.

Three variables were used to create the first "electronic profile" for each vehicle: the OBD-downloaded VIN, the PCM ID, and the PID Count. The downloaded values for these three variables from all OBD tests conducted over the two-year audit period are summarized below:

- OBD VIN: OBD-downloaded VINs (valid or invalid) were only available in 56% of the test records. The OBD VIN or the manually entered VIN was null in the remaining 44% of the OBD test records. Because of this, use of the OBD VIN in itself would not be sufficient to positively identify clean-scanning.

- PCM Module ID: PCM Module ID was available in all but 11 of the test records. 65 unique PCM Module IDs were seen, but 56% of all PCM

Module IDs had a value of “10”. One other PCM Module ID represented another 22% of records, two other PCM Module IDs each comprised an additional 2 to 4% of the test records, and the remaining test records were distributed among the other 61 PCM Module IDs. Because of this, as with the OBD VIN, use of PCM Module ID alone would not be sufficient to positively identify clean-scanning (a substituted vehicle could easily have a value of “10” or one of the other eight common PCM Module IDs).

- PID Count: 96 unique PID Count values were seen, and all but 4 OBD test records contained a value for PID Count. Seven PID Count values were seen in 67% of all OBD test records, while the remaining test records contained one of the remaining 89 PID Count values.

- When the PCM Module ID and PID Count are looked at in combination, the three most common combinations comprise 14, 10, and 8% of inspections, with 776 combinations making up the remainder of inspections. Thus the combination of PCM Module ID and PID Count actually is highly variable and may be a good indicator of a different vehicle being substituted for the test.

The second electronic profile that was created was an “enabled profile”. For this, OBD monitors were identified that are commonly found to be both “monitored” and “not monitored,” depending on the make/model/model year of vehicle being inspected. For example, very few vehicles have monitored positive crankcase ventilation or air conditioning systems, so these would be poor indicators of potential clean-scanning since the monitored status is almost surely the same for two different vehicles. Similarly, catalysts and oxygen sensors are almost always monitored, so these too would be poor indicators of potential clean-scanning. Again, two different vehicles will likely both have these monitored. As shown below, EGR systems, evaporative systems, and to a lesser extent heated oxygen sensor systems and secondary air injection systems were seen to have significant percentages of vehicles with both “monitored” and “not monitored” status:

- EGR systems: 44% not monitored, 56% monitored

- Evaporative systems: 7% not monitored, 93% monitored

- heated $O_2$ systems: 3% not monitored, 97% monitored

- secondary air systems: 93% not monitored, 7% monitored

- When the status of the four monitors is looked at together, two combinations of monitor status dominated the dataset, with 49% and 35% of vehicles. Smaller numbers of vehicles comprised the remaining 14 combinations and 16% of vehicles. Since the combined monitored status of these four monitors could provide a distinguishing and characteristic profile from vehicle to vehicle, these four monitors were used for this analysis.

An electronic profile and a monitored-status profile were created for each vehicle, for its initial inspection and for any re-inspections. Any tests where either profile differed from inspection to inspection were flagged. Tests where both the electronic profile and the monitored-status profiles changed would be an indicator that a different vehicle was being substituted for the test. Note that for any individual vehicle, these downloaded values may vary among analyzer manufacturers (in particular the PCM Module ID and the PID Count), so the analysis was based on vehicle/analyzer combinations. All inspections where the initial inspection took place on a different type of analyzer than that used for the retest inspection were excluded from the analysis.

Occasionally, analyzer hardware upgrades or software updates could result in OBD system PID count mismatches between multiple tests on the same vehicle, and the OBD-downloaded VIN could be mismatched on multiple tests from the same vehicle in extremely rare instances where the PCM on the vehicle was improperly reprogrammed in an attempt to repair the vehicle. An assessment of the likelihood of fraud is provided for each of the scenarios listed below. It is also worthwhile to note that since each vehicle's OBD system "profile" was assigned based on the information collected during the vehicle's first test, this analysis would not identify any tests where a vehicle was substituted, i.e., clean-scanned, during the initial inspection.

As described above, the dataset included 760,506 initial inspections and 831,767 retests. Of those retests, 88,388 took place on a different type of analyzer than that of the initial test, and were excluded from the results. This left 743,379 retests for analysis. The results of the analysis were:

- 668,475 (89.9% of the 743,379-record dataset) tests had matches for both the electronic profile and the readiness profile between initial test and subsequent retests on the same analyzer. These tests very likely indicate compliant testing.
- 33,191 (4.5% of the 743,379 record dataset) tests had a mismatch for both the electronic profile info and the readiness profile, between the initial test and at least one retest on the same analyzer. Test pairs where both computer ID information and readiness profile differ are likely to be performed on two different vehicles (i.e., an indication of clean-scanning).

- 39,859 (5.4% of the 743,379 record dataset) tests had an electronic profile mismatch info between the initial test and at least one retest on the same analyzer, but the “readiness profile” matched between the initial test and all subsequent retests on the same analyzer. Since the computer ID serves as a unique identifier for any vehicle, this information should always match for retests on the same vehicle. A mismatch could occur only in the following scenarios:
    - if another vehicle was substituted for a retest (clean-scanning)
    - if an anomaly in the analyzer software interpreted the computer ID info two different ways on subsequent retests for the same vehicle
    - if a vehicle repair was performed in which the vehicle’s PCM was re-programmed with new ID info as a part of a repair

Although the last two scenarios are unlikely, it was not possible to quantify the likelihood of this occurring in this analysis. It is possible for two different vehicles to have common readiness profiles, so a readiness profile match does not confirm that clean-scanning did not occur. Therefore, this scenario (computer ID mismatch) is felt to be a good indicator of clean-scanning.

- 1,854 (0.2% of the 743,379 record dataset) tests had a “readiness profile” mismatch between the initial test and at least one retest on the same analyzer, but the electronic profile matched between the initial test and all subsequent retests on the same analyzer. This scenario is difficult to interpret, since the readiness profile is based on “monitored vs. unmonitored” status of various systems, as opposed to ready/not ready status, and therefore should never change for a vehicle despite the vehicle’s state of readiness. Similarly, the computer ID information should be static for any one vehicle except for the case when PCM reprogramming is part of the repair process. Because of the contradictory results, the scenario of a readiness profile mismatch with a computer ID info match is not considered to be a strong indicator of non-compliant testing.

A summary of this information is provided in Table 6-3.

**Table 6-3. Percentages of Tests with Various OBD Fraud Indicators**

| Retest Match Scenario | Retest-only Dataset (795,446 tests total) |
|---|---|
| All match (compliant) | 89.9 % |
| Readiness mismatch (ambiguous) | 0.2 % |
| PCM ID info mismatch (fraud likely) | 5.4 % |
| Both mismatch (fraud very likely) | 4.5 % |
| Estimated % of clean-scanning | 4% to 6% |

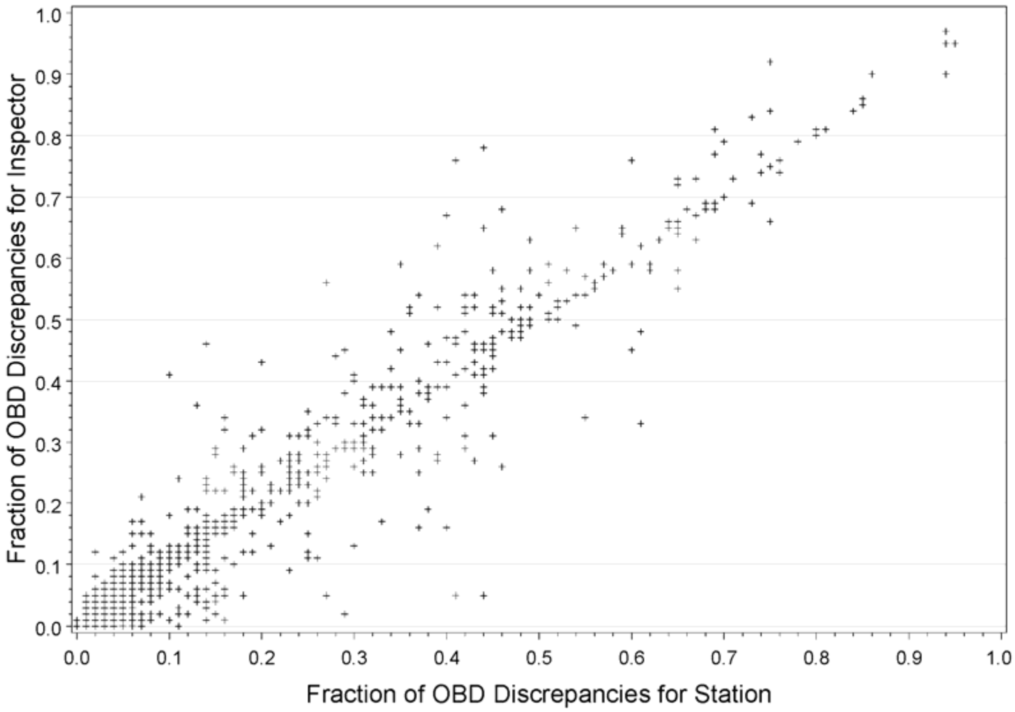
Next, using the complete dataset, which includes tests classified as initial tests, the following general statistics were seen for stations and inspectors with computer ID information or "readiness profile" mismatches.

- Over the two-year audit period, 77% of the 4,812 inspection stations had at least one test record with either a readiness profile or computer ID information mismatch between an initial test and a subsequent test for the same vehicle (tested using the same analyzer as the initial test). The maximum number of mismatch retest records for any one station was 1,374 records over the two-year period, and another 48 stations had more than 200 records with a mismatch. Some stations had mismatch rates as high as 89%.

- Over the two-year audit period, 33% of the 28,179 inspectors had at least one test record with either a readiness profile or computer ID information mismatch between an initial test and a subsequent test on the same vehicle using the same analyzer. The maximum number of mismatch retest records for any one inspector was 769 records over the two-year period, while an additional 15 inspectors had more than 200 mismatch retest records. Inspector mismatch rates as high as 97% were seen.

The distribution of station and inspector mismatch rates is shown in Figure 6-2. The horizontal axis shows the fraction of retest records that contained an electronic profile or readiness profile mismatch, for each station. The vertical axis shows the fraction for each inspector. The large concentration of data points in the lower left corner are stations and inspectors that produced retest records that rarely had a mismatch when compared to the information from the initial inspection. In contrast, the stations/inspectors in the upper right-hand portion of the chart are those that are most likely to be clean-scanning.

**Figure 6-2. Rates of Re-Test Discrepancies in OBD Computer and Readiness Information, by Station and Inspector**




These results were condensed into a rank for each station, based on the fraction of retest inspections performed at that station that included both an electronic profile mismatch and a readiness profile mismatch. Stations with fewer than 100 OBD retest inspections over the two year period were excluded from the results, due to the possibility of spurious results from the small sample size. The 10 stations with the highest rates of profile mismatches are listed in Table 6-4. Some electronic profile and/or readiness mismatches are to be expected, and as mentioned above, more than 78% of stations had at least one case of a mismatch. However, most of those stations had only one or a few mismatches. Overall, about 4.5% of retest inspections resulted in a readiness profile and electronic profile mismatch. When stations with a mismatch in as many as 89% of their inspections are seen, one can start to suspect that something beyond the expected occasional difference is taking place.

**Table 6-4. Stations with Highest Percents of Electronic Profile and Readiness Profile Mismatches**

| Station ID | Percent of Re-inspections with BOTH Electronic & Readiness Mismatch | Number of Re-inspections at Station | Percentile Rank for Station |
|---|---|---|---|
| **Ten worst stations:** | | | |
| 1P44311 | 88.8 | 107 | 100.0 |
| 2P34213 | 79.9 | 169 | 100.0 |
| 2P42264 | 75.0 | 1,462 | 99.9 |
| 2P40511 | 69.5 | 292 | 99.9 |
| 2P40348 | 68.6 | 118 | 99.8 |
| 1P42519 | 67.8 | 118 | 99.8 |
| 1P40268 | 65.3 | 121 | 99.7 |
| 2P34306 | 64.8 | 261 | 99.7 |
| 1P40207 | 62.2 | 143 | 99.6 |
| 1P40789 | 62.0 | 163 | 99.6 |

## 6.2 Tailpipe Inspection Data Checks for Fraud

Unlike OBD inspections, tailpipe emissions inspections do not include the download of vehicle-specific information that remains unchanged from an initial inspection to a re-inspection. However, several different types of inspection results have been identified that may provide good indicators that tailpipe emissions inspection fraud may be occurring at a given station. Several of these are extremely uncommon in the TIMS dataset as a whole, but are relatively common for a handful of stations.

- Sometimes a failing inspection is followed by a passing inspection only a few minutes later. This could indicate the occasional warm-up or easy repair when it happens once or twice for each station, but when it occurs a large number of times at only a few stations, it is more likely to indicate clean-piping.
- Occasionally a vehicle receives an initial inspection that is an ASM test, and a retest inspection that is a TSI test. When such switches occur a large number of times at a single station, and when the test results also show that most of the ASM tests were failed for high $NO_x$ levels ($NO_x$ is not measured in a TSI test), it is likely to indicate a version of inspection fraud.
- Similarly, an initial failed inspection of a light-duty vehicle (GVWR<8,500 lbs) is sometimes followed by a passed inspection of that vehicle as a heavy-duty vehicle. Cutpoints are higher for HD vehicles, making the inspection easier to pass. This happens very infrequently in the dataset as a whole, but much more frequently at some stations.
- The overall failure rate at a station can be used as an indicator of whether fraud is occurring. Unusually high or unusually low failure rates may both

be a cause for concern. This factor can be difficult to analyze, since it is known that different areas with a different type of fleet (or a different socio-economic status) often have real differences in failure rates.

Each of these factors is discussed in more detail in the following sections, and a ranking is assigned to each station, for each factor.

### 6.2.1 Short Time Interval Between Inspections

For inspection cycles that begin with a failing inspection, a retest (or retests) usually follows a day or several days after the initial failed inspection. Presumably, repairs are performed during that interval between inspections. However, some failing inspections are followed by a passing inspection within minutes, leading one to wonder how the vehicle was successfully repaired so quickly, or if instead clean-piping occurred for the passing retest. The dataset shows that many stations have one or a few cases of a passing retest following a failing initial test within a short time. These occasional cases may be the real result of a simple fix: a reconnection of a loose line or wire or other simple change, or from retesting a vehicle that previously had not been properly warmed-up. Some vehicles which failed with emissions levels very near the cutpoints might also be retested after no repairs, and pass due to the I/M test variability. However, some stations show a much more frequent occurrence of initial inspections being quickly followed by passing inspections when compared to the majority of stations. In these cases, there may be cause for a suspicion of inspection fraud.

For this analysis, any inspections that were aborted or had dilution problems were deleted from the dataset, and only TSI or ASM inspections were considered. This left 0.9 million observations in the dataset. In addition, only time differences on retest inspections that were conducted at the same inspection station as the initial inspection were used. This resulted in a dataset of about 95,000 retest observations.

The distribution of the number of times that a failed initial inspection was followed by a passing retest within 15 minutes at a given station over a 2 year period is listed in Table 6-5. The table shows that this happened 13 times at the station with the highest frequency of occurrences, while for most of the 2,151 stations that performed tailpipe inspections, it did not ever happen.

### Table 6-5. Number of Close-in-Time Retests per Station

| Number of Close-In-Time Retests | Number of Stations | Percent of Stations |
|---|---|---|
| 13 | 1 | 0.1 |
| 6 | 1 | 0.1 |
| 5 | 5 | 0.2 |
| 4 | 7 | 0.3 |
| 3 | 22 | 1.0 |
| 2 | 49 | 2.3 |
| 1 | 194 | 9.0 |
| 0 | 1,872 | 87.0 |
| Total | 2,151 | 100 |

The ten stations with the highest rate of close-in-time retests are listed in Table 6-6. The percentage was calculated from the number of close-in-time retests and the total number of retests, at that station. Stations that performed fewer than 100 retest inspections over the 2 year period are excluded from the results.

### Table 6-6. Percent of Close-In-Time Retest Inspections for 10 Highest Ranking Stations

| Station ID | Percent of Close-In-Time Retests | Number of Close-In-Time Retests | Total Number of Retest Inspections | Percentile Rank for Station |
|---|---|---|---|---|
| 2P12621 | 4.9% | 5 | 102 | 100.0 |
| 1P44250 | 3.9% | 5 | 129 | 99.6 |
| 2P39398 | 3.8% | 5 | 130 | 99.2 |
| 1P04523 | 3.2% | 13 | 410 | 98.8 |
| 1P11286 | 3.1% | 4 | 128 | 98.4 |
| 2P28516 | 3.0% | 3 | 100 | 98.0 |
| 1P33875 | 3.0% | 5 | 168 | 97.5 |
| 1P39928 | 2.6% | 3 | 114 | 97.1 |
| 1P31247 | 2.6% | 4 | 152 | 96.7 |
| 1P38533 | 2.5% | 4 | 158 | 96.3 |

### 6.2.2 Changing from ASM to TSI Inspection to Pass

Given that the overall failure rate for the TSI inspection is much lower than that for the ASM inspection, and that the TSI inspection does not measure $NO_x$, while the ASM inspection does measure $NO_x$, ERG investigated whether switching from an ASM inspection to a TSI inspection was ever used to manipulate emissions inspection results.

For this analysis, any inspections that were aborted or had dilution problems were deleted from the dataset, and only TSI or ASM inspections were considered. This left 0.9 million observations in the dataset. Only inspection cycles where the initial inspection and the retest inspection were conducted at the same station were used. This left about 95,000 retests in the dataset.

Overall, it was found that for ASM inspections that were failed for HC and/or CO, but where $NO_x$ was passed, 1.8% of retests were TSI instead of ASM. For ASM inspections that included a $NO_x$ failure, 2.3% of retests were TSI instead of ASM. These percentages are similar, but the fact that the percentage is slightly higher when a $NO_x$ failure is present may indicate that some intentional test-type switching is taking place to avoid the stricter ASM standards. Table 6-7 shows the frequency and percentage of stations switching to a TSI inspection, which was passed, following a failed ASM initial inspection that included a failure for $NO_x$. Stations that performed fewer than 100 retest inspections were excluded from the results. The table shows that this happened 25 times at the station with the highest frequency of occurrences. The stations in Table 6-7 had rates of 7-25% of all retests being switches from ASM to TSI inspections.

**Table 6-7. Percent of Retest Inspections Switched from ASM to TSI for 10 Highest Ranking Stations**

| Station ID | Percent of Retests Switched from ASM to TSI | Number of Switched Retests | Total Number of Retest Inspections | Percentile Rank for Station |
|---|---|---|---|---|
| 2P12621 | 25 | 25 | 102 | 100.0 |
| 1P40852 | 18 | 19 | 105 | 99.6 |
| 1P33875 | 15 | 26 | 168 | 99.2 |
| 1P00576 | 15 | 44 | 295 | 98.8 |
| 1P42718 | 10 | 11 | 114 | 98.4 |
| 1P38484 | 10 | 10 | 105 | 98.0 |
| 1P28615 | 9 | 9 | 104 | 97.5 |
| 1P04523 | 9 | 35 | 410 | 97.1 |
| 2P26640 | 8 | 8 | 100 | 96.7 |
| 1P39564 | 7 | 9 | 127 | 96.3 |

### 6.2.3 Changing Vehicle Type from Light Duty to Heavy Duty to Pass Vehicle

Given that inspection standards are less stringent for heavy-duty vehicles than for light-duty vehicles, ERG investigated whether switching a vehicle from having a light-duty GVWR (less than 8,500 lbs) to a heavy-duty GVWR was ever used to manipulate emissions inspection results. The vehicle GVWR is an inspector-entered field in the inspection record.

For this analysis, any inspections that were aborted or had dilution problems were deleted from the dataset, and OBD, TSI and ASM inspections were considered. This resulted in a dataset of 20 million inspection records. Only inspection cycles where the initial inspection and the retest inspection were conducted at the same station were used. This left 790,000 retest inspections in the dataset.

Overall, it was found that only 0.4% of inspections that were initially failed as a light-duty vehicle were followed by a passing retest as a heavy-duty vehicle. However, these inspections were clustered at a handful of stations, shown below in Table 6-8. The table shows the ten inspection stations with the highest frequency of retests that involved a vehicle that failed as a light-duty vehicle on the initial inspection, followed by a passed retest of the same vehicle as a heavy-duty vehicle. At the first station on the list, fully 51% of vehicles that failed as a light-duty vehicle were switched to a heavy-duty vehicle, and then passed.

**Table 6-8. Percent of Retest Inspections Switched from Light-Duty to Heavy-Duty, for 10 Highest Ranking Stations**

| Station ID | Percent of Retests Switched from LD to HD | Number of Switched Retests | Total Number of Retest Inspections | Percentile Rank for Station |
|---|---|---|---|---|
| 2P42042 | 51 | 134 | 265 | 100.0 |
| 1P43253 | 27 | 79 | 295 | 100.0 |
| 2P33665 | 14 | 47 | 339 | 99.9 |
| 1P39587 | 13 | 80 | 619 | 99.9 |
| 1P02394 | 12 | 35 | 304 | 99.8 |
| 2P38602 | 11 | 49 | 448 | 99.8 |
| 2P22729 | 10 | 19 | 186 | 99.7 |
| 2P40519 | 10 | 38 | 374 | 99.7 |
| 1P35429 | 9 | 33 | 376 | 99.6 |
| 2P32329 | 8 | 21 | 263 | 99.6 |

### 6.2.4 Pass/Fail Outliers

Stations can also be evaluated based upon the percentage of vehicles that they pass or fail. Extremely high rates of either passing or failing vehicles may warrant further scrutiny by the DPS. Since typical pass/fail rates vary widely among inspection types (OBD, ASM, and TSI), this analysis was done separately for OBD and ASM inspections, resulting in two separate percentile rankings for each station. TSI inspections are performed much less frequently than OBD or ASM inspections; therefore, they were not included in this analysis.

It is recognized that differences in inspection failure rates among stations are often due to factors other than fraud. For instance, the age and maintenance level of the fleet tested at each station may vary widely. However, evaluation of the fleet quality and/or socio-economic status of the area each station is beyond the scope of this evaluation, and only overall pass/fail rates for each station are considered here.

Since it was necessary to identify both very low and very high failure rates, the stations were divided into two groups: stations with a failure rate that was above the mean failure rate over all stations, and stations with a failure rate that was below the mean failure rate over all stations. The stations with a failure rate that was above the mean were ranked with the 0% rank for the station at the mean and the 100% rank for the station with the highest failure rate. The stations with a failure rate that was below the mean were ranked with the 0% rank for the station at the mean, and the 100% rank for the station with the lowest failure rate. Thus each station gets one rank, either for being high or being low. The highest failure rate stations are listed in Table 6-9, with failure rates for OBD and ASM inspections listed separately. The lowest failure rate stations are listed in Table 6-10, with failure rates for OBD and ASM inspections listed separately. Stations with fewer than 100 inspections are excluded from the results.

**Table 6-9. Stations with Highest Failure Rates, OBD and ASM**

| Station ID | Failure Rate (%) | Number of Failed Inspections | Total Number of Inspections | Percentile Rank for Station |
|---|---|---|---|---|
| **OBD Inspection Results:** | | | | |
| 2P32154 | 36 | 1,098 | 3,082 | 100.0 |
| 2G20314 | 30 | 38 | 125 | 99.9 |
| 2P44704 | 27 | 32 | 117 | 99.9 |
| 1P43178 | 27 | 38 | 139 | 99.8 |
| 1P42774 | 26 | 52 | 198 | 99.8 |
| 1P42999 | 26 | 56 | 214 | 99.7 |
| 2P39800 | 25 | 96 | 390 | 99.7 |
| 2P44715 | 24 | 30 | 125 | 99.6 |
| 1P44682 | 23 | 34 | 145 | 99.6 |
| 1G26849 | 23 | 73 | 313 | 99.5 |
| **ASM Inspection Results:** | | | | |
| 1P27817 | 52 | 52 | 100 | 100.0 |
| 1P03482 | 41 | 48 | 116 | 99.9 |
| 2P04038 | 41 | 62 | 151 | 99.7 |
| 1P00349 | 39 | 59 | 150 | 99.6 |
| 2P12905 | 38 | 329 | 876 | 99.5 |
| 1P25057 | 37 | 228 | 619 | 99.4 |
| 1P39510 | 36 | 38 | 106 | 99.2 |
| 1P40852 | 36 | 164 | 459 | 99.1 |
| 1P29799 | 36 | 130 | 366 | 99.0 |
| 1P17053 | 35 | 128 | 365 | 98.9 |

**Table 6-10. Stations with Lowest Failure Rates, OBD and ASM**

| Station ID | Failure Rate (%) | Number of Failed Inspections | Total Number of Inspections | Percentile Rank for Station |
|---|---|---|---|---|
| **OBD Inspection Results:** | | | | |
| 2P38918 | 0 | 0 | 1,289 | 100.0 |
| 1P45352 | 0 | 0 | 115 | 100.0 |
| 1P44974 | 0 | 0 | 111 | 99.9 |
| 1P44503 | 0 | 0 | 296 | 99.9 |
| 1P44016 | 0 | 0 | 260 | 99.9 |
| 1P43061 | 0 | 0 | 290 | 99.8 |
| 1P42203 | 0 | 0 | 2,082 | 99.8 |
| 1P42202 | 0 | 0 | 125 | 99.8 |
| 1P42189 | 0 | 0 | 102 | 99.7 |
| 1P39555 | 0 | 0 | 313 | 99.7 |
| **ASM Inspection Results:** | | | | |
| 2P42928 | 0 | 0 | 374 | 100.0 |
| 2P41308 | 0 | 0 | 341 | 99.9 |
| 2P41057 | 0 | 0 | 314 | 99.7 |
| 2P40507 | 0 | 0 | 404 | 99.6 |
| 2P39206 | 0 | 0 | 198 | 99.5 |
| 2P38905 | 0 | 0 | 147 | 99.3 |
| 2P38266 | 0 | 0 | 429 | 99.2 |
| 2P37514 | 0 | 0 | 454 | 99.1 |
| 2P35912 | 0 | 0 | 305 | 99.0 |
| 1P44835 | 0 | 0 | 129 | 98.8 |

## 6.3 Repeated use of Analyzers with Less-Than-Optimal Functionality

The accuracy of vehicle inspection results and the quality of the data that is stored in the TIMS database depends in part on each analyzer being fully functional at all times. Consistently using an analyzer that is out-of-specification reduces the accuracy of inspection results.

### 6.3.1 High Degree of Drift

In Section 3.4.1, the impact of analyzer drift was evaluated. Analyzers that consistently drift little from calibration to calibration can be expected to produce more accurate measures of vehicle emissions than those that drift greatly. If the difference between the bottle label value and the pre-calibration analyzer reading is very large, then one presumes that some of the emissions measurements made during the previous 72 hours were more inaccurate than necessary. Here, the percentage of the time that analyzers were found to have drifted out of the specification range prior to the calibration was calculated for each station. Stations with fewer than 40 calibration events in the dataset were excluded from the results. An analyzer was defined as having drifted out of tolerance if any of the gas values (HC, CO, $NO_x$, $CO_2$, or $O_2$) at any level (zero, low, or mid span) were measured to be outside of the specified tolerance at the beginning of the calibration. However, since HC at the zero level was found to be out-of-tolerance in about half of all calibrations, it was not used here because it would not be a useful predictor of poor performance. Using this strict standard, 98% of stations were found to have had at least 1 or more calibrations on initially out-of-tolerance analyzers; however, the worst stations that are shown in Table 6-11 had almost all calibrations on out-of-tolerance analyzers.

**Table 6-11. Percent of Calibrations that Began with an Out-of-Tolerance Analyzer**

| Station ID | Analyzer ID | Percent of Calibrations that Began with Out-of-Tolerance Analyzer | Number of Calibrations that Began Out-of-Tolerance | Total Number of Calibration Events | Percentile Rank for Station |
|---|---|---|---|---|---|
| 2P45090 | ES212992 | 100.0 | 45 | 45 | 100.0 |
| 2P41493 | ES212682 | 100.0 | 57 | 57 | 100.0 |
| 2P38905 | ES721238 | 100.0 | 119 | 119 | 99.9 |
| 2P36709 | ES520626 | 99.0 | 100 | 101 | 99.9 |
| 1P42816 | ES112528 | 98.4 | 184 | 187 | 99.8 |
| 2P41322 | ES212590 | 98.0 | 49 | 50 | 99.8 |
| 2P41875 | ES212613 | 97.8 | 45 | 46 | 99.7 |
| 1P43168 | ES419640 | 97.6 | 165 | 169 | 99.7 |
| 2P34303 | ES721389 | 96.9 | 95 | 98 | 99.6 |
| 2P38589 | ES315234 | 96.2 | 76 | 79 | 99.6 |

### 6.3.2 Frequently Failing Span Gas Audits

Another time that the accuracy of analyzers is checked is during a span gas audit. Span gas audits were discussed in detail in Section 3.4.3. Here, the audit failure rate for each station was calculated. Stations with fewer than 6 audits in the dataset were excluded from the results. Most stations passed all of their audits. The ten stations with the highest span gas audit failure rates are shown below in Table 6-12.

## Table 6-12. Percent of Span Gas Audits that were Failed

| Station ID | Analyzer ID | Percent of Audits that were Failed | Number of Audits that were Failed | Total Number of Audits for Station | Percentile Rank for Station |
|---|---|---|---|---|---|
| 2P33974 | ES719051 | 100.0 | 11 | 11 | 100.0 |
| 1G20288 | ES213985 | 100.0 | 7 | 7 | 99.9 |
| 2P45009 | ES314943 | 87.5 | 7 | 8 | 99.8 |
| 2P44604 | ES315487 | 85.7 | 6 | 7 | 99.7 |
| 2P37695 | ES212615 | 85.7 | 6 | 7 | 99.6 |
| 2P34533 | ES419533 | 85.7 | 6 | 7 | 99.5 |
| 2P09312 | ES721243 | 83.3 | 10 | 12 | 99.4 |
| 2P19575 | ES022855 | 81.3 | 13 | 16 | 99.3 |
| 2P34296 | ES317049 | 80.0 | 8 | 10 | 99.3 |
| 1P03175 | WW510072 | 80.0 | 8 | 10 | 99.2 |

### 6.3.3 Failure to Perform All Calibrations

Analyzers that are used for emissions inspections are required to undergo several types of calibration every 72-hours. If they do not receive all required calibrations, they are supposed to be locked out from performing I/M inspections until all calibrations are completed and passed. In Section 3.4.4, it was found that some analyzers pass only one calibration type without receiving all calibrations, and then proceed to perform inspections. Additionally, some analyzers receive one or more calibrations but do not pass them, and are allowed to continue performing inspections. Here, those results are examined to identify stations with a higher than average rate of performing incomplete or failed 72-hour calibrations, and then performing I/M inspections. The results for the top ten highest ranking stations are shown in Table 6-13, which gives the percentage of I/M inspections that were performed while the analyzer should have been locked out. Stations with fewer than 100 inspections in the dataset are excluded from the results. While most stations never perform any inspections while the analyzer should have been locked out, the table shows that some stations fail to perform complete analyzer calibrations on a routine basis.

**Table 6-13. Percent of Inspections When Analyzer Should Have Been Locked Out**

| Station ID | Analyzer ID | Percent of Inspections Performed on Analyzer that should have been locked out | Number of Inspections on Analyzer that should have been locked out | Total Number of Inspections for Station | Percentile Rank for Station |
|---|---|---|---|---|---|
| 1P40039 | WW510457 | 51.4 | 1,587 | 3,087 | 100.0 |
| 1P32480 | WW510453 | 51.0 | 1,428 | 2,798 | 100.0 |
| 1P42733 | WW510353 | 49.4 | 559 | 1,132 | 99.9 |
| 1P43141 | WW510040 | 47.6 | 199 | 418 | 99.9 |
| 1P37930 | WW610082 | 47.0 | 664 | 1,414 | 99.8 |
| 1P44645 | WW510738 | 46.9 | 246 | 524 | 99.8 |
| 1P42305 | WW510193 | 46.4 | 161 | 347 | 99.7 |
| 1P25151 | WW510452 | 45.1 | 937 | 2,079 | 99.7 |
| 1P43035 | WW510063 | 44.2 | 503 | 1,138 | 99.6 |
| 1P00841 | WW510014 | 43.9 | 1,182 | 2,695 | 99.6 |

## 6.4 Data Entry Issues

Several VID fields are subject to manual data entry by inspectors during the inspection process. Consistently unusual data entry patterns can be detected at certain stations when the data are analyzed. This section presents the analysis results for several data entry metrics.

### 6.3.4 Consistently Entering Repair Type as "Misc"

Repairs performed are categorized by inspectors into five different types: fuel system, ignition/electrical system, emissions system, engine-mechanical, and miscellaneous repairs. Miscellaneous repairs accounted for approximately 40% of the repairs recorded in the TIMS during the most recent analysis period. At certain stations, miscellaneous repairs account for much more than that. The ten stations with the highest percentages of miscellaneous repairs are presented in Table 6-14. Stations that performed fewer than 100 inspections following repairs are excluded from the results.

**Table 6-14. Miscellaneous Repair Percentage**

| Station ID | Percent of "Misc" repairs | Number of "Misc" repairs | Total Repairs | Percentile Rank for Station |
|---|---|---|---|---|
| 2P01468 | 100.0 | 132 | 132 | 100.0 |
| 1P44081 | 100.0 | 104 | 104 | 99.9 |
| 1P41775 | 100.0 | 101 | 101 | 99.9 |
| 1P37937 | 100.0 | 159 | 159 | 99.8 |
| 1P25738 | 100.0 | 166 | 166 | 99.8 |
| 2P35275 | 99.7 | 336 | 337 | 99.7 |
| 2P34709 | 99.6 | 279 | 280 | 99.7 |
| 1P27817 | 99.6 | 229 | 230 | 99.6 |
| 2P40495 | 99.4 | 163 | 164 | 99.6 |
| 1P42969 | 99.4 | 162 | 163 | 99.5 |

### 6.3.5 Consistently Entering Repair Cost as $0

Repairs performed must also be recorded with an associated repair cost. Repairs recorded with a cost of $0 accounted for approximately one-half of the values in the TIMS during the most recent analysis period. At certain stations, zero-cost repairs account for much more than that. A summary of stations with a high percentage of zero-cost repairs is presented in Table 6-15 below. Stations that performed fewer than 100 inspections following repairs are excluded from the results.

**Table 6-15. Zero-Cost Repair Percentage**

| Station ID | Percent of $0 Repairs | Number of $0 Repairs | Total Number of Repairs | Percentile Rank for Station |
|---|---|---|---|---|
| 2P42090 | 100.0 | 513 | 513 | 100.0 |
| 2P41331 | 100.0 | 177 | 177 | 99.8 |
| 2P40495 | 100.0 | 163 | 163 | 99.7 |
| 2P40123 | 100.0 | 174 | 174 | 99.5 |
| 2P39828 | 100.0 | 153 | 153 | 99.4 |
| 2P39786 | 100.0 | 129 | 129 | 99.2 |
| 2P38912 | 100.0 | 118 | 118 | 99.1 |
| 2P38584 | 100.0 | 127 | 127 | 98.9 |
| 2P35713 | 100.0 | 147 | 147 | 98.8 |
| 2P35218 | 100.0 | 268 | 268 | 98.6 |

### 6.3.6 VIN Check Digit Errors

In the 2009 IM Evaluation Report, about 1.5% of VINs on record contained a bad check digit or an illegal character. More recently, this year and in the 2012 report, closer to 0.1% of VINs contained a bad check digit, representing such a small portion of total inspections that that metric was not used for the 2012 analysis. For the same reason, this metric was not used in the 2014 analysis. Most VINS are likely pre-populated through the record retrieval during the analyzer's initial "get-info" call, or are entered by bar-code reader.

### 6.3.7 Anomalous Inspection Sequences (other than 1P or FP)

Each vehicle that participates in the I/M program produces a brief history when it is inspected, repaired, and retested. 99.2% of the vehicles that participate in the program have a repair sequence of either pass (P) or fail-pass (FP). The remaining portion of the fleet consists of vehicles with histories that contain multiple passes or fails. Table 6-16 below lists stations that were in contact at some point with vehicles that had anomalous inspection sequences. Stations that performed fewer than 100 inspections are excluded from the results.

**Table 6-16. Anomalous Inspection Sequence Percentage**

| Station ID | Percent of Inspections with Odd Sequence | Number of Inspections with Odd Sequence | Total Inspections | Percentile Rank for Station |
|---|---|---|---|---|
| 2G25803 | 22.6 | 147 | 650 | 100.0 |
| 1P44734 | 18.0 | 62 | 344 | 100.0 |
| 1G26849 | 16.1 | 54 | 336 | 100.0 |
| 1G27362 | 15.5 | 44 | 284 | 99.9 |
| 2P41748 | 12.2 | 17 | 139 | 99.9 |
| 1G27360 | 11.0 | 60 | 544 | 99.9 |
| 2P44736 | 9.8 | 10 | 102 | 99.9 |
| 2G25778 | 9.6 | 47 | 489 | 99.8 |
| 2P40693 | 9.6 | 198 | 2,073 | 99.8 |
| 1G27353 | 9.4 | 34 | 361 | 99.8 |

## 6.4 Anomalous Test Results

In Section 3.4.2, several types of tailpipe inspection results displayed emissions concentrations that are not consistent with those expected for stoichiometric combustion. These include $CO_2$ levels higher than 16%, $O_2$ levels near ambient concentrations, and high dilution correction factors. In this section the rate of each of these anomalies by station is investigated.

### 6.4.1 Tailpipe Inspections with $CO_2$ Greater Than 16%

Table 6-17 presents stations with a high percentage of vehicles whose ASM or TSI tests produced $CO_2$ readings greater than 16%, outside the normal combustion range. Stations that performed fewer than 100 inspections are excluded from the table.

**Table 6-17. Percent of Inspections with CO2 Greater Than 16%**

| Station ID | Percent of Inspections with CO2 Greater Than 16% | Number of Inspections with CO2 Greater Than 16% | Total Number of Inspections for Station | Percentile Rank for Station |
|---|---|---|---|---|
| 2P35737 | 76.6 | 111 | 145 | 100.0 |
| 2P36541 | 73.3 | 143 | 195 | 99.9 |
| 2P19639 | 69.2 | 164 | 237 | 99.9 |
| 2P37142 | 68.4 | 587 | 858 | 99.8 |
| 1P42353 | 66.4 | 81 | 122 | 99.8 |
| 2P26640 | 59.9 | 522 | 872 | 99.7 |
| 1P32872 | 52.7 | 231 | 438 | 99.6 |
| 1P44243 | 45.1 | 46 | 102 | 99.6 |
| 1P29799 | 42.6 | 191 | 448 | 99.5 |
| 1P39100 | 39.9 | 414 | 1,037 | 99.5 |

### 6.4.2 Tailpipe Inspections with $O_2$ Greater than 20.5%

Table 6-18 presents stations with a high percentage of vehicles whose ASM or TSI tests produced $O_2$ readings greater than 20.5%, which is outside the normal combustion range and is very close to the ambient $O_2$ concentration of 20.9%. Stations that performed fewer than 100 inspections are excluded from the table.

**Table 6-18. Percent of Inspections with $O_2$ Greater Than 16%**

| Station ID | Percent of Inspections with O2 Greater Than 20.5% | Number of Inspections with O2 Greater Than 20.5% | Total Number of Inspections for Station | Percentile Rank for Station |
|---|---|---|---|---|
| 2P38612 | 100.0 | 118 | 118 | 100.0 |
| 2P38596 | 100.0 | 975 | 975 | 99.9 |
| 2P34519 | 100.0 | 163 | 163 | 99.9 |
| 2P33043 | 100.0 | 863 | 863 | 99.8 |
| 1P43265 | 100.0 | 417 | 417 | 99.8 |
| 1P39035 | 100.0 | 476 | 476 | 99.7 |
| 1P42297 | 99.9 | 1111 | 1,112 | 99.6 |
| 2P12507 | 99.6 | 1,209 | 1,214 | 99.6 |
| 1P33144 | 99.1 | 324 | 327 | 99.5 |
| 1P43010 | 98.1 | 157 | 160 | 99.5 |

## 6.5 Tailpipe Inspections with High Dilution Correction Factor Differences

Table 6-19 presents stations with a high rate of inspections where the $CO/CO_2$-based DCF was out of agreement with the $O_2$-based DCF. This indicates a problem with the measurement of one or more of the pollutants. Stations that performed fewer than 100 inspections are excluded from the table. It can be seen from the table that the top ten stations had differences between the two DCFs for every inspection. It should be noted that there is overlap between the results in this section and the results in the previous two sections ($CO_2$ greater than 16% and $O_2$ greater than 20.5%), since the DCF is based on CO, $CO_2$, and $O_2$ measurements. Anomalous concentrations are also indicators of problems with the emissions measurements, and are also likely to result in a disagreement between the two DCFs.

**Table 6-19. Percent of Inspections with Disagreement Between CO/$CO_2$ and $O_2$ DCFs**

| Station ID | Percent of Inspections with DCF Disagreement | Number of Inspections with DCF Disagreement | Total Number of Inspections for Station | Percentile Rank for Station |
|---|---|---|---|---|
| 2P41504 | 100.0 | 163 | 163 | 100.0 |
| 2P40503 | 100.0 | 437 | 437 | 99.9 |
| 2P39786 | 100.0 | 174 | 174 | 99.9 |
| 2P38612 | 100.0 | 118 | 118 | 99.8 |
| 2P38596 | 100.0 | 975 | 975 | 99.8 |
| 2P36379 | 100.0 | 615 | 615 | 99.7 |
| 2P34519 | 100.0 | 163 | 163 | 99.6 |
| 2P33826 | 100.0 | 611 | 611 | 99.6 |
| 2P33043 | 100.0 | 863 | 863 | 99.5 |
| 2P32059 | 100.0 | 111 | 111 | 99.5 |

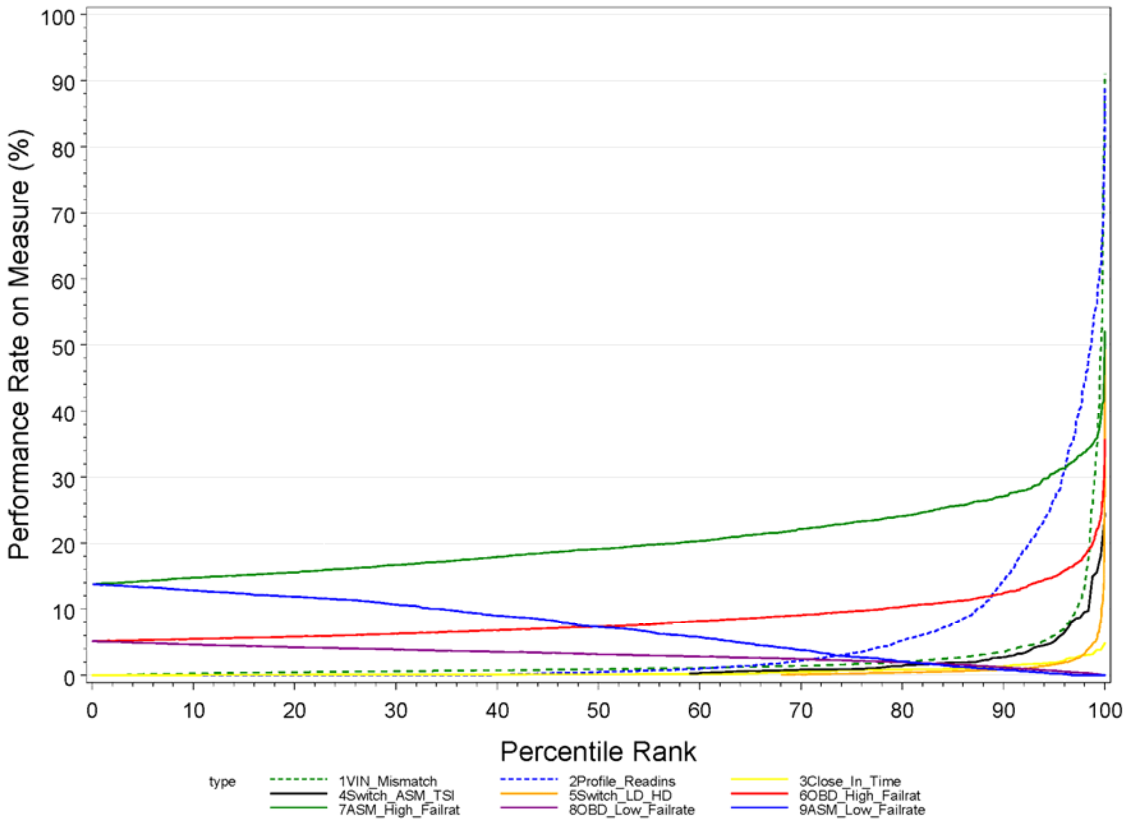
## 6.6 Compilation of Percentile Rankings

After a separate ranking was assigned for each of the measures of errors of commission, the ranks were used to score the stations and identify the stations with the highest likelihood of either errors of commission, or errors of omission.

Some of the details of the ranking procedure and the resulting ranks make it challenging to combine the ranks for an overall score. First, most stations did not perform enough inspections of one type or another (i.e., OBD retests, ASM inspections, etc.) to receive a rank for all of the measures. Secondly, it is known from the measures listed in the previous sections that the range of results was not the same for each measure. For example, for the OBD VIN mismatch section, about 75% of stations had very low VIN mismatch rates. The remaining 25% had VIN mismatch rates that might be cause for concern, or about the top 25 percentiles in the ranking. In contrast, for the tailpipe inspection being switched from light-duty to heavy-duty in order to pass, at least 90% of stations had reasonably low rates of switching from ASM to TSI, and only the top 10% of stations would lead one to suspect possible fraud. Figure 6-3 below shows the distribution of the results and the rankings that were created from those results for each of the measures of errors of commission (from sub-sections 6.1 and 6.2).

The green dashed line for the OBD VIN mismatch shows that the stations from 0 to the 85th percentile had a very low percentage of mismatches. Above the 85th percentile, the mismatch rate quickly increases. Similarly, the blue dashed line for OBD electronic readiness profile show that stations up to the 75th percentile had a low rate of mismatches. For two of the tailpipe measures, the rate of overly close in time inspections and retests switched from light-duty to HD, the stations below about the 95th percentile had very low results. Above the 95th percentile, the rate of potentially fraudulent results rapidly increases. For the other tailpipe measure, the rate of retests switched from ASM to TSI, the “break” occurred closer to the 90th percentile. The red and purple lines show the rankings for OBD inspection failure rates. For both of those lines, the 0th percentile is the mean failure rate over all stations. The percentiles for the red line increase as the failure rate increases further above the mean, while the percentiles for the purple line increase as the failure rate decreases further below the mean. For both of these, one sees a “break” at about the 90th percentile, where the OBD fail rate starts to change rapidly as the percentile continues to increase. The solid green and blue lines show similar results for the ASM failure rates, and again the “break” for the low ASM failure rates is close to the 90th percentile.

**Figure 6-3. Distribution of Results and Percentiles for Errors of Commission**




At percentiles below the "break" (the percentile above which the results rapidly worsen) in each line on Figure 6-3, it is probably not likely that the station is performing that type of fraudulent activity that can be detected through this analysis. At percentiles above the break, there is evidence for suspicion of fraud. Thus, the visual results of the location of the break were used to create an indicator flag for each of the measures. Stations above the break for the given measure were flagged. Then, the total number of flags that each station received was determined. The list of all stations was then sorted by the descending number of flags received, in order to create a final list in order of most-suspicious to least-suspicious. The results for the top 50 most suspicious stations are given in Table 6-20. Table 6-21 gives the results for an additional 50 stations from near the middle of the range of results for comparison purposes.

Some of the first lines in the table show stations that should be investigated (if they haven't already been, as a result of triggers or other audits). For example, the third station, 1P41797, had a very high rate of OBD VIN mismatches, a high rate of OBD readiness and electronic profile mismatches, and then a very low OBD failure rate. This combined result is indicative of possible OBD clean-scanning. Some of the lines do not tell as clear a story, such as the tenth line for station 2P12621, with very high percentiles for most of the tailpipe inspection clean-piping measures, but then a higher than average ASM failure rate. If this table were to be used for identifying stations for enforcement, audits, etc., the user would have to look through the lines and identify the stations with the clearest combination of factors for the type of fraud being considered. The entire table with all stations is available in electronic format.

A similar strategy was used for identifying the stations most likely to need some improvement on proper inspection procedures. The results of errors of omission from the measures in sub-sections 6.3, 6.4, and 6.5 were used here. Figure 6-4 shows the distribution of the results vs. the percentiles for each of the measures. Some of the "break" points are difficult to discern, such as that for the green line, which is for calibrations that began with the analyzer out of tolerance. After consideration of Figure 6-4, the "break" percentiles were assigned at the 80$^{th}$ percentile for analyzers out of tolerance, the 80$^{th}$ percentile for span gas audit failures, the 90$^{th}$ percentile for performing inspections when analyzer is not fully calibrated and should be locked out, the 95$^{th}$ percentile for inspections with unusual pass/fail sequences, the 60$^{th}$ percentile for stations entering repair types as "Misc", the 30$^{th}$ percentile for stations entering repair costs as $0, the 90$^{th}$ percentile for inspections with $CO_2$ greater than 16%, the 80$^{th}$ percentile for inspections with $O_2$ greater than 20.5%, and the 70$^{th}$ percentile for inspections with disagreement between the DCFs. It should be noted these percentile flags were determined subjectively and could be adjusted over time as one becomes more familiar with how sensitive each metric is for detecting irregular calibration or test activities.

The results for the top 50 worst-performing stations for errors of omission are listed in Table 6-22. Some of the rows do appear to show a clear picture of the inspectors at some stations having particular trouble entering data accurately and completely, with high scores for repair types entered as "Misc", and repair costs entered as $0. Other stations may have consistent problems with their analyzers, with the analyzer often out of tolerance at the beginning of a calibration, and a high rate of inspections with $CO_2$ greater than 16% and $O_2$ greater than 20.5%. Again, the table could be used to identify different types of enforcement that are indicated by the combinations of results on each line.

## Table 6-20. Top 50 Most Suspicious Stations for Errors of Commission

| Station ID | Sum of Rank Flags | Max Rank for Station | Individual Ranks | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | OBD VIN Mismatch | OBD Profile/ Readiness | Tailpipe Close-In-Time | Switch ASM to TSI | Switch LD to HD | OBD High Fail Rate | ASM High Fail Rate | OBD Low Fail Rate | ASM Low Fail Rate |
| 2P42042 | 4 | 100.0 | 97.3 | 84.1 | . | . | 100.0 | 92.5 | . | . | . |
| 1P33875 | 4 | 99.2 | 89.8 | 87.4 | 97.5 | 99.2 | 79.9 | 76.0 | 77.3 | . | . |
| 2P02227 | 4 | 99.0 | 99.0 | 98.0 | 0.0 | 76.2 | 99.0 | 98.7 | 38.8 | . | . |
| 2P31529 | 4 | 98.6 | 92.1 | 83.3 | 0.0 | 92.6 | 98.6 | 80.4 | . | . | 16.5 |
| 1P29906 | 4 | 98.3 | 98.3 | 94.3 | 0.0 | 93.4 | 98.0 | 54.2 | 84.8 | . | . |
| 2P40439 | 4 | 95.7 | 88.0 | 80.1 | . | . | 60.7 | . | . | 91.0 | 95.7 |
| 1P41797 | 4 | 95.1 | 93.8 | 95.1 | . | . | 29.5 | . | . | 91.6 | 90.7 |
| 1P27817 | 3 | 100.0 | 95.2 | 91.6 | . | . | 7.6 | 77.4 | 100.0 | . | . |
| 1P44311 | 3 | 100.0 | 1.0 | 100.0 | . | . | . | . | . | 98.6 | 93.6 |
| 2P12621 | 3 | 100.0 | 80.5 | 83.1 | 100.0 | 100.0 | 93.9 | 88.4 | 83.0 | . | . |
| 2P42264 | 3 | 99.9 | 71.5 | 99.9 | . | . | 65.4 | . | . | 96.8 | 95.2 |
| 1P40329 | 3 | 99.6 | 0.7 | 92.4 | . | . | . | . | . | 99.6 | 97.0 |
| 2P40507 | 3 | 99.6 | 21.3 | 93.1 | . | . | . | . | . | 97.8 | 99.6 |
| 1P40789 | 3 | 99.6 | . | 99.6 | . | . | 26.5 | . | . | 94.6 | 92.9 |
| 2P32329 | 3 | 99.6 | 86.8 | 79.7 | . | . | 99.6 | 60.8 | . | . | . |
| 2P41186 | 3 | 99.5 | 95.8 | 86.8 | . | . | 99.5 | 73.5 | . | . | . |
| 2P39963 | 3 | 99.5 | 55.6 | 99.5 | . | . | 59.5 | . | . | 97.1 | 92.3 |
| 1P40667 | 3 | 99.5 | 88.3 | 90.4 | . | . | 99.5 | 58.8 | . | . | . |
| 1P40750 | 3 | 99.4 | 99.4 | 97.5 | . | . | 26.4 | . | . | 90.0 | 49.5 |
| 1P25057 | 3 | 99.4 | 96.4 | 88.0 | 0.0 | 4.9 | 77.7 | 85.1 | 99.4 | . | . |
| 2P38266 | 3 | 99.2 | 24.1 | 98.3 | . | . | . | . | . | 97.2 | 99.2 |
| 1P17053 | 3 | 98.9 | 94.1 | 3.5 | 0.0 | 90.6 | 4.7 | 64.1 | 98.9 | . | . |
| 1P35260 | 3 | 98.8 | 81.9 | 83.3 | . | . | 98.8 | . | . | 15.7 | 91.9 |
| 1P00576 | 3 | 98.8 | 89.9 | 91.4 | 0.0 | 98.8 | 88.9 | . | 75.4 | 49.2 | . |
| 1P41585 | 3 | 98.7 | 93.3 | . | . | . | . | . | . | 98.7 | 97.3 |
| 1P42636 | 3 | 98.6 | 98.1 | 98.6 | . | . | . | . | . | 90.7 | 87.1 |
| 2P26640 | 3 | 98.4 | 31.8 | 53.4 | 95.5 | 96.7 | 98.4 | 56.2 | . | . | 36.7 |
| 1P37643 | 3 | 98.4 | 98.4 | 92.8 | . | . | . | . | . | 90.9 | 65.8 |
| 1P40181 | 3 | 98.2 | 85.3 | 90.7 | . | . | 25.3 | . | . | 98.2 | 85.5 |
| 1P42291 | 3 | 98.2 | 95.6 | 85.4 | . | . | 98.2 | . | . | 5.6 | 40.7 |
| 1P37961 | 3 | 98.2 | 94.3 | 91.9 | . | . | 19.7 | 98.2 | . | . | 73.9 |
| 2P29353 | 3 | 98.1 | 95.9 | 86.5 | . | . | 98.1 | 76.6 | 19.4 | . | . |

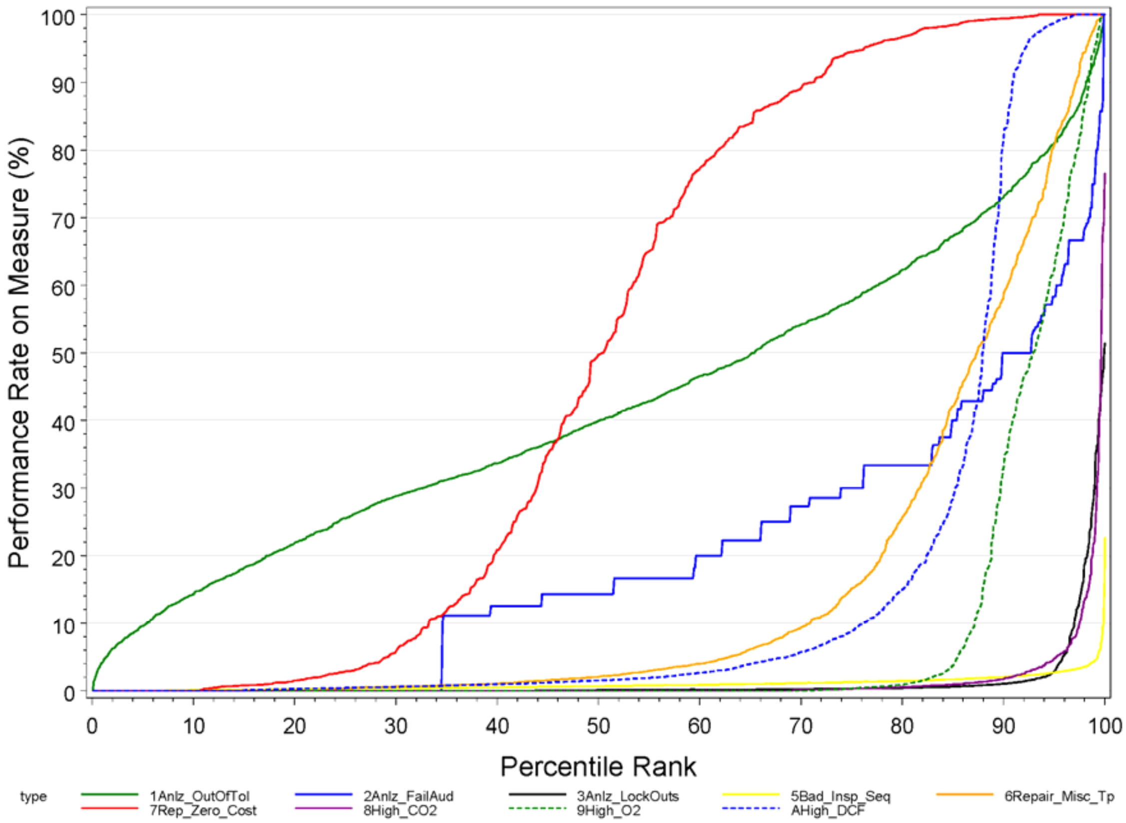
| Station ID | Sum of Rank Flags | Max Rank for Station | Individual Ranks | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | OBD VIN Mismatch | OBD Profile/ Readiness | Tailpipe Close-In-Time | Switch ASM to TSI | Switch LD to HD | OBD High Fail Rate | ASM High Fail Rate | OBD Low Fail Rate | ASM Low Fail Rate |
| 1P43197 | 3 | 98.0 | 82.3 | 66.1 | . | . | 98.0 | 95.7 | 97.4 | . | . |
| 2P40632 | 3 | 97.9 | 88.5 | 81.9 | . | . | . | . | . | 97.9 | 80.7 |
| 1P36442 | 3 | 97.9 | 95.3 | 83.1 | . | . | 97.9 | 76.3 | 57.0 | . | . |
| 1P31752 | 3 | 97.9 | 97.9 | 88.9 | 0.0 | 93.9 | 10.4 | 40.3 | 78.4 | . | . |
| 1P39481 | 3 | 97.8 | 96.2 | 85.7 | . | . | 23.4 | 87.4 | 97.8 | . | . |
| 2P31289 | 3 | 97.8 | 81.2 | 97.8 | . | . | . | . | . | 97.3 | 95.0 |
| 1P37583 | 3 | 97.6 | 89.3 | 13.5 | 0.0 | 92.2 | 19.0 | 74.1 | 97.6 | . | . |
| 1P41621 | 3 | 97.5 | 89.7 | . | . | . | . | . | . | 97.5 | 97.4 |
| 2P43104 | 3 | 97.3 | 84.6 | 97.3 | . | . | . | . | . | 90.4 | 91.4 |
| 2P34127 | 3 | 96.9 | 91.8 | 95.7 | . | . | 96.9 | . | . | 24.4 | 35.7 |
| 2P40939 | 3 | 96.7 | 53.2 | 82.8 | 0.0 | 56.6 | 68.2 | . | . | 96.7 | 94.4 |
| 2P27494 | 3 | 96.7 | 96.7 | 91.6 | . | . | 91.6 | 91.3 | . | . | . |
| 2P42481 | 3 | 96.6 | 66.8 | 96.5 | . | . | . | . | . | 93.6 | 96.6 |
| 2P36194 | 3 | 96.2 | 94.2 | 85.3 | . | . | 83.3 | 96.2 | . | . | . |
| 2P42586 | 3 | 96.1 | 91.4 | 90.0 | . | . | 96.1 | 7.5 | . | . | . |
| 1P33332 | 3 | 96.0 | 96.0 | 79.8 | . | . | 12.4 | 91.5 | 83.9 | . | . |
| 2P41505 | 3 | 96.0 | 96.0 | 77.0 | . | . | 63.3 | 94.1 | . | . | . |
| 2P42377 | 3 | 95.7 | 93.5 | 84.6 | . | . | 95.7 | 81.8 | 86.4 | . | . |

## Table 6-21. 50 Mid-Range Stations for Errors of Commission

| Station ID | Sum of Rank Flags | Max Rank for Station | Individual Ranks | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | OBD VIN Mismatch | OBD Profile/ Readiness | Tailpipe Close-In-Time | Switch ASM to TSI | Switch LD to HD | OBD High Fail Rate | ASM High Fail Rate | OBD Low Fail Rate | ASM Low Fail Rate |
| 2P42936 | 0 | 78.1 | 78.1 | 68.7 | . | . | 67.2 | . | . | 31.3 | . |
| 2P44232 | 0 | 78.1 | 78.1 | . | . | . | . | . | . | 16.9 | . |
| 1P11624 | 0 | 78.1 | 7.3 | 2.9 | . | . | 78.1 | . | . | 30.7 | . |
| 1P42793 | 0 | 78.1 | 35.4 | 22.2 | . | . | 32.5 | . | . | 78.1 | . |
| 1P43084 | 0 | 78.1 | . | . | . | . | . | 78.1 | . | . | . |
| 1P05150 | 0 | 78.1 | 78.1 | 1.7 | . | . | . | 40.9 | . | . | . |
| 2P29466 | 0 | 78.1 | 3.2 | . | . | . | . | . | . | 78.1 | . |
| 2P41977 | 0 | 78.0 | 14.1 | 46.0 | . | . | 78.0 | . | . | 25.1 | 21.3 |
| 2P44161 | 0 | 78.0 | 78.0 | . | . | . | . | . | . | 0.1 | . |
| 1P40591 | 0 | 78.0 | 19.3 | . | . | . | . | . | . | 78.0 | . |
| 1P41813 | 0 | 78.0 | 36.1 | 20.2 | . | . | 29.7 | . | . | 78.0 | . |
| 1P36206 | 0 | 78.0 | 0.5 | . | . | . | . | 78.0 | . | . | . |
| 1P30764 | 0 | 78.0 | 78.0 | . | . | . | . | . | . | 77.1 | . |
| 2P30963 | 0 | 78.0 | 27.9 | 28.6 | . | . | 78.0 | . | . | 37.9 | 22.2 |
| 1P41773 | 0 | 77.9 | 76.7 | . | . | . | 29.4 | 52.7 | 77.9 | . | . |
| 1P40396 | 0 | 77.9 | 40.5 | . | . | . | . | . | . | 77.9 | . |
| 1P42765 | 0 | 77.9 | 27.7 | 22.1 | 77.9 | 28.3 | 32.4 | 44.7 | 73.9 | . | . |
| 2P41750 | 0 | 77.9 | 2.2 | . | . | . | . | 77.9 | . | . | . |
| 1P34281 | 0 | 77.9 | 22.6 | 9.7 | . | . | 77.9 | . | . | 69.3 | . |
| 1P42315 | 0 | 77.8 | 4.2 | . | . | . | . | . | . | 77.8 | . |
| 2P44193 | 0 | 77.8 | 77.8 | . | . | . | . | . | . | 40.4 | . |
| 2G20368 | 0 | 77.8 | 30.7 | . | . | . | . | 77.8 | . | . | . |
| 1G27362 | 0 | 77.8 | . | . | . | . | 0.2 | 65.9 | 77.8 | . | . |
| 1P42917 | 0 | 77.8 | 77.8 | . | . | . | . | . | . | 13.5 | . |
| 2P32323 | 0 | 77.8 | 77.8 | 29.1 | . | . | 46.2 | . | . | 28.2 | 67.1 |
| 1P42354 | 0 | 77.8 | 11.9 | . | . | . | . | . | . | 77.8 | . |
| 1P31039 | 0 | 77.8 | 41.4 | 44.9 | 0.0 | 9.4 | 77.8 | . | . | 43.7 | 5.1 |
| 2P26202 | 0 | 77.8 | 77.8 | . | . | . | . | . | . | 9.3 | . |
| 1P38868 | 0 | 77.7 | 53.1 | . | . | . | 22.1 | . | . | 77.7 | 20.7 |
| 1P27836 | 0 | 77.7 | 18.6 | 43.2 | 0.0 | 66.0 | 77.7 | . | 74.0 | 35.1 | . |
| 1P11863 | 0 | 77.7 | 77.7 | 55.7 | . | . | 4.3 | . | 72.8 | 23.6 | . |
| 1P38068 | 0 | 77.7 | 71.2 | . | . | . | . | . | . | 77.7 | 23.1 |

| Station ID | Sum of Rank Flags | Max Rank for Station | Individual Ranks | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | OBD VIN Mismatch | OBD Profile/ Readiness | Tailpipe Close-In-Time | Switch ASM to TSI | Switch LD to HD | OBD High Fail Rate | ASM High Fail Rate | OBD Low Fail Rate | ASM Low Fail Rate |
| 2P42360 | 0 | 77.7 | 10.0 | . | . | . | . | 77.7 | . | . | . |
| 1P44918 | 0 | 77.7 | 77.7 | . | . | . | . | . | . | 14.7 | . |
| 1P33994 | 0 | 77.7 | 68.2 | 9.3 | . | . | 74.9 | . | 77.7 | 42.1 | . |
| 2P33704 | 0 | 77.7 | 10.6 | . | . | . | . | . | . | 77.7 | . |
| 2P38606 | 0 | 77.6 | 28.8 | 58.6 | . | . | 75.8 | . | . | 77.6 | 21.2 |
| 1P42307 | 0 | 77.6 | 43.7 | 21.1 | . | . | 77.6 | . | . | 2.6 | . |
| 1P44027 | 0 | 77.6 | 77.6 | . | . | . | . | 43.4 | . | . | . |
| 1P42808 | 0 | 77.6 | 62.0 | . | . | . | . | . | 63.3 | 77.6 | . |
| 1P41234 | 0 | 77.6 | 26.2 | 69.3 | . | . | 77.6 | . | . | 60.7 | 22.5 |
| 1P41807 | 0 | 77.6 | 77.6 | . | . | . | . | 25.0 | . | . | . |
| 1P38156 | 0 | 77.6 | 77.6 | . | . | . | 20.3 | . | . | 38.1 | 44.2 |
| 1P42571 | 0 | 77.5 | 77.5 | . | . | . | . | . | . | 62.8 | . |
| 1P35841 | 0 | 77.5 | 14.1 | . | . | . | . | . | . | 77.5 | . |
| 1P40720 | 0 | 77.5 | 68.6 | . | . | . | . | . | . | 77.5 | . |
| 1P40012 | 0 | 77.5 | 77.5 | . | . | . | . | 46.2 | . | . | . |
| 1P42124 | 0 | 77.5 | 72.3 | 69.9 | 0.0 | 26.2 | 77.5 | . | 27.6 | 70.1 | . |
| 1P45006 | 0 | 77.5 | 77.5 | . | . | . | . | 19.4 | . | . | . |
| 2P38024 | 0 | 77.5 | 15.9 | 34.2 | 77.5 | 49.6 | 71.9 | 16.5 | . | . | 31.6 |

**Figure 6-4. Distribution of Results and Percentiles for Errors of Omission**



## Table 6-22. Top 50 Stations with Errors of Omission

| Station ID | Sum of Rank Flags | Max Rank for St. | Individual Ranks | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Anlz Out of Tol | Anlz Locked Out | Anlz Fail Audits | Bad P/F Seq | Repair Type "Misc" | Repair Cost $0 | CO2 gt 16% | O2 gt 20.5% | DCF Disagreement |
| 2P19639 | 6 | 99.9 | 64.5 | 88.3 | 52.2 | 99.9 | 84.0 | 84.6 | 66.4 | 63.1 | 42.9 |
| 2P37142 | 6 | 99.8 | 90.3 | 95.6 | 45.4 | 99.8 | 87.8 | 85.3 | 37.9 | 46.3 | 55.0 |
| 1P42228 | 6 | 98.5 | 90.7 | 10.1 | 98.3 | 98.5 | 35.5 | 86.2 | 74.9 | 82.2 | 42.2 |
| 1P41236 | 6 | 98.1 | 82.5 | . | 97.3 | 96.4 | 97.7 | 98.1 | 81.4 | 62.7 | . |
| 1P25039 | 6 | 98.1 | 98.1 | 90.0 | 76.3 | 90.8 | 80.4 | 58.0 | 44.5 | 93.3 | 69.1 |
| 2P41047 | 6 | 98.0 | 39.8 | 89.1 | 94.6 | 96.7 | 73.0 | 70.9 | 22.4 | 98.0 | 90.6 |
| 2P35725 | 6 | 97.9 | 86.1 | 97.9 | 94.2 | 97.8 | 58.2 | 75.2 | 72.3 | 38.3 | 85.3 |
| 1P28634 | 6 | 97.2 | 90.5 | . | 97.2 | 8.5 | 94.1 | 92.9 | 58.8 | 95.7 | 72.8 |
| 2P34823 | 6 | 96.4 | 72.4 | 92.0 | 96.4 | 84.0 | 90.4 | 95.6 | 89.3 | 70.4 | 60.0 |
| 1P38955 | 6 | 85.7 | 81.0 | 84.0 | 73.0 | 25.2 | 85.7 | 75.5 | 67.2 | 77.0 | 43.6 |
| 2P35737 | 5 | 100.0 | 59.3 | 98.1 | 61.7 | 100.0 | 58.3 | 79.6 | 83.2 | 77.3 | 64.0 |
| 1P42816 | 5 | 99.8 | 99.8 | 97.0 | 61.6 | 98.2 | 37.4 | 56.7 | 13.5 | 60.7 | 52.4 |
| 1P44251 | 5 | 99.5 | 39.3 | . | 99.5 | 39.2 | 87.3 | 80.0 | 91.9 | 84.1 | 54.4 |
| 2P32603 | 5 | 99.3 | 90.6 | 94.8 | 31.9 | 99.3 | 83.8 | 80.2 | 50.1 | 17.0 | . |
| 1P40619 | 5 | 99.3 | 99.3 | . | 98.8 | 97.4 | 87.0 | 81.0 | 16.5 | . | . |
| 2P09548 | 5 | 99.2 | 35.7 | 80.2 | 71.3 | 79.0 | 93.8 | 99.2 | 49.8 | 95.8 | 68.2 |
| 2P34817 | 5 | 99.1 | 79.8 | 95.0 | 68.6 | 99.1 | 98.9 | 91.9 | 63.3 | 66.8 | . |
| 1P37446 | 5 | 98.9 | 98.2 | . | 98.9 | . | . | . | 98.4 | 97.0 | 85.6 |
| 2P08104 | 5 | 98.9 | 20.0 | 95.5 | 26.9 | 42.4 | 88.3 | 98.9 | 12.0 | 94.5 | 82.2 |
| 1P39855 | 5 | 98.9 | 13.1 | 72.6 | 98.6 | 98.9 | 28.4 | 75.2 | 26.9 | 98.1 | 84.8 |
| 2P35218 | 5 | 98.6 | 84.4 | . | 34.3 | 88.1 | 94.6 | 90.2 | 60.9 | 98.2 | 98.6 |
| 1P42871 | 5 | 98.6 | 29.0 | . | 90.7 | 36.3 | 84.3 | 78.2 | 84.9 | 98.6 | 77.2 |
| 2P12202 | 5 | 98.6 | 69.8 | 98.6 | 67.4 | 84.6 | 83.0 | 83.3 | 23.8 | 83.4 | 31.2 |
| 1P42895 | 5 | 98.4 | 44.2 | . | 21.3 | 94.1 | 90.6 | 98.4 | 15.4 | 71.0 | 68.5 |
| 1P38867 | 5 | 98.2 | 90.9 | . | 98.2 | 24.8 | 87.6 | 87.7 | 74.9 | 92.4 | 17.3 |
| 1P40748 | 5 | 98.1 | 47.9 | . | 54.9 | 90.6 | 92.5 | 98.1 | 19.7 | 93.4 | 45.6 |
| 1P39272 | 5 | 97.9 | 83.5 | . | 15.1 | 93.2 | 94.9 | 97.9 | 18.4 | 64.2 | 2.4 |
| 2P37054 | 5 | 97.7 | 80.6 | 94.6 | 36.3 | 97.7 | 76.3 | 83.1 | 92.8 | 73.2 | . |
| 1P41290 | 5 | 97.1 | 97.1 | 86.8 | 67.7 | 86.8 | 31.9 | 84.3 | 70.6 | 85.6 | 63.8 |
| 2P12905 | 5 | 96.8 | 64.7 | 57.7 | 90.3 | 96.8 | 45.6 | 74.5 | 91.1 | 83.0 | 45.4 |
| 1P40729 | 5 | 96.4 | 27.9 | . | 17.0 | 29.4 | 85.5 | 76.7 | 14.9 | 87.5 | 59.9 |

| Station ID | Sum of Rank Flags | Max Rank for St. | Individual Ranks | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | **Anlz Out of Tol** | **Anlz Locked Out** | **Anlz Fail Audits** | **Bad P/F Seq** | **Repair Type "Misc"** | **Repair Cost $0** | **CO2 gt 16%** | **O2 gt 20.5%** | **DCF Disagreement** |
| 1P40729 | 5 | 96.4 | 27.9 | . | 17.1 | 29.4 | 85.5 | 76.7 | 14.9 | 87.5 | 59.9 |
| 1P40729 | 5 | 96.4 | 27.9 | . | 96.4 | 29.4 | 85.5 | 76.7 | 14.9 | 87.5 | 59.9 |
| 1P40222 | 5 | 95.9 | 42.0 | . | 59.8 | 93.8 | 93.1 | 95.9 | 11.1 | 61.9 | 43.8 |
| 2P34820 | 5 | 95.6 | 69.9 | 87.2 | 90.9 | 95.6 | 55.6 | 11.9 | 69.3 | 93.5 | 70.4 |
| 1P39332 | 5 | 95.5 | 93.1 | . | 75.2 | 95.5 | 27.0 | 86.7 | 61.1 | 68.6 | 88.4 |
| 2P41147 | 5 | 95.3 | 95.3 | 51.0 | 93.0 | 79.3 | 80.8 | 78.3 | 43.8 | 36.1 | 30.1 |
| 2P33877 | 5 | 93.9 | 10.3 | 88.5 | 93.9 | 52.5 | 83.7 | 71.5 | 44.2 | 52.4 | 67.9 |
| 2P01268 | 5 | 93.7 | 59.9 | 93.7 | 73.6 | 41.1 | 88.8 | 86.9 | 51.4 | 90.6 | 83.1 |
| 2P36725 | 5 | 93.5 | 92.1 | 43.1 | 91.2 | 93.5 | 60.0 | 72.2 | 42.7 | 87.0 | 7.9 |
| 2P31645 | 5 | 93.4 | 49.9 | 93.4 | 87.7 | 50.0 | 82.5 | 88.7 | 29.3 | 77.2 | 35.1 |
| 2P42928 | 5 | 92.4 | 89.1 | 89.2 | 42.2 | 92.4 | 90.9 | 88.8 | 21.6 | . | . |
| 1P27273 | 5 | 92.0 | 91.7 | . | 59.4 | 92.0 | 7.5 | 71.9 | 70.3 | 81.5 | 40.6 |
| 2P00329 | 5 | 91.8 | 91.8 | . | 25.7 | 40.9 | 89.1 | 87.4 | 48.7 | 91.7 | 56.1 |
| 2P12442 | 5 | 91.8 | 29.3 | 35.1 | 64.2 | 43.7 | 91.8 | 91.2 | 61.1 | 74.3 | 65.3 |
| 2P12442 | 5 | 91.8 | 55.2 | 88.2 | 69.1 | 43.7 | 91.8 | 91.2 | 61.1 | 74.3 | 65.3 |
| 2P40941 | 5 | 91.7 | 91.7 | 32.2 | 77.2 | 79.9 | 83.9 | 84.8 | 29.1 | 83.3 | 33.7 |
| 2P31968 | 5 | 91.7 | 86.0 | 19.9 | 68.6 | 91.7 | 82.6 | 82.9 | 37.9 | 63.7 | 25.1 |
| 2P37909 | 5 | 91.6 | 85.5 | 68.5 | 77.5 | 91.6 | 82.0 | 83.8 | 74.9 | 33.3 | 37.1 |
| 1P38794 | 5 | 91.3 | 91.3 | . | 43.8 | 24.7 | 85.4 | 85.4 | 16.5 | 71.3 | 48.2 |

## 7.0 References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# Appendix A

# DTC Groups

## Table A-1. Evap DTCs

| DTC | DTC Description | DTC | DTC Description |
|---|---|---|---|
| P0093 | Fuel System Leak Detected - Large Leak | P0496 | Evap High Purge Flow |
| P0094 | Fuel System Leak Detected - Small Leak | P0497 | Evap Low Purge Flow |
| P0440 | Evap Malfunction | P0498 | Evap Vent Valve Control Circuit Low |
| P0441 | Evap Incorrect Purge Flow | P0499 | Evap Vent Valve Control Circuit High |
| P0442 | Evap Leak Detected (small leak) | P2024 | Evap Fuel Vapor Temperature Sensor Circuit |
| P0443 | Evap Purge Control Valve Circuit | P2025 | Evap Fuel Vapor Temperature Sensor Performance |
| P0444 | Evap Purge Control Valve Circuit Open | P2026 | Evap Fuel Vapor Temperature Sensor Circuit Low Voltage |
| P0445 | Evap Purge Control Valve Circuit Shorted | P2027 | Evap Fuel Vapor Temperature Sensor Circuit High Voltage |
| P0446 | Evap Vent Control Circuit Malfunction | P2028 | Evap Fuel Vapor Temperature Sensor Circuit Intermittent |
| P0447 | Evap Vent Control Circuit Open | P2400 | Evap Leak Detection Pump Control Circuit/Open |
| P0448 | Evap Vent Control Circuit Shorted | P2401 | Evap Leak Detection Pump Control Circuit Low |
| P0449 | Evap Vent Valve/Solenoid Circuit Malfunction | P2402 | Evap Leak Detection Pump Control Circuit High |
| P0450 | Evap Pressure Sensor Malfunction | P2403 | Evap Leak Detection Pump Sense Circuit/Open |
| P0451 | Evap Pressure Sensor Range/Performance | P2404 | Evap Leak Detection Pump Sense Circuit Range/Performance |
| P0452 | Evap Pressure Sensor Low Input | P2405 | Evap Leak Detection Pump Sense Circuit Low |
| P0453 | Evap Pressure Sensor High Input | P2406 | Evap Leak Detection Pump Sense Circuit High |
| P0454 | Evap Pressure Sensor Intermittent | P2407 | Evap Leak Detection Pump Sense Circuit Intermittent/Erratic |
| P0455 | Evap Leak Detected (gross leak) | P2408 | Fuel Cap Sensor/Switch Circuit |
| P0456 | Evap Leak Detected (very small leak) | P2409 | Fuel Cap Sensor/Switch Circuit Range/Performance |
| P0457 | Evap Leak Detected (fuel cap loose/off) | P2410 | Fuel Cap Sensor/Switch Circuit Low |
| P0458 | Evap Purge Control Valve Circuit Low | P2411 | Fuel Cap Sensor/Switch Circuit High |
| P0459 | Evap Purge Control Valve Circuit High | P2412 | Fuel Cap Sensor/Switch Circuit Intermittent/Erratic |
| P0465 | Purge Flow Sensor Circuit Malfunction | P2418 | Evap Switching Valve Control Circuit / Open |
| P0466 | Purge Flow Sensor Circuit Range/Performance | P2419 | Evap Switching Valve Control Circuit Low |
| P0467 | Purge Flow Sensor Circuit Low Input | P2420 | Evap Switching Valve Control Circuit High |
| P0468 | Purge Flow Sensor Circuit High Input | P2421 | Evap Vent Valve Stuck Open |
| P0469 | Purge Flow Sensor Circuit Intermittent | P2422 | Evap Vent Valve Stuck Closed |

## Table A-2. Catalyst DTCs[6]

| DTC | DTC Description | DTC | DTC Description |
|---|---|---|---|
| P0420 | Catalyst System Efficiency Below Threshold | P0431 | Warm Up Catalyst Efficiency Below Threshold |
| P0421 | Warm Up Catalyst Efficiency Below Threshold | P0432 | Main Catalyst Efficiency Below Threshold |
| P0422 | Main Catalyst Efficiency Below Threshold | P0433 | Heated Catalyst Efficiency Below Threshold |
| P0423 | Heated Catalyst Efficiency Below Threshold | P0434 | Heated Catalyst Temperature Below Threshold |
| P0424 | Heated Catalyst Temperature Below Threshold | P0435 | Catalyst Temperature Sensor |
| P0425 | Catalyst Temperature Sensor | P0436 | Catalyst Temperature Sensor Range/Performance |
| P0426 | Catalyst Temperature Sensor Range/Performance | P0437 | Catalyst Temperature Sensor Low |
| P0427 | Catalyst Temperature Sensor Low | P0438 | Catalyst Temperature Sensor High |
| P0428 | Catalyst Temperature Sensor High | P0439 | Catalyst Heater Control Circuit |
| P0429 | Catalyst Heater Control Circuit | P2423 | HC Adsorption Catalyst Efficiency Below Threshold |
| P0430 | Catalyst System Efficiency Below Threshold | P2424 | HC Adsorption Catalyst Efficiency Below Threshold |

## Table A-3. EGR DTCs

| DTC | DTC Description | DTC | DTC Description |
|---|---|---|---|
| P0400 | EGR Flow | P0489 | EGR Control Circuit Low |
| P0401 | EGR Flow Insufficient Detected | P0490 | EGR Control Circuit High |
| P0402 | EGR Flow Excessive Detected | P2141 | EGR Throttle Control Circuit Low |
| P0403 | EGR Control Circuit | P2142 | EGR Throttle Control Circuit High |
| P0404 | EGR Control Circuit Range/Performance | P2143 | EGR Vent Control Circuit/Open |
| P0405 | EGR Sensor "A" Circuit Low | P2144 | EGR Vent Control Circuit Low |
| P0406 | EGR Sensor "A" Circuit High | P2145 | EGR Vent Control Circuit High |
| P0407 | EGR Sensor "B" Circuit Low | P2413 | EGR System Performance |
| P0408 | EGR Sensor "B" Circuit High | P2425 | EGR Cooling Valve Control Circuit/Open |
| P0409 | EGR Sensor "A" Circuit | P2426 | EGR Cooling Valve Control Circuit Low |
| P0486 | EGR Sensor "B" Circuit | P2427 | EGR Cooling Valve Control Circuit High |
| P0487 | EGR Throttle Position Control Circuit | P2428 | Exhaust Gas Temperature Too High |
| P0488 | EGR Throttle Position Control Range/Perf | P2429 | Exhaust Gas Temperature Too High |

[6] Includes heated catalyst DTCs, although none were present in the data analyzed for this study

## Table A-4. $O_2$ System DTCs[7]

| DTC | DTC Description | DTC | DTC Description |
|---|---|---|---|
| P0030 | HO2S Heater Control Circuit | P0166 | O2 Sensor Circuit No Activity Detected |
| P0031 | HO2S Heater Control Circuit Low | P0167 | O2 Sensor Heater Circuit |
| P0032 | HO2S Heater Control Circuit High | P2195 | O2 Sensor Signal Stuck Lean |
| P0036 | HO2S Heater Control Circuit | P2196 | O2 Sensor Signal Stuck Rich |
| P0037 | HO2S Heater Control Circuit Low | P2197 | O2 Sensor Signal Stuck Lean |
| P0038 | HO2S Heater Control Circuit High | P2198 | O2 Sensor Signal Stuck Rich |
| P0040 | O2 Sensor Signals Swapped B1 S1/ B2 S1 | P2231 | O2 Sensor Signal Circuit Shorted to Heater Circuit |
| P0041 | O2 Sensor Signals Swapped B1 S2/ B2 S2 | P2232 | O2 Sensor Signal Circuit Shorted to Heater Circuit |
| P0042 | HO2S Heater Control Circuit | P2233 | O2 Sensor Signal Circuit Shorted to Heater Circuit |
| P0043 | HO2S Heater Control Circuit Low | P2234 | O2 Sensor Signal Circuit Shorted to Heater Circuit |
| P0044 | HO2S Heater Control Circuit High | P2235 | O2 Sensor Signal Circuit Shorted to Heater Circuit |
| P0050 | HO2S Heater Control Circuit | P2236 | O2 Sensor Signal Circuit Shorted to Heater Circuit |
| P0051 | HO2S Heater Control Circuit Low | P2237 | O2 Sensor Positive Current Control Circuit/Open |
| P0052 | HO2S Heater Control Circuit High | P2238 | O2 Sensor Positive Current Control Circuit Low |
| P0053 | HO2S Heater Resistance | P2239 | O2 Sensor Positive Current Control Circuit High |
| P0054 | HO2S Heater Resistance | P2240 | O2 Sensor Positive Current Control Circuit/Open |
| P0055 | HO2S Heater Resistance | P2241 | O2 Sensor Positive Current Control Circuit Low |
| P0056 | HO2S Heater Control Circuit | P2242 | O2 Sensor Positive Current Control Circuit High |
| P0057 | HO2S Heater Control Circuit Low | P2243 | O2 Sensor Reference Voltage Circuit/Open |
| P0058 | HO2S Heater Control Circuit High | P2244 | O2 Sensor Reference Voltage Performance |
| P0059 | HO2S Heater Resistance | P2245 | O2 Sensor Reference Voltage Circuit Low |
| P0060 | HO2S Heater Resistance | P2246 | O2 Sensor Reference Voltage Circuit High |
| P0061 | HO2S Heater Resistance | P2247 | O2 Sensor Reference Voltage Circuit/Open |
| P0062 | HO2S Heater Control Circuit | P2248 | O2 Sensor Reference Voltage Performance |
| P0063 | HO2S Heater Control Circuit Low | P2249 | O2 Sensor Reference Voltage Circuit Low |
| P0064 | HO2S Heater Control Circuit High | P2250 | O2 Sensor Reference Voltage Circuit High |
| P0130 | O2 Sensor Circuit | P2251 | O2 Sensor Negative Current Control Circuit/Open |
| P0131 | O2 Sensor Circuit Low Voltage | P2252 | O2 Sensor Negative Current Control Circuit Low` |

[7] Includes oxygen sensor and oxygen sensor heater

| DTC | DTC Description | DTC | DTC Description |
|---|---|---|---|
| P0132 | O2 Sensor Circuit High Voltage | P2253 | O2 Sensor Negative Current Control Circuit High |
| P0133 | O2 Sensor Circuit Slow Response | P2254 | O2 Sensor Negative Current Control Circuit/Open |
| P0134 | O2 Sensor Circuit No Activity Detected | P2255 | O2 Sensor Negative Current Control Circuit Low |
| P0135 | O2 Sensor Heater Circuit | P2256 | O2 Sensor Negative Current Control Circuit High |
| P0136 | O2 Sensor Circuit | P2270 | O2 Sensor Signal Stuck Lean |
| P0137 | O2 Sensor Circuit Low Voltage | P2271 | O2 Sensor Signal Stuck Rich |
| P0138 | O2 Sensor Circuit High Voltage | P2272 | O2 Sensor Signal Stuck Lean |
| P0139 | O2 Sensor Circuit Slow Response | P2273 | O2 Sensor Signal Stuck Rich |
| P0140 | O2 Sensor Circuit No Activity Detected | P2274 | O2 Sensor Signal Stuck Lean |
| P0141 | O2 Sensor Heater Circuit | P2275 | O2 Sensor Signal Stuck Rich |
| P0142 | O2 Sensor Circuit | P2276 | O2 Sensor Signal Stuck Lean |
| P0143 | O2 Sensor Circuit Low Voltage | P2277 | O2 Sensor Signal Stuck Rich |
| P0144 | O2 Sensor Circuit High Voltage | P2278 | O2 Sensor Signals Swapped B1 S3 / B2 S3 |
| P0145 | O2 Sensor Circuit Slow Response | P2297 | O2 Sensor Out of Range During Deceleration |
| P0146 | O2 Sensor Circuit No Activity Detected | P2298 | O2 Sensor Out of Range During Deceleration |
| P0147 | O2 Sensor Heater Circuit | P2414 | O2 Sensor Exhaust Sample Error |
| P0150 | O2 Sensor Circuit | P2415 | O2 Sensor Exhaust Sample Error |
| P0151 | O2 Sensor Circuit Low Voltage | P2416 | O2 Sensor Signals Swapped B1 S2 / B1 S3 |
| P0152 | O2 Sensor Circuit High Voltage | P2417 | O2 Sensor Signals Swapped B2 S2 / B2 S3 |
| P0153 | O2 Sensor Circuit Slow Response | P2626 | O2 Sensor Pumping Current Trim Circuit/Open |
| P0154 | O2 Sensor Circuit No Activity Detected | P2627 | O2 Sensor Pumping Current Trim Circuit Low |
| P0155 | O2 Sensor Heater Circuit | P2628 | O2 Sensor Pumping Current Trim Circuit High |
| P0156 | O2 Sensor Circuit | P2629 | O2 Sensor Pumping Current Trim Circuit/Open |
| P0157 | O2 Sensor Circuit Low Voltage | P2630 | O2 Sensor Pumping Current Trim Circuit Low |
| P0158 | O2 Sensor Circuit High Voltage | P2631 | O2 Sensor Pumping Current Trim Circuit High |
| P0159 | O2 Sensor Circuit Slow Response | P2A00 | O2 Sensor Circuit Range/Performance |
| P0160 | O2 Sensor Circuit No Activity Detected | P2A01 | O2 Sensor Circuit Range/Performance |
| P0161 | O2 Sensor Heater Circuit | P2A02 | O2 Sensor Circuit Range/Performance |
| P0162 | O2 Sensor Circuit | P2A03 | O2 Sensor Circuit Range/Performance |
| P0163 | O2 Sensor Circuit Low Voltage | P2A04 | O2 Sensor Circuit Range/Performance |
| P0164 | O2 Sensor Circuit High Voltage | P2A05 | O2 Sensor Circuit Range/Performance |
| P0165 | O2 Sensor Circuit Slow Response | | |

## Table A-6. Secondary Air Intake System DTCs

| DTC | DTC Description | DTC | DTC Description |
|---|---|---|---|
| P0410 | Secondary Air Injection System | P2431 | Secondary Air Injection System Air Flow/Pressure Sensor Circuit Range/Performance |
| P0411 | Secondary Air Injection System Incorrect Flow Detected | P2432 | Secondary Air Injection System Air Flow/Pressure Sensor Circuit Low |
| P0412 | Secondary Air Injection System Switching Valve "A" Circuit | P2433 | Secondary Air Injection System Air Flow/Pressure Sensor Circuit High |
| P0413 | Secondary Air Injection System Switching Valve "A" Circuit Open | P2434 | Secondary Air Injection System Air Flow/Pressure Sensor Circuit Intermittent/Erratic |
| P0414 | Secondary Air Injection System Switching Valve "A" Circuit Shorted | P2435 | Secondary Air Injection System Air Flow/Pressure Sensor Circuit |
| P0415 | Secondary Air Injection System Switching Valve "B" Circuit | P2436 | Secondary Air Injection System Air Flow/Pressure Sensor Circuit Range/Performance |
| P0416 | Secondary Air Injection System Switching Valve "B" Circuit Open | P2437 | Secondary Air Injection System Air Flow/Pressure Sensor Circuit Low |
| P0417 | Secondary Air Injection System Switching Valve "B" Circuit Shorted | P2438 | Secondary Air Injection System Air Flow/Pressure Sensor Circuit High |
| P0418 | Secondary Air Injection System Control "A" Circuit | P2439 | Secondary Air Injection System Air Flow/Pressure Sensor Circuit Intermittent/Erratic |
| P0419 | Secondary Air Injection System Control "B" Circuit | P2440 | Secondary Air Injection System Switching Valve Stuck Open |
| P0491 | Secondary Air Injection System Insufficient Flow | P2441 | Secondary Air Injection System Switching Valve Stuck Closed |
| P0492 | Secondary Air Injection System Insufficient Flow | P2442 | Secondary Air Injection System Switching Valve Stuck Open |
| P2257 | Secondary Air Injection System Control "A" Circuit Low | P2443 | Secondary Air Injection System Switching Valve Stuck Closed |
| P2258 | Secondary Air Injection System Control "A" Circuit High | P2444 | Secondary Air Injection System Pump Stuck On |
| P2259 | Secondary Air Injection System Control "B" Circuit Low | P2445 | Secondary Air Injection System Pump Stuck Off |
| P2260 | Secondary Air Injection System Control "B" Circuit High | P2446 | Secondary Air Injection System Pump Stuck On |
| P2430 | Secondary Air Injection System Air Flow/Pressure Sensor Circuit | P2447 | Secondary Air Injection System Pump Stuck Off |