Eastern Research Group, Inc.

FINAL

Evaluation of the Texas Vehicle Emissions 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 VEHICLE EMISSIONS 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 Vehicle Emissions Inspection and Maintenance (I/M) program for the 2014 and 2015 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, 2014 through December 31, 2015.

This evaluation generally follows the United States Environmental Protection Agency (EPA) draft guidance on using in-program data for the evaluation of the Texas I/M program performance [Reference 1][1] and the EPA guidance on the use of RS for the evaluation of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 focuses on program coverage, the inspection process, and the repair process. Additionally, program benefits were estimated on an annual basis. However, because of the increasingly lower tailpipe test volumes, which are now 5% or less of the overall test volume, some analyses that were competed in previous program evaluation reports are not presented in this report.

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.

A. COVERAGE

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

Participation Rates (Section ILB) – 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) program area, the participation rate was 91.5% in 2014 and 93.4% in 2015. In the Houston-Galveston- Brazoria (HGB) program area, the participation rates were 91.6% and 94.4%, respectively. The overall program participation rates were 91.5% in 2014 and 94% in 2015.

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

Inspection

Appropriateness of Major TIMS Fields (Section III.A) – The TIMS was used to document the Texas 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 were all positively skewed (that is, most observations were at low emissions concentrations), and there is no evidence of large numbers of very high concentration values. The shapes of the distributions looked typical for a fleet of modern in-use vehicles. Overall, the figures indicated that no gross errors were being made in measuring and recording tailpipe emissions. Very few out-of-range emission values were found.

Inspection Statistics (Section III.B) – Analysis of the TIMS data indicated that during the evaluation period over 14.9 million ASM, TSI, and On-board Diagnostics (OBD) tests were performed on approximately than 13.7 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. The DFW and HGB program areas had comparable test failure 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. It is worth noting that the higher percentage of OBD tests in this report versus those seen in the previous studies means that fleet-wide, fewer vehicles are now initially failing, resulting in fewer repairs. This change will impact any fleet-wide comparisons between the results from this report and the earlier studies.

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

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

- Approximately 99.2% of the test sequences were a verified initial test or an initial test that could reasonably be assumed to be a true initial test, and a final certified test.

Emissions Analyzer Data Quality (Section III.D) – 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, carbon dioxide (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 85.7% 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 Texas I/M inspections performed just before the calibration can be expected to be within the instrument tolerance except for very low values of HC.
- DCFs based on CO/CO_2 compared with DCFs based on O_2 for all inspections in the evaluation period indicated that 98% of the ASM & TSI tests produced measured CO, CO_2, and O_2 values that were consistent with the expected stoichiometric relationship for gasoline combustion.
- The Texas state implementation plan (SIP) requires that each analyzer be audited at least twice per year. The TIMS data indicates that over 92% of the analyzers in the state were audited at least twice per year and many of them were audited more times than that. Of the 1,809 analyzer audits performed, 1,518 analyzers received three or more audits.
- 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, 6.2% of all ASM inspections were performed when the dynamometer systems had not successfully passed their calibration check within the 72-hour window, with analyzers made by Worldwide Environmental Products, Inc. (WW) 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 Environmental Systems Products (ESP) bench was the most frequent.

OBD Inspection Analyzer Communication Performance (Section III.E) – Overall, OBD communication rates between vehicle computers and program analyzers was greater than 99.9%.

TIMS Handling of OBD Codes (Section III.F) – It appears that the OBD inspection logic used in Texas for light-duty gasoline-powered vehicles is in agreement with EPA policies. For the very few cases where this was found not to be true, ERG believes these instances were 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 IV.A) –During the evaluation period, analysis of the TIMS data indicated that 179,445 repairs were made to vehicles in order to bring them in compliance with the Texas I/M program. The 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%, 10%, 26%, 2%, and 42%, respectively.

Repair information is also available through the AirCheckTexas Drive a Clean Machine (DACM) program. Texas created the DACM program under the statutory authority granted in the Low-income Vehicle Repair Assistance, Retrofit, and Accelerated Vehicle Retirement Program (LIRAP) legislation to enhance the objectives of the Texas I/M program. The DACM program provides financial assistance to low-income vehicle owners to repair or retire vehicles that have failed an emissions test, or retire vehicles ten years old or older. For the period covering December 1, 2013 through November 30, 2015, there were 7,522 vehicle emissions-related repairs completed at Recognized Emissions Repair Facility (RERF) stations under the DACM program. Of those repairs, 6,837 were made in the DFW and HGB program areas.

Emissions Changes Associated with Repairs (Section IV.B) – ERG analyzed the 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 57%, 66%, and 60%, respectively. Note that almost all of these vehicles were fast-pass ASM tests[3], therefore the after-repair emissions concentrations are biased high. However, because repair and emissions degradation begin immediately after certification and continue 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 IV.D) – ERG's analyses indicate approximately 79% of OBD tests that initially fail for an illuminated malfunction indicator light (MIL) with stored diagnostic trouble codes (DTCs) eventually receive a passing inspection. 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 39% of "repaired" vehicles. This large range is consistent with the findings in previous program evaluation reports and reflects the uncertainty in identifying cases where unset readiness monitors are masking MIL illumination in repaired vehicles.

Average Repair Costs (Section IV.E) – 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 $15.5 million during this evaluation period performing 81,566 repairs so that they would be in compliance with the Texas I/M program, but it should be noted that vehicle emissions inspectors hand-enter repair costs and, accordingly, these values can have errors.

As in the previous studies, a large percentage (51.4%) of the repair costs in the TIMS were recorded as zero. Again, with zero repair costs and those over $2,000 removed, the median and mean repair costs ranged from $45-$260 and $101-$331.

[3] Fast-pass refers to a vehicle receiving a passing test prior to the completion of the full test time because its emissions measurements for each pollutant are sufficiently below the test standard to project the vehicle will pass if the test is run for the full test time.

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 V.A) – ERG calculated the change in emissions concentrations at the time of inspection using the initial and final emissions concentrations of annual inspection sequences as recorded in TIMS data, which is in-program data. About 87% of the I/M sequences were produced by vehicles that simply initially passed. Of course, the emissions reductions from these I/M events were zero. Additionally, about 11% of the I/M sequences were produced by vehicles that initially failed, were repaired, and finally passed. When all ASM sequences were considered together using the TIMS data, the apparent changes in emissions concentrations at the inspection event were: ASM HC decreased 13 to 17%, ASM CO decreased 24 to 28%, ASM NO_x decreased 16 to 18%. TSI emissions decreased 59 to 84%.

Estimate of Annual I/M Benefits from Paired I/M and RS Data (Section V.B) – The analysis of RS data, which is out-of-program data, provides a different view of the Annual I/M Benefit of the Texas 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 87% of the vehicles measured by RS had I/M sequences produced by passing their initial inspections, while 5% had a Fail-Pass I/M test sequence. Initial pass vehicles had RS emissions changes of roughly +2.1% for HC, +5.4% for CO and -6.9% for NO_x, while the Fail-Pass vehicles had RS emissions changes of +25.2% for HC, +8.1% for CO and -9.9% for NO_x.

Measures for Evaluating Station Performance (Section VI) – 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.

Recommendations

As a result of performing this biennial evaluation of the Texas I/M program, ERG has developed a list of recommendations the TCEQ may 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 Texas I/M program.

OBD Recommendations

The future of vehicle testing at Texas I/M inspection stations will continue to be dominated by OBD testing as it replaces ASM and TSI tailpipe emissions testing due to fleet turnover. Since the 2006 report, the OBD test fleet has grown from 70% to over 95% of the vehicles inspected in the Texas I/M Program. Because this trend will continue, any OBD problems identified in this evaluation are viewed as more critical to the overall success of the program, and any recommendations pertaining to tailpipe testing should be closely evaluated to ensure changes are cost effective for the TCEQ.

OBD Recommendation 1 (***): Investigate requiring a "set" status for certain monitors to prevent hiding malfunctions. Our analysis found that in 2% to 39% of instances when a vehicle received an initial fail for a certain monitored component, the re-test 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 re-test that follows certain types of initial failures.

OBD Recommendation 2 (***): Improve response to trigger flags. ERG believes the current trigger system is well designed and well run. However, in other state I/M 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.

OBD Recommendation 3 (***): Include OBD communications protocol in electronic profile. The OBD communication protocol is available in the Thermostat field of the TIMS data and including this variable in the fraud analysis would help detect if a vehicle's electronic profile had changed from the initial test.

OBD Recommendation 4 (*): 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. The EPA's position on this may change in the future or pilot testing could be performed in some jurisdictions. ERG suggests the TCEQ stay abreast of any developments in this area.

ASM and TSI Recommendations

Even though OBD testing will eventually replace tailpipe emissions testing, tailpipe testing will probably be used on the 1995 and older vehicles until they become exempt from the emissions inspection requirements in 2020[4]. Therefore, efforts need to continue to provide quality tailpipe tests and accurate TIMS records of them. However, as the volume of tailpipe testing continues to diminish, ERG recommends that future program evaluation reports reassess which tailpipe quality control metrics should be analyzed and discuss this matter with the EPA in order to focus the majority of the program evaluation analysis on the OBD fleet. OBD testing will likely encompass 97-98% of all Texas I/M tests in the next program evaluation report.

ASM & TSI 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. This recommendation has been given three stars (***) because if this is addressed for OBD testing, it is assumed it would require minimal effort to include tailpipe testing.

[4] Only light-duty gasoline passenger vehicles between 2 and 24 years old are required to be tested.

ASM & TSI Recommendation 2 (*): O_2 Channel Calibration. Two analyzer makes manufactured by Snap-On, John Bean (JB) and Sun Electric (SE), had the majority of suspicious O_2 concentration readings during tailpipe testing, and these same two analyzer makes showed disagreement in DCF CO/CO_2 and DCF O_2 values. ERG recommends the TCEQ the TCEQ investigate to determine if there is an acceptable technical reason for these observations.

ASM & TSI Recommendation 4 (*): Dynamometer Calibration. ERG recommends the TCEQ inquire about the 6.2% of all ASM inspections that were performed when the dynamometer systems had not successfully passed their calibration check within the 72-hour window.

ASM & TSI Recommendation 5 (*): Gas Bottle Values. 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.

ASM & TSI Recommendation 6 (*): Pre-Calibration Record Gas Data. ERG recommends the TCEQ inquire into the discrepancy in the recording of the pre-calibration gas data as it was found that about 269,000 records were available at the zero level, but only 266,000 records at the low-span level and only 255,000 records 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.

RS Recommendations

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.

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 program areas, a paired I/M TIMS / RS air quality analysis can be performed.

Recommendation 2 (**): Volume of RS data collected in DFW & HGB. The Comprehensive RS method was not used in Section V due to an insufficient number of RS records. When the RS data were examined more closely, it was found that fewer records were collected in 2015 than 2014. Also, the number of RS records collected in the DFW and HGB program areas are not the same from year to year.

Repair Tracking Recommendations

Whether malfunctioning vehicle emission control systems are detected by ASM, TSI, 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.

Repair Tracking 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 the TCEQ 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.

Repair Tracking Recommendation 2 (***). Recording Repair Costs. There are a large number of repairs with a cost of $0 or greater than $2,000. ERG recommends that if values of $0 or above $2,000 are entered into the TIMS, an explanation be required before the records can be closed.

Repair Tracking Recommendation 3 (***). Recognized Emissions Repair Facility Data. In previous reports, repair information collected from The Texas Department of Public Safety (DPS) RERF program was also included. However, because of a transition to a new data collection system, insufficient RERF data were available to analyze for the current report. ERG recommends that the TCEQ ask the DPS if this change is permanent.

I. 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 most recent biennial evaluation of the Texas program was performed by the TCEQ in 2014. This report follows a similar format by choosing 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.

A. 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 Texas I/M program in 2000 [Reference 3] and later ERG used the updated EPA guidance [References 1 2] as a framework for an evaluation performed in 2006 [Reference 4]. Since then, ERG has performed evaluations in 2009 [Reference 5], 2012 [Reference 6], and 2014 [Reference 7] using the same approach as the 2006 Report.

This 2016 report follows the same general methodology, 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 a reasonable cost, as well as provide an objective assessment on the overall status of the Texas I/M program, with the intent of identifying both areas that may be improved and those that are performing well.

B. STRUCTURE OF THE REPORT

As previously stated, this report follows the same outline as past reports. Section II investigates coverage by comparing vehicle license plates read during RS measurements with the vehicles seen in the Texas I/M program TIMS database.

Section III 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 IV, the TIMS data and RERF data were analyzed to determine the level, cost, and effects, such as emissions changes and OBD system status, resulting from repairs associated with the Texas I/M program.

Section V provides emission benefits estimates based on the 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 VI is a fairly detailed analysis of station performance based on TIMS data. It covers errors of commission, such as “clean-scanning” or VIN mismatches, as well as errors that are more difficult to categorize such as data entry issues or anomalous test results.

II. 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 Texas I/M program TIMS record.

A. PARTICIPATION RATES

Estimates of the participation rate of vehicles subject to I/M in the DFW program area and in the HGB program area were made through a comparison of RS data and TIMS data. The RS data provides a sample of vehicles that were driven on the road, and if these vehicles were eligible for I/M, they should have an I/M test record in the TIMS database.

To perform this analysis, ERG first created a dataset of I/M-eligible vehicles captured on the road by RS at least once. This dataset does not include vehicles from out-of-state or registered in non-I/M counties. It only consists of I/M-eligible model years. Therefore, vehicles newer than 2 years and older than 24 years at the time of the RS measurement are excluded from the analysis. Table II-1 shows the counts of unique I/M-eligible vehicles from the DFW or HGB program areas that were measured by RS between January 1, 2014 and December 31, 2015. In 2015, Texas changed the vehicle registration process and now requires vehicles to pass inspection before they can be registered. For that reason, the data were broken out by calendar year.

Table II-1. Count of Unique I/M-Eligible Remote Sensing Vehicles Registered in Texas I/M Program Areas by Calendar Year

Registered at Time of Remote Sensing	Unique RS-Captured Vehicles by Calendar Year		
	2014	**2015**	**Total**
DFW	129,926	64,564	194,490
HGB	82,037	76,240	158,277
Total	211,963	140,804	352,767

Next, the number of unique I/M-compliant vehicles (vehicles that were tested and ultimately passed or received a waiver) in each of the Texas I/M program areas during that same time frame was determined. Table II-2 shows the overall counts for the I/M tests in the DFW and HGB program areas.

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

I/M Area where Test Performed	Unique I/M-Tested Vehicles
DFW	4,812,626
HGB	4,417,098
Total	9,229,724

The I/M tests were then matched to RS measurements by VIN. If an I/M test occurred any time between January 1, 2014, and December 31, 2015, and was found to have a corresponding VIN with a RS measurement taken any time between January 1, 2014 and December 31, 2015, this was a matched pair. Table II-3 summarizes these results for the DFW and HGB program areas. These values were then divided by their respective values for each program area in Table II-1 to obtain an estimate for the Texas I/M program participation rate, e.g. in 2014 the DFW program area participation rate was calculated as 118,831/129,926 * 100. Table II-3 shows that the participation rate did increase slightly overall from 2014 to 2015.

Table II-3. Count of Unique I/M Eligible Remote Sensing Vehicles Paired with Unique I/M-Compliant Vehicles in Texas I/M Program Areas by Calendar Year

I/M Program Area where Test Performed	Paired RS and TIMS VIN Matches		Participation Rate	
	2014	2015	2014	2015
DFW	118,831	60,308	91.5%	93.4%
HGB	75,171	72,002	91.6%	94.4%
Total	194,002	132,310	91.5%	94.0%

III. INSPECTION

A. CHECK MAJOR DATA FIELDS FOR APPROPRIATENESS

The goal of this section 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 Texas I/M program's analyzers and database system to accurately record the activities of the Texas I/M program. If any variables have values that are out of range or missing for unexplained reasons, it suggests that the Texas I/M program activities are not being conducted properly or adequately monitored. An iterative series of steps were used to evaluate the accuracy and completeness of the data in the database. First, a set of basic filters were applied to remove unusual or incomplete inspections from the dataset (i.e., aborted inspections, inspections with no emissions component, covert audits, etc.). Then, a frequency distribution was performed on nearly all database variables to evaluate the accuracy and completeness of data fields. Additional records with obvious problems were tallied and removed from the dataset (such as invalid/undefined characters stored for a coded categorical variable, or dramatically out-of-range numerical results). Finally, combinations of variables were evaluated for consistency (such as TSI results recorded for an inspection that is marked as an ASM inspection). These steps are described in detail below.

Initial filters and frequency distributions

The first set of filters removed incomplete or unusual inspections from the dataset, as well as non-emissions inspections. Beginning with the full database of 21.2 million inspection records for 2014 – 2015, any records that were not for successful inspections that included an emissions inspection were deleted. This deletion covered:

- aborted inspections (TX96_ABORT=”J”,”A”);
- safety-only or visual-only inspections (TX96_TEST_TYPE=”H”, “P”);
- inspections that timed-out due to a dilution condition (TX96_EMISS_PF_FL=”T”,”D”);
- inspections that were covert audits (TX96_covert_FL not “N”);
- out-of-program model years, older than 1990 or newer than 2015;
- inspections with invalid VINs, either fewer than 17 characters, including invalid characters (such as “!”, “@”, etc), or flagged (TX96_VIN_FL=”B”), and
- any remaining inspections with TX96_TEST_SEQUENCE less than 1.

In total, these deletions removed 3.4 million records from the dataset (mostly for safety-only inspections), leaving 17.8 million emissions inspections in the dataset.

Almost every database variable that stores a categorical result was checked for completeness and appropriateness of information. The vast majority of the variables in the dataset contained the expected information. After the 3.4 million record deletions described above, a few variables that still contained anomalous information include:

- 19,000 records with an overall inspection cost greater than $1000 (TX96_OVERALL_COST>1000);
- 315 records with a repair cost greater than $2000 (TX96_REP_OVERALL_COST>2000);
- 185 TSI inspections recorded a curb idle RPM greater than 3000 RPM (TX96_PRI_CURB_IDLE_RPM>3000);
- 834 ASM5015 inspections recorded an average RPM of 10,000, and 720 ASM2525 inspections recorded an average RPM of 10,000;
- 11% of TSI and 21% of ASM inspections included an RPM Bypass (TX96_RPM_BYPASS=”B”); and
- Various other variables had a small number of missing value results or otherwise odd results that did not appear to be significant.

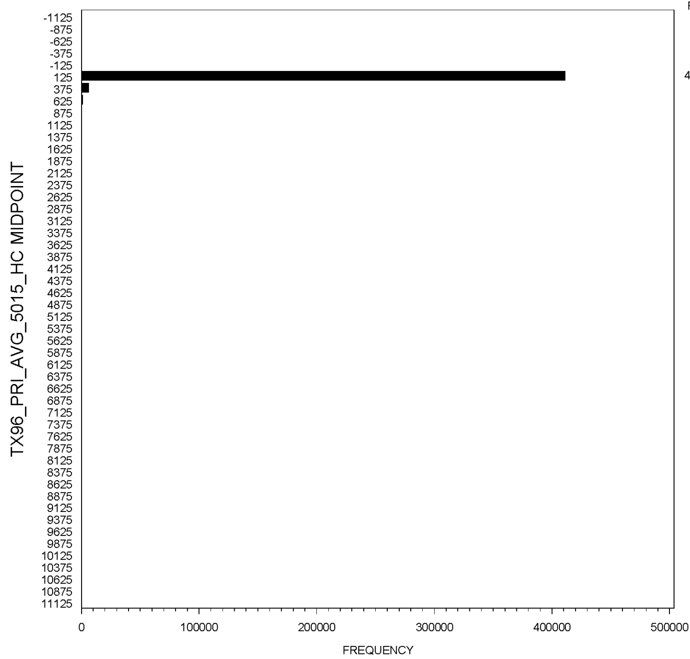
The anomalous records in the list above were counted and listed, but were not deleted from the dataset. Most of the anomalies are investigated in further detail in other areas of the report.

A distribution of the emissions measurements is a special case of the above. Ideally, no observations with missing values or extremely high values (outliers) should be present.

Figure III-1 through Figure III-4 show the distributions of the emissions measurements for HC, CO, NO_x, and CO_2 for the ASM5015 inspection. Similar results were seen for the ASM2525 data. Figure III-5 through Figure III-7 show the HC, CO, and CO_2 concentrations for the TSI curb idle inspection. 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 CO_2 concentration between about 6%

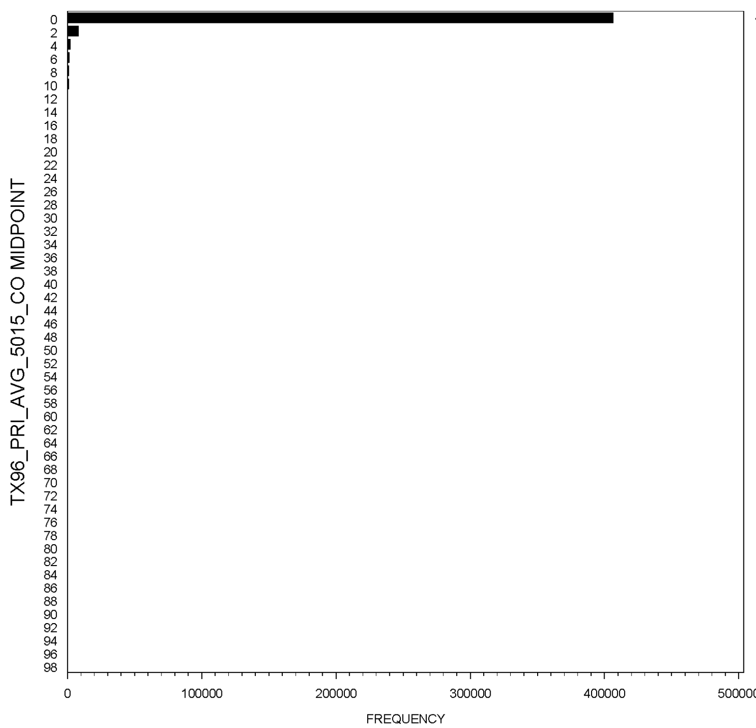
and 16%, indicating a combustion process is occurring in the vehicle's engine. The figures for CO_2 show that this is almost always the case. The exceptions will be investigated further in later sections of this report.

Figure III-1. Distribution of HC Emissions for ASM5015 Inspection



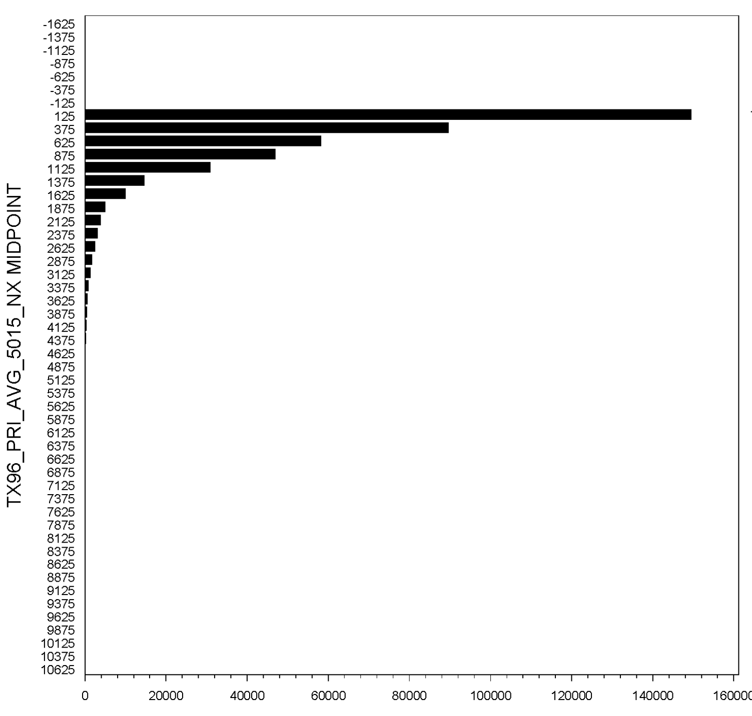
TX96_PRI_AVG_5015_HC MIDPOINT	FREQ.	CUM. FREQ.	PCT.	CUM. PCT.
-1125	0	0	0.00	0.00
-875	0	0	0.00	0.00
-625	0	0	0.00	0.00
-375	0	0	0.00	0.00
-125	0	0	0.00	0.00
125	411143	411143	98.00	98.00
375	6170	417313	1.47	99.47
625	880	418193	0.21	99.68
875	313	418506	0.07	99.76
1125	193	418699	0.05	99.80
1375	151	418850	0.04	99.84
1625	115	418965	0.03	99.87
1875	80	419045	0.02	99.89
2125	76	419121	0.02	99.90
2375	55	419176	0.01	99.92
2625	57	419233	0.01	99.93
2875	59	419292	0.01	99.95
3125	37	419329	0.00	99.95
3375	21	419350	0.00	99.96
3625	26	419376	0.00	99.97
3875	20	419396	0.00	99.97
4125	10	419406	0.00	99.97
4375	14	419420	0.00	99.98
4625	11	419431	0.00	99.98
4875	18	419449	0.00	99.98
5125	9	419458	0.00	99.98
5375	7	419465	0.00	99.99
5625	9	419474	0.00	99.99
5875	7	419481	0.00	99.99
6125	8	419489	0.00	99.99
6375	10	419499	0.00	99.99
6625	4	419503	0.00	100.00
6875	2	419505	0.00	100.00
7125	0	419505	0.00	100.00
7375	1	419506	0.00	100.00
7625	1	419507	0.00	100.00
7875	0	419507	0.00	100.00
8125	3	419510	0.00	100.00
8375	1	419511	0.00	100.00
8625	2	419513	0.00	100.00
8875	3	419516	0.00	100.00
9125	1	419517	0.00	100.00
9375	2	419519	0.00	100.00
9625	0	419519	0.00	100.00
9875	3	419522	0.00	100.00
10125	0	419522	0.00	100.00
10375	0	419522	0.00	100.00
10625	0	419522	0.00	100.00
10875	0	419522	0.00	100.00
11125	0	419522	0.00	100.00

Figure III-2. Distribution of CO Emissions for ASM5015 Inspection



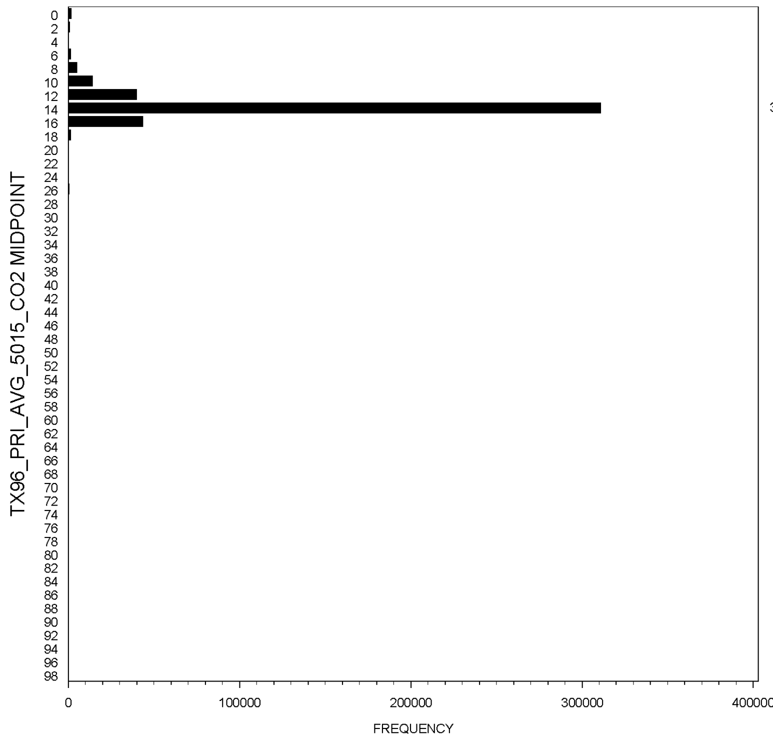
TX96_PRI_AVG_5015_CO MIDPOINT	FREQ.	CUM. FREQ.	PCT.	CUM. PCT.
0	406226	406226	96.83	96.83
2	8090	414316	1.93	98.76
4	1971	416287	0.47	99.23
6	1300	417587	0.31	99.54
8	797	418384	0.19	99.73
10	760	419144	0.18	99.91
12	314	419458	0.07	99.98
14	50	419508	0.01	100.00
16	6	419514	0.00	100.00
18	1	419515	0.00	100.00
20	0	419515	0.00	100.00
22	0	419515	0.00	100.00
24	0	419515	0.00	100.00
26	0	419515	0.00	100.00
28	0	419515	0.00	100.00
30	0	419515	0.00	100.00
32	0	419515	0.00	100.00
34	1	419516	0.00	100.00
36	0	419516	0.00	100.00
38	0	419516	0.00	100.00
40	0	419516	0.00	100.00
42	1	419517	0.00	100.00
44	0	419517	0.00	100.00
46	2	419519	0.00	100.00
48	0	419519	0.00	100.00
50	0	419519	0.00	100.00
52	0	419519	0.00	100.00
54	0	419519	0.00	100.00
56	0	419519	0.00	100.00
58	0	419519	0.00	100.00
60	0	419519	0.00	100.00
62	0	419519	0.00	100.00
64	0	419519	0.00	100.00
66	0	419519	0.00	100.00
68	0	419519	0.00	100.00
70	0	419519	0.00	100.00
72	0	419519	0.00	100.00
74	0	419519	0.00	100.00
76	0	419519	0.00	100.00
78	1	419520	0.00	100.00
80	0	419520	0.00	100.00
82	0	419520	0.00	100.00
84	1	419521	0.00	100.00
86	0	419521	0.00	100.00
88	0	419521	0.00	100.00
90	0	419521	0.00	100.00
92	0	419521	0.00	100.00
94	0	419521	0.00	100.00
96	0	419521	0.00	100.00
98	1	419522	0.00	100.00

Figure III-3. Distribution of NOx Emissions for ASM5015 Inspection



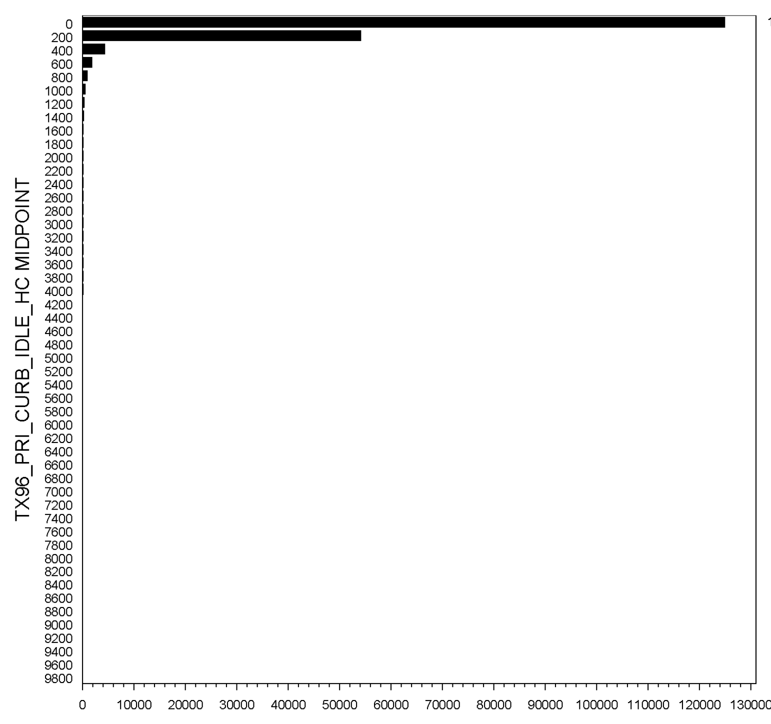
TX96_PRI_AVG_5015_NX MIDPOINT	FREQ.	CUM. FREQ.	PCT.	CUM. PCT.
-1625	0	0	0.00	0.00
-1375	0	0	0.00	0.00
-1125	0	0	0.00	0.00
-875	1	1	0.00	0.00
-625	0	1	0.00	0.00
-375	0	1	0.00	0.00
-125	2	3	0.00	0.00
125	149436	149439	35.62	35.62
375	89554	238993	21.35	56.97
625	58083	297076	13.85	70.81
875	46922	343998	11.18	82.00
1125	30812	374810	7.34	89.34
1375	14596	389406	3.48	92.82
1625	9924	399330	2.37	95.19
1875	4967	404297	1.18	96.37
2125	3798	408095	0.91	97.28
2375	2983	411078	0.71	97.99
2625	2428	413506	0.58	98.57
2875	1729	415235	0.41	98.98
3125	1252	416487	0.30	99.28
3375	853	417340	0.20	99.48
3625	614	417954	0.15	99.63
3875	444	418398	0.11	99.73
4125	294	418692	0.07	99.80
4375	215	418907	0.05	99.85
4625	141	419048	0.03	99.89
4875	113	419161	0.03	99.91
5125	73	419234	0.02	99.93
5375	49	419283	0.01	99.94
5625	48	419331	0.01	99.95
5875	30	419361	0.01	99.96
6125	26	419387	0.01	99.97
6375	29	419416	0.01	99.97
6625	26	419442	0.01	99.98
6875	19	419461	0.00	99.99
7125	11	419472	0.00	99.99
7375	13	419485	0.00	99.99
7625	14	419499	0.00	99.99
7875	2	419501	0.00	99.99
8125	4	419505	0.00	100.00
8375	2	419507	0.00	100.00
8625	4	419511	0.00	100.00
8875	4	419515	0.00	100.00
9125	2	419517	0.00	100.00
9375	2	419519	0.00	100.00
9625	2	419521	0.00	100.00
9875	1	419522	0.00	100.00
10125	0	419522	0.00	100.00
10375	0	419522	0.00	100.00
10625	0	419522	0.00	100.00

Figure III-4. Distribution of CO_2 Emissions for ASM5015 Inspection



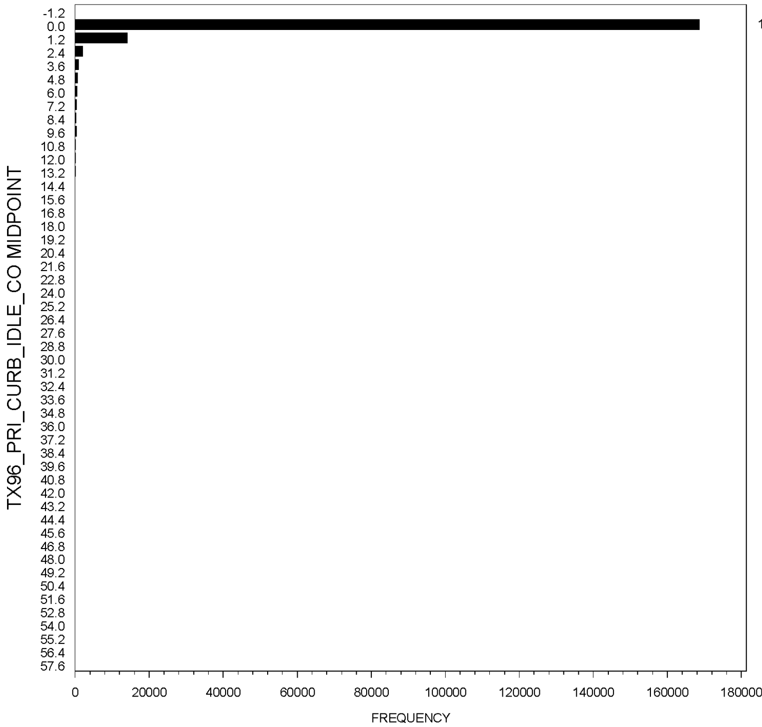
MIDPOINT	FREQ.	CUM. FREQ.	PCT.	CUM. PCT.
0	1665	1665	0.40	0.40
2	913	2578	0.22	0.61
4	255	2833	0.06	0.68
6	1315	4148	0.31	0.99
8	5002	9150	1.19	2.18
10	14176	23326	3.38	5.56
12	39832	63158	9.49	15.05
14	310866	374024	74.10	89.15
16	43389	417413	10.34	99.50
18	1343	418756	0.32	99.82
20	253	419009	0.06	99.88
22	82	419091	0.02	99.90
24	35	419126	0.01	99.91
26	354	419480	0.08	99.99
28	7	419487	0.00	99.99
30	0	419487	0.00	99.99
32	3	419490	0.00	99.99
34	0	419490	0.00	99.99
36	1	419491	0.00	99.99
38	2	419493	0.00	99.99
40	0	419493	0.00	99.99
42	2	419495	0.00	99.99
44	1	419496	0.00	99.99
46	1	419497	0.00	99.99
48	0	419497	0.00	99.99
50	1	419498	0.00	99.99
52	1	419499	0.00	99.99
54	3	419502	0.00	100.00
56	1	419503	0.00	100.00
58	1	419504	0.00	100.00
60	0	419504	0.00	100.00
62	1	419505	0.00	100.00
64	1	419506	0.00	100.00
66	1	419507	0.00	100.00
68	1	419508	0.00	100.00
70	0	419508	0.00	100.00
72	2	419510	0.00	100.00
74	0	419510	0.00	100.00
76	1	419511	0.00	100.00
78	0	419511	0.00	100.00
80	1	419512	0.00	100.00
82	1	419513	0.00	100.00
84	3	419516	0.00	100.00
86	0	419516	0.00	100.00
88	2	419518	0.00	100.00
90	2	419520	0.00	100.00
92	0	419520	0.00	100.00
94	0	419520	0.00	100.00
96	0	419520	0.00	100.00
98	2	419522	0.00	100.00

Figure III-5. Distribution of Curb Idle HC Emissions for TSI Inspection



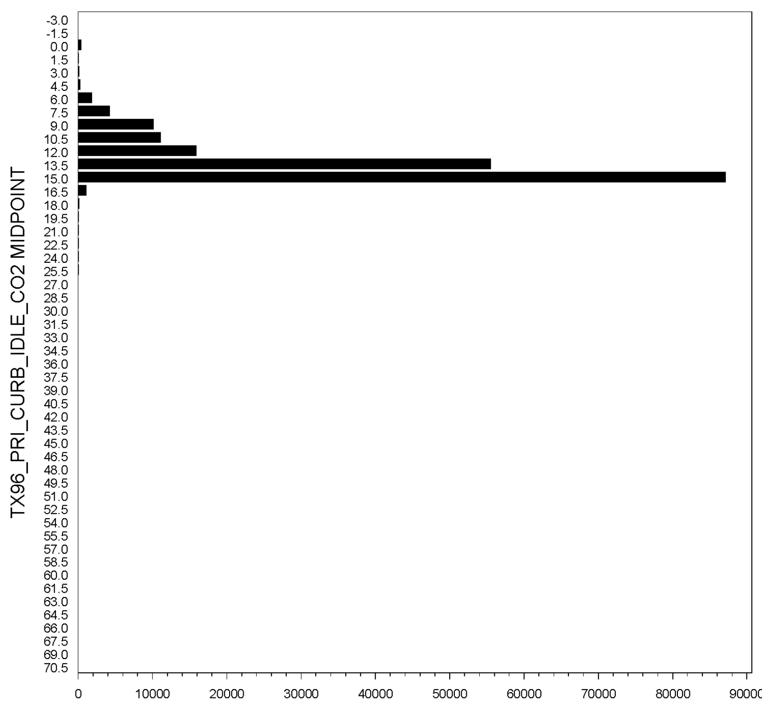
MIDPOINT	FREQ.	CUM. FREQ.	PCT.	CUM. PCT.
0	124821	124821	66.47	66.47
200	54126	178947	28.82	95.29
400	4294	183241	2.29	97.58
600	1771	185012	0.94	98.52
800	881	185893	0.47	98.99
1000	448	186341	0.24	99.23
1200	291	186632	0.15	99.39
1400	211	186843	0.11	99.50
1600	150	186993	0.08	99.58
1800	119	187112	0.06	99.64
2000	101	187213	0.05	99.69
2200	94	187307	0.05	99.74
2400	58	187365	0.03	99.78
2600	64	187429	0.03	99.81
2800	32	187461	0.02	99.83
3000	35	187496	0.02	99.85
3200	35	187531	0.02	99.86
3400	32	187563	0.02	99.88
3600	21	187584	0.01	99.89
3800	20	187604	0.01	99.90
4000	115	187719	0.06	99.96
4200	10	187729	0.00	99.97
4400	8	187737	0.00	99.97
4600	3	187740	0.00	99.98
4800	3	187743	0.00	99.98
5000	1	187744	0.00	99.98
5200	6	187750	0.00	99.98
5400	4	187754	0.00	99.98
5600	4	187758	0.00	99.99
5800	4	187762	0.00	99.99
6000	2	187764	0.00	99.99
6200	2	187766	0.00	99.99
6400	4	187770	0.00	99.99
6600	2	187772	0.00	99.99
6800	2	187774	0.00	99.99
7000	1	187775	0.00	99.99
7200	2	187777	0.00	100.00
7400	1	187778	0.00	100.00
7600	1	187779	0.00	100.00
7800	0	187779	0.00	100.00
8000	2	187781	0.00	100.00
8200	0	187781	0.00	100.00
8400	0	187781	0.00	100.00
8600	1	187782	0.00	100.00
8800	0	187782	0.00	100.00
9000	1	187783	0.00	100.00
9200	0	187783	0.00	100.00
9400	1	187784	0.00	100.00
9600	0	187784	0.00	100.00
9800	2	187786	0.00	100.00

Figure III-6. Distribution of Curb Idle CO Emissions for TSI Inspection



TX96_PRI_CURB_IDLE_CO MIDPOINT	FREQ.	CUM. FREQ.	PCT.	CUM. PCT.
-1.2	0	0	0.00	0.00
0.0	168600	168600	89.78	89.78
1.2	14036	182636	7.47	97.26
2.4	1968	184604	1.05	98.31
3.6	881	185485	0.47	98.77
4.8	602	186087	0.32	99.10
6.0	502	186589	0.27	99.36
7.2	372	186961	0.20	99.56
8.4	281	187242	0.15	99.71
9.6	381	187623	0.20	99.91
10.8	65	187688	0.03	99.95
12.0	66	187754	0.04	99.98
13.2	26	187780	0.01	100.00
14.4	1	187781	0.00	100.00
15.6	2	187783	0.00	100.00
16.8	0	187783	0.00	100.00
18.0	1	187784	0.00	100.00
19.2	0	187784	0.00	100.00
20.4	0	187784	0.00	100.00
21.6	1	187785	0.00	100.00
22.8	0	187785	0.00	100.00
24.0	0	187785	0.00	100.00
25.2	0	187785	0.00	100.00
26.4	0	187785	0.00	100.00
27.6	0	187785	0.00	100.00
28.8	0	187785	0.00	100.00
30.0	0	187785	0.00	100.00
31.2	0	187785	0.00	100.00
32.4	0	187785	0.00	100.00
33.6	0	187785	0.00	100.00
34.8	0	187785	0.00	100.00
36.0	0	187785	0.00	100.00
37.2	0	187785	0.00	100.00
38.4	0	187785	0.00	100.00
39.6	0	187785	0.00	100.00
40.8	0	187785	0.00	100.00
42.0	0	187785	0.00	100.00
43.2	0	187785	0.00	100.00
44.4	0	187785	0.00	100.00
45.6	0	187785	0.00	100.00
46.8	0	187785	0.00	100.00
48.0	0	187785	0.00	100.00
49.2	0	187785	0.00	100.00
50.4	0	187785	0.00	100.00
51.6	0	187785	0.00	100.00
52.8	0	187785	0.00	100.00
54.0	0	187785	0.00	100.00
55.2	0	187785	0.00	100.00
56.4	1	187786	0.00	100.00
57.6	0	187786	0.00	100.00

Figure III-7. Distribution of Curb Idle CO_2 Emissions for TSI Inspection



TX96_PRI_CURB_IDLE_CO2 MIDPOINT	FREQ.	CUM. FREQ.	PCT.	CUM. PCT.
-3.0	0	0	0.00	0.00
-1.5	0	0	0.00	0.00
0.0	383	383	0.20	0.20
1.5	7	390	0.00	0.21
3.0	58	448	0.03	0.24
4.5	232	680	0.12	0.36
6.0	1821	2501	0.97	1.33
7.5	4255	6756	2.27	3.60
9.0	10128	16884	5.39	8.99
10.5	11074	27958	5.90	14.89
12.0	15860	43818	8.45	23.33
13.5	55525	99343	29.57	52.90
15.0	87122	186465	46.39	99.30
16.5	1065	187530	0.57	99.86
18.0	128	187658	0.07	99.93
19.5	37	187695	0.02	99.95
21.0	22	187717	0.01	99.96
22.5	7	187724	0.00	99.97
24.0	9	187733	0.00	99.97
25.5	47	187780	0.03	100.00
27.0	0	187780	0.00	100.00
28.5	0	187780	0.00	100.00
30.0	0	187780	0.00	100.00
31.5	0	187780	0.00	100.00
33.0	1	187781	0.00	100.00
34.5	0	187781	0.00	100.00
36.0	0	187781	0.00	100.00
37.5	1	187782	0.00	100.00
39.0	0	187782	0.00	100.00
40.5	0	187782	0.00	100.00
42.0	0	187782	0.00	100.00
43.5	0	187782	0.00	100.00
45.0	1	187783	0.00	100.00
46.5	0	187783	0.00	100.00
48.0	0	187783	0.00	100.00
49.5	0	187783	0.00	100.00
51.0	0	187783	0.00	100.00
52.5	0	187783	0.00	100.00
54.0	1	187784	0.00	100.00
55.5	0	187784	0.00	100.00
57.0	0	187784	0.00	100.00
58.5	0	187784	0.00	100.00
60.0	0	187784	0.00	100.00
61.5	0	187784	0.00	100.00
63.0	1	187785	0.00	100.00
64.5	0	187785	0.00	100.00
66.0	0	187785	0.00	100.00
67.5	1	187786	0.00	100.00
69.0	0	187786	0.00	100.00
70.5	0	187786	0.00	100.00

This procedure of checking the contents of the variables in the database is simply an initial QC/QA procedure. Most of the variables will be investigated much more thoroughly in the other sections of the report.

B. INSPECTION STATISTICS: NUMBER OF VEHICLES INSPECTED BY INSPECTION TYPE

As a basic summary of the emissions inspections being performed under the Texas I/M program, a number of inspection statistics were calculated. Table III-1 shows the total number of each type of emissions inspection that were performed in the 2014 – 2015 calendar years, the number of these that were initial inspections (the first inspection in a test cycle), and then the number of these that were unique vehicles, for the HGB and DFW program areas separately. A unique vehicle is synonymous with a unique VIN and a unique initial inspection is the first inspection in a test cycle on a unique vehicle. There are considerably fewer unique initial inspections than total inspections. Table III-2 shows the number of initial inspections that were passed and failed, by program area and inspection type. Finally, Table III-3 shows the number of re-test inspections that were passed and failed, by program area and inspection type.

Table III-1. Number of Inspections

	DFW			HGB		
Test Type	Total Inspections	Initial Inspections	Unique Initial Inspections	Total Inspections	Initial Inspections	Unique Initial Inspections
OBD	7,470,973	7,085,473	4,645,537	6,994,250	6,613,418	4,272,125
TSI	39,510	35,066	25,794	32,218	28,873	21,270
ASM	226,268	191,904	141,081	193,254	168,984	123,295
Total	7,736,751	7,312,443	4,812,412	7,219,722	6,811,275	4,416,690

Table III-2. Number of Passed and Failed Initial Inspections

	DFW			HGB		
Test Type	Pass	Fail	Failure Percent	Pass	Fail	Failure Percent
OBD	6,808,318	277,152	3.9%	6,349,044	264,369	4.0%
TSI	32,657	2,409	6.9%	26,956	1,917	6.6%
ASM	167,679	24,225	12.6%	152,965	16,019	9.5%
Total	7,008,654	303,786	4.2%	6,528,965	282,305	4.1%

Table III-3. Number of Passed and Failed Retest Inspections

	DFW			HGB		
Test Type	Pass	Fail	Failure Percent	Pass	Fail	Failure Percent
OBD	346,237	39,260	10.2%	347,435	33,389	8.8%
TSI	3,403	1,041	23.4%	2,714	630	18.8%
ASM	22,809	11,555	33.6%	19,107	5,161	21.3%
Total	372,449	51,856	12.2%	369,256	39,180	9.6%

For additional information, inspection counts by model year are presented in the figures below. In Figure III-8 and Figure III-9, the number of inspections of each type are shown by model year, for the DFW and HGB program areas, respectively. The number of inspections by month of inspection is shown in Figure III-10. Finally, the failure rate by model year and type of inspection is shown in Figure III-11 and Figure III-12 for the DFW and HGB program areas, respectively. Only initial inspections are included (no re-tests). In general, the trends shown are to be expected: more vehicles of newer model years are inspected than vehicles of older model years, and failure rates are much higher for older vehicles.

Figure III-8. Number of Inspections by Inspection Type, DFW Program Area

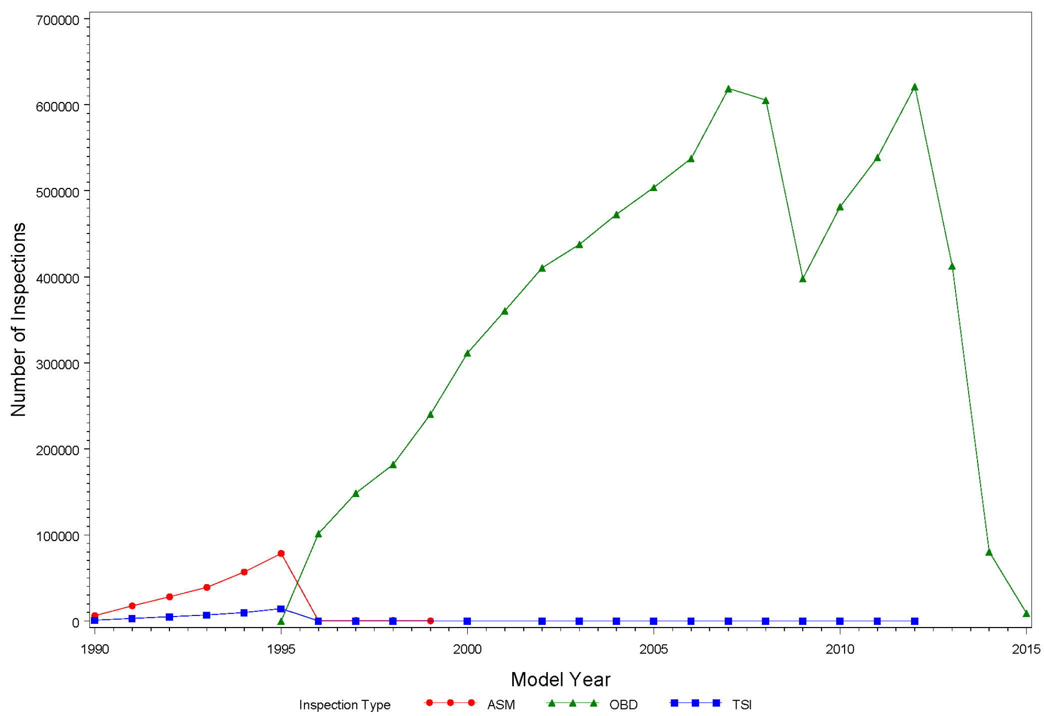


Figure III-9. Number of Inspections by Inspection Type, HGB Program Area

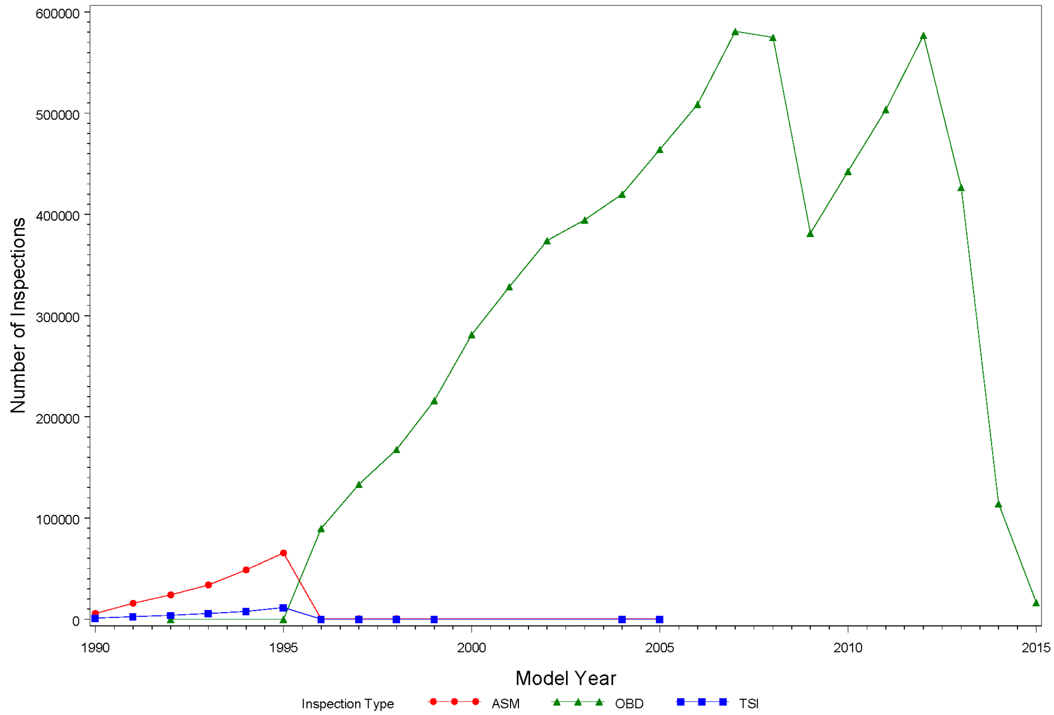


Figure III-10. Number of Inspections by Year and Month of Inspection

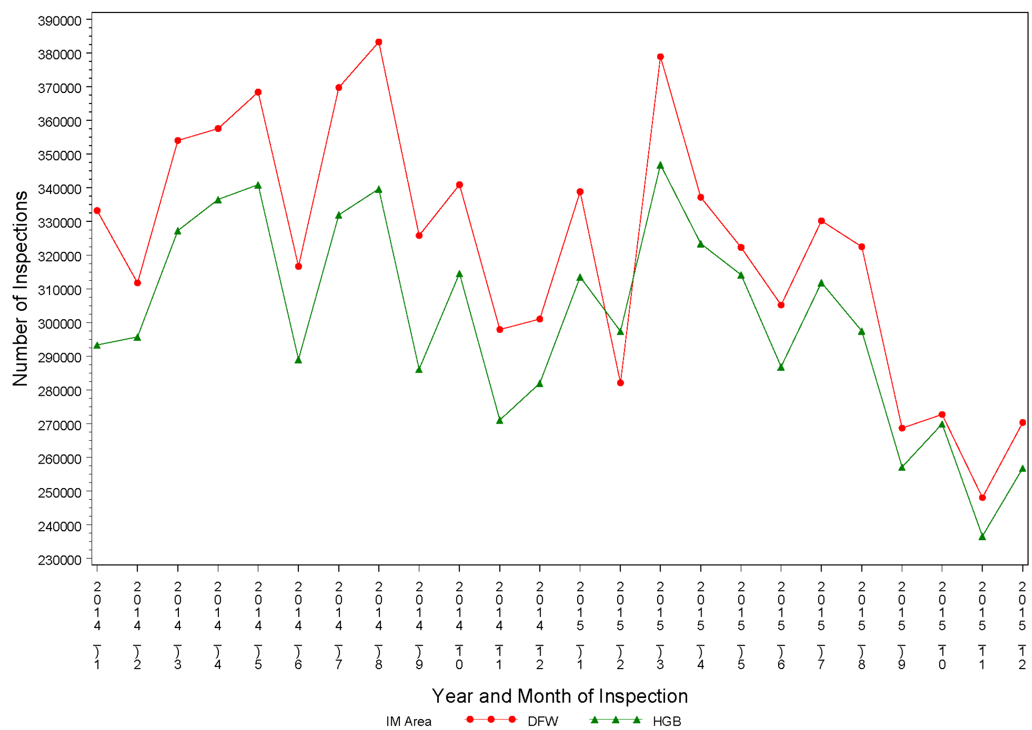


Figure III-11. Initial Inspection Failure Rate by Inspection Type, DFW Program Area

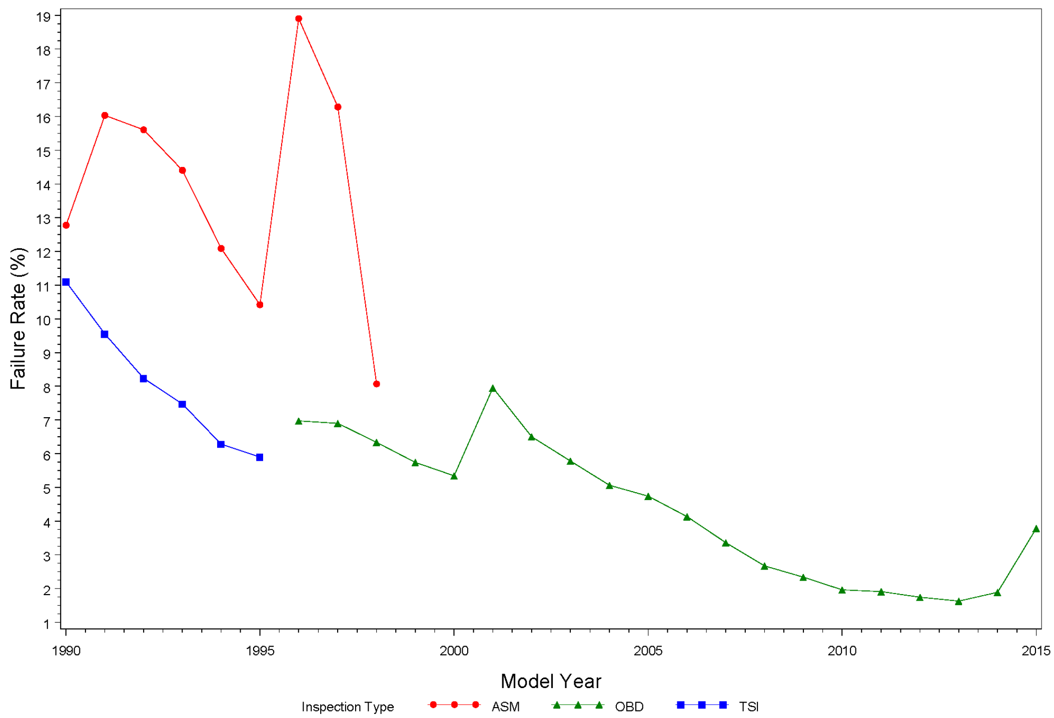
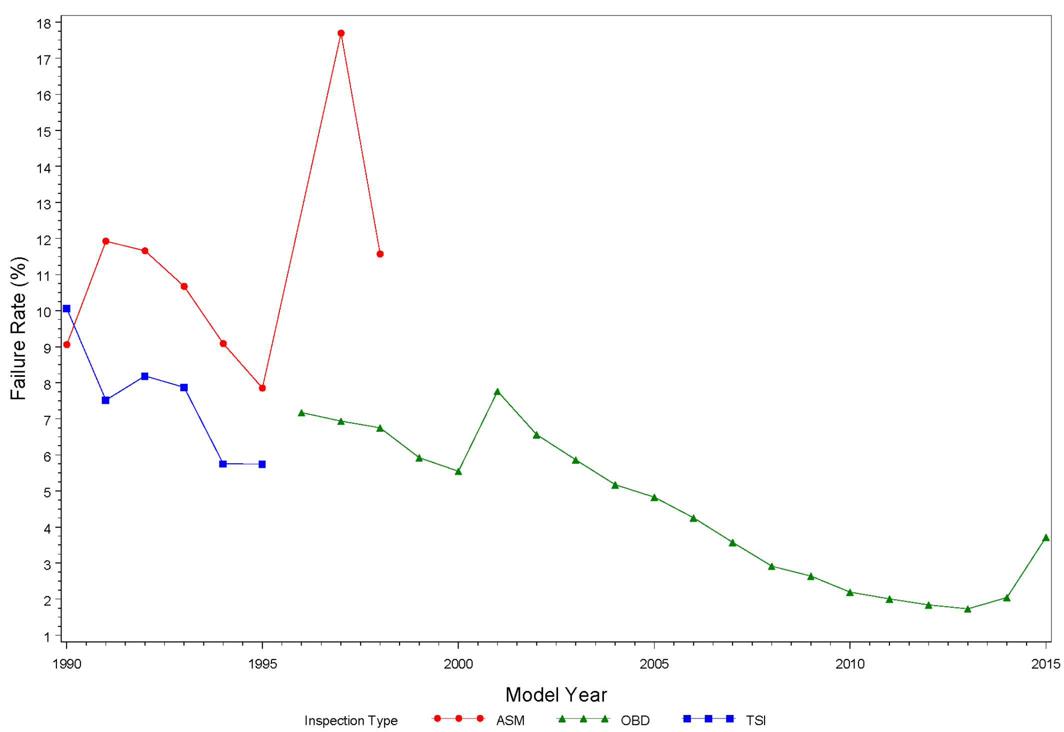


Figure III-12. Initial Inspection Failure Rate by Inspection Type, HGB Program Area



One trend that can be seen in Figure III-10 is a decrease in the number of inspections per month in the latter half of 2015. This is probably an effect of Texas' new single sticker program, implementation of which began in March of 2015. Under this program, vehicles no longer receive separate stickers for passing the I/M inspection and for registration. Vehicles are now required to pass their I/M inspection, and then they can receive their registration sticker. In the past, an I/M inspection could be due at any month of the year, regardless of when the registration was due. Under this program the two became linked so that the I/M inspection is a prerequisite for vehicle registration. There was a one-year transition period while the months for the two requirements became linked, starting in March 2015. During this transition, vehicles that received an I/M inspection within the year before their registration was due were not required to have another I/M inspection until the 90-day window before the registration expired in the following year. This prevented vehicles from being required to receive more than one I/M inspection within a one-year period, but it also meant that fewer I/M inspections than usual were performed between March 2015 and March 2016.

C. 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 Texas I/M program. This analysis was based on the two-year inspection period including all of 2014 and 2015. Initial and re-test inspections were not determined using the TX96_TEST_SEQUENCE or TX96_TEST_TYPE variables. These database variables are intended to store the number of inspections in an inspection sequence, and whether an inspection is an initial or a re-test inspection. However, many factors can affect the information stored in these variables (such as the time span between an initial and a re-test inspection, whether the motorist chose a different inspection station for the re-test, or whether a safety-only inspection was performed at some point). For the purposes of this section and this report, ERG made new initial/re-test assignments. The first inspection for a VIN was labeled an initial inspection. Additional inspections to that VIN were labeled as re-tests, until an inspection was passed or a waiver was granted. The next inspection following a passed inspection or a waiver was labeled an initial inspection. For the purpose of identifying initial inspections, inspection cycles that appeared to begin in the first three months of 2014 were excluded from the counts, as they could have been preceded by additional inspections in 2013. Also, for the purpose of identifying final inspections, any inspection cycles that appeared to end in the last three months of 2015 were excluded, as there could be additional inspections in early 2016.

An “inspection sequence” is the series of inspections a vehicle receives as it moves through the Texas I/M program requirements. By far, the most common sequence is a single passed inspection. The second most common sequence is a failed inspection, followed by repair and a passed re-test. Additional sequences might include additional failed inspections before the ultimately passed inspection. Sequences should not be found where additional re-test inspections follow a passed inspection as these indicate that the measurements and efficacy of the repairs made to the vehicles in the program are less than ideal. For example, a sequence that is fail, 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 dataset contains 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). Failed inspections were designated with an “F” and passes with a “P.” Inspections that resulted in a waiver were designated with a “W.” For each unique VIN in the dataset, 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 is shown in Table III-4, with results for the DFW and HGB program areas shown separately. The waiver inspections are included in the “Other” category.

Table III-4. Frequency Distribution of Test Sequences

DFW			HGB		
Inspection Sequence	Number of Vehicles	Percent of Vehicles	Inspection Sequence	Number of Vehicles	Percent of Vehicles
P	6,014,197	94.61%	P	5,598,078	94.31%
FP	285,673	4.49%	FP	289,184	4.87%
F	23,992	0.38%	F	21,416	0.36%
FFP	22,571	0.36%	FFP	19,990	0.34%
FFFP	4,243	0.07%	FFFP	3,168	0.05%
FF	3,173	0.05%	FF	2,440	0.04%
FFFFP	1,103	0.02%	FFFFP	702	0.01%
FFF	696	0.01%	FFF	403	0.01%
Other	1,181	0.02%	Other	714	0.01%

In Table III-4, the top two rows, which represent the two "ideal" inspection sequences, comprise about 99% of the total distribution, both in the DFW and HGB program areas. However, some of the other sequences raise questions, such as, what becomes of the vehicles that fail an inspection and do not receive a passing re-test? One check that was performed for this set of vehicles was to make sure that they are not being affected by sequences that start near the end of the dataset and might have later re-tests. It was found that the sequences that end with a failed inspection are distributed fairly uniformly over all months of 2014 and 2015, although some increase is seen in the later months of the dataset. The vehicles that did not complete their inspection sequences, and ended with no final passed inspection (NFP), may have moved out of the I/M program area, and therefore may no longer be required to participate in the I/M program. However, some of the NFP vehicles were observed in the I/M program area by remote sensing, after their incomplete inspection cycle. These non-compliant vehicles were observed at approximately half the frequency as compliant vehicles.

Several hundred less common sequences accounted for the remaining 0.01-0.02% of the tested fleets. Many of these remaining sequences seem to be unlikely, involving numerous failed inspections and/or multiple passed inspections. Some of these could be the result of resale vehicles, unidentified covert audit vehicles, or possibly test classification errors instead of real situations. While it might be possible to reduce the occurrence of these unlikely test sequences, the problem is relatively uncommon.

D. 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 TIMS data: Drift, Dilution Correction Factors, Gas Audits, and Lockouts.

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.

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 III-5 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 III-5. 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
CO_2 (%)	<4.0		±0.3
O_2 (%)	20.7		±1.04
Low-Span Bottle Gas			

Gas	Specified Bottle Gas Concentration	Bottle Gas Blend Tolerance	Analyzer Tolerance for I/M Inspections
HC (ppm)	200	±10	±6
CO (%)	0.5	±0.025	±0.02
NOx (ppm)	300	±15	±25
CO_2 (%)	6.0	±0.3	±0.3
Mid-Span Bottle Gas			
HC (ppm)	3200	±160	±160
CO (%)	8.0	±0.4	±0.24
NOx (ppm)	3000	±150	±120
CO_2 (%)	12.0	±0.6	±0.36

The actual concentrations of the bottle gases used in each calibration are recorded in the TIMS. More than 99.8% of calibration records include bottle gas label concentrations within the tolerances listed in Table III-5. However, the remaining small fraction of records include some surprisingly high and low bottle gas values, such as 19 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.

Results

Span test calibration records (381,565 records) from the TIMS between January 1, 2014, and December 31, 2015, were available for this analysis. Records with a propane equivalency factor (PEF) result of “0” were deleted, since these records appeared to contain no calibration information, leaving 358,191 records in the dataset. Records for the Austin and El Paso program areas were deleted from the dataset by deleting all analyzers where the NO_x calibration readings were always zero, leaving 269,093 HGB/DFW program area records in the dataset. Finally, an additional 8 records in which the pre-calibration reading for each gas concentration was zero were deleted, leaving 269,085 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.

Figure III-13 through Figure III-26 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 Figure III-17 and Figure III-18. 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 98% of calibrations, while analyzers with the manufacturer code ESP measured less than 3% O_2 in 93.2% 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 III-13. Distribution of Difference Between Zero and HC Pre-Calibration Reading

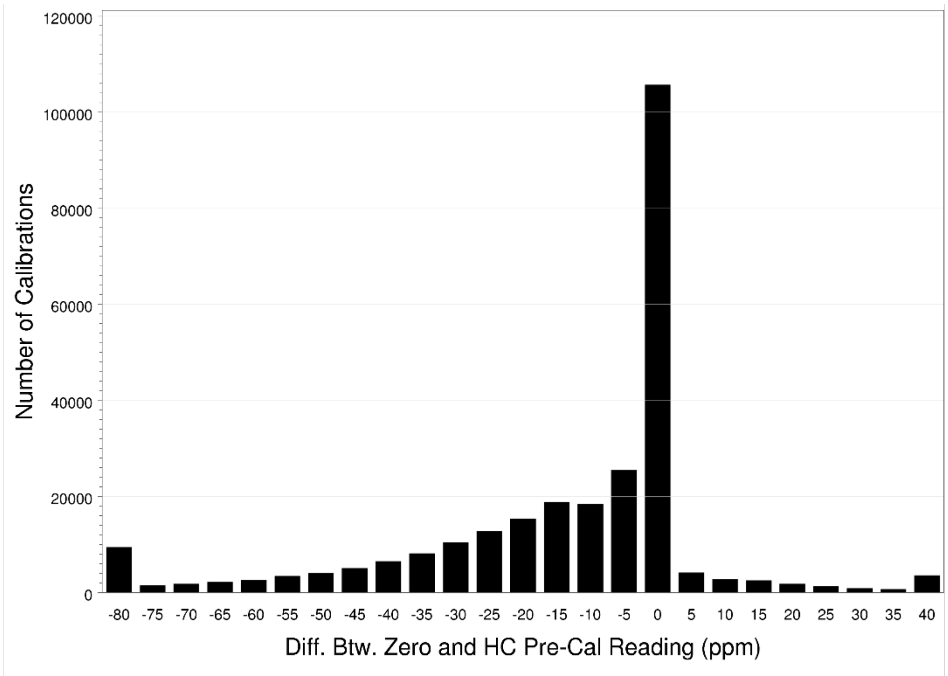


Figure III-14. Distribution of Difference Between Zero and CO Pre-Calibration Reading

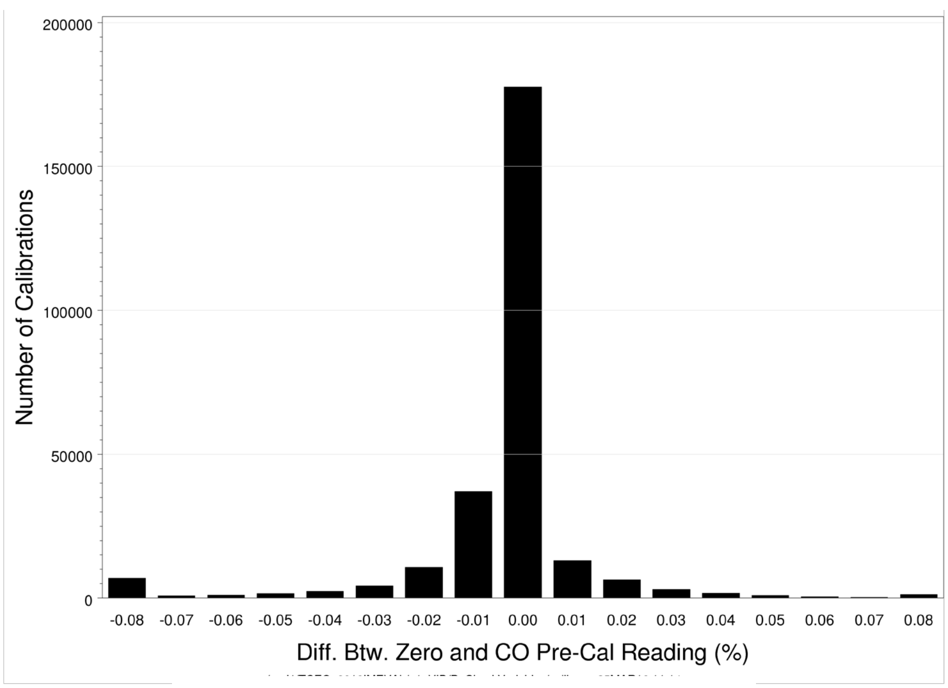


Figure III-15. Distribution of Difference Between Zero and NO_x Pre-Calibration Reading

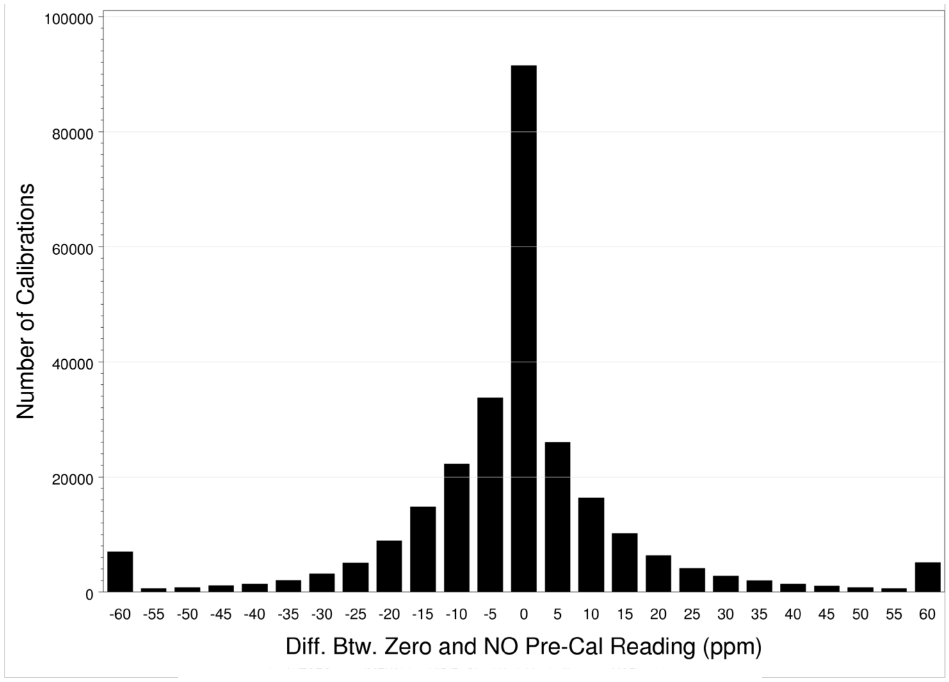


Figure III-16. Distribution of Difference Between Zero and CO_2 Pre-Calibration Reading

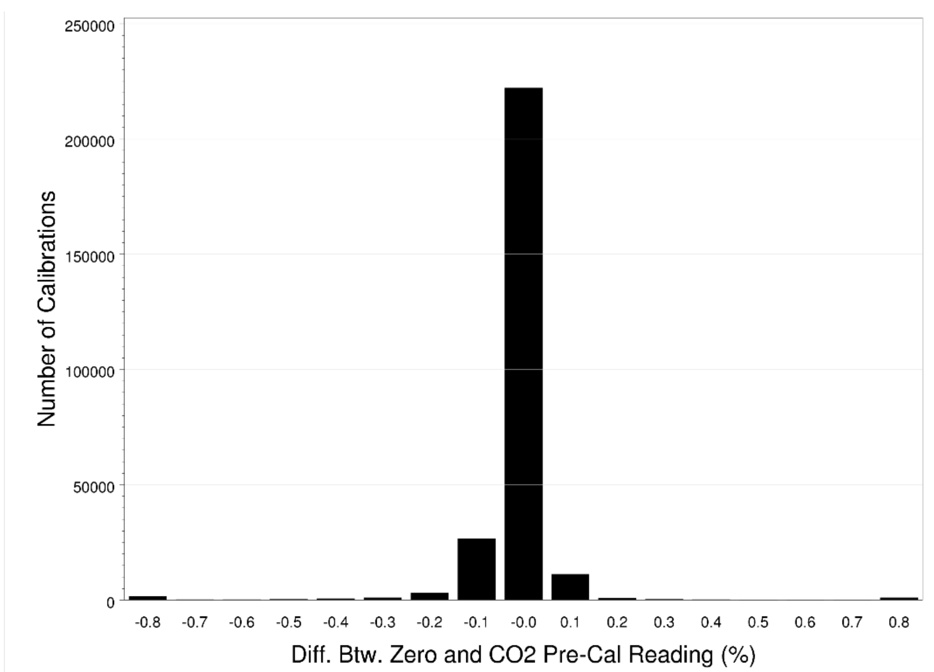


Figure III-17. Distribution of Difference Between Zero and O_2 Pre-Calibration Reading

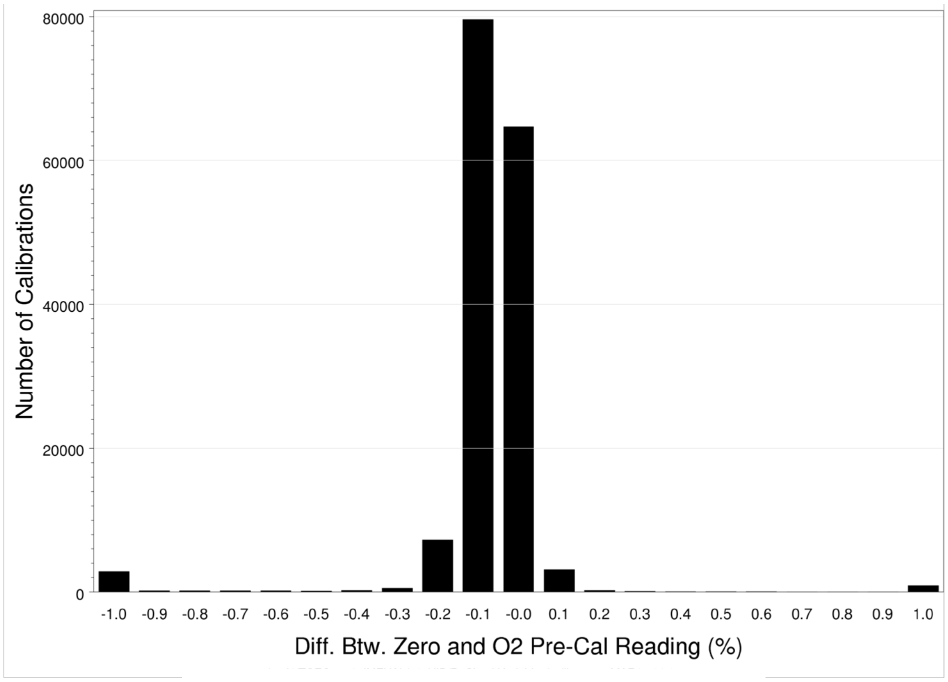


Figure III-18. Distribution of Difference Between 20.7% and O_2 Pre-Calibration Reading

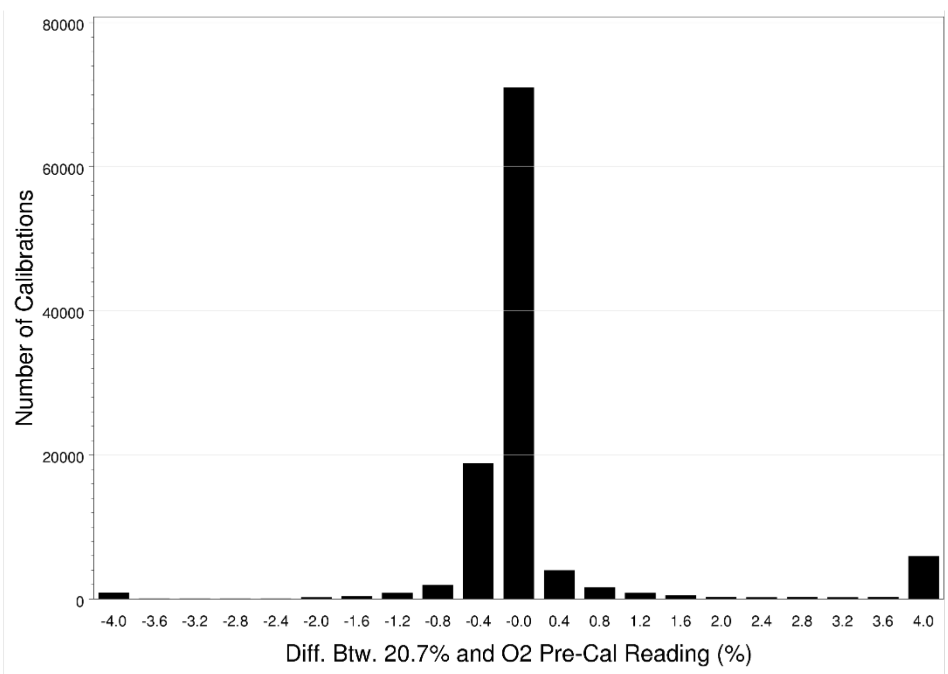


Figure III-19. Distribution of Difference Between Low-Span Bottle and HC Pre-Calibration Reading

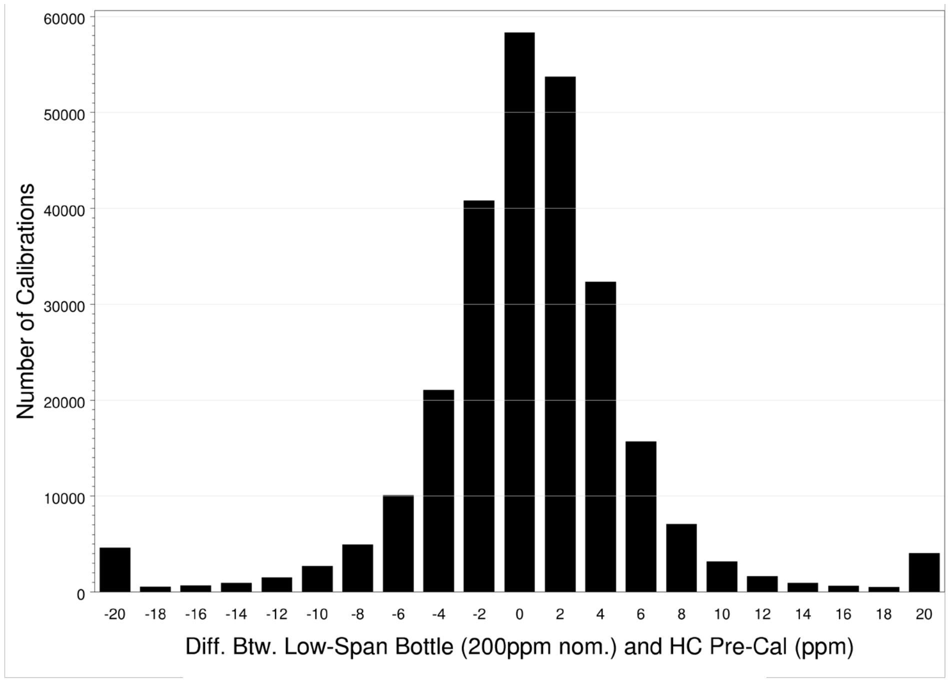


Figure III-20. Distribution of Difference Between Low-Span Bottle and CO Pre-Calibration Reading

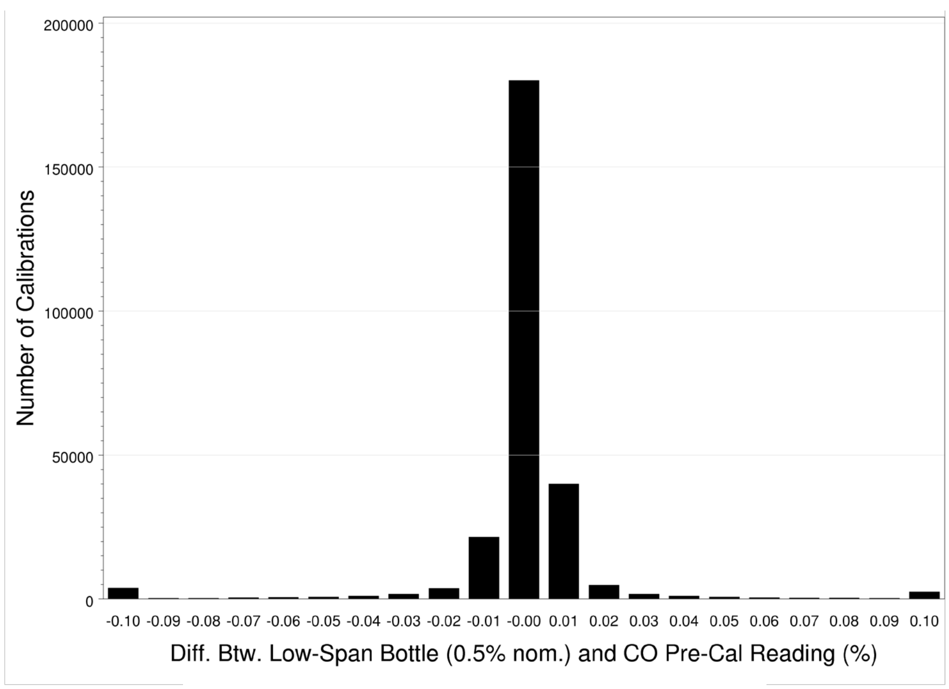


Figure III-21. Distribution of Difference Between Low-Span Bottle and NO_x Pre-Calibration Reading

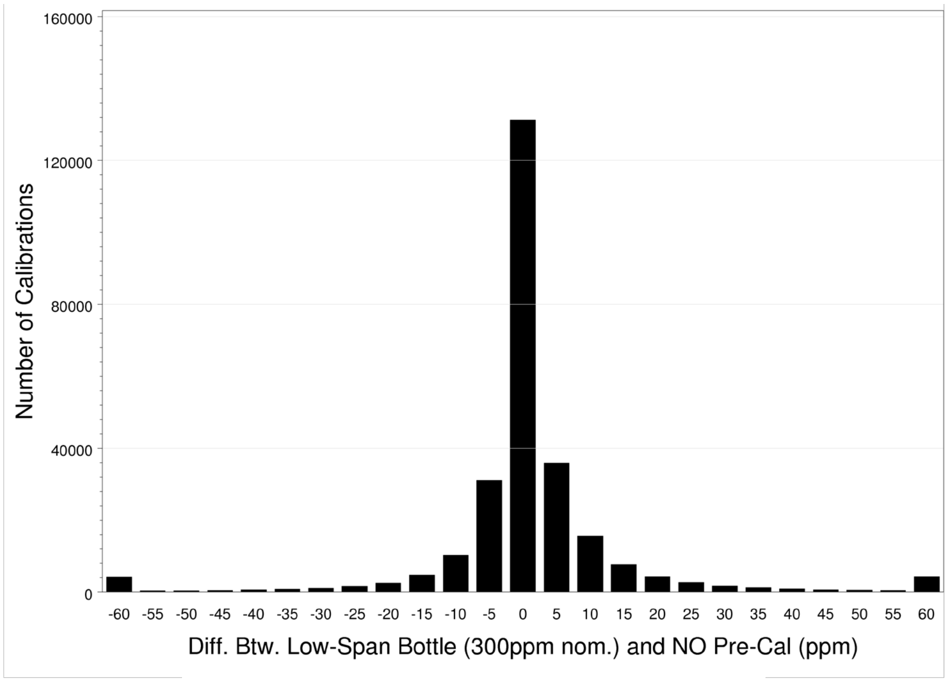


Figure III-22. Distribution of Difference Between Low-Span Bottle and CO_2 Pre-Calibration Reading

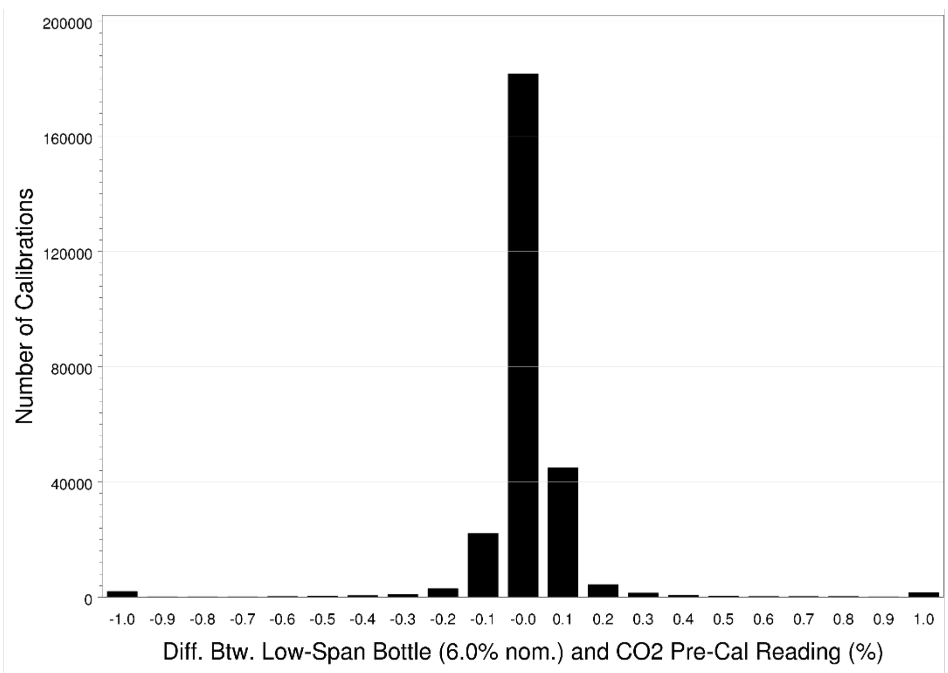


Figure III-23. Distribution of Difference Between Mid-Span Bottle and HC Pre-Calibration Reading

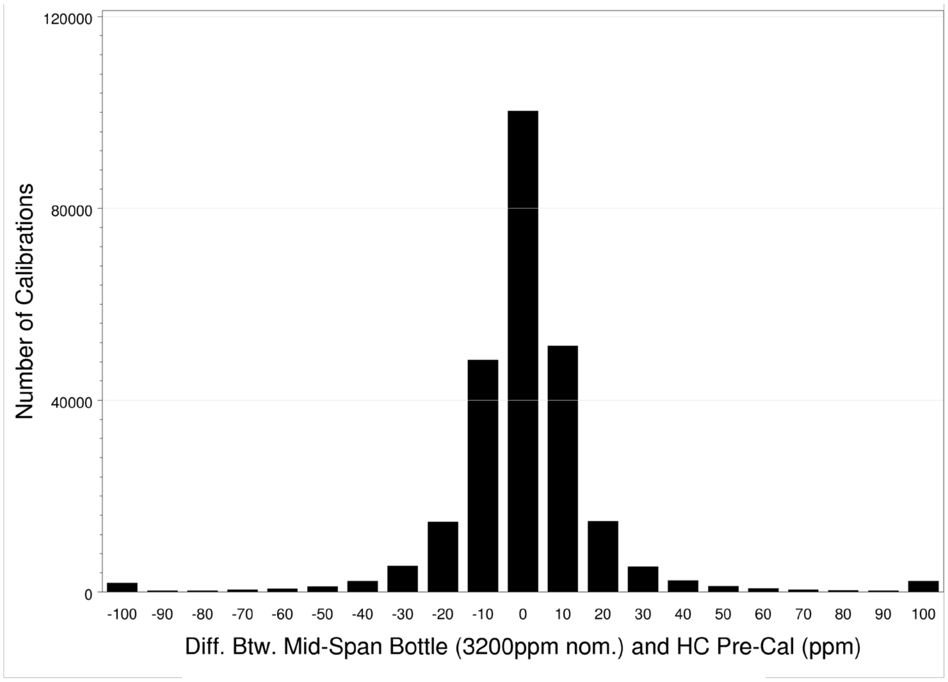


Figure III-24. Distribution of Difference Between Mid-Span Bottle and CO Pre-Calibration Reading

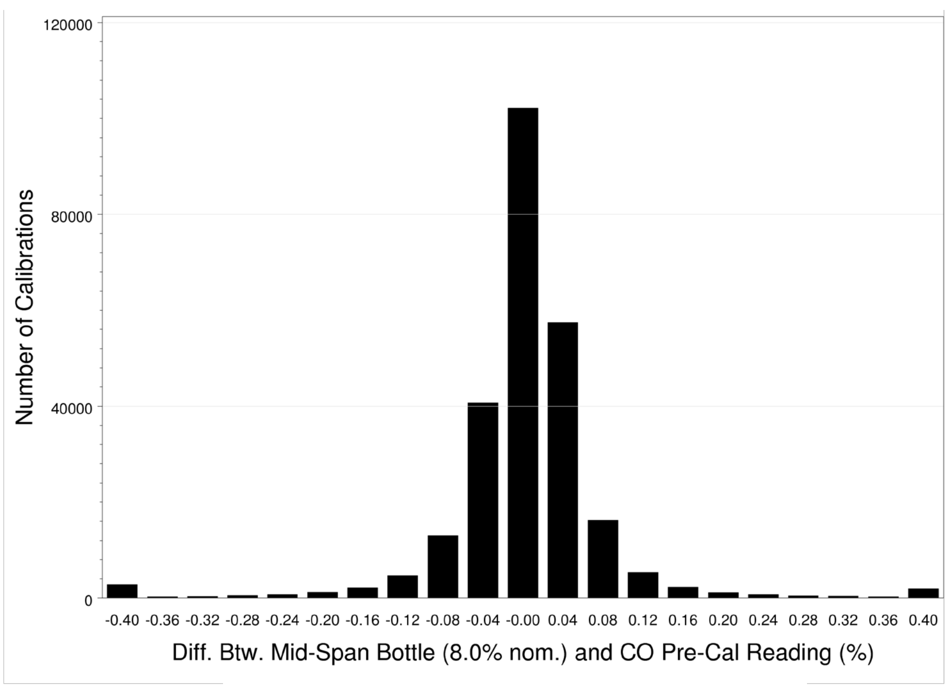


Figure III-25. Distribution of Difference Between Mid-Span Bottle and NO_x Pre-Calibration Reading

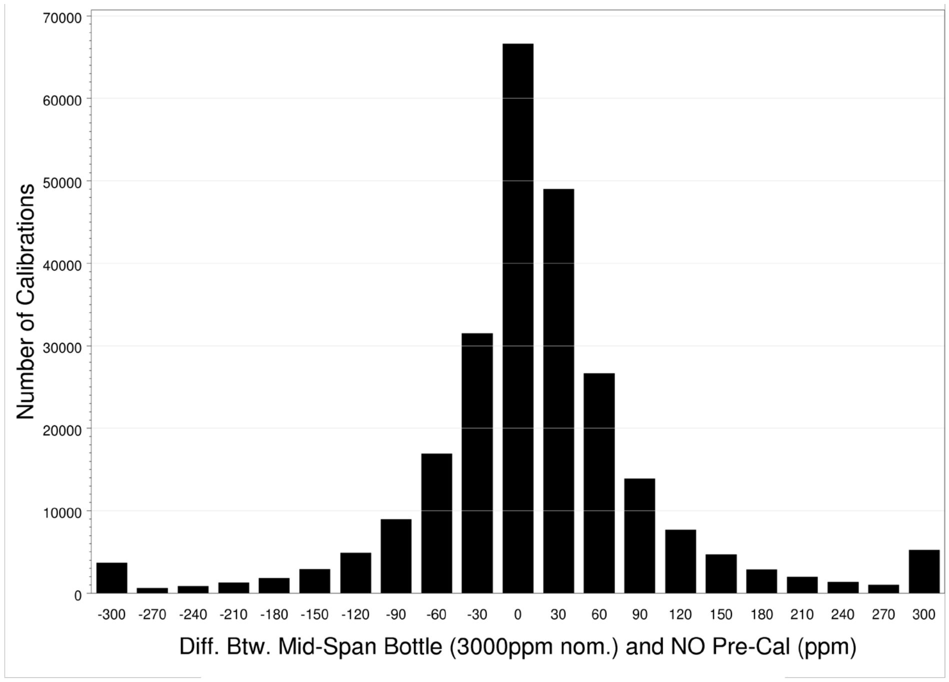


Figure III-26. Distribution of Difference Between Mid-Span Bottle and CO_2 Pre-Calibration Reading

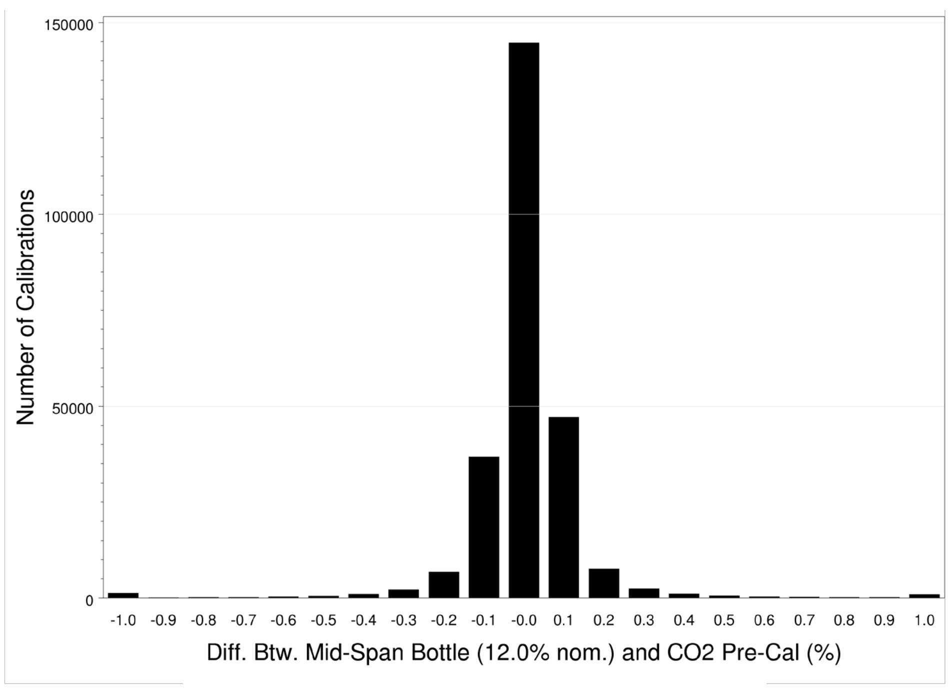


Table III-6 shows the specified value and tolerance for each gas type/concentration level, the total number of pre-calibration records available at that level, the percent of records whose values fell within the tolerance bounds, and finally, the amount of difference from the specified value that would include 90% of calibration records (the 90th percentile).

Note that the total record counts vary by concentration level in Table III-6. About 269,000 records were available at the zero level, but only 266,000 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 255,000 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 85% of pre-calibration records fell within the tolerance of the analyzer. The exception is the zero level HC, where only 45% of records were within tolerance (the wide distribution can be seen in Figure III-13 as well). This indicates that results for more than 85% 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 III-6. Number and Percent of Pre-Calibration Records Occurring Within Analyzer Tolerance

Gas	Specification	Total Number of Pre-Cal Records	Within Tolerance N	Within Tolerance %	90th Percentile
Zero Gas					
HC (ppm)	0±4	269,085	122,206	45.4	48
CO (%)	0.00±0.02	269,085	244,696	90.9	0.02
NOx (ppm)	0±25	269,085	236,178	87.8	30
CO_2 (%)	0.0±0.3	269,085	264,978	98.5	0.1
O_2 (%)	0.0±0.1	160,595	147,313	91.7	0.1
O_2 (%)	20.7±1.04	108,490	97,592	90.0	1.1
Low-Span Gas					
HC (ppm)	200±6	265,781	227,773	85.7	8
CO (%)	0.50±0.02	265,798	241,550	90.9	0.01
NOx (ppm)	300±25	264,855	245,645	92.7	19
CO_2 (%)	6.0±0.3	265,774	258,512	97.3	0.1
Mid-Span Gas					
HC (ppm)	3200±160	254,772	252,465	99.1	25
CO (%)	8.00±0.24	254,807	246,937	96.9	0.1
NOx (ppm)	3000±150	254,266	220,984	86.9	144
CO_2 (%)	12.00±0.36	254,800	247,544	97.2	0.2

Analyzer Dilution Correction Factors

For every ASM or TSI emissions test, a dilution correction factor (DCF) based on the measured CO and CO_2 concentration is calculated. DCFs can also be calculated based on the measured O_2 concentration. The DCFs from these two separate sources of tailpipe emissions should be within agreement with a relatively small tolerance. For 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 emissions measurement is in error, but does indicate that something is wrong with one of the CO, CO_2, or O_2 measurements used to calculate the DCF. Unless all three of these pollutants are in agreement with respect to their corresponding DCFs, the HC, CO, and NO_x measurements reported by the instrument are in question.

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.

Although the CO/CO_2 DCFs are the official DCFs used for the emissions test, 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 DCFs, the resulting HC, CO, and NO_x measurements reported by the instrument are in question.

Background

Assuming stoichiometric combustion of gasoline, an exhaust DCF 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 DCF 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. Typically, 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 3].

Results

For this analysis, vehicle inspection records from the TIMS for vehicles tested in the DFW and HGB program areas were used. Results for 493,571 inspections of gasoline-fueled vehicles that received either the ASM or 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 421,346 records for the ASM2525 test condition, 421,394 records for the ASM5015 test condition, 71,999 records for the low-idle TSI inspection, and 72,113 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 III-27 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 Figure III-28, Figure III-29, and Figure III-30. 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 DCFO_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 III-27. Comparison of ASM2525 DCF CO/CO_2 and DCF O_2

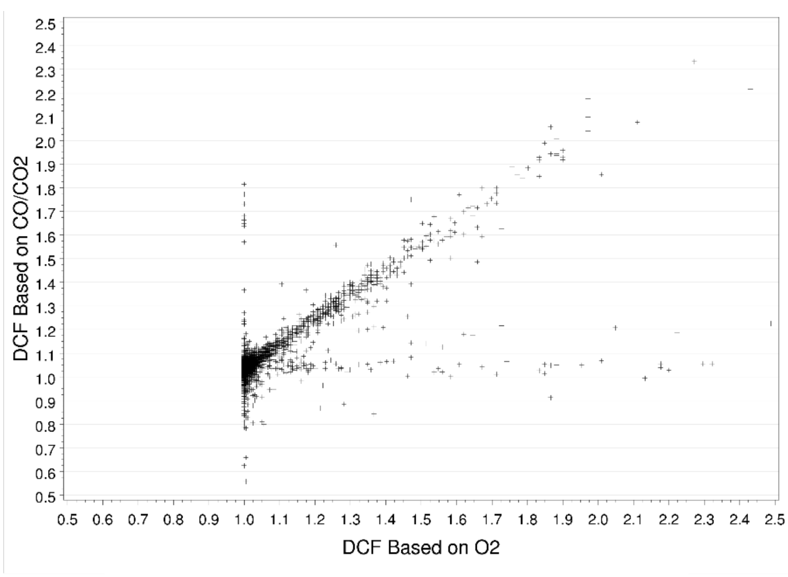


Figure III-28. Comparison of ASM5015 DCF CO/CO_2 and DCF O_2

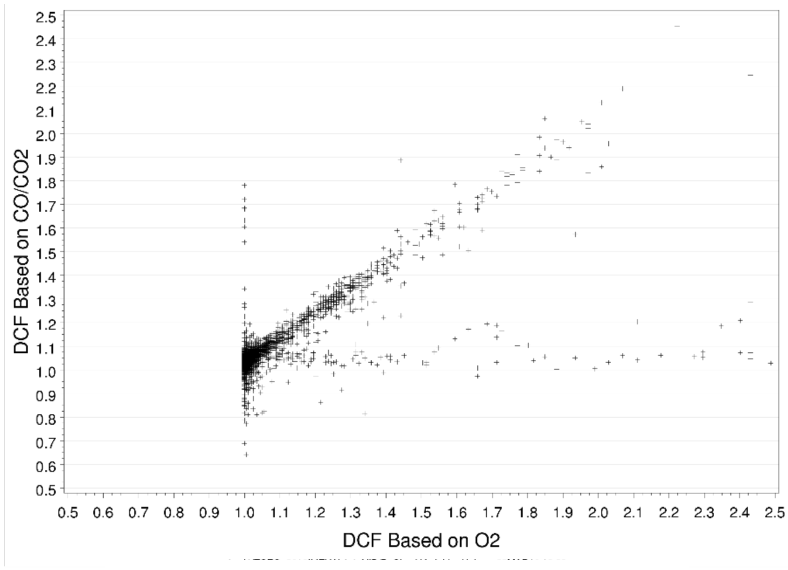


Figure III-29. Comparison of Low-Speed Idle TSI DCF CO/CO_2 and DCF O_2

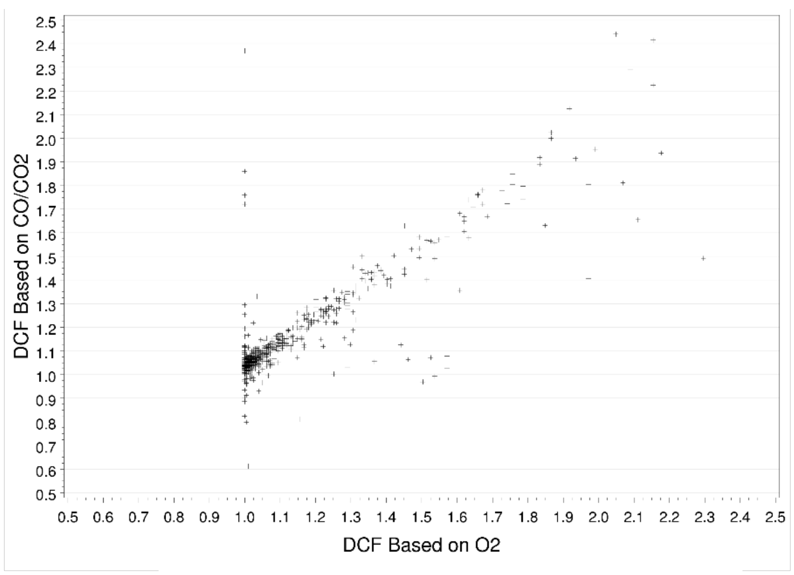
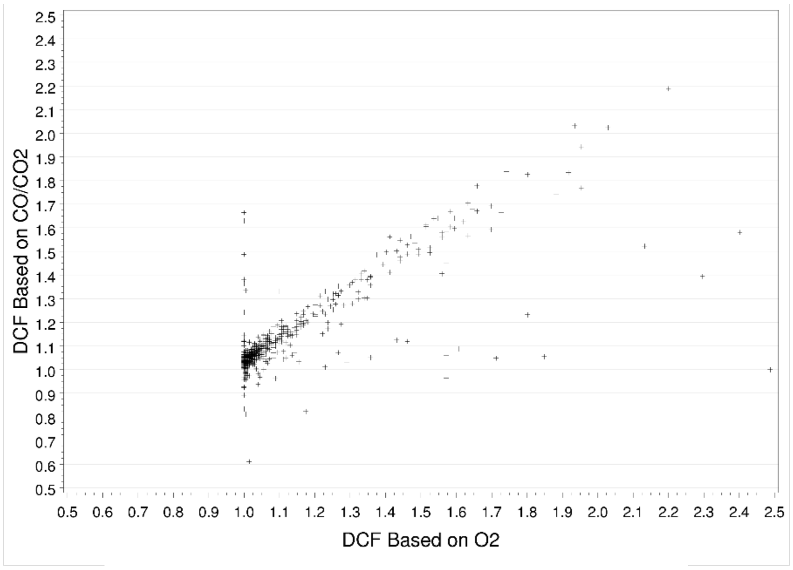


Figure III-30. Comparison of High-Speed Idle TSI DCF CO/CO_2 and DCF O_2



The information presented graphically in Figure III-27 through Figure III-30 is quantified in Table III-7. 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 III-7 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 III-7. Distribution of Differences Between DCFCO/CO_2 and DCFO2

DCF Difference	ASM2525		ASM5015		TSI Low		TSI High	
<0.01	30,756	7.3%	34,988	8.3%	4,668	6.5%	4,156	5.8%
0.01-0.14	332,824	79.0%	327,689	77.8%	55,045	76.5%	56,282	78.1%
0.14-0.3	6,636	1.6%	6,336	1.5%	2,317	3.2%	1,740	2.4%
0.3-1.0	5,541	1.3%	6,004	1.4%	1,280	1.8%	1,212	1.7%
1-10	11,120	2.6%	11,300	2.7%	1,899	2.6%	1,897	2.6%
>10	34,469	8.2%	35,077	8.3%	6,790	9.4%	6,826	9.5%
Total	421,346	100.0%	421,394	100.0%	71,999	100.0%	72,113	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 III-8. 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 III-8 that agreement was very good; more than 98% of records had a difference of less than 0.14.

Table III-8. Distribution of Differences Between ERG DCF CO/CO_2 and TIMS DCF CO/CO_2

DCF Difference	ASM2525		ASM5015	
<0.01	389,717	92.5%	383,839	91.1%
0.01-0.14	26,935	6.4%	32,605	7.7%
0.14-0.3	1,409	0.3%	1428	0.3%
0.3-1.0	771	0.2%	788	0.2%
1-10	825	0.2%	1,005	0.2%
>10	1,689	0.4%	1,729	0.4%
Total	421,346	100.0%	421,394	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 III-9. The ESP and WW rates of differences of less 0.14 are near 92-96%, while the JB and SE rates of differences of less than 0.14 are very low (less than 20%). This is probably due to erroneous O_2 concentrations for these manufacturer's analyzers, as discussed in the following section.

Table III-9. Distribution of Differences Between DCF CO/CO_2 and DCF O_2 by Analyzer Manufacturer, for ASM5015 Inspections

DCF Difference	ESP		JB		SE		WW	
<0.01	26,037	10.2%	0	0.0%	671	1.6%	8,280	6.7%
0.01-0.14	209,246	82.0%	10	1.3%	7,411	17.9%	111,022	89.6%
0.14-0.3	3,461	1.4%	2	0.3%	658	1.6%	2,215	1.8%
0.3-1.0	3,812	1.5%	3	0.4%	1,241	3.0%	948	0.8%
1-10	5,293	2.1%	39	5.0%	5,525	13.3%	443	0.4%
>10	7,476	2.9%	729	93.1%	25,894	62.5%	978	0.8%
Total	255,325	100.0%	783	100.0%	41,400	100.0%	123,886	100.0%

O_2 Emissions Concentration Anomalies

One factor that was found to cause problems with the DCF calculations was inaccuracy in the reported O_2 emissions concentrations. The tailpipe oxygen concentration for stoichiometric combustion and no air in-leakage would be 0.0% O_2, while the ambient air concentration of O_2 is approximately 20.9%. The percent of otherwise-valid inspection records that included O_2 concentrations greater than 20.5% is shown in Table III-10, for each test condition. From the table, 6% of ASM and 8% of TSI records included suspicious O_2 concentrations, with tailpipe exhaust O_2 concentrations very close to or equal to ambient O_2 concentrations. These will cause the O_2-based DCF to have a very high (or undefined, when O_2 equaled exactly 20.9%) value.

Table III-10. Number and Percent of Suspicious O_2 Concentrations by Test Mode

	ASM2525		ASM5015		TSI Low		TSI High	
O_2 >20.5%	6,407	6.3%	26,851	6.4%	5,454	7.6%	5,523	7.7%
O_2 <20.5%	394,941	93.7%	394,545	93.6%	66,552	92.4%	66,598	92.3%
Total	421,348	100.0%	421,396	100.0%	72,006	100.0%	72,121	100.0%

It was also found that the rate of suspicious O_2 concentrations was much higher for the JB and SE analyzer manufacturers than for the other two, as shown in Table III-11. The ESP and WW analyzers were responsible for 90% of inspection records, but only 22% of suspicious O_2 concentrations (6,108 of 26,851 tests with O_2>20.5%).

Table III-11. Number and Percent of Suspicious O_2 Concentrations (O_2 >20.5%), by Analyzer Manufacturer, for ASM5015

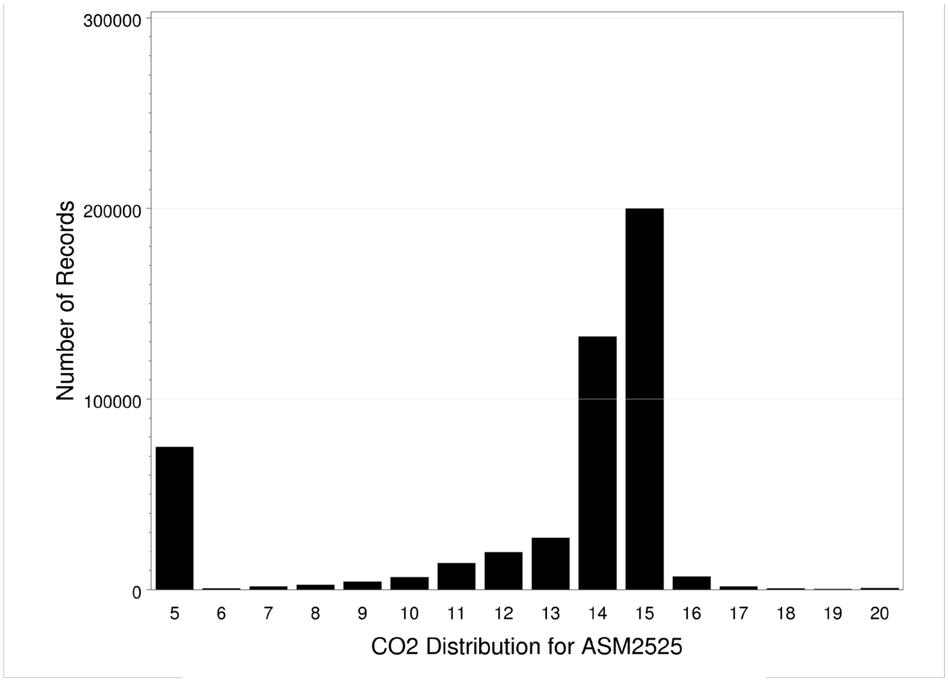
Analyzer Mfg. ID	O_2 >20.5%	O_2 <20.5%	Total
ESP	5,270	250,057	255,327
	2.1 %	97.9%	100.0%
JB	673	110	783
	86.0%	14.0%	100.0%
SE	20,070	21,330	41,400
	48.5%	51.5%	100.0%
WW	838	123,048	123,886
	0.7%	99.3%	100.0%

CO_2 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 CO_2 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 III-31. 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 exceed 16%, for 0.4% of ASM2525 inspection records. These records were investigated further.

Figure III-31. Distribution of CO_2 Values for ASM2525 Inspection



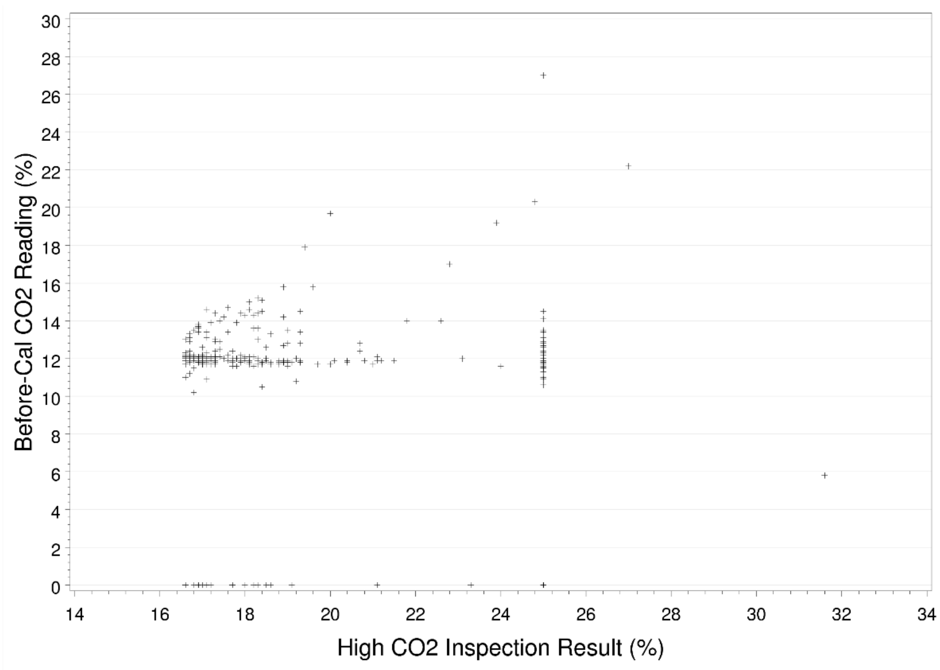
The rate of high CO_2 concentrations was found to vary slightly among the different analyzer manufacturers, as shown in Table III-12, although the differences were not as pronounced as those found for the suspicious O_2 concentrations.

Table III-12. Number and Percent of Suspicious CO_2 Concentrations (CO_2 >16.5%), by Analyzer Manufacturer, for ASM2525

Analyzer Mfg. ID	CO_2 >16.5%	CO_2 <16.5%	Total
ESP	1,727 0.6%	297,918 99.4%	299,645 100.0%
JB	0 0.0%	935 100.0%	935 100.0%
SE	116 0.2%	49,041 99.8%	49,157 100.0%
WW	1,164 0.8%	142,378 99.2%	143,542 100.0%

The high-CO_2 inspection records were matched to calibration records (described in Section III.D) 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 III-32, 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 III-32. 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 DCF 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 Figure III-27 through Figure III-30. For the ASM2525 inspection, 51 records (0.01% of total inspection records) have DCF CO/CO_2 between 0 and 0.55, and 5,224 records have DCF CO/CO_2 between 0.55 and 0.95 (1.2% of total inspection records).

Extra Vertical and Horizontal Rays

It was noted above that Figure III-27 and Figure III-28 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 did not 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 Figure III-33 through Figure III-35.

Figure III-33 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. Figure III-34 and Figure III-35 show that the distributions of CO_2 and CO concentration for the horizontal ray are very similar to the distributions for the diagonal ray.

In contrast, the vertical ray (comprised of records with high DCF CO/CO_2 and DCF O_2 near 1) is characterized by lower CO_2 concentrations (Figure III-34) and similar O_2 concentrations (Figure III-33) compared to the diagonal ray. 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. The CO concentration for records in the vertical ray was similar to that of records in the diagonal ray (Figure III-35). Overall, Figure III-33, Figure III-34, and Figure III-35 indicate the records in each ray were systematically different from the records in each other ray.

Figure III-33. Distribution of O_2 Concentrations, by "Ray"

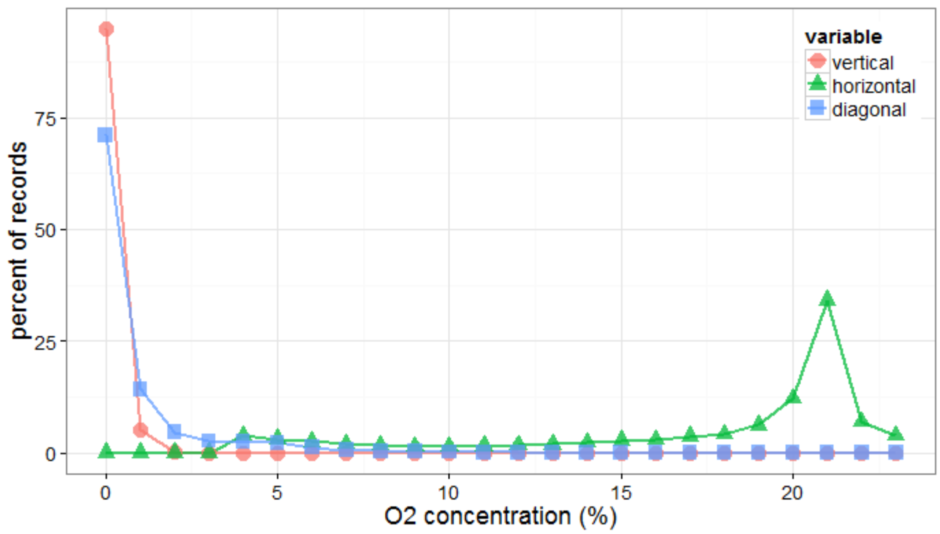


Figure III-34. Distribution of CO_2 Concentrations, by "Ray"

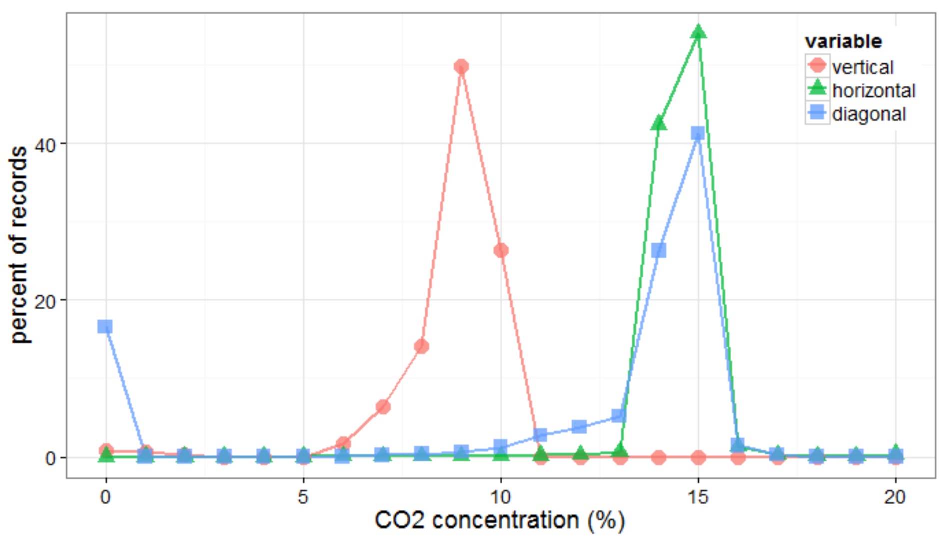
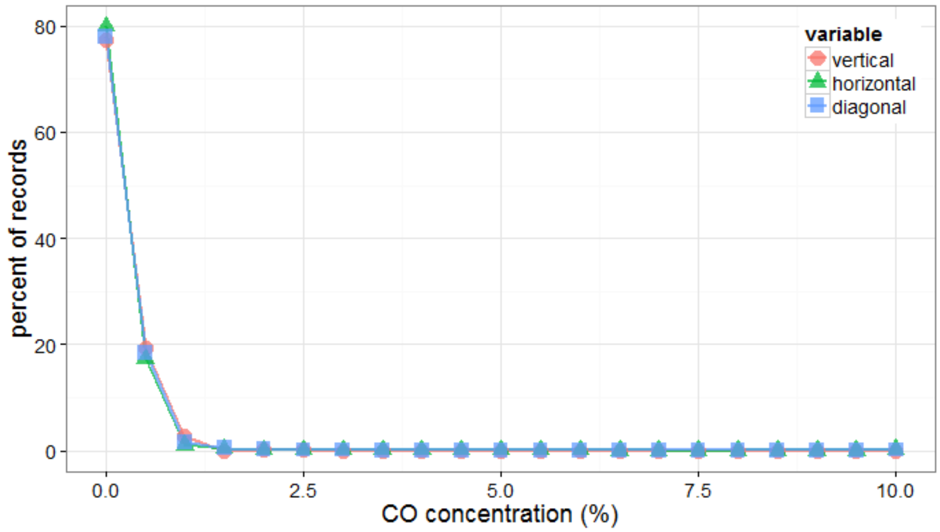


Figure III-35. Distribution of CO Concentrations, by "Ray"



The distribution of records into each ray-group was tabulated by analyzer manufacturer, as shown in Table III-13 below. As expected, the manufacturers represented by codes JB and SE contributed a large portion of the records for the horizontal ray. In Figure III-33 it was seen that this ray includes most of the records with O_2 concentrations near 20.9% (ambient concentration), and in Table III-11 it was seen that the JB and SE manufacturers contributed the majority of the records with the high O_2 concentrations. Table III-13 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 did not 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 III-13. Number and Percent of Records in Each Ray by Analyzer Manufacturer, for ASM2525

Analyzer Mfg. ID	Vertical	Horizontal	Diagonal	Other	Total
ESP	242	10,650	280,301	8,611	299,804
	0.1%	3.6%	93.5%	2.9%	100.0%
JB	0	607	164	164	935
	0.0%	64.9%	17.5%	17.5%	100.0%
SE	57	24,363	16,010	8,732	49,162
	0.1%	49.6%	32.6%	17.8%	100.0%
WW	64	1,394	139,228	2,961	143,647
	0.0%	1.0%	96.9%	2.1%	100.0%

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 III-14 (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 III-14. 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
CO_2 (%)	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 III-15. As can be seen from the table, 1,329 of the 1,809 analyzers, or approximately 74%, received 4 or more audits and 92.5% received 2 or more audits. Some stations may not have been operating the entire period, so it may have been appropriate for them to only receive a few audits. Many of the analyzers received more than four audits; in fact, about a 40% 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 III-15. Number of Gas Audits per Analyzer Over a Two-Year Period

Number of Audits	Number of Analyzers	Percent of Analyzers
1	135	7.5%
2	156	8.6%
3	189	10.4%
4	180	10.0%
5	144	8.0%
6	129	7.1%
7	155	8.6%
8	261	14.4%
More than 8	460	25.4%
Total	1,809	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:

Difference (%) = 100 x [(Reading – Bottle Value) / Bottle Value]

The distribution of percentage differences between readings and bottle gas values is shown in Figure III-36 through Figure III-43 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 III-36. Percent Difference Between Reading and Bottle Gas, Low-Span CO

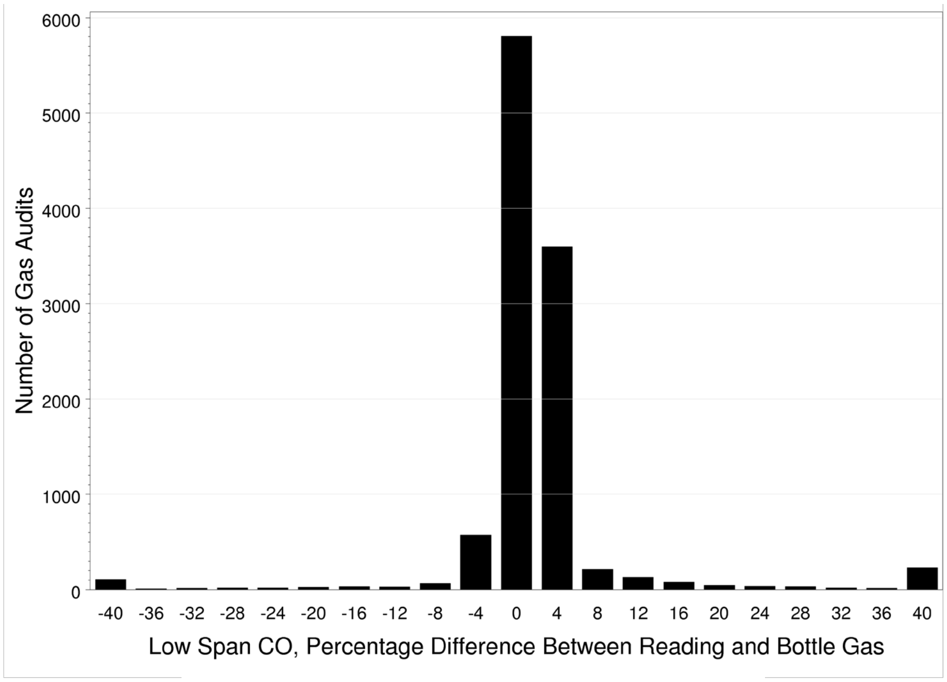


Figure III-37. Percent Difference Between Reading and Bottle Gas, Low-Span HC

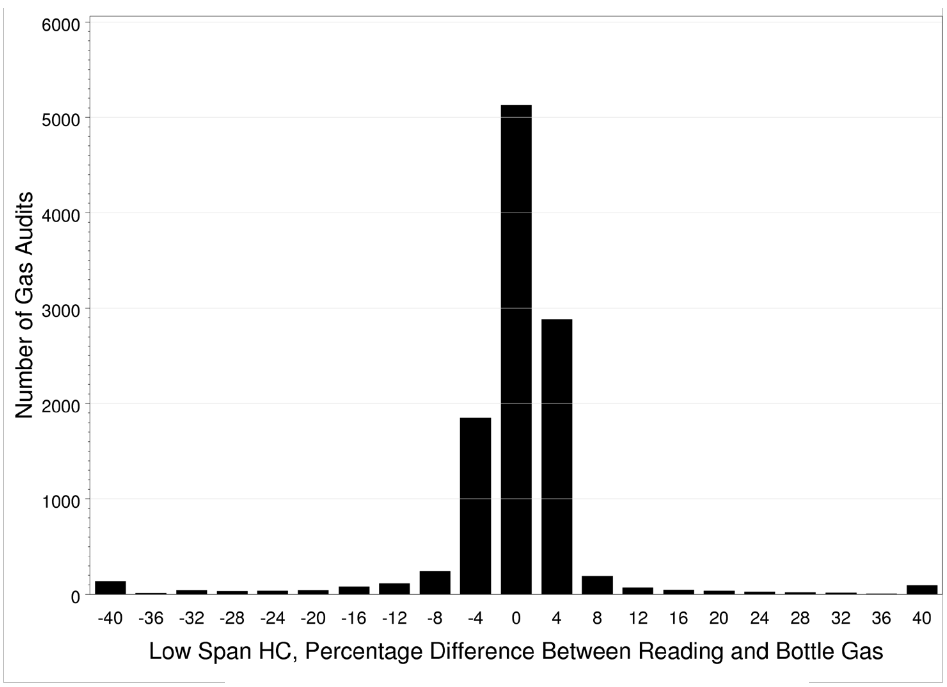


Figure III-38. Percent Difference Between Reading and Bottle Gas, Low-Span CO_2

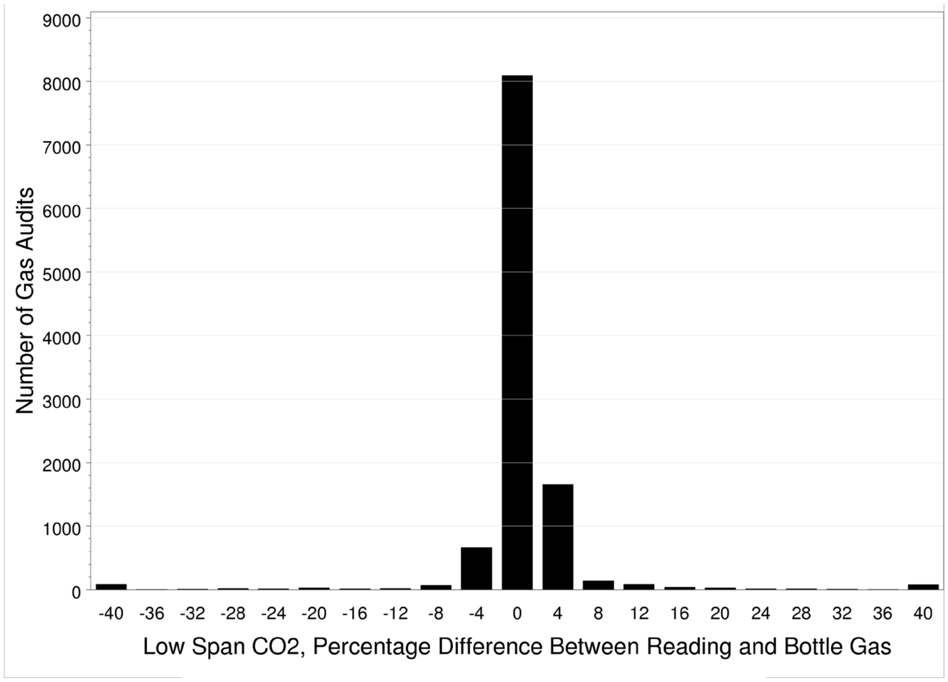


Figure III-39. Percent Difference Between Reading and Bottle Gas, Low-Span NO_x

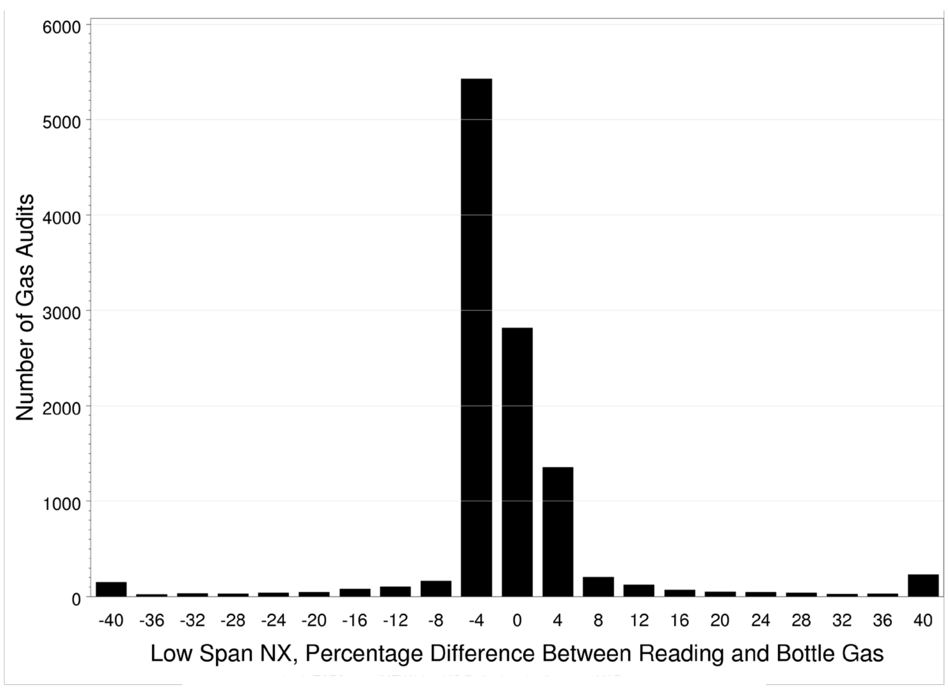


Figure III-40. Percent Difference Between Reading and Bottle Gas, Mid-Span CO

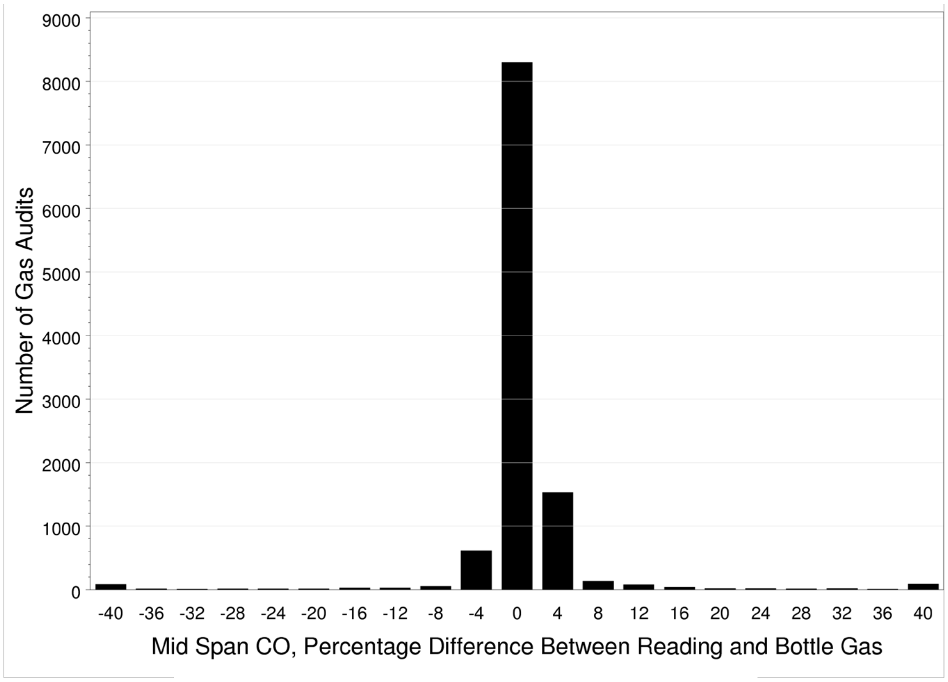


Figure III-41. Percent Difference Between Reading and Bottle Gas, Mid-Span HC

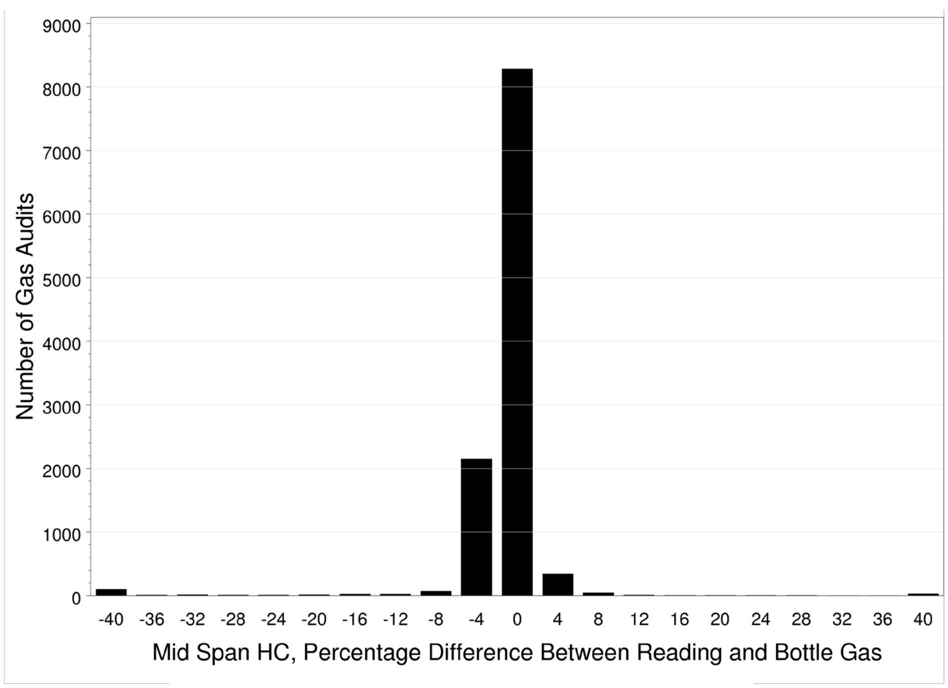


Figure III-42. Percent Difference Between Reading and Bottle Gas, Mid-Span CO_2

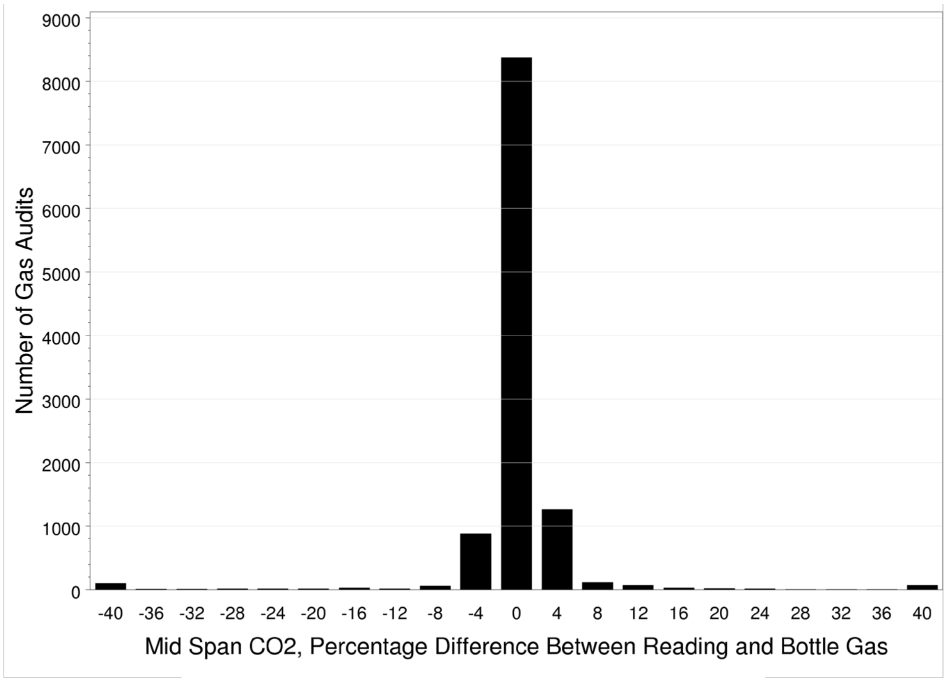


Figure III-43. Percent Difference Between Reading and Bottle Gas, Mid-Span NO_x

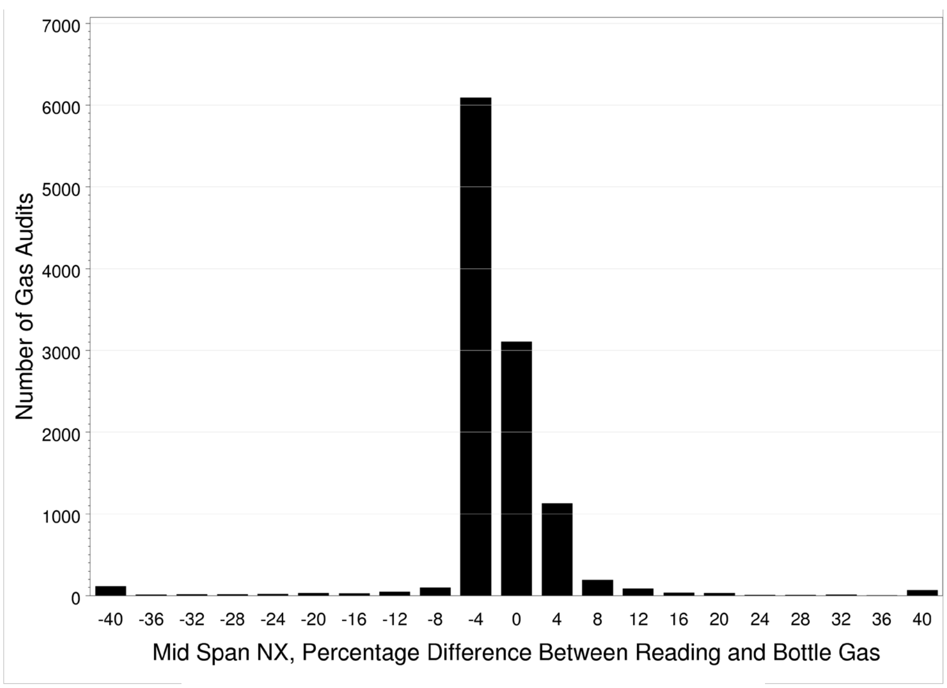


Table III-16 shows pass/fail results for gas audits at the low- and mid- span levels. The table includes the pass/fail results that were recorded in the TIMS, as well pass/fail results calculated by ERG for this analysis (based on the labeled bottle gas value entered in the TIMS, the measured emissions concentration, and a 5.5% tolerance). It can be seen from Table III-16 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 10 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 from the labeled bottle gas value, indicating that the discrepancy is probably caused by a slight difference in the rounding of results.

Table III-16. Span Gas Pass/Fail Results from TIMS Compared to Calculated Results

Calculated Results	TIMS Result			
	Pass	Fail	No Result	Total
Pass	8,333	9	46	8,388
Fail	10	2,660	75	2,745
Comb. Pass & Missing	3	21	2	26
Entirely Missing	-	6	-	6
Total	8,346	2,696	123	11,165

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 36% of cases, an analyzer that failed an audit was calibrated or re-audited and passed within the next 60 minutes. In an additional 7% of cases, the failing analyzer was calibrated or re-audited and passed within 24 hours, and another 36% of failing analyzers were calibrated or re-audited and passed within one week. The remaining 21% 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.

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:

- 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.

- Gas analyzers must pass an internal leak check at least every 72 hours, or they cannot be used for ASM or TSI inspections.
- Dynamometer calibrations must be successfully verified using a coast-down check at least every 72 hours, or they cannot be used for ASM inspections.
- 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 Texas I/M inspection records. Only I/M inspection records for the HGB or DFW program areas in calendar years 2014 or 2015 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 III-17. 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, 7.33% of ASM inspections were performed at times that the dynamometer was overdue for calibration and should have been locked out, and 0.34% of ASM and TSI inspections were performed at times that the analyzer was overdue for calibration and should have been locked out.

Table III-17. 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	1,669	0.34%	492,828
Leak Check	255	0.05%	492,828
Dynamometer Check	30,855	7.33%	420,802

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 III-18. 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 III-18. 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	298,549	99.8%	0	0.0%	498	0.2%	108	0.0%	299,155	100.0%
JB	935	100.0%	0	0.0%	0	0.0%	0	0.0%	935	100.0%
SE	43,036	87.5%	5,970	12.1%	140	0.3%	10	0.0%	49,156	100.0%
WW	117,833	82.1%	24,753	17.2%	733	0.5%	263	0.2%	143,582	100.0%
Total for all analyzers	460,353	93.4%	30,723	6.2%	1371	0.3%	381	0.1%	492,828	100.0%

E. 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 failure 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 the following four subsections.

Eighty-four of the 17,806,461 OBD test records 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. Of these 84 records, 70 had an overall passing result (a "P" in the "OVERALL_RESULTS" field); four had an overall failing result ("F" in the "OVERALL_RESULTS" field); and 10 had a null value in the "OVERALL_RESULTS" field. A small percentage (3.4% or 604,928 records) of OBD test records had vehicle model years earlier than 1996 or later than 2016. There were also 505,387 records for heavy-duty (HD) vehicles or vehicles of unknown GVWR. All these records were excluded from the following results, leaving 16,696,062 OBD records in the dataset.

Communication Rates by Vehicle Model Year - Table III-19 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, 217,765 OBD tests were conducted on model year 1996 vehicles, and only 137 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 very low. In addition, most tests with a “failure to communicate” result were followed by a subsequent test of the same vehicle in which OBD communication was successfully established. The overall program-wide communication rate between vehicles and analyzers, excluding the inspections that were removed from the data set as described in Section III.A, is 99.93%.

Table III-19. 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	166	0.08%	137	0.06%	217,462	99.86%	217,765
1997	162	0.05%	179	0.06%	319,526	99.89%	319,867
1998	178	0.04%	222	0.06%	399,060	99.90%	399,460
1999	243	0.05%	314	0.06%	514,908	99.89%	515,465
2000	319	0.05%	378	0.06%	671,178	99.90%	671,875
2001	375	0.05%	432	0.06%	777,690	99.90%	778,497
2002	345	0.04%	458	0.05%	896,136	99.91%	896,939
2003	385	0.04%	560	0.06%	952,622	99.90%	953,567
2004	377	0.04%	638	0.06%	1,028,790	99.90%	1,029,805
2005	373	0.03%	629	0.06%	1,123,212	99.91%	1,124,214
2006	327	0.03%	595	0.05%	1,213,786	99.92%	1,214,708
2007	291	0.02%	565	0.04%	1,395,807	99.94%	1,396,663
2008	216	0.02%	382	0.03%	1,366,930	99.96%	1,367,528
2009	92	0.01%	258	0.03%	905,044	99.96%	905,394
2010	110	0.01%	227	0.02%	1,082,977	99.97%	1,083,314
2011	125	0.01%	369	0.03%	1,199,614	99.96%	1,200,108
2012	179	0.01%	436	0.03%	1,387,952	99.96%	1,388,567
2013	82	0.01%	321	0.03%	977,496	99.96%	977,899
2014	21	0.01%	85	0.04%	224,906	99.95%	225,012
2015	4	0.01%	10	0.03%	29,401	99.95%	29,415
Total	4,370	0.03%	7,195	0.04%	16,684,497	99.93%	16,696,062

Communication Rates by Equipment Manufacturer –Table III-20 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.

Communication Rates by Vehicle Make - To assess communication rates by vehicle make, vehicle registration records were merged with vehicle test records by VIN. Makes that were represented by 100 or fewer vehicles were removed from the table, since sample sizes would be too small to provide meaningful results.

Table III-21 provides a summary of communication rates among the various vehicle makes. Except for a small number of very uncommon vehicle makes (e.g., Rolls Royce, Ferrari), the incident rates for “damaged, inaccessible, or cannot be found” or “no communication” were very low.

Communication Rates by Vehicle Model - To assess communication rates by vehicle models, the model codes and model names (series) as reported in the vehicle test results tables were used. Table III-22 lists communication rates for each vehicle model code. Records for the more uncommon series, i.e., less than 100 inspection records, were 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, with the exception of three models with small numbers of inspection records (less than 500).

Table III-20. 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	3,325	0.03%	4,892	0.04%	11,217,442	99.93%	11,225,659	67.24%
JB	-	-	9	0.10%	9,075	99.90%	9,084	0.05%
SE	431	0.05%	671	0.08%	800,180	99.86%	801,282	4.80%
WW	614	0.01%	1,623	0.03%	4,657,800	99.95%	4,660,037	27.91%
Total	4,370	0.03%	7,195	0.04%	16,684,497	99.93%	16,696,062	100.00%

Table III-21. 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	44	0.02%	58	0.03%	198,480	99.95%	198,582	1.19%
ASTON MARTIN	1	0.06%	7	0.45%	1,532	99.48%	1,540	0.01%
AUDI	18	0.03%	30	0.04%	70,344	99.93%	70,392	0.42%
BENTLEY	-	0.00%	1	0.04%	2,477	99.96%	2,478	0.01%
BMW	86	0.03%	193	0.06%	310,449	99.91%	310,728	1.86%
BUICK	41	0.02%	92	0.05%	179,135	99.93%	179,268	1.07%
CADILLAC	89	0.04%	159	0.07%	226,355	99.89%	226,603	1.36%
CHEVROLET	841	0.04%	1,208	0.05%	2,220,200	99.91%	2,222,249	13.31%
CHRYSLER	86	0.03%	139	0.04%	318,019	99.93%	318,244	1.91%
DAEWOO	5	0.44%	4	0.35%	1,127	99.21%	1,136	0.01%
DODGE	228	0.03%	387	0.04%	868,107	99.93%	868,722	5.20%
EAGLE	1	0.45%	-	0.00%	220	99.55%	221	0.00%
FERRARI	3	0.17%	1	0.06%	1,814	99.78%	1,818	0.01%
FORD	914	0.04%	1,223	0.05%	2,338,019	99.91%	2,340,156	14.02%
GEO	-	0.00%	5	0.13%	3,897	99.87%	3,902	0.02%
GMC	149	0.04%	221	0.05%	422,910	99.91%	423,280	2.54%
HONDA	177	0.01%	227	0.02%	1,353,741	99.97%	1,354,145	8.11%
HUMMER	3	0.02%	13	0.08%	17,173	99.91%	17,189	0.11%
HYUNDAI	60	0.02%	153	0.04%	361,429	99.94%	361,642	2.17%
INFINITI	16	0.01%	39	0.02%	189,590	99.97%	189,645	1.14%
ISUZU	23	0.06%	32	0.09%	35,716	99.85%	35,771	0.21%
JAGUAR	9	0.02%	20	0.05%	37,080	99.92%	37,109	0.22%
JEEP	66	0.02%	142	0.04%	372,636	99.94%	372,844	2.23%
KIA	28	0.01%	50	0.02%	279,506	99.97%	279,584	1.67%
LAMBORGHINI	-	0.00%	-	0.00%	843	100.00%	843	0.01%
LAND ROVER	10	0.03%	14	0.04%	39,722	99.94%	39,746	0.24%
LEXUS	52	0.01%	125	0.03%	423,745	99.96%	423,922	2.54%
LINCOLN	104	0.07%	118	0.08%	149,983	99.85%	150,205	0.90%
LOTUS	-	0.00%	-	0.00%	534	100.00%	534	0.00%

Table III-21. 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		
MASERATI	1	0.05%	-	0.00%	2,055	99.95%	2,056	0.01%
MAZDA	138	0.04%	264	0.08%	310,984	99.87%	311,386	1.87%
MERCEDES	44	0.02%	73	0.03%	279,934	99.96%	280,051	1.68%
MERCURY	44	0.03%	54	0.04%	128,705	99.92%	128,803	0.77%
MINI	-	0.00%	1	0.03%	3,119	99.97%	3,120	0.02%
MITSUBISHI	80	0.05%	112	0.07%	152,448	99.87%	152,640	0.91%
NISSAN	202	0.02%	341	0.03%	1,080,871	99.95%	1,081,414	6.48%
OLDSMOBILE	15	0.05%	22	0.07%	31,848	99.88%	31,885	0.19%
PLYMOUTH	11	0.08%	4	0.03%	13,408	99.89%	13,423	0.08%
PONTIAC	65	0.03%	89	0.05%	188,785	99.92%	188,939	1.13%
PORSCHE	18	0.05%	65	0.19%	34,643	99.76%	34,726	0.21%
ROLLS ROYCE	1	0.24%	-	0.00%	424	99.76%	425	0.00%
SAAB	8	0.06%	7	0.05%	14,363	99.90%	14,378	0.09%
SATURN	108	0.09%	191	0.16%	121,121	99.75%	121,420	0.73%
SCION	5	0.01%	26	0.04%	70,466	99.96%	70,497	0.42%
SUBARU	15	0.02%	24	0.03%	68,828	99.94%	68,867	0.41%
SUZUKI	12	0.03%	26	0.06%	40,961	99.91%	40,999	0.25%
TOYOTA	223	0.01%	489	0.03%	1,906,188	99.96%	1,906,900	11.42%
VOLKSWAGEN	74	0.03%	122	0.05%	228,858	99.91%	229,054	1.37%
VOLVO	15	0.02%	25	0.03%	88,062	99.95%	88,102	0.53%
OTHER	237	0.02%	599	0.04%	1,493,643	99.94%	1,494,479	8.95%
Total	4370	0.03%	7,195	0.04%	16,684,497	99.93%	16,696,062	100.00%

Table III-22. 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		
16	VAN 20(G20)	1	0.20%	1	0.20%	488	99.59%	490	0.00%
17	VAN 30(G30)	2	0.70%	0	0.00%	283	99.30%	285	0.00%
21	COMM0 VAN-P10/20/30	0	0.00%	1	0.48%	206	99.52%	207	0.00%
88	EIGHTY-EIGHT	0	0.00%	2	0.26%	758	99.74%	760	0.00%
94	RAM 1500 2WD	26	0.02%	71	0.07%	104,892	99.91%	104,989	0.63%
133	F250 SUPERCAB(TRUCK)	3	0.22%	1	0.07%	1,364	99.71%	1,368	0.01%
175	K1500 SIERRA	0	0.00%	0	0.00%	114	100.00%	114	0.00%
180	SIERRA	2	0.03%	3	0.04%	7,498	99.93%	7,503	0.04%
184	VAN 25/2500 G SER0	0	0.00%	1	0.70%	141	99.30%	142	0.00%
185	VAN 35/3500 G SER0	0	0.00%	1	0.90%	110	99.10%	111	0.00%
200	TRACKER	0	0.00%	1	0.03%	3,530	99.97%	3,531	0.02%
230	SLK230 KOMPRESSOR	0	0.00%	0	0.00%	725	100.00%	725	0.00%
231	PICKUP 2WD	1	0.03%	0	0.00%	3,297	99.97%	3,298	0.02%
240	240SX	0	0.00%	0	0.00%	511	100.00%	511	0.00%
254	GRAND CHEROKEE 2WD	3	0.01%	17	0.04%	46,147	99.96%	46,167	0.28%
300	3-SERIES	37	0.03%	75	0.06%	118,966	99.91%	119,078	0.71%
320	S320	0	0.00%	0	0.00%	415	100.00%	415	0.00%
400	LS400	1	0.02%	5	0.09%	5,701	99.89%	5,707	0.03%
420	S420	0	0.00%	0	0.00%	196	100.00%	196	0.00%
500	5-SERIES	7	0.03%	11	0.04%	24,911	99.93%	24,929	0.15%
528	528I	0	0.00%	0	0.00%	189	100.00%	189	0.00%
550	550	7	1.94%	0	0.00%	353	98.06%	360	0.00%
600	6-SERIES	1	0.04%	2	0.07%	2,804	99.89%	2,807	0.02%
626	626	15	0.12%	12	0.09%	12,896	99.79%	12,923	0.08%
700	7-SERIES	2	0.04%	6	0.13%	4,603	99.83%	4,611	0.03%
820	G3500	0	0.00%	1	0.70%	142	99.30%	143	0.00%
850	850	1	0.09%	0	0.00%	1,061	99.91%	1,062	0.01%
900	900	0	0.00%	0	0.00%	307	100.00%	307	0.00%
911	911	0	0.00%	0	0.00%	643	100.00%	643	0.00%

Table III-22. 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		
960	960	2	0.29%	1	0.14%	690	99.57%	693	0.00%
22C	202CL	0	0.00%	0	0.00%	274	100.00%	274	0.00%
23C	203CL	0	0.00%	2	0.58%	340	99.42%	342	0.00%
25T	205TL	2	0.53%	2	0.53%	376	98.95%	380	0.00%
28i	328I	0	0.00%	0	0.00%	601	100.00%	601	0.00%
30C	300CL	0	0.00%	1	0.13%	787	99.87%	788	0.00%
32i	325I	0	0.00%	0	0.00%	208	100.00%	208	0.00%
32T	302TL	2	0.03%	1	0.01%	7,041	99.96%	7,044	0.04%
35R	305RL	0	0.00%	2	0.10%	2,003	99.90%	2,005	0.01%
3GT	3000 GT	0	0.00%	1	0.14%	731	99.86%	732	0.00%
4RN	4RUNNER 2WD	3	0.01%	12	0.03%	44,489	99.97%	44,504	0.27%
74i	740I	0	0.00%	1	0.72%	137	99.28%	138	0.00%
75l	750I	0	0.00%	0	0.00%	241	100.00%	241	0.00%
85F	850	1	0.17%	1	0.17%	570	99.65%	572	0.00%
AA4	A4	12	0.06%	17	0.09%	19,875	99.85%	19,904	0.12%
AA6	A6	1	0.03%	4	0.13%	3,193	99.84%	3,198	0.02%
AA8	A8	0	0.00%	0	0.00%	2,553	100.00%	2,553	0.02%
ACC	ACCORD	39	0.01%	57	0.02%	315,053	99.97%	315,149	1.89%
ACV	ACHIEVA	0	0.00%	0	0.00%	421	100.00%	421	0.00%
AER	AEROSTAR	0	0.00%	0	0.00%	531	100.00%	531	0.00%
ALO	ALERO	3	0.02%	11	0.09%	12,228	99.89%	12,242	0.07%
ALT	ALTIMA	60	0.02%	125	0.04%	303,281	99.94%	303,466	1.82%
AMG	AMIGO	0	0.00%	0	0.00%	270	100.00%	270	0.00%
AQ5	Q5	0	0.00%	0	0.00%	259	100.00%	259	0.00%
ARL	RL	1	0.04%	1	0.04%	2,488	99.92%	2,490	0.01%
ARN	ARNAGE	0	0.00%	0	0.00%	212	100.00%	212	0.00%
AS4	S4	0	0.00%	1	0.05%	2,133	99.95%	2,134	0.01%
AS6	S6	0	0.00%	0	0.00%	251	100.00%	251	0.00%
ASP	ASPEN	1	0.05%	0	0.00%	2,205	99.95%	2,206	0.01%

Table III-22. 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		
AST	ASTRO 2WD	4	0.05%	8	0.10%	8,349	99.86%	8,361	0.05%
ATL	TL	1	0.00%	3	0.01%	34,931	99.99%	34,935	0.21%
AUR	AURORA	1	0.05%	2	0.10%	2,023	99.85%	2,026	0.01%
AVA	AVALON	18	0.02%	25	0.03%	78,761	99.95%	78,804	0.47%
AVN	AVENGER	5	0.01%	15	0.04%	34,943	99.94%	34,963	0.21%
B23	B2300	0	0.00%	0	0.00%	326	100.00%	326	0.00%
BEE	NEW BEETLE	3	0.03%	7	0.06%	11,090	99.91%	11,100	0.07%
BER	BERETTA	0	0.00%	0	0.00%	122	100.00%	122	0.00%
BLZ	BLAZER 2WD	8	0.05%	8	0.05%	17,527	99.91%	17,543	0.11%
BON	BONNEVILLE	2	0.03%	3	0.05%	5,964	99.92%	5,969	0.04%
BOX	BOXSTER	4	0.07%	6	0.10%	6,007	99.83%	6,017	0.04%
BRO	BRONCO	0	0.00%	0	0.00%	330	100.00%	330	0.00%
BRZ	BREEZE	0	0.00%	0	0.00%	1,528	100.00%	1,528	0.01%
BUG	BEETLE	0	0.00%	0	0.00%	187	100.00%	187	0.00%
BVD	BRAVADA	0	0.00%	1	0.12%	825	99.88%	826	0.00%
C15	C1500	69	0.03%	141	0.07%	213,548	99.90%	213,758	1.28%
C22	C220	1	0.28%	0	0.00%	354	99.72%	355	0.00%
C23	C230	3	0.02%	17	0.13%	13,421	99.85%	13,441	0.08%
C25	C/K 2500 (C/K/R20)	13	0.18%	13	0.18%	7,145	99.64%	7,171	0.04%
C28	C280	2	0.05%	7	0.18%	3,796	99.76%	3,805	0.02%
C35	C/K 3500 (C/K/R30)	2	0.14%	2	0.14%	1,381	99.71%	1,385	0.01%
C70	C70	0	0.00%	1	0.02%	4,276	99.98%	4,277	0.03%
CAB	CABRIO	2	0.13%	1	0.07%	1,526	99.80%	1,529	0.01%
CAM	CAMRY	61	0.01%	153	0.03%	500,128	99.96%	500,342	3.00%
CAP	CAPRICE	0	0.00%	1	0.09%	1,166	99.91%	1,167	0.01%
CAR	911 CARRERA 2	3	0.12%	5	0.20%	2,538	99.69%	2,546	0.02%
CAT	CATERA	1	0.10%	0	0.00%	985	99.90%	986	0.01%
CAV	CAVALIER	33	0.06%	44	0.09%	51,232	99.85%	51,309	0.31%
CEN	CENTURY	5	0.02%	9	0.03%	26,604	99.95%	26,618	0.16%

Table III-22. 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		
CHA	CHARGER	9	0.01%	20	0.03%	79,232	99.96%	79,261	0.47%
CHL	CHALLENGER	2	0.01%	6	0.03%	22,552	99.96%	22,560	0.14%
CI1	DEL SOL	0	0.00%	0	0.00%	326	100.00%	326	0.00%
CIE	CIERA	0	0.00%	0	0.00%	314	100.00%	314	0.00%
CIR	CIRRUS	1	0.07%	1	0.07%	1,385	99.86%	1,387	0.01%
CIV	CIVIC	52	0.01%	61	0.02%	346,606	99.97%	346,719	2.08%
CL3	CLK320	1	0.06%	0	0.00%	1,709	99.94%	1,710	0.01%
CL4	CLK430	1	0.05%	0	0.00%	2,059	99.95%	2,060	0.01%
CL5	CL500	0	0.00%	0	0.00%	457	100.00%	457	0.00%
CNC	CONCORDE	7	0.14%	7	0.14%	5,018	99.72%	5,032	0.03%
CNT	CONTOUR	3	0.06%	6	0.13%	4,775	99.81%	4,784	0.03%
COA	COROLLA	32	0.01%	73	0.02%	332,856	99.97%	332,961	1.99%
CON	CONTINENTAL	1	0.02%	2	0.04%	4,703	99.94%	4,706	0.03%
COU	COUGAR	4	0.07%	4	0.07%	5,643	99.86%	5,651	0.03%
CRS	CORSICA	0	0.00%	0	0.00%	469	100.00%	469	0.00%
CRV	CR-V	6	0.01%	7	0.01%	52,652	99.98%	52,665	0.32%
CST	CELICA	3	0.03%	8	0.08%	10,617	99.90%	10,628	0.06%
CUT	CUTLASS	1	0.06%	1	0.06%	1,800	99.89%	1,802	0.01%
CVC	CROWN VICTORIA	16	0.04%	32	0.08%	40,572	99.88%	40,620	0.24%
CVN	CARAVAN 2WD	14	0.04%	46	0.12%	39,245	99.85%	39,305	0.24%
CVT	CORVETTE	7	0.02%	16	0.04%	41,464	99.94%	41,487	0.25%
CW2	CLUB WAGON E250	0	0.00%	0	0.00%	343	100.00%	343	0.00%
CW3	CLUB WAGON E350	1	0.41%	0	0.00%	240	99.59%	241	0.00%
DAK	DAKOTA 2WD	2	0.01%	7	0.04%	15,806	99.94%	15,815	0.09%
DAR	DART	0	0.00%	0	0.00%	448	100.00%	448	0.00%
DEN	DENALI	1	0.20%	1	0.20%	486	99.59%	488	0.00%
DEV	DEVILLE	17	0.05%	17	0.05%	32,625	99.90%	32,659	0.20%
DIA	DIAMANTE	2	0.06%	2	0.06%	3,126	99.87%	3,130	0.02%
DIS	DISCOVERY	1	0.06%	0	0.00%	1,791	99.94%	1,792	0.01%

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		Count	Percent	Count	Percent	Count	Percent		
DLT	DELTA 88	0	0.00%	0	0.00%	457	100.00%	457	0.00%
DUR	DURANGO 2WD	10	0.04%	13	0.06%	23,505	99.90%	23,528	0.14%
E32	E320	9	0.05%	3	0.02%	16,800	99.93%	16,812	0.10%
E42	E420	0	0.00%	0	0.00%	884	100.00%	884	0.01%
E43	E430	1	0.07%	0	0.00%	1,434	99.93%	1,435	0.01%
E50	E500	0	0.00%	0	0.00%	1,087	100.00%	1,087	0.01%
E55	E55 AMG	0	0.00%	0	0.00%	278	100.00%	278	0.00%
EC2	ECONOLINE E250	4	0.15%	3	0.11%	2,619	99.73%	2,626	0.02%
EC3	ECONOLINE E350	3	0.27%	1	0.09%	1,095	99.64%	1,099	0.01%
ECH	ECHO	0	0.00%	3	0.06%	4,641	99.94%	4,644	0.03%
ECL	ECLIPSE	24	0.09%	34	0.13%	27,057	99.79%	27,115	0.16%
ELD	ELDORADO	2	0.07%	1	0.04%	2,737	99.89%	2,740	0.02%
ELN	ELANTRA	20	0.02%	25	0.03%	87,577	99.95%	87,622	0.52%
EPD	EXPEDITION	44	0.06%	43	0.06%	76,563	99.89%	76,650	0.46%
ES1	ESTEEM	0	0.00%	0	0.00%	385	100.00%	385	0.00%
ESC	ESCORT	11	0.04%	11	0.04%	30,175	99.93%	30,197	0.18%
EST	ESTEEM	0	0.00%	2	0.32%	618	99.68%	620	0.00%
EUR	EUROVAN	0	0.00%	0	0.00%	123	100.00%	123	0.00%
EXC	EXCURSION	0	0.00%	1	0.22%	447	99.78%	448	0.00%
	F150 2WD	426	0.01%	1,158	0.04%	3,162,040	99.95%	3,163,624	18.95%
F15	F150 REG CAB LONG	19	0.03%	11	0.01%	73,981	99.96%	74,011	0.44%
F25	F250	26	0.87%	4	0.13%	2,950	98.99%	2,980	0.02%
F35	F350	6	1.23%	4	0.82%	479	97.96%	489	0.00%
FBD	FIREBIRD	5	0.06%	3	0.03%	8,938	99.91%	8,946	0.05%
FI1	FIESTA	2	0.02%	3	0.02%	12,776	99.96%	12,781	0.08%
FLE	FLEETWOOD	0	0.00%	2	0.50%	395	99.50%	397	0.00%
FOC	FOCUS	11	0.01%	16	0.02%	79,659	99.97%	79,686	0.48%
FOR	FORESTER	0	0.00%	1	0.02%	4,552	99.98%	4,553	0.03%
FRT	FRONTIER 2WD	3	0.01%	14	0.05%	30,515	99.94%	30,532	0.18%

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		Count	Percent	Count	Percent	Count	Percent		
G15	G15	0	0.00%	0	0.00%	352	100.00%	352	0.00%
G20	G20	2	0.06%	0	0.00%	3,191	99.94%	3,193	0.02%
G35	G35	1	0.01%	7	0.04%	16,913	99.95%	16,921	0.10%
GAL	GALANT	38	0.09%	45	0.11%	40,591	99.80%	40,674	0.24%
GCK	GRAND CHEROKEE	5	0.11%	3	0.07%	4,532	99.82%	4,540	0.03%
GOL	GOLF	3	0.06%	6	0.11%	5,323	99.83%	5,332	0.03%
GRA	GRAND PRIX	20	0.05%	19	0.05%	38,277	99.90%	38,316	0.23%
GRM	GRAND AM	8	0.03%	11	0.04%	29,628	99.94%	29,647	0.18%
GS3	GS300	2	0.01%	5	0.03%	16,821	99.96%	16,828	0.10%
GS4	GS400	0	0.00%	0	0.00%	1,654	100.00%	1,654	0.01%
GT	GT	1	0.40%	0	0.00%	252	99.60%	253	0.00%
GTI	GTI	2	0.02%	6	0.05%	11,008	99.93%	11,016	0.07%
GTO	GTO	0	0.00%	2	0.07%	2,896	99.93%	2,898	0.02%
GVT	GRAND VITARA	4	0.12%	8	0.23%	3,407	99.65%	3,419	0.02%
hom	HOMBRE	0	0.00%	0	0.00%	646	100.00%	646	0.00%
HOM	HOMBRE 2WD	0	0.00%	0	0.00%	121	100.00%	121	0.00%
HUM	HUMMER	0	0.00%	0	0.00%	216	100.00%	216	0.00%
I30	I30	3	0.03%	3	0.03%	10,344	99.94%	10,350	0.06%
IMP	IMPALA	33	0.02%	45	0.02%	186,310	99.96%	186,388	1.12%
INT	INTREPID	15	0.09%	18	0.10%	17,536	99.81%	17,569	0.11%
J30	J30	0	0.00%	0	0.00%	785	100.00%	785	0.00%
JET	JETTA	31	0.03%	44	0.04%	98,697	99.92%	98,772	0.59%
JMY	JIMMY	2	0.08%	1	0.04%	2,440	99.88%	2,443	0.01%
L45	LX450	0	0.00%	0	0.00%	197	100.00%	197	0.00%
L47	LX470	1	0.06%	0	0.00%	1,746	99.94%	1,747	0.01%
LAN	LANCER	5	0.02%	8	0.03%	24,337	99.95%	24,350	0.15%
LCR	LAND CRUISER	0	0.00%	0	0.00%	2,590	100.00%	2,590	0.02%
LEG	LEGACY	6	0.06%	10	0.09%	10,628	99.85%	10,644	0.06%
LES	LESABRE	6	0.05%	11	0.08%	12,972	99.87%	12,989	0.08%

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		Count	Percent	Count	Percent	Count	Percent		
LHS	LHS	0	0.00%	1	0.06%	1,632	99.94%	1,633	0.01%
LIM	LIMOUSINE	0	0.00%	0	0.00%	214	100.00%	214	0.00%
LS6	LS	4	0.05%	4	0.05%	7,781	99.90%	7,789	0.05%
LSS	LSS	0	0.00%	2	0.84%	237	99.16%	239	0.00%
LUM	LUMINA	4	0.04%	3	0.03%	10,313	99.93%	10,320	0.06%
M3	M3	1	0.02%	12	0.18%	6,547	99.80%	6,560	0.04%
M5	M5	4	0.22%	3	0.16%	1,819	99.62%	1,826	0.01%
M6	M6	0	0.00%	0	0.00%	951	100.00%	951	0.01%
MAG	MAGNUM	1	0.01%	2	0.03%	7,892	99.96%	7,895	0.05%
MAL	MALIBU	41	0.03%	43	0.03%	158,948	99.95%	159,032	0.95%
MAR	GRAND MARQUIS	7	0.04%	1	0.01%	18,812	99.96%	18,820	0.11%
MAU	MARAUDER	0	0.00%	0	0.00%	455	100.00%	455	0.00%
MAX	MAXIMA	20	0.02%	35	0.03%	100,072	99.95%	100,127	0.60%
MET	METRO	0	0.00%	0	0.00%	1,234	100.00%	1,234	0.01%
MGO	MONTEGO	0	0.00%	0	0.00%	3,261	100.00%	3,261	0.02%
MIA	MIATA	5	0.04%	8	0.06%	12,906	99.90%	12,919	0.08%
MIL	MILLENIA	2	0.07%	1	0.03%	2,861	99.90%	2,864	0.02%
MIR	MIRAGE	1	0.02%	0	0.00%	6,322	99.98%	6,323	0.04%
MK8	MARK VIII	0	0.00%	0	0.00%	193	100.00%	193	0.00%
ML3	ML320	0	0.00%	1	0.05%	2,107	99.95%	2,108	0.01%
ML4	ML430	0	0.00%	0	0.00%	478	100.00%	478	0.00%
MOC	MONTE CARLO	5	0.03%	6	0.04%	16,992	99.94%	17,003	0.10%
MON	MONTERO SPORT	0	0.00%	3	0.04%	6,778	99.96%	6,781	0.04%
MPV	MPV	5	0.13%	13	0.34%	3,808	99.53%	3,826	0.02%
MR2	MR2	1	0.06%	2	0.13%	1,558	99.81%	1,561	0.01%
MTA	MONTANA FWD	0	0.00%	4	0.16%	2,548	99.84%	2,552	0.02%
MTN	MOUNTAINEER	1	0.03%	1	0.03%	3,159	99.94%	3,161	0.02%
MUS	MUSTANG	34	0.02%	53	0.03%	157,747	99.94%	157,834	0.95%
MYS	MYSTIQUE	1	0.07%	0	0.00%	1,418	99.93%	1,419	0.01%

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NAV	NAVIGATOR	20	0.07%	22	0.07%	30,003	99.86%	30,045	0.18%
NEO	NEON	10	0.03%	18	0.06%	30,703	99.91%	30,731	0.18%
NSX	NSX	0	0.00%	0	0.00%	204	100.00%	204	0.00%
NUB	NUBIRA	0	0.00%	0	0.00%	265	100.00%	265	0.00%
OAS	OASIS	0	0.00%	0	0.00%	105	100.00%	105	0.00%
ODY	ODYSSEY	4	0.01%	12	0.03%	41,662	99.96%	41,678	0.25%
PAS	PASSAT	22	0.05%	33	0.08%	43,454	99.87%	43,509	0.26%
PAV	PARK AVENUE	1	0.03%	5	0.15%	3,405	99.82%	3,411	0.02%
PHA	PHANTOM	0	0.00%	0	0.00%	105	100.00%	105	0.00%
PRE	PRELUDE	1	0.02%	0	0.00%	4,677	99.98%	4,678	0.03%
PRI	PRIUS	3	0.01%	15	0.03%	53,496	99.97%	53,514	0.32%
PRO	PROTEGE	26	0.12%	41	0.18%	22,097	99.70%	22,164	0.13%
PRV	PREVIA	0	0.00%	0	0.00%	107	100.00%	107	0.00%
PRW	PROWLER	0	0.00%	0	0.00%	211	100.00%	211	0.00%
PTH	PATHFINDER 2WD	3	0.01%	10	0.05%	21,125	99.94%	21,138	0.13%
Q45	Q45	1	0.03%	0	0.00%	3,447	99.97%	3,448	0.02%
QST	QUEST	2	0.02%	3	0.03%	9,330	99.95%	9,335	0.06%
QTO	A4 QUATTRO	0	0.00%	2	0.03%	6,219	99.97%	6,221	0.04%
QUA	QUATTROPORTE	0	0.00%	0	0.00%	855	100.00%	855	0.01%
QX4	QX4	0	0.00%	0	0.00%	596	100.00%	596	0.00%
QXA	QX4	0	0.00%	0	0.00%	1,773	100.00%	1,773	0.01%
R25	RAM 2500 PU (D250)	2	0.20%	0	0.00%	994	99.80%	996	0.01%
RAB	RABBIT	0	0.00%	1	0.02%	4,822	99.98%	4,823	0.03%
RAV	RAV4 2WD	1	0.00%	7	0.02%	33,366	99.98%	33,374	0.20%
REG	REGAL	2	0.01%	5	0.03%	15,104	99.95%	15,111	0.09%
RIV	RIVIERA	0	0.00%	0	0.00%	778	100.00%	778	0.00%
RNG	RANGER REG CAB SHORT	4	0.02%	1	0.00%	23,006	99.98%	23,011	0.14%
ROA	ROADMASTER	0	0.00%	0	0.00%	480	100.00%	480	0.00%
ROD	RODEO 2WD	2	0.03%	4	0.06%	7,165	99.92%	7,171	0.04%

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RRV	RANGE ROVER	3	0.04%	6	0.09%	6,925	99.87%	6,934	0.04%
RST	M ROADSTER	0	0.00%	1	0.70%	141	99.30%	142	0.00%
RX3	RX300 2WD	1	0.01%	3	0.04%	7,632	99.95%	7,636	0.05%
S10	S10 2WD	6	0.04%	5	0.03%	15,479	99.93%	15,490	0.09%
S20	S2000	1	0.03%	1	0.03%	3,512	99.94%	3,514	0.02%
S30	SC300	0	0.00%	0	0.00%	939	100.00%	939	0.01%
S40	S40	4	0.04%	3	0.03%	9,267	99.92%	9,274	0.06%
S70	S70	2	0.05%	4	0.09%	4,245	99.86%	4,251	0.03%
S80	S80	1	0.01%	1	0.01%	8,773	99.98%	8,775	0.05%
S90	S90	0	0.00%	3	0.61%	487	99.39%	490	0.00%
SAB	SABLE	5	0.03%	5	0.03%	15,219	99.93%	15,229	0.09%
SAF	SAFARI	0	0.00%	1	0.05%	1,901	99.95%	1,902	0.01%
SAV	G1500 SAVANA	2	0.18%	0	0.00%	1,103	99.82%	1,105	0.01%
SC	SC	12	0.19%	14	0.22%	6,458	99.60%	6,484	0.04%
SDK	SIDEKICK	0	0.00%	0	0.00%	142	100.00%	142	0.00%
SEB	SEBRING	15	0.03%	26	0.06%	43,453	99.91%	43,494	0.26%
SEN	SENTRA	37	0.03%	42	0.03%	128,912	99.94%	128,991	0.77%
SEP	SEPHIA	2	0.09%	0	0.00%	2,189	99.91%	2,191	0.01%
SEV	SEVILLE	3	0.06%	2	0.04%	4,772	99.90%	4,777	0.03%
SIL	SILHOUETTE	0	0.00%	1	0.08%	1,329	99.92%	1,330	0.01%
SKY	SKYLARK	0	0.00%	0	0.00%	583	100.00%	583	0.00%
SL	SL	32	0.18%	71	0.40%	17,677	99.42%	17,780	0.11%
SL5	SL500	0	0.00%	1	0.03%	3,721	99.97%	3,722	0.02%
SL6	SL600	0	0.00%	0	0.00%	278	100.00%	278	0.00%
SNA	SIENNA	5	0.01%	9	0.03%	35,089	99.96%	35,103	0.21%
SNF	SUNFIRE	11	0.08%	6	0.05%	13,129	99.87%	13,146	0.08%
SOL	SOLARA	0	0.00%	1	0.21%	466	99.79%	467	0.00%
SON	SONATA	20	0.02%	67	0.06%	110,269	99.92%	110,356	0.66%
SPT	OUTBACK	0	0.00%	5	0.04%	12,881	99.96%	12,886	0.08%

Table III-22. 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		
SSE	S SERIES	1	0.62%	0	0.00%	160	99.38%	161	0.00%
STA	STRATUS	15	0.06%	18	0.07%	25,489	99.87%	25,522	0.15%
STS	STS	0	0.00%	1	0.03%	2,963	99.97%	2,964	0.02%
SUB	SUBURBAN	12	0.08%	12	0.08%	15,462	99.85%	15,486	0.09%
SUP	SUPRA	0	0.00%	2	1.11%	178	98.89%	180	0.00%
SW	SW	10	0.97%	4	0.39%	1,013	98.64%	1,027	0.01%
T10	T100	0	0.00%	1	0.08%	1,277	99.92%	1,278	0.01%
TAC	TACOMA 2WD	2	0.00%	11	0.02%	57,475	99.98%	57,488	0.34%
TAH	TAHOE	15	0.02%	51	0.06%	87,817	99.92%	87,883	0.53%
TAL	TALON	1	0.60%	0	0.00%	166	99.40%	167	0.00%
TAM	TRANS AM	0	0.00%	0	0.00%	139	100.00%	139	0.00%
TAU	TAURUS	17	0.02%	28	0.03%	99,603	99.95%	99,648	0.60%
TC	TC	1	0.01%	3	0.03%	11,713	99.97%	11,717	0.07%
TER	TERCEL	1	0.05%	0	0.00%	1,911	99.95%	1,912	0.01%
THU	THUNDERBIRD	3	0.05%	5	0.08%	6,395	99.88%	6,403	0.04%
TIB	TIBURON	5	0.05%	10	0.09%	10,815	99.86%	10,830	0.06%
TL	TL	1	0.07%	1	0.07%	1,356	99.85%	1,358	0.01%
TOW	TOWN CAR	52	0.07%	69	0.09%	76,763	99.84%	76,884	0.46%
TRA	TRACER	0	0.00%	1	0.10%	1,043	99.90%	1,044	0.01%
TRP	TROOPER 2WD	1	0.06%	2	0.13%	1,577	99.81%	1,580	0.01%
TSP	TRANS SPORT	0	0.00%	1	0.29%	348	99.71%	349	0.00%
TUN	TUNDRA 2WD	3	0.01%	10	0.02%	54,957	99.98%	54,970	0.33%
V15	RAM 1500	3	0.03%	5	0.04%	11,372	99.93%	11,380	0.07%
V25	RAM 2500	0	0.00%	0	0.00%	821	100.00%	821	0.00%
V35	RAM 3500 VAN (B350)	0	0.00%	0	0.00%	128	100.00%	128	0.00%
V40	V40	0	0.00%	0	0.00%	287	100.00%	287	0.00%
V70	V70	0	0.00%	2	0.08%	2,597	99.92%	2,599	0.02%
VAN	VANDEN PLAS	0	0.00%	7	0.46%	1,509	99.54%	1,516	0.01%
VEN	VENTURE	0	0.00%	1	0.09%	1,146	99.91%	1,147	0.01%

Table III-22. 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		
VGR	VILLAGER	1	0.05%	0	0.00%	1,842	99.95%	1,843	0.01%
VIP	VIPER	1	0.07%	2	0.15%	1,343	99.78%	1,346	0.01%
VIT	VITARA	0	0.00%	0	0.00%	510	100.00%	510	0.00%
VOY	VOYAGER	3	0.09%	1	0.03%	3,268	99.88%	3,272	0.02%
WIN	WINDSTAR	0	0.00%	3	0.03%	8,868	99.97%	8,871	0.05%
WRG	WRANGLER	10	0.04%	13	0.05%	27,530	99.92%	27,553	0.17%
XJ	XJ	0	0.00%	0	0.00%	287	100.00%	287	0.00%
XJ6	XJ6	0	0.00%	1	0.13%	742	99.87%	743	0.00%
XJ8	XJ8	5	0.09%	4	0.07%	5,380	99.83%	5,389	0.03%
XJR	XJR	1	0.11%	0	0.00%	878	99.89%	879	0.01%
XJS	XJS	0	0.00%	0	0.00%	101	100.00%	101	0.00%
XK	XK	0	0.00%	1	0.07%	1,393	99.93%	1,394	0.01%
XK8	XK8	0	0.00%	2	0.27%	727	99.73%	729	0.00%
XPL	EXPLORER 4DR	6	0.02%	8	0.02%	39,669	99.96%	39,683	0.24%
XTE	XTERRA 2WD	1	0.00%	5	0.02%	21,174	99.97%	21,180	0.13%
XXX	WRANGLER	10	0.03%	31	0.10%	32,588	99.87%	32,629	0.20%
YUK	YUKON	5	0.01%	19	0.06%	33,824	99.93%	33,848	0.20%
Z3	Z3	1	0.05%	4	0.20%	2,044	99.76%	2,049	0.01%
Z3C	Z3 COUPE	0	0.00%	3	0.74%	401	99.26%	404	0.00%
Z3R	Z3 ROADSTER	0	0.00%	0	0.00%	440	100.00%	440	0.00%
ZEP	ZEPHYR	0	0.00%	0	0.00%	1,096	100.00%	1,096	0.01%
OTH	OTHER	2,305	0.03%	3,350	0.05%	7,322,143	99.92%	7,327,798	43.89%
	All Models	4,370	0.03%	7,195	0.04%	16,684,497	99.93%	16,696,062	100.00%

F. TIMS HANDLING OF OBD CODES

ERG analyzed TIMS OBD data to evaluate the accuracy of OBD data collected in the Texas I/M 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" DTCs, or a vehicle that fails to communicate with the analyzer.

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 (CFR) 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 January 1, 2014 and December 31, 2015. 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. OBD test pass/fail results are not enforced for HD vehicles (>8500 lbs GVWR); therefore, these vehicles were removed from the dataset. HD vehicles were identified as those with the tx96_type field equal to 1 and the tx96_gvw_actual field between zero and 8,501. Vehicles with no GVWR given were also removed, since these might be HD vehicles. Following these removals, 16,693,260 records remained 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" (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 III-23.

Table III-23. Comparison of DLC Communication Status with Overall OBD Test Results

DLC Communication Status	Overall OBD Test Results	
	Fail	Pass
“D” (damaged)	2,227	-
“I” (DLC is inaccessible)	819	4
“L” (inspector cannot find DLC)	1,176	111
"N" (connected but will not communicate)	7,169	2
Total count of “D”, “I”, “L”, and “N” Tests	11,391	117
“P” (communication successful)	732,926	15,948,826
Total	744,317	15,948,943

As can be seen in the table, 117 test records have a DLC communication status of “D”, “I”, “L”, or “N,” 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 failure 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 16,681,752 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 III-24 shows that 2,033 tests were recorded with a “fail” in the OBD portion of the test but a “pass” for the overall test. Additional analyses were performed to determine the source of this apparent discrepancy. However, no waivers were granted to these vehicles, and no other explanation for the overall passing result could be found. This is a very small fraction of the total number of inspections performed; more than 99.7% of OBD inspections have agreement between the OBD result and the overall test result.

Table III-24. Comparison of OBD Test Result with Overall Test Result

Result of OBD Test	Overall Test Result				Total	
	Fail		Pass			
Fail	730,893	99.72%	2,033	0.28%	732,926	4.39%
Pass	286,886	1.80%	15,661,940	98.20%	15,948,826	95.61%
Total	1,017,779	6.10%	15,663,973	93.90%	16,681,752	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). There were 103 records where a KOEO MIL result of "N" (fail) did not receive a failing OBD result. The results are presented in Table III-25 below.

Table III-25. 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)	20,600	103	20,703
K (pass)	9,182	475,374	484,556
Y (pass)	703,144	15,473,452	16,197,196
Total	732,926	15,948,826	16,681,752

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 III-26 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.

As shown in Table III-27, in 199,430 inspections a "pass" result was manually entered when the downloaded MIL status indicated a "fail" result, and a "fail" result was entered 7,689 times when the MIL status indicated a "pass" result.

Table III-26. Comparison of Inspector-Entered MIL Illumination Status (Engine Running, KOER) with Overall OBD Test Result

Result of MIL Illumination Status	Overall OBD Test Result		Total
	Fail	Pass	
N (Fail)	59,923	-	59,923
Y (Pass)	673,002	15,948,826	16,621,829
Total	732,926	15,948,826	16,681,752

Table III-27. Comparison of Downloaded MIL Command Status with Inspector-Entered MIL Illumination Status (Engine Running, KOER)

Result of Downloaded MIL Status	Result of MIL Illumination Status		Total
	Fail	Pass	
Fail	52,234	199,430	251,664
Pass	7,689	16,422,399	16,430,088
Total	59,923	16,621,829	16,681,752

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 III-28 provides the results of this review.

Table III-28. Comparison of Downloaded MIL Command Status with Overall OBD Test Result

Result of Downloaded MIL Status	Overall OBD Test Result				Total	
	Fail		Pass			
Fail	195,167	26.63%	56,497	0.35%	251,664	1.51%
Pass	537,759	73.37%	15,892,329	99.65%	16,430,088	98.49%
Total	732,926	100.00%	15,948,826	100.00%	16,681,752	100.00%

From Table III-28, it can be seen that 56,497 test records (0.35% of all OBD "pass" test records) have a MIL commanded on status yet receive an overall OBD pass result. However, 56,452 of these tests had no stored DTCs, in which case it is appropriate to pass the test. The 45 remaining inspections had one or more DTC stored, and 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, 10,499 records with transitional vehicles were excluded from this analysis of readiness, leaving 16,671,253 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). The 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 III-29 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 III-29. 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	11	1,390,651	144	12,578,976
1	2	438,346	13	1,520,226
2	-	189,563	205,229	459
3	43,809	-	128,723	3
4	29,601	-	88,992	-
5	18,025	-	35,762	1
6	792	-	1,922	-
8	0	-	3	-
Total Count	92,240	2,018,560	460,788	14,099,665

Results in Table III-29 show that a small number of tests (a total of 155) appear to have received an OBD "not ready" status despite having no unset monitors. Also, 459 vehicles of model year 2001 or newer with two unset readiness monitors still received a readiness result of "pass." The majority of these were tested using the ESP equipment.

Table III-30shows these data in greater detail, separated by model year.

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 if 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. These 10,499 records with transitional vehicles were excluded from this analysis of readiness to prevent any confusion in the results, leaving 16,671,253 records in the dataset for this analysis. The results are shown in Table III-31.

Table III-30. Unset Monitors Vs. Test Readiness Status for Inspections, by Model Year

Model Year	Count of Unset Non-Continuous Monitors															
	0		1		2		3		4		5		6		8	
	OBD Not Ready	OBD Ready	OBD Not Ready	OBD Ready	OBD Not Ready	OBD Ready	OBD Not Ready	OBD Ready	OBD Not Ready	OBD Ready	OBD Not Ready	OBD Ready	OBD Not Ready	OBD Ready	OBD Not Ready	OBD Ready
1996	2	129,276	1	52,535	0	21,608	5,867	0	3,916	0	1,010	0	104	0	0	0
1997	1	196,526	0	72,072	0	31,270	7,036	0	5,252	0	2,601	0	97	0	0	0
1998	1	260,909	0	80,833	0	36,191	8,381	0	5,567	0	3,986	0	108	0	0	0
1999	2	343,403	1	104,760	0	44,198	10,404	0	6,582	0	5,195	0	165	0	0	0
2000	5	460,537	0	128,146	0	56,296	12,121	0	8,284	0	5,233	0	318	0	0	0
2001	6	554,433	1	167,815	27,226	81	12,592	0	9,031	0	5,779	0	413	0	0	0
2002	3	680,007	1	165,624	23,548	67	13,246	0	8,977	0	4,146	0	253	0	0	0
2003	6	727,076	1	178,858	21,951	80	12,819	0	7,509	0	3,808	0	265	0	1	0
2004	9	824,506	0	159,763	20,525	53	12,689	0	7,868	0	2,943	0	224	0	0	0
2005	9	926,176	1	152,430	19,777	51	13,103	1	8,373	0	2,866	0	212	0	0	0
2006	14	1,013,801	2	158,426	18,420	48	12,662	0	7,778	0	2,357	0	124	0	0	0
2007	12	1,205,464	1	151,145	15,678	34	12,862	0	8,380	0	2,014	0	48	0	0	0
2008	11	1,223,390	2	111,301	14,128	19	9,853	0	6,597	0	1,478	0	40	0	1	0
2009	11	824,739	0	60,319	8,806	14	5,989	2	3,837	0	1,230	1	38	0	0	0
2010	15	1,005,432	3	57,054	8,456	3	5,529	0	4,547	0	1,816	0	70	0	1	0
2011	12	1,116,972	0	60,647	8,619	6	5,739	0	4,857	0	2,641	0	59	0	0	0
2012	21	1,307,744	1	56,494	9,336	1	6,142	0	5,714	0	2,378	0	87	0	0	0
2013	11	929,440	0	31,591	6,506	2	4,013	0	4,122	0	1,727	0	62	0	0	0
2014	4	213,125	0	7,218	1,735	0	1,172	0	1,140	0	486	0	24	0	0	0
2015	0	26,671	0	1,541	518	0	313	0	262	0	93	0	3	0	0	0
Total	155	13,969,627	15	1,958,572	205,229	190,022	172,532	3	118,593	0	53,787	1	2,714	0	3	0

Table III-31. Comparison of Readiness Status Field with Overall OBD Test Result

Readiness Status Check	Overall OBD Test Result				Total	
	Fail		Pass			
Fail (Not Ready)	552,747	75.72%	281	0.0%	553,028	3.32%
Pass (Ready)	177,205	24.28%	15,941,020	100.0%	16,118,225	96.68%
Total	729,952	100.00%	15,941,301	100.0%	16,671,253	100.00%

As can be seen in Table III-31, only 281 of the vehicles with a "not ready" status received an overall "pass" result for the OBD portion of the test. This represents less than 0.002%; therefore, the value in Table III-31 is 0.0%. 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.

IV. REPAIR

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

A. NUMBER AND TYPES OF REPAIRS

ERG performed analysis on the number and types of repairs for the two years of TIMS data. The inspectors at Texas I/M stations have an opportunity to enter vehicle repair information into the inspection analyzer prior to conducting an emissions re-test. A simple count of the number of repairs entered and stored in the TIMS and a distribution of the repair types suggests the Texas I/M program is causing repairs to be performed. Since the repairs performed through the LIRAP are documented on paper and not electronically, LIRAP repairs are not included in this analysis but will be described generally.

In previous reports, repair information collected from the DPS RERF program was also included. However, because of a transition to a new data collection system at the DPS, only 310 records were available for the current report, which were too few to provide a meaningful analysis.

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 IV-1 by model year group. Comparing Table III-2 test totals from the DFW and HGB program areas shows total OBD, ASM, and TSI fails dropped from 643,712 fails in the 2014 report to 586,091 fails in this report (57,621 fewer fails).

Table IV-1. Repairs Listed in the TIMS

Repair Type	Model Year	Number of Repairs	% of Repair Type	% of Total
Fuel System	1990-1995	3,470	9.49%	1.93%
	1996-1999	5,284	14.44%	2.94%
	2000-2006	19,230	52.57%	10.72%
	post-2007	8,599	23.51%	4.79%
	Total	36,583	100.00%	20.39%
Ignition / Electrical system	1990-1995	2,978	16.83%	1.66%
	1996-1999	2,807	15.86%	1.56%
	2000-2006	8,625	48.73%	4.81%
	post-2007	3,289	18.58%	1.83%
	Total	17,699	100.00%	9.86%
Emissions system	1990-1995	10,621	22.58%	5.92%
	1996-1999	6,767	14.38%	3.77%
	2000-2006	22,273	47.34%	12.41%
	post-2007	7,386	15.70%	4.12%
	Total	47,047	100.00%	26.22%
Engine Mechanical	1990-1995	386	12.26%	0.22%
	1996-1999	472	14.99%	0.26%
	2000-2006	1,684	53.49%	0.94%
	post-2007	606	19.25%	0.34%
	Total	3,148	100.00%	1.75%
Miscellaneous	1990-1995	9,004	12.01%	5.02%
	1996-1999	10,488	13.99%	5.84%
	2000-2006	38,666	51.58%	21.55%
	post-2007	16,810	22.42%	9.37%
	Total	74,968	100.00%	41.78%
	Grand Total	179,445		100.00%

Drive a Clean Machine (DACM) program

Texas created the DACM program to enhance the objectives of the Texas I/M program. Using the statutory authority granted in the LIRAP legislation, the DACM program provides financial assistance to low-income vehicle owners to repair or retire vehicles that have failed an emissions test, or retire vehicles 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.

To qualify for repair assistance, the vehicle must pass the safety portion of the DPS motor-vehicle safety and emissions inspection and be driven under its own power to the inspection station; must have failed an emissions test within 30 days of application submission; and must be currently registered in and have been registered in the program area for at least 12 of the 15 months preceding the application for assistance. The repair assistance portion of the DACM program provides a voucher worth up to $600 for emissions-related repairs performed at a participating DPS RERF.

To qualify for vehicle retirement and replacement assistance, the vehicle must have failed an emissions test, passed the DPS motor-vehicle safety and emissions inspection within 15 months of application submission and driven under its own power to the automobile dealership, and be currently registered in and have been registered in the program area for at least 12 of the 15 months preceding the application for assistance; or be at least 10 years old and gasoline powered, passed the DPS motor-vehicle safety inspection (if more than 24 years old) or safety and emissions inspection (if 24 years old or less) within 15 months of application and driven under its own power to the automobile dealership, and be currently registered in and have been registered in the program area for at least 12 of the 15 months preceding the application for assistance.

The retirement and replacement assistance portion of the DACM program offers a voucher up to $3,000 towards the purchase of a replacement car, current model year or up to three model years old; a voucher up to $3,000 towards the purchase of a replacement truck, current model year or up to two model years old; or a voucher up to $3,500 towards the purchase of a replacement car of the current model year or the previous three model years if the vehicle is a hybrid vehicle, an electric vehicle, or a 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 CFR §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, a gross vehicle weight rating less than 10,000 pounds, 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 Bin certification of the current model year or up to three model years old.

For the period covering December 1, 2013 through November 30, 2015, 7,522 vehicle repairs were done at RERF stations under the DACM program, with 6,837 being made in the DFW and HGB programs.

B. EMISSIONS CHANGES ASSOCIATED WITH REPAIR

One way to measure the effectiveness of an 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.

Emissions Changes as a Result of Repair

The average emissions of all vehicles in this analysis of the Texas I/M program that received repairs are shown in Table IV-2 and Table IV-3. In Table IV-2, ASM5015 and ASM2525 test results for HC, CO, and NO_x are presented for pre-OBD vehicles with model years between 1990 and 1995, broken down by the most common repair slates (groups of common types of repairs). Average before and after repair emissions levels were calculated for each repair category to determine the emissions effects of different combinations of repair types. Table IV-3 shows TSI curb idle and high idle emissions for these same model years, and

Table IV-4 shows these data for the post-1995 (i.e., OBD) model years. Only HC and CO emissions are obtained from the TSI tests. Average emissions for both inspections prior to and following repair cycles are shown, along with the average change between the two.

Table IV-2. Model Years 1990-1995 (Pre-OBD) Average Emissions Before and After Repairs by Repair Category, ASM Mode

Repair Category	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	5015	5,334	188.39	97.24	-91.15	-48%	1.05	0.44	-0.61	-58%	1434.72	687.38	-747.34	-52%
Engine Mechanical	5015	250	163.76	78.05	-85.71	-52%	1.23	0.31	-0.91	-74%	1410.24	539.05	-871.19	-62%
Emissions System	5015	7,413	160.11	70.61	-89.50	-56%	0.87	0.28	-0.59	-68%	1682.02	608.87	-1073.15	-64%
Emissions System & Misc	5015	420	195.26	72.57	-122.70	-63%	0.91	0.30	-0.61	-67%	1651.29	685.22	-966.07	-59%
Ignition/Electrical System	5015	1,795	238.69	100.47	-138.22	-58%	1.47	0.47	-0.99	-68%	1170.98	578.44	-592.54	-51%
Fuel System	5015	2,033	191.45	90.89	-100.57	-53%	1.23	0.43	-0.79	-65%	1338.78	674.57	-664.21	-50%
Fuel System & Emissions System	5015	211	205.73	86.35	-119.38	-58%	0.92	0.42	-0.51	-55%	1631.79	745.33	-886.45	-54%
All Repairs	5015	18,120	183.61	84.89	-98.72	-54%	1.04	0.37	-0.67	-64%	1507.07	639.97	-867.10	-58%
Miscellaneous	2525	5,334	165.51	79.60	-85.90	-52%	1.01	0.40	-0.61	-60%	1288.06	594.32	-693.75	-54%
Engine Mechanical	2525	250	158.16	57.27	-100.89	-64%	1.13	0.28	-0.85	-75%	1263.58	456.18	-807.40	-64%
Emissions System	2525	7,413	141.21	57.18	-84.03	-60%	0.83	0.26	-0.57	-68%	1500.19	507.02	-993.18	-66%
Emissions System & Misc	2525	420	181.05	57.21	-123.84	-68%	0.95	0.26	-0.69	-72%	1482.42	612.63	-869.80	-59%
Ignition/Electrical System	2525	1,795	205.16	82.75	-122.41	-60%	1.34	0.43	-0.91	-68%	1051.21	490.38	-560.84	-53%
Fuel System	2525	2,033	171.01	76.04	-94.97	-56%	1.18	0.39	-0.79	-67%	1206.74	577.86	-628.88	-52%
Fuel System & Emissions System	2525	211	176.52	68.09	-108.44	-61%	0.78	0.35	-0.43	-55%	1403.72	657.11	-746.61	-53%
All Repairs	2525	18,120	161.90	69.29	-92.61	-57%	0.99	0.34	-0.65	-66%	1349.08	544.46	-804.62	-60%

Table IV-3. Model Years 1990-1995 (Pre-OBD) Average Emissions Before and After Repairs by Repair Category and Model Year Group, TSI Mode

			HC (ppm)				CO (%)			
					Change				Change	
Repair Category	TSI Mode	N	Before Repair	After Repair	Conc.	(%)	Before Repair	After Repair	Conc.	(%)
Miscellaneous	curb idle	413	618.53	249.86	-368.66	-60%	2.25	0.89	-1.37	-61%
Engine Mechanical	curb idle	22	549.05	106.36	-442.68	-81%	2.20	0.36	-1.84	-84%
Emissions System	curb idle	485	686.11	171.23	-514.88	-75%	2.24	0.58	-1.66	-74%
Emissions System & Misc	curb idle	17	431.18	245.35	-185.82	-43%	1.90	0.44	-1.46	-77%
Ignition/Electrical System	curb idle	265	620.94	207.11	-413.84	-67%	2.29	0.77	-1.51	-66%
Fuel System	curb idle	229	502.82	199.62	-303.20	-60%	2.34	0.61	-1.73	-74%
Fuel System & Emissions System	curb idle	10	809.50	141.60	-667.90	-83%	2.14	0.48	-1.66	-77%
All Repairs	curb idle	1,478	616.57	204.92	-411.65	-67%	2.28	0.71	-1.57	-69%
Miscellaneous	high idle	413	363.75	146.66	-217.08	-60%	1.73	0.76	-0.97	-56%
Engine Mechanical	high idle	22	537.36	36.91	-500.45	-93%	2.41	0.31	-2.10	-87%
Emissions System	high idle	485	445.41	117.73	-327.68	-74%	1.90	0.53	-1.37	-72%
Emissions System & Misc	high idle	17	150.00	91.12	-58.88	-39%	1.32	0.45	-0.87	-66%
Ignition/Electrical System	high idle	265	387.36	125.22	-262.14	-68%	1.91	0.66	-1.25	-65%
Fuel System	high idle	229	280.90	111.88	-169.02	-60%	1.84	0.60	-1.25	-68%
Fuel System & Emissions System	high idle	10	278.80	63.70	-215.10	-77%	1.20	0.51	-0.69	-58%
All Repairs	high idle	1,478	377.00	124.11	-252.88	-67%	1.85	0.64	-1.22	-66%

Table IV-4. Post-1995 Model Years (OBD) Average Emissions Before and After Repairs by Repair Category and Model Year Group, TSI Mode

Repair Category	TSI Mode	N	HC (ppm)				CO (%)			
			Before Repair	After Repair	Change		Before Repair	After Repair	Change	
					Conc.	(%)			Conc.	(%)
Miscellaneous	curb idle	0	0.00	0.00	0.00	N/A	0.00	0.00	0.00	N/A
Engine Mechanical	curb idle	0	0.00	0.00	0.00	N/A	0.00	0.00	0.00	N/A
Emissions System	curb idle	3	291.00	189.00	-102.00	-35%	0.50	0.23	-0.27	-53%
Emissions System & Misc	curb idle	0	0.00	0.00	0.00	N/A	0.00	0.00	0.00	N/A
Ignition/Electrical System	curb idle	0	0.00	0.00	0.00	N/A	0.00	0.00	0.00	N/A
Fuel System	curb idle	1	54.00	0.00	-54.00	-100%	0.08	0.00	-0.08	-100%
Fuel System & Emissions System	curb idle	0	0.00	0.00	0.00	N/A	0.00	0.00	0.00	N/A
All Repairs	curb idle	0	0.00	0.00	0.00	N/A	0.00	0.00	0.00	N/A
Miscellaneous	high idle	0	0.00	0.00	0.00	N/A	0.00	0.00	0.00	N/A
Engine Mechanical	high idle	0	0.00	0.00	0.00	N/A	0.00	0.00	0.00	N/A
Emissions System	high idle	3	201.00	120.67	-80.33	-40%	0.59	0.25	-0.34	-57%
Emissions System & Misc	high idle	0	0.00	0.00	0.00	N/A	0.00	0.00	0.00	N/A
Ignition/Electrical System	high idle	0	0.00	0.00	0.00	N/A	0.00	0.00	0.00	N/A
Fuel System	high idle	1	76.00	1.00	-75.00	-99%	1.51	0.00	-1.51	-100%
Fuel System & Emissions System	high idle	0	0.00	0.00	0.00	N/A	0.00	0.00	0.00	N/A
All Repairs	high idle	0	0.00	0.00	0.00	N/A	0.00	0.00	0.00	N/A

C. ISSUES WITH THE REPAIR DATA IN THE TIMS DATASET

There are several issues with the repair data contained in the TIMS dataset 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.

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 re-inspection 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 re-inspection 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 IV-1, "miscellaneous" repairs make up over 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 are common issues in I/M programs that attempt to collect repair data.

It is recommended that the TCEQ 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 exist in the dataset, along with some extremely high (e.g. 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.

D. 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 an 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 is 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 is tightened upon a vehicle refuel) or an OBD problem that is masked by unset readiness monitors (e.g., through a battery disconnect) on a subsequent passing re-test. This "masking" issue is analyzed in Section IV-D of this report. This analysis is analogous to the tailpipe emissions changes observed with repairs in Section IV-D.

Since OBD test pass/fail results are not enforced on HD vehicles, Class 2 vehicles were excluded from this analysis. This left a dataset of 16,681,800 OBD inspection records available for the analysis.

Overall Success of Repairs to Vehicles Failing OBD

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 or until the vehicle received a waiver. 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, until a waiver was granted, or until the end of the evaluation period.

Once the vehicle passed its inspection, 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, 2015, 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, 2015, and there would be no information for those inspections. Using these criteria, the dataset contained 14,101,280 I/M cycles that started before October 1, 2015.

After grouping by I/M cycle for vehicles with OBD failures (as previously defined), 155,1624 I/M cycles were seen to include at least one failed OBD test. Of these cycles, 125,944 (80.9%) 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 29,680 vehicles never passed a subsequent OBD test; for these vehicles it was learned that 25,843 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 2015, which would increase the overall "repaired" numbers. Additionally, 615 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 IV-D.

Success of Repairs to Specific Emission Control Systems Failing OBD

For this analysis, DTCs 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. This task was performed as a continuation of the analysis in Section C. It uses combinations of vehicles and I/M cycles defined in that section. However, for this task, failure modes were assigned based on the DTCs contained in the failed test records.

Specifically, the analysis was performed on vehicles with DTC failures associated with oxygen sensors (O_2 Sensor), exhaust gas recirculation systems (EGR System), secondary air injection systems (AI System), catalytic converter efficiency (Catalyst), and evaporative emissions control system (Evap System) components[5]. The O_2 Sensor, EGR

[5] A list of DTCs that were included in each of these groups is given in Appendix A.

System, AI System, and Catalyst 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 re-test (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 re-tests, 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 I/M 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 the Texas I/M program, 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 IV-5 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, 2014 through December 31, 2015, it is possible that some of the un-repaired vehicles were repaired in 2016. This would increase the "repaired" counts from the numbers shown in this table.

Table IV-5. 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	39,400	32,452	82.4%	15,356	39.0%	17,096	43.4%
O_2 Sensor	25,818	20,037	77.6%	473	1.8%	19,564	75.8%
EGR System	14,525	11,240	77.4%	1,164	8.0%	10,076	69.4%
AI System	2,334	1,663	71.3%	262	11.2%	1,401	60.0%
Catalyst	32,974	25,982	78.8%	4,931	15.0%	21,051	63.8%

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 IV-5. Also, only categories directly monitored with non-continuous monitors are tabulated in Table IV-5. Other failure categories for which readiness status would be more difficult to assess are excluded from the table. Table IV-5 indicates that readiness status may be masking 2% to 39% of vehicles that pass OBD re-tests 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 IV-6 presents a summary of these results.

Table IV-6. 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	16,068,191	98.4%	84,694	0.5%	16,152,885	98.9%
Fail	176,151	1.1%	3,286	0.02%	179,437	1.1%
Total	16,244,342	99.5%	87,980	0.5%	16,332,322	100.0%

As can be seen from this table, approximately 1.1% of the tests had failed the OBD portion of the test with evaporative system DTCs, and gas cap failures were seen in 0.5% 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.

The most common repair slates for vehicles receiving each type of inspection (OBD, ASM, TSI) were also identified. The top six slates for each inspection type are listed in Table IV-7. The top set of repair slates was slightly different for each of the inspection types; since each inspection tests the vehicle somewhat differently, it would be expected that different types of repairs would result. The table also gives the total number of vehicles that received repairs (i.e., received one of the top six repairs or some other repair). It can be seen from Table IV-7 that substantially more repair data were available for ASM and OBD vehicles than for TSI vehicles.

Table IV-7. Top Six Most Common Repair Slates for Each Inspection Test

Repair Description	OBD		TSI		ASM	
	Count	Percent	Count	Percent	Count	Percent
Miscellaneous	75,017	43.2%	1,707	34.2%	6,127	30.8%
Emissions System	40,904	23.5%	1,456	29.2%	7,958	40.0%
Fuel System	36,957	21.3%	760	15.2%	2,274	11.4%
Ignition/Electrical System	15,283	8.8%	835	16.7%	1,976	9.9%
Engine Mechanical	2,814	1.6%	72	1.4%	274	1.4%
Fuel System & Misc	861	0.5%	N/A	N/A	N/A	N/A
Emissions System & Misc	N/A	N/A	41	0.8%	421	2.1%
Other repair slates	2,012	1.2%	120	2.4%	876	4.4%
Total	173,848	100.0%	4,991	100.0%	19,906	100.0%

For OBD inspections, a failed inspection includes one or more Diagnostic Trouble Codes (DTCs) that are set. The DTCs give information about what type of problem(s) the vehicle has that may necessitate repairs. When an OBD inspection is passed, no DTCs will be set. Therefore, the DTCs that are initially set and then finally unset (turned off) were compared to the repairs for OBD vehicles. Since there are far too many possible combinations of DTCs to create a "DTC slate" analogous to the repair slates (where all DTCs that were turned on during an inspection sequence are considered as a group, and the analysis is done on these groups), repairs were correlated with DTCs on an individual basis rather than as slates for the OBD repair analysis.

In Table IV-8, the five repair types are listed horizontally across the top. Each row of the table represents one DTC. The number of times that each DTC was "turned off" in the same inspection cycle as each repair is given in the cells of the table. For example, in row 1 of the table, it can be seen that DTC P0420 (a catalyst system DTC) was most frequently turned off by “Emissions System” repairs (3,621 times), followed by “Miscellaneous” repairs (2.354 times). Rows with DTCs that relate to similar components or problems are grouped together in the table. The DTCs listed in Table IV-8 are the most commonly recorded DTCs, representing about two-thirds of the total DTC repair counts.

Table IV-8. Most Common OBD DTCs and Associated Repairs

DTC Name	Repair Description	Repair Type										Total
		Fuel System		Ignition/ Electrical System		Emissions System		Engine Mechanical		Miscellaneous		
		N	%	N	%	N	%	N	%	N	%	N
P0420	Catalyst System Efficiency Below Threshold (Bank 1)	1,281	16%	530	7%	3,621	46%	122	2%	2,354	30%	7,908
P0430	Catalyst System Efficiency Below Threshold (Bank 2)	420	16%	179	7%	1,227	46%	38	1%	776	29%	2,640
P0300	Random/Multiple Cylinder Misfire Detected	552	17%	671	21%	904	28%	121	4%	1,014	31%	3,262
P0301	Cylinder 1 Misfire Detected	262	16%	398	24%	420	26%	45	3%	519	32%	1,644
P0302	Cylinder 2 Misfire Detected	251	17%	363	24%	373	25%	51	3%	477	31%	1,515
P0303	Cylinder 3 Misfire Detected	254	17%	385	26%	371	25%	57	4%	415	28%	1,482
P0304	Cylinder 4 Misfire Detected	231	16%	352	24%	375	26%	46	3%	458	31%	1,462
P0305	Cylinder 5 Misfire Detected	135	15%	194	22%	244	27%	29	3%	290	33%	892
P0306	Cylinder 6 Misfire Detected	132	16%	191	23%	228	27%	25	3%	256	31%	832
P0440	Evaporative Emission Control System Malfunction	342	19%	115	6%	748	42%	23	1%	558	31%	1,786
P0441	Evaporative Emission Control System Incorrect Purge Flow	277	18%	95	6%	656	42%	34	2%	500	32%	1,562
P0442	Evaporative Emission Control System Leak Detected (small leak)	504	18%	176	6%	1,092	39%	39	1%	996	35%	2,807
P0446	Evap Emiss Control Sys. Vent Control Circuit Malfunction	300	18%	114	7%	746	44%	34	2%	513	30%	1,707
P0449	Evap Emiss Control Sys. Vent Valve/Solenoid Circuit Malfunction	219	18%	74	6%	545	44%	19	2%	374	30%	1,231
P0455	Evaporative Emiss Control Sys. Leak Detected (gross leak)	599	18%	245	7%	1,261	38%	45	1%	1,140	35%	3,290
P0456	Evap Emissions System Small Leak Detected	330	21%	94	6%	560	36%	24	2%	561	36%	1,569

Table IV-8. Most Common OBD DTCs and Associated Repairs

DTC Name	Repair Description	Repair Type: Fuel System		Ignition/ Electrical System		Emissions System		Engine Mechanical		Miscellaneous		Total
		N	%	N	%	N	%	N	%	N	%	N
P0457	Evaporative Emission System Leak Detected (fuel cap loose/off)	143	23%	43	7%	201	33%	13	2%	216	35%	616
P0401	Exhaust Gas Recirculation Flow Insufficient Detected	549	17%	238	7%	1,495	45%	51	2%	973	29%	3,306
P0171	Fuel System too Lean (Bank 1)	1,284	23%	521	9%	1,838	33%	142	3%	1,853	33%	5,638
P0174	Fuel System too Lean (Bank 2)	876	23%	332	9%	1,221	32%	99	3%	1,268	33%	3,796
P0101	Mass Air Flow (MAF) Circuit Range/Performance	96	24%	27	7%	118	30%	13	3%	144	36%	398
P0102	Mass or Volume Air Flow Circuit Low Input	135	19%	61	9%	227	33%	22	3%	252	36%	697
P0133	O_2 Sensor Circuit Slow Response (Bank 11 Sens.)	190	27%	60	9%	212	30%	14	2%	220	32%	696
P0135	O_2 Sensor Heater Circuit Malfunction (Bank 11 Sensor 1)	535	30%	139	8%	547	31%	28	2%	533	30%	1,782
P0139	O_2 Sensor Circuit Slow Response Bank 1 Sensor 2	55	34%	13	8%	44	27%	1	1%	48	30%	161
P0141	O_2 Sensor Heater Circuit Malfunction (Bank 11 Sensor2)	455	29%	130	8%	472	30%	32	2%	491	31%	1,580
P0325	Knock Sensor 1 Circuit Malfunction (Bank 1 or Single Sensor2)	157	17%	115	13%	287	32%	38	4%	303	34%	900
P0328	Knock Sensor 1 Circuit High, Bank 1 or Single Sensor	33	18%	25	13%	53	28%	7	4%	70	37%	188

Table IV-8. Most Common OBD DTCs and Associated Repairs

DTC Name	Repair Description	Repair Type										Total
		Fuel System		Ignition/ Electrical System		Emissions System		Engine Mechanical		Miscellaneous		
		N	%	N	%	N	%	N	%	N	%	N
P0121	Throttle Position Sensor/Switch A Circuit Malfunction	150	20%	67	9%	195	26%	23	3%	303	41%	738
P0128	Coolant Temperature Below Thermostat Regulating Temp.	358	16%	173	8%	637	29%	86	4%	947	43%	2,201
P0340	Camshaft Position Sensor Circuit Malfunction	125	17%	92	12%	184	24%	73	10%	280	37%	754
P0700	Transmission Control System Malfunction	76	17%	41	9%	136	30%	20	4%	185	40%	458

E. AVERAGE REPAIR COSTS

The TIMS dataset contains manually entered costs for I/M program repairs. This information was analyzed to provide a rough estimate of the cost of vehicle repairs as a result of the Texas I/M program.

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. The five different repair types listed in Table IV-1 were combined to produce the seven most common repair categories, which account for approximately 99.1% of all vehicle and I/M cycle combinations. These categories are presented in Table IV-9.

Over one half (51.4%) 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 re-inspection; motorists performing their own repairs; lack of repair data available during a vehicle re-inspection; or vehicles receiving a re-test without receiving repairs, such as vehicles that fail due to a readiness monitor and need to simply be driven until the monitors pass their readiness tests. 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 IV-9 presents the number of records with a cost of $0 by repair category. It was observed that most categories listed contained about 20-40% $0 repair costs, but fuel system and miscellaneous repairs contained a much higher percentage (about 58.6% and 66.2%, respectively). All of these percentages are comparable to those in the 2014 report, but markedly higher than those observed in previous TIMS data analyses.

It was also noted than many of the repair costs 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 re-inspections. Figure IV-1 presents a histogram of repairs that cost more than $2000.

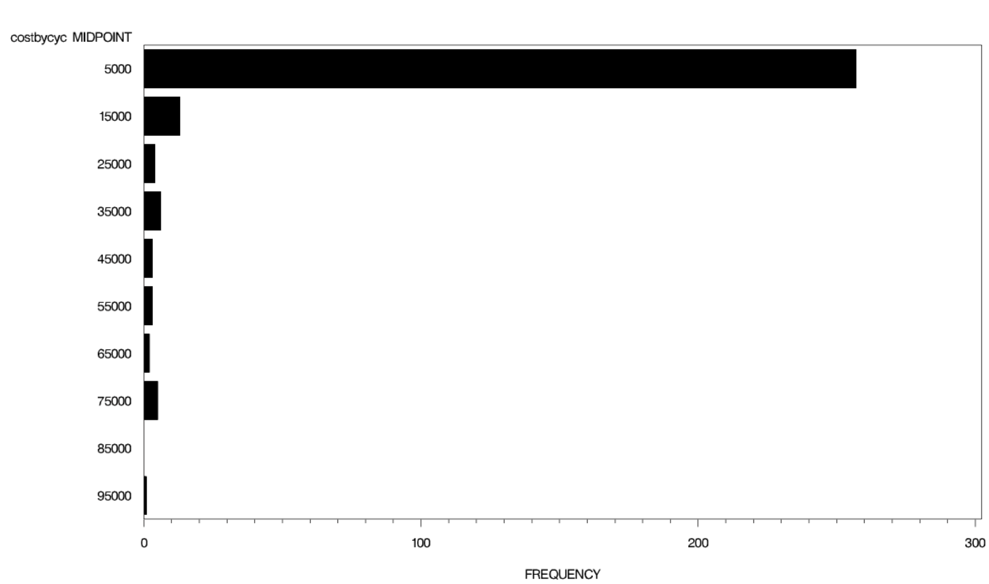
Table IV-9. TIMS Records with a Repair Cost of $0, by Category

Repair Category	Cost > 0	Cost = Zero	Total	% of Cost = 0
Fuel System and Emissions System	451	168	619	27.1
Emissions System & Miscellaneous	841	191	1,032	18.5
Engine Mechanical	2,003	819	2,822	29.0
Ignition / Electrical System	11,342	4,852	16,194	30.0
Fuel System	13,827	19,572	33,399	58.6
Miscellaneous	23,159	45,282	68,441	66.2
Emissions System	28,762	13,978	42,740	32.7
Total (of Selected Repair Slates)	80,385	84,862	165,247	51.4

Table IV-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 167,303 repairs while spending approximately $17.7 million. According to the edited dataset, which leaves out $0 cost and greater than 2,000 cost observations, vehicle owners performed 81,566 repairs while spending approximately $15.5 million.

Figure IV-2 and Figure IV-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 IV-1. Repairs with Cost Greater than $2000



costbycyc MIDPOINT	FREQ.	CUM. FREQ.	PCT.	CUM. PCT.
5000	257	257	87.41	87.41
15000	13	270	4.42	91.84
25000	4	274	1.36	93.20
35000	6	280	2.04	95.24
45000	3	283	1.02	96.26
55000	3	286	1.02	97.28
65000	2	288	0.68	97.96
75000	5	293	1.70	99.66
85000	0	293	0.00	99.66
95000	1	294	0.34	100.00

Table IV-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
2014	Fuel System and Emissions System	339	$150	$252	243	$250	$331
2014	Emissions System & Miscellaneous	569	$160	$247	453	$200	$286
2014	Engine Mechanical	1,570	$120	$246	1,088	$200	$302
2014	Ignition / Electrical System	8,812	$100	$167	6,319	$150	$194
2014	Fuel System	18,723	$0	$79	7,697	$95	$152
2014	Miscellaneous	37,107	$0	$45	15,778	$189	$254
2014	Emissions System	23,547	$120	$186	12,610	$50	$102
2015	Fuel System and Emissions System	280	$175	$253	205	$260	$331
2015	Emissions System & Miscellaneous	463	$180	$221	384	$200	$260
2015	Engine Mechanical	1,252	$126	$249	880	$200	$290
2015	Ignition / Electrical System	7,382	$95	$143	4,983	$150	$197
2015	Fuel System	14,676	$0	$83	6,089	$100	$177
2015	Miscellaneous	31,334	$0	$38	12,881	$200	$259
2015	Emissions System	19,193	$120	$187	10,494	$45	$101

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

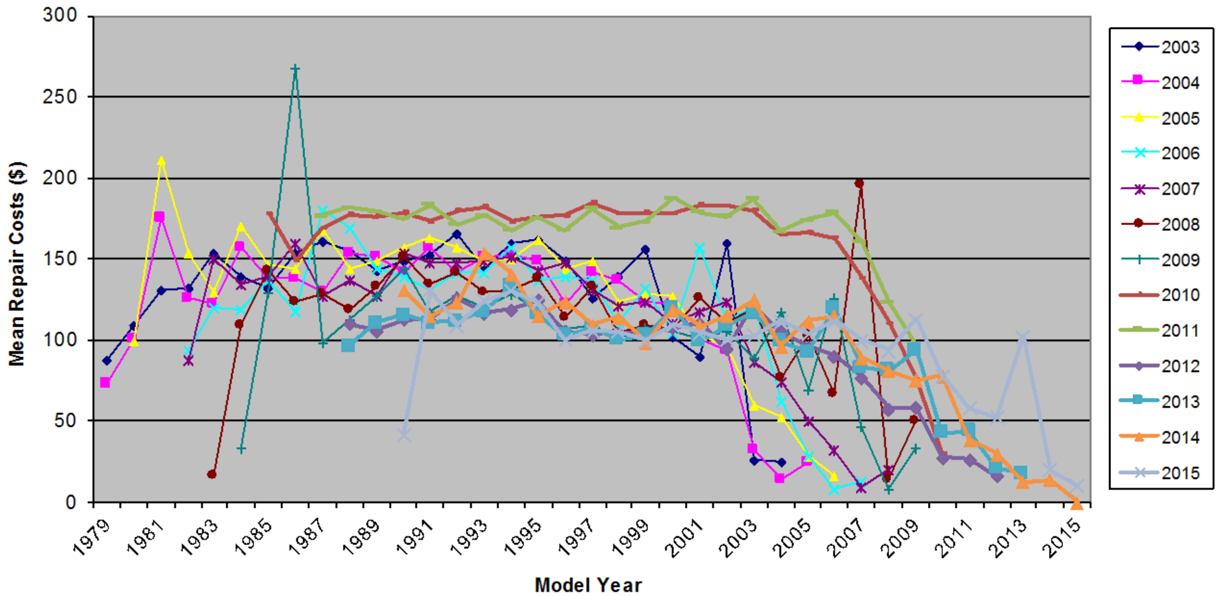


Figure IV-3. Mean Repair Costs by Model Year and Inspection Year (Edited Dataset)

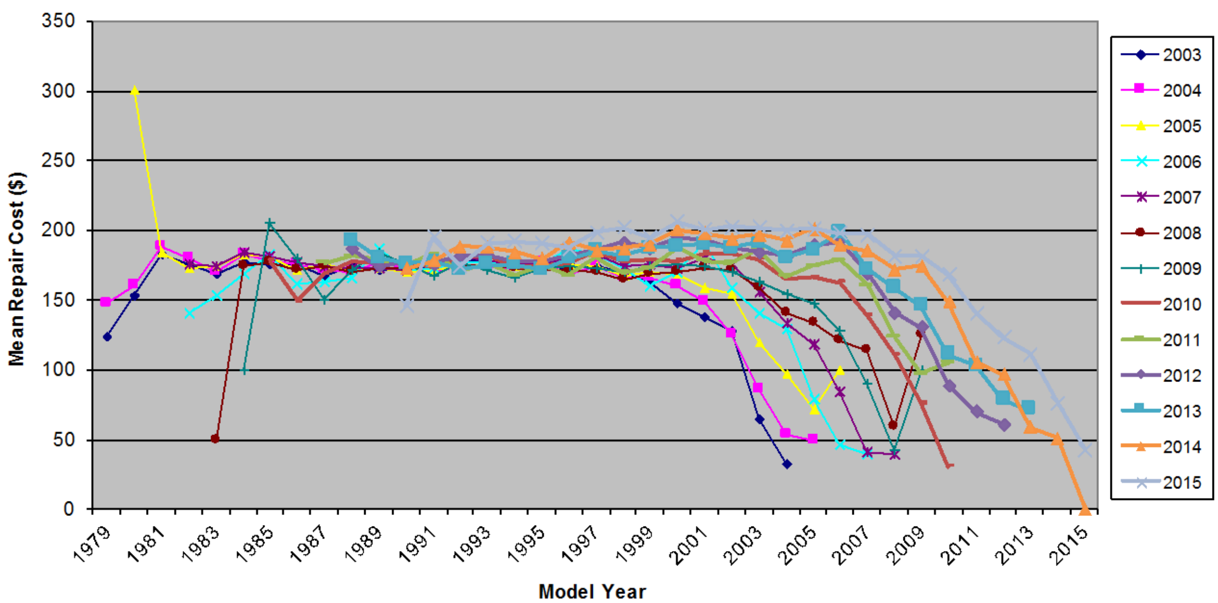


Figure IV-4 and Figure IV-5 present the percentile distribution of repair costs for the most common TIMS repair categories, for both the unedited and edited datasets. The unedited data contains repairs with an average cost of $0 for all repair slates, but miscellaneous repairs costing $0 extend close 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 IV-4. Distribution of Repair Costs by Category (Unedited Dataset)

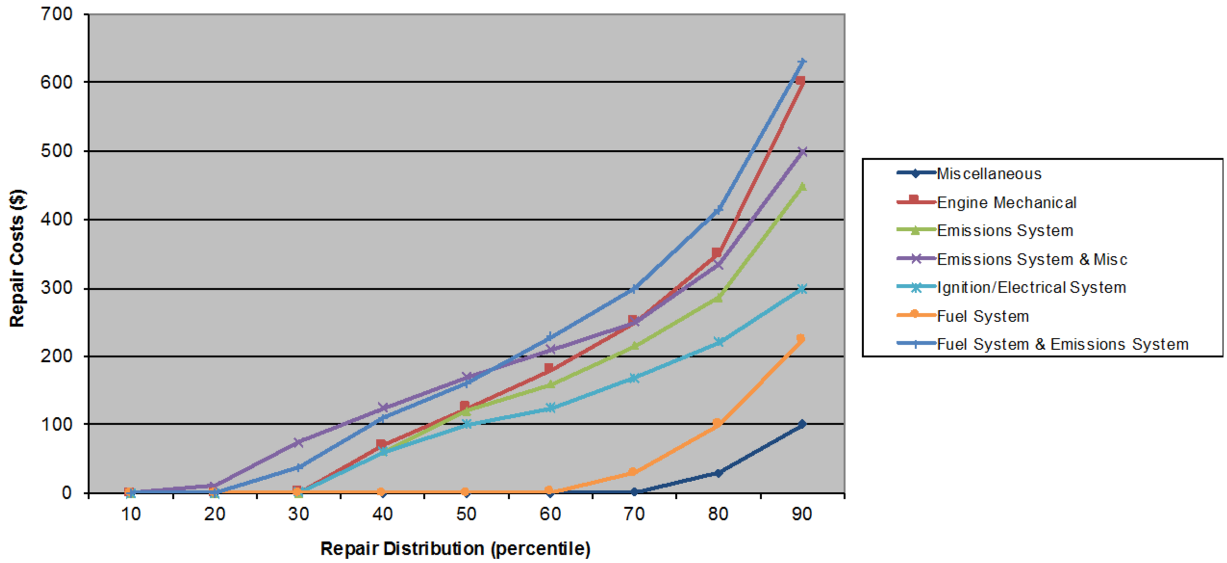
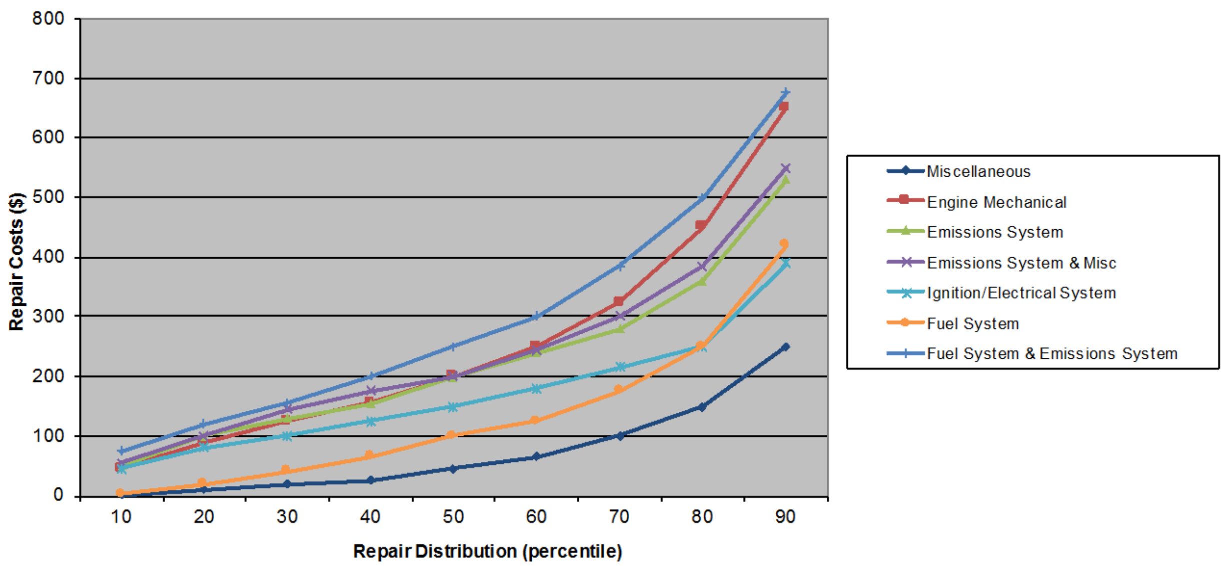


Figure IV-5. Distribution of Repair Costs by Category (Edited Dataset)



V. 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 repair and then upward from emissions degradation 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 V.A) or pairing the TIMS data with RS data (Section V.B).

A. ESTIMATE OF ANNUAL I/M BENEFIT FROM TIMS DATA

ERG used two years of the TIMS data to calculate the Annual Benefit of the Texas I/M program. This analysis only applies to estimating the benefits of the ASM and TSI test because the OBD test does not provide any emission measurement data. 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 Texas 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 III.C 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 87% of all sequences. The FP sequences are the next most common and make up about 11% of all sequences. The 1F and FF sequences are less common and make up the remaining 2% 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 program areas during this evaluation period (i.e., the 2016 report covering 2014 and 2015 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 13 to 17%, ASM CO decreased 24 to 28%, ASM NO_x decreased 16 to 18%, TSI HC decreased 18 to 19%, and TSI CO decreased 19 to 24%. 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 DFW and HGB program areas categorized by the two major I/M sequence categories, 1P and FP. These two categories make up 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 59 to 84%. 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 the DFW and HGB program areas 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 complicates 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 2014 Report (covering 2012 and 2013 program years) and are included here as a point of reference. Tables 5-5 and 5-6 contain these same values from the 2012 report (covering 2010 and 2011 program years), and tables 5-7 and 5-8 contain these same values from the 2009 report (covering 2007 and 2008 program years). In general, the emission percent reduction values were slightly larger in the 2009 report than the later reports. The new results in this current report are very similar to the 2014 and the 2012 results, or slightly lower for some pollutants. It is possible this could be because the Texas 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 V-1. 2016 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	135,052	64.8	64.8	0.0%	42.9	42.9	0.0%
	FP	18,496	156.7	64.5	-58.8%	132.9	47.7	-64.1%
	1P+FP	157,331	78.9	68.3	-13.5%	56.8	46.9	-17.4%
HGB	1P	122,112	61.0	61.0	0.0%	40.7	40.7	0.0%
	FP	15,446	141.0	60.8	-56.9%	120.9	43.6	-64.0%
	1P+FP	139,786	72.3	63.6	-12.0%	52.0	43.5	-16.2%
DFW & HGB	1P	257,164	63.0	63.0	0.0%	41.8	41.8	0.0%
	FP	33,942	149.6	62.8	-58.0%	127.5	45.8	-64.1%
	1P+FP	297,117	75.8	66.1	-12.9%	54.5	45.3	-16.9%
ASM CO (%)								
DFW	1P	135,052	0.20	0.20	0.0%	0.15	0.15	0.0%
	FP	18,496	0.83	0.20	-75.5%	0.78	0.17	-78.1%
	1P+FP	157,331	0.30	0.22	-24.4%	0.25	0.18	-28.1%
HGB	1P	122,112	0.19	0.19	0.0%	0.15	0.15	0.0%
	FP	15,446	0.81	0.19	-76.6%	0.75	0.15	-79.6%
	1P+FP	139,786	0.27	0.21	-24.3%	0.23	0.16	-28.2%
DFW & HGB	1P	257,164	0.20	0.20	0.0%	0.15	0.15	0.0%
	FP	33,942	0.82	0.20	-76.0%	0.76	0.16	-78.8%
	1P+FP	297,117	0.29	0.22	-24.3%	0.24	0.17	-28.1%
ASM NOx (ppm)								
DFW	1P	135,052	456	456	0.0%	348	348	0.0%
	FP	18,496	1319	482	-63.5%	1157	391	-66.2%
	1P+FP	157,331	582	485	-16.6%	466	378	-19.0%
HGB	1P	122,112	426	426	0.0%	328	328	0.0%

Table V-1. 2016 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
	FP	15,446	1122	443	-60.5%	986	352	-64.3%
	1P+FP	139,786	518	445	-14.2%	415	346	-16.5%
DFW & HGB	1P	257,164	442	442	0.0%	338	338	0.0%
	FP	33,942	1230	464	-62.3%	1079	373	-65.4%
	1P+FP	297,117	552	466	-15.5%	442	363	-17.9%

Table V-2. 2016 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	26,985	81.6	81.6	0.0%	45.5	45.5	0.0%
	FP	2,789	434.7	95.2	-78.1%	255.3	53.0	-79.3%
	1P+FP	30,131	109.7	90.3	-17.7%	61.9	50.4	-18.5%
HGB	1P	21,925	77.1	77.1	0.0%	43.6	43.6	0.0%
	FP	2,221	350.8	87.5	-75.1%	215.1	48.3	-77.5%
	1P+FP	24,440	102.8	84.6	-17.7%	60.3	48.8	-19.1%
DFW & HGB	1P	126,950	76.9	76.9	0.0%	42.6	42.6	0.0%
	FP	12,609	322.3	92.3	-71.4%	190.6	50.3	-73.6%
	1P+FP	141,470	103.4	85.3	-17.5%	58.8	47.7	-18.8%
TSI CO (%)								
DFW	1P	26,985	0.20	0.20	0.0%	0.22	0.22	0.0%
	FP	2,789	1.44	0.24	-83.5%	1.28	0.26	-79.7%
	1P+FP	30,131	0.30	0.23	-23.4%	0.30	0.24	-19.2%
HGB	1P	21,925	0.19	0.19	0.0%	0.21	0.21	0.0%
	FP	2,221	1.27	0.24	-81.4%	1.06	0.25	-76.5%
	1P+FP	24,440	0.29	0.22	-24.1%	0.29	0.23	-18.7%
DFW & HGB	1P	126,950	0.18	0.18	0.0%	0.21	0.21	0.0%
	FP	12,609	1.07	0.22	-79.3%	0.99	0.26	-73.8%
	1P+FP	141,470	0.28	0.21	-23.9%	0.29	0.24	-19.2%

Table V-3. 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%
	FP	56,643	1459	476	-67.3%	1303	381	-70.7%
	1P+FP	662,529	560	477	-14.7%	443	366	-17.4%

Table V-4. 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 V-5. 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	0.0%	42.10	42.10	0.0%
	FP	51,133	166.90	62.92	-62.3%	146.87	45.91	-68.7%
	1P+FP	540,337	77.43	67.79	-12.4%	54.91	45.57	-17.0%
HGB	1P	409,231	61.98	61.98	0.0%	40.79	40.79	0.0%
	FP	38,895	161.94	60.12	-62.9%	144.67	43.59	-69.9%
	1P+FP	457,187	72.97	64.44	-11.7%	52.07	43.62	-16.2%
DFW & HGB	1P	886,979	63.48	63.48	0.0%	41.49	41.49	0.0%
	FP	90,028	164.75	61.71	-62.5%	145.91	44.91	-69.2%
	1P+FP	997,524	75.38	66.26	-12.1%	53.61	44.67	-16.7%
ASM CO (%)								
DFW	1P	477,748	0.203	0.203	0.0%	0.147	0.147	0.0%
	FP	51,133	1.060	0.204	-80.8%	1.036	0.165	-84.1%
	1P+FP	540,337	0.305	0.226	-26.0%	0.253	0.172	-31.9%
HGB	1P	409,231	0.193	0.193	0.0%	0.145	0.145	0.0%
	FP	38,895	1.106	0.188	-83.0%	1.080	0.156	-85.6%
	1P+FP	457,187	0.289	0.212	-26.6%	0.244	0.167	-31.7%
DFW & HGB	1P	886,979	0.198	0.198	0.0%	0.146	0.146	0.0%
	FP	90,028	1.080	0.197	-81.8%	1.055	0.161	-84.7%
	1P+FP	997,524	0.298	0.219	-26.3%	0.249	0.170	-31.8%
ASM NOx (ppm)								
DFW	1P	477,748	472.77	472.77	0.0%	355.73	355.73	0.0%
	FP	51,133	1467.22	491.20	-66.5%	1,306.02	393.42	-69.9%
	1P+FP	540,337	584.82	494.10	-15.5%	462.93	378.18	-18.3%
HGB	1P	409,231	461.37	461.37	0.0%	351.51	351.51	0.0%
	FP	38,895	1441.50	472.61	-67.2%	1,292.90	378.06	-70.8%
	1P+FP	457,187	559.31	477.93	-14.6%	445.48	368.69	-17.2%
DFW & HGB	1P	886,979	467.51	467.51	0.0%	353.78	353.78	0.0%
	FP	90,028	1456.08	483.17	-66.8%	1,300.34	386.78	-70.3%
	1P+FP	997,524	573.13	486.69	-15.1%	454.93	373.83	-17.8%

Table V-6. 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	0.0%	43.76	43.76	0.0%
	FP	6,137	544.39	93.74	-82.8%	325.24	54.17	-83.3%
	1P+FP	72,472	111.86	90.28	-19.3%	62.35	49.37	-20.8%
HGB	1P	50,582	79.34	79.34	0.0%	43.07	43.07	0.0%
	FP	3,845	560.32	90.86	-83.8%	332.93	52.79	-84.1%
	1P+FP	55,123	109.45	87.73	-19.8%	61.04	48.18	-21.1%
DFW & HGB	1P	115,953	80.64	80.64	0.0%	43.46	43.46	0.0%
	FP	9,982	551.21	92.64	-83.2%	328.53	53.64	-83.7%
	1P+FP	127,595	110.81	89.18	-19.5%	61.78	48.86	-20.9%
TSI CO (%)								
DFW	1P	65,371	0.203	0.203	0.0%	0.217	0.217	0.0%
	FP	6,137	2.028	0.254	-87.5%	1.678	0.263	-84.3%
	1P+FP	72,472	0.320	0.235	-26.5%	0.310	0.242	-21.7%
HGB	1P	50,582	0.205	0.205	0.0%	0.214	0.214	0.0%
	FP	3,845	2.061	0.263	-87.2%	1.699	0.252	-85.2%
	1P+FP	55,123	0.316	0.233	-26.4%	0.303	0.236	-22.2%
DFW & HGB	1P	115,953	0.204	0.204	0.0%	0.215	0.215	0.0%
	FP	9,982	2.042	0.258	-87.4%	1.687	0.259	-84.7%
	1P+FP	127,595	0.319	0.234	-26.4%	0.307	0.239	-21.9%

Table V-7. 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	1.5%	40.52	40.52	0.0%
	FP	114,413	179.68	65.49	63.6%	155.22	46.44	70.1%
	1P+FP	1,356,858	74.33	64.70	13.0%	50.19	41.02	18.3%
HGB	1P	100,998	64.94	64.94	0.0%	41.30	41.30	0.0%
	FP	92,806	181.38	66.04	63.6%	156.80	46.73	70.2%
	1P+FP	1,093,804	74.82	65.03	13.1%	51.10	41.76	18.3%
DFW & HGB	1P	2,243,443	64.77	64.77	0.0%	40.87	40.87	0.0%
	FP	207,219	180.44	65.73	63.6%	155.93	46.57	70.1%
	1P+FP	2,450,662	74.55	64.85	13.0%	50.60	41.35	18.3%
ASM CO (%)								
DFW	1P	1,242,445	0.195	0.195	0.0%	0.132	0.132	0.0%
	FP	114,413	1.114	0.205	81.6%	1.047	0.160	84.8%
	1P+FP	1,356,858	0.272	0.196	28.1%	0.209	0.134	35.8%
HGB	1P	100,998	0.192	0.192	0.0%	0.133	0.133	0.0%
	FP	92,806	1.106	0.201	81.9%	1.043	0.158	84.9%
	1P+FP	1,093,804	0.269	0.193	28.5%	0.210	0.135	35.8%
DFW & HGB	1P	2,243,443	0.193	0.193	0.0%	0.132	0.132	0.0%
	FP	207,219	1.110	0.203	81.7%	1.045	0.159	84.8%
	1P+FP	2,450,662	0.271	0.194	28.3%	0.210	0.135	35.8%
ASM NOx (ppm)								
DFW	1P	1,242,445	434.52	434.52	0.0%	307.34	307.34	0.0%
	FP	114,413	1297.32	462.90	64.3%	1,088.42	351.34	67.7%
	1P+FP	1,356,858	507.27	436.91	13.9%	373.20	311.05	16.7%
HGB	1P	100,998	432.88	432.88	0.0%	311.56	311.56	0.0%
	FP	92,806	1261.82	463.48	63.3%	1061.95	352.96	66.8%
	1P+FP	1,093,804	503.21	435.47	13.5%	375.23	315.07	16.0%
DFW & HGB	1P	2,243,443	433.79	433.79	0.0%	309.22	309.22	0.0%
	FP	207,219	1281.42	463.16	63.9%	1076.56	352.07	67.3%
	1P+FP	2,450,662	505.46	436.27	13.7%	374.11	312.85	16.4%

Table V-8. 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	0.0%	35.737	35.737	0.0%
	FP	12,806	472.859	85.459	81.9%	266.783	47.949	82.0%
	1P+FP	177,198	96.612	68.615	29.0%	52.434	36.620	30.2%
HGB	1P	133,775	66.152	66.152	0.0%	35.501	35.501	0.0%
	FP	9,633	452.337	83.524	81.5%	263.543	47.361	82.0%
	1P+FP	143,408	92.093	67.319	26.9%	50.819	36.298	28.6%
DFW & HGB	1P	298,167	66.787	66.787	0.0%	35.631	35.631	0.0%
	FP	22,439	464.049	84.628	81.8%	265.392	47.697	82.0%
	1P+FP	320,606	94.591	68.035	28.1%	51.712	36.476	29.5%
TSI CO (%)								
DFW	1P	164,392	0.180	0.180	0.0%	0.175	0.175	0.0%
	FP	12,806	1.677	0.274	83.7%	1.269	0.246	80.6%
	1P+FP	177,198	0.288	0.187	35.2%	0.254	0.180	29.1%
HGB	1P	133,775	0.183	0.183	0.0%	0.173	0.173	0.0%
	FP	9,633	1.699	0.269	84.2%	1.261	0.236	81.3%
	1P+FP	143,408	0.284	0.188	33.8%	0.246	0.177	28.0%
DFW & HGB	1P	298,167	0.181	0.181	0.0%	0.174	0.174	0.0%
	FP	22,439	1.686	0.272	83.9%	1.266	0.242	80.9%
	1P+FP	320,606	0.286	0.187	34.6%	0.250	0.179	28.6%

B. 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 Texas 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 (87% of the fleet) go through the Texas 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 Texas 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 program areas to determine the Annual I/M Benefit produced by the Texas 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 Texas 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 Texas I/M program that is independent of the program itself.

Preparation of RS Data – In this task, the RS data were collected in the DFW and HGB program areas to evaluate the Annual I/M Benefit. The goal was to use the RS data already being collected by the DPS as an independent means of measuring the benefit. The RS data provided by DPS started out with about 2.3 million records, collected between July 1, 2013, and December 31, 2015, statewide. After records from the El Paso and Austin I/M program areas were removed from the dataset, there were 1.9 million remaining RS records: 0.9 million records collected in the HGB program area and 1.0 million records collected in the DFW program area.

The remote sensing contractor matched the RS records to registration records in the weeks after they were collected, so that matching process did not have to be performed for this analysis. The match of RS records to registration records provided a VIN (wherever a successful match was made) that ERG could then match to the TIMS dataset. The RS records provided to ERG also contained vehicle information from the match to the registration dataset, including model year, make, and model. This information, in addition to the vehicle information in the TIMS dataset, can be used to characterize the on-road fleet for the Comprehensive Method [Reference 2] calculations.

The RS records provided to ERG by DPS were already checked for validity by the RS data collection contractor. Therefore, there was no additional check made for the validity of the values within each of the RS data fields. However, a filter on the vehicle specific power (VSP) was applied, to remove vehicles that happened to be observed while under very high or very low loads. Any records with a VSP outside the range of 5-25 kilowatt per ton were removed from the dataset. This left 1.2 million records in the dataset: 660,000 records in the DFW program area and 580,000 records in the HGB program area.

It was found that the number of RS observations collected per month decreased dramatically during the period of analysis: almost 50% of the total records provided to ERG were collected during the last six months of 2013, with the remaining records collected over all 24 months of 2014 and 2015. This will result in much smaller groups of vehicles when the RS observations are paired with close-in-time I/M inspections.

Calculation of the Annual I/M Benefit – The calculation of the Annual I/M Benefit was done using the Comprehensive Method outlined by the EPA. [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 program area and in Figures 5-4 through 5-6 for the DFW program 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 V-1. Average RS HC Versus Month from the I/M Test RS Readings from the HGB Program Area

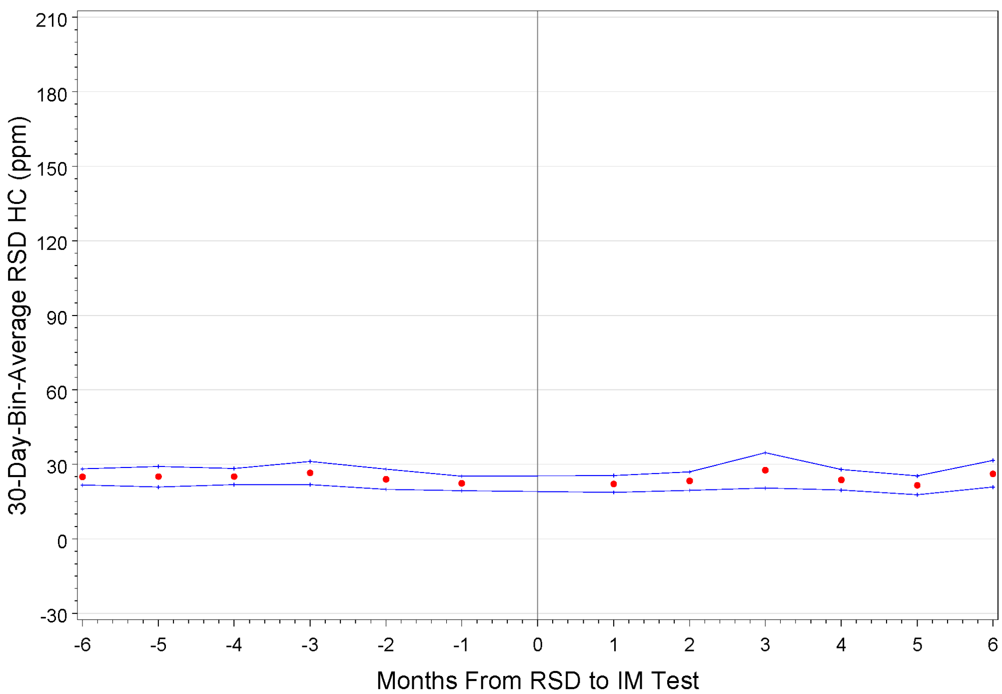


Figure V-2. Average RS CO Versus Month from the I/M Test RS Readings from the HGB Program Area

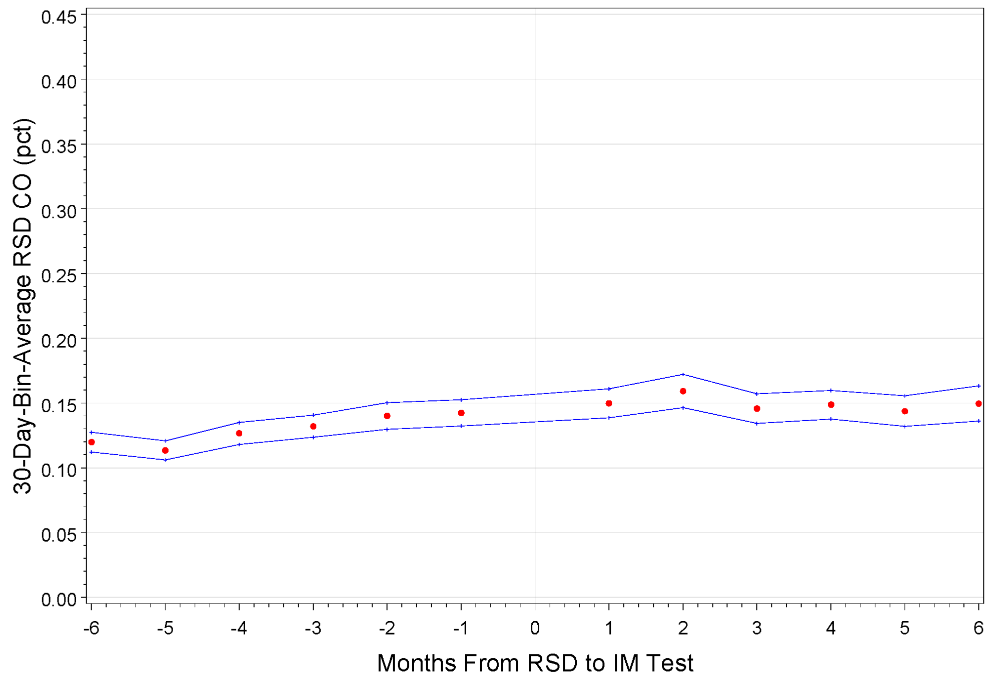


Figure V-3. Average RS NO_x Versus Month from the I/M Test RS Readings from the HGB Program Area

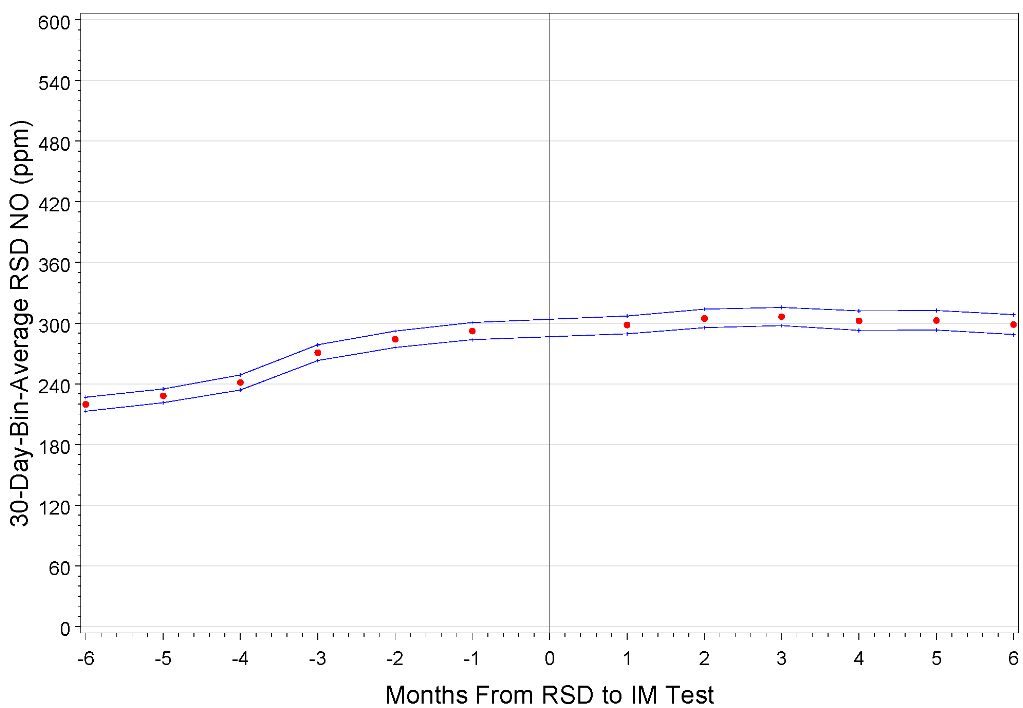


Figure V-4. Average RS HC Versus Month from the I/M Test RS Readings from the DFW Program Area

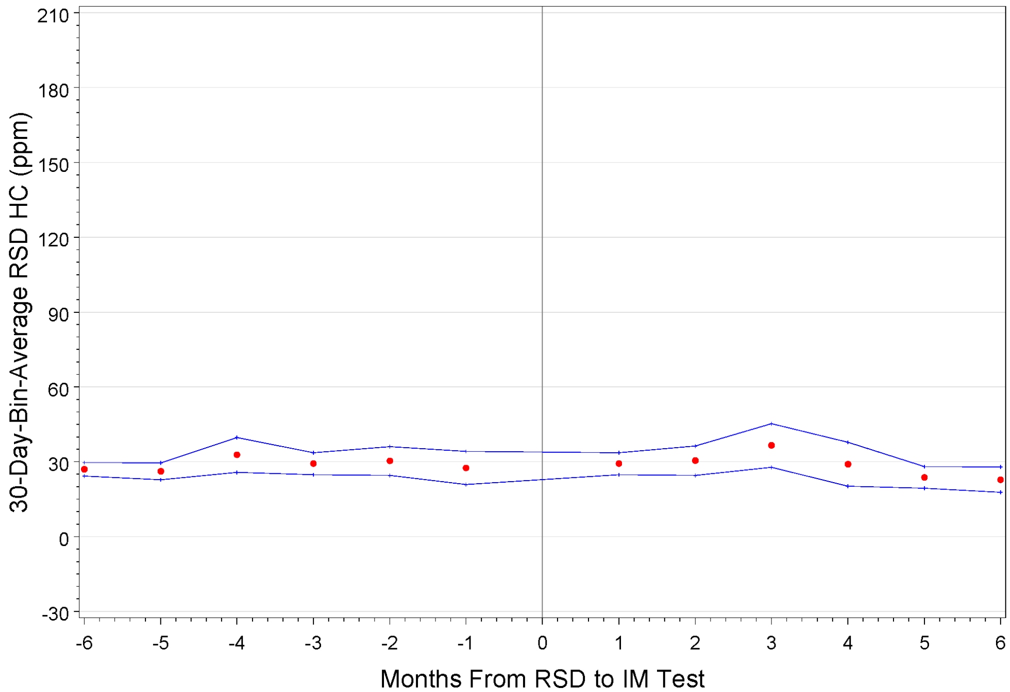


Figure V-5. Average RS CO Versus Month from the I/M Test RS Readings from the DFW Program Area

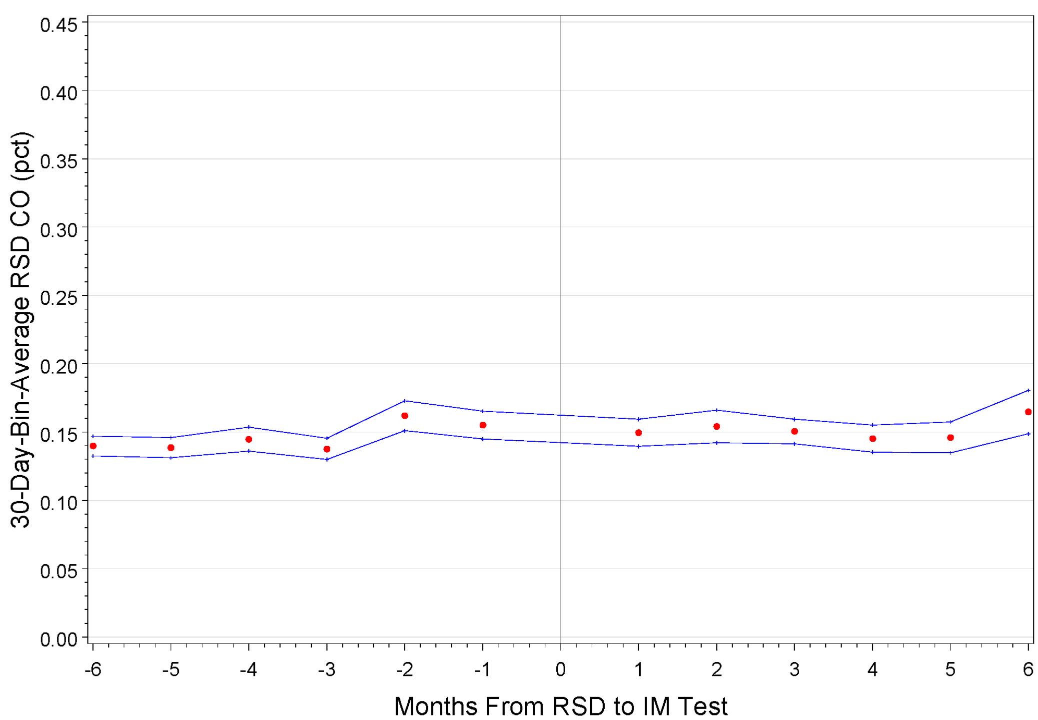
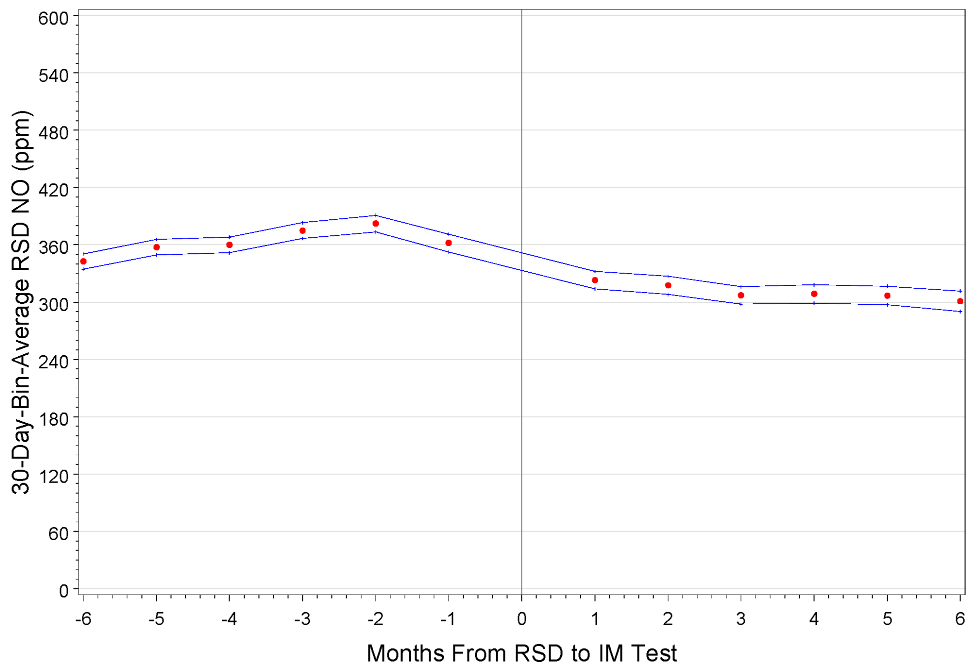


Figure V-6. Average RS NO_x Versus Month from the I/M Test RS Readings from the DFW Program Area



It is difficult to assess the impact of I/M testing from these figures as the HC readings are relatively constant around 30 ppm for both program areas, the CO readings are also similar in the HGB and DFW program areas in the range of 12-15 ppm; however, the NOx values are somewhat different with the HGB program area in the range of 220-300 ppm and the DFW program area between 300-350 ppm. 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 V-9 shows the number of records in the RS-matched-with-TIMS dataset (for both HGB and DFW program areas) that fall into each I/M sequence category. The sample sizes are for the total number of I/M vehicles matched to RS records, but they are not necessarily the same vehicle before and after the I/M test. The table clearly demonstrates that the 1P and FP I/M sequence categories dominate the Texas I/M program. At this point, the separate effects of the 1P and FP categories are examined.

Table V-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)	212,551	94.9%	269,810	95.0%
Fail Initial (1F)	543	0.2%	863	0.3%
Fail Initial, Fail Final (FF)	66	0.0%	128	0.0%

Fail Initial, Pass Final (FP)	10,781	4.8%	13,266	4.7%
Other Misc. Sequences	9	0.0%	23	0.0%
Total	223,950	100.0%	284,090	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 program 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 95% of the vehicles in the HGB program 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 4.8% of the vehicles in the HGB program 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 Texas 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 4.8% of the HGB fleet. An additional 94.9% 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 program area; therefore, they were not included here to conserve space.

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

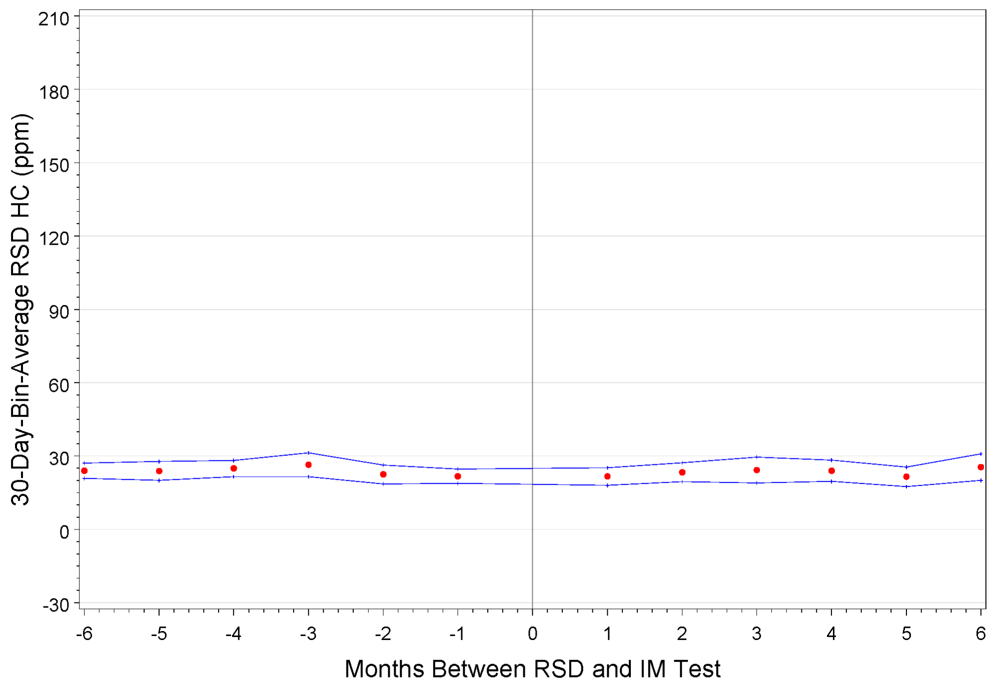


Figure V-8. Average RS HC vs. Month After the I/M Test for HGB Vehicles with I/M Sequence Category = FP

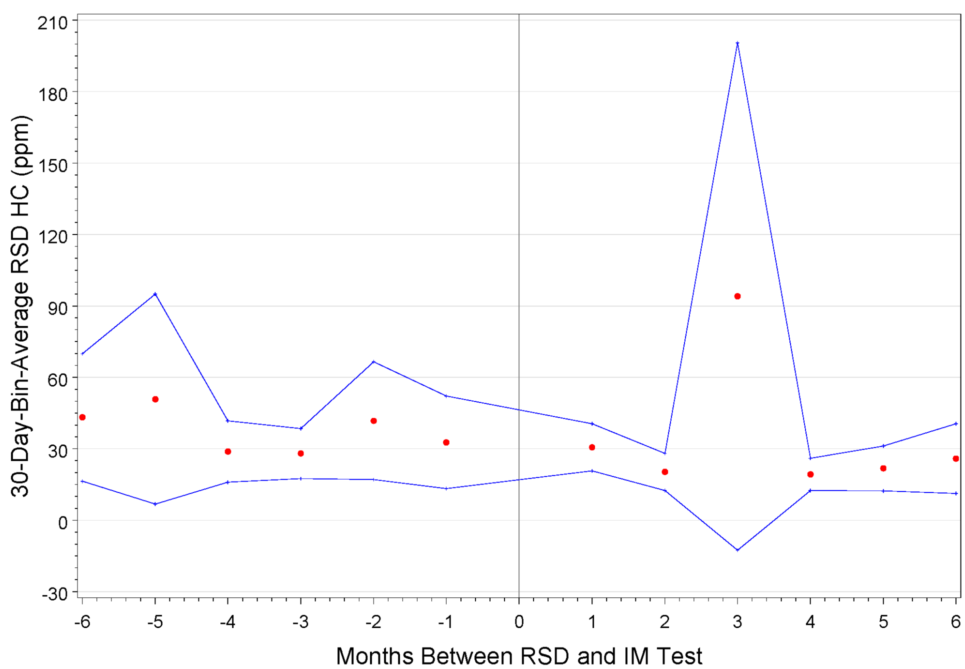


Figure V-9. Average RS CO vs. Month After the I/M Test for HGB Vehicles with I/M Sequence Category = 1P

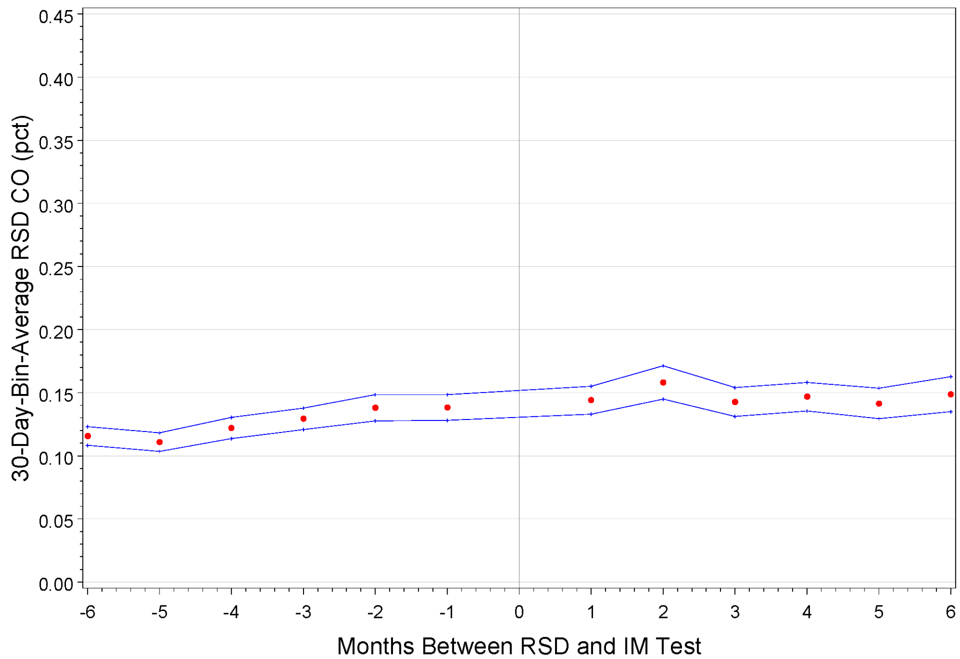


Figure V-10. Average RS CO vs. Month After the I/M Test for HGB Vehicles with I/M Sequence Category = FP

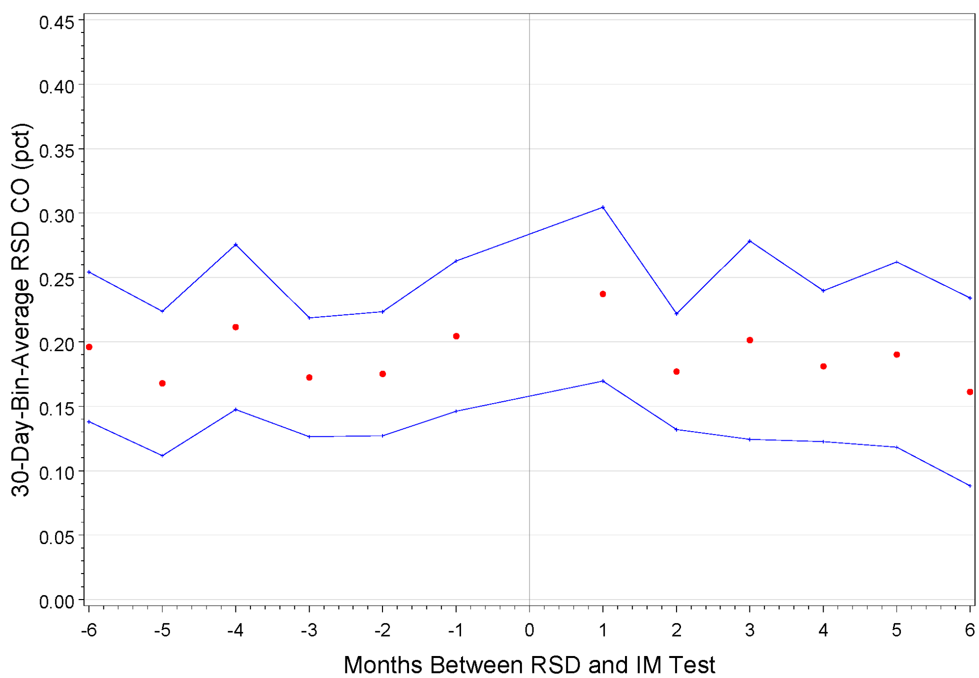


Figure V-11. Average RS NO_x vs. Month After the I/M Test for HGB Vehicles with I/M Sequence Category = 1P

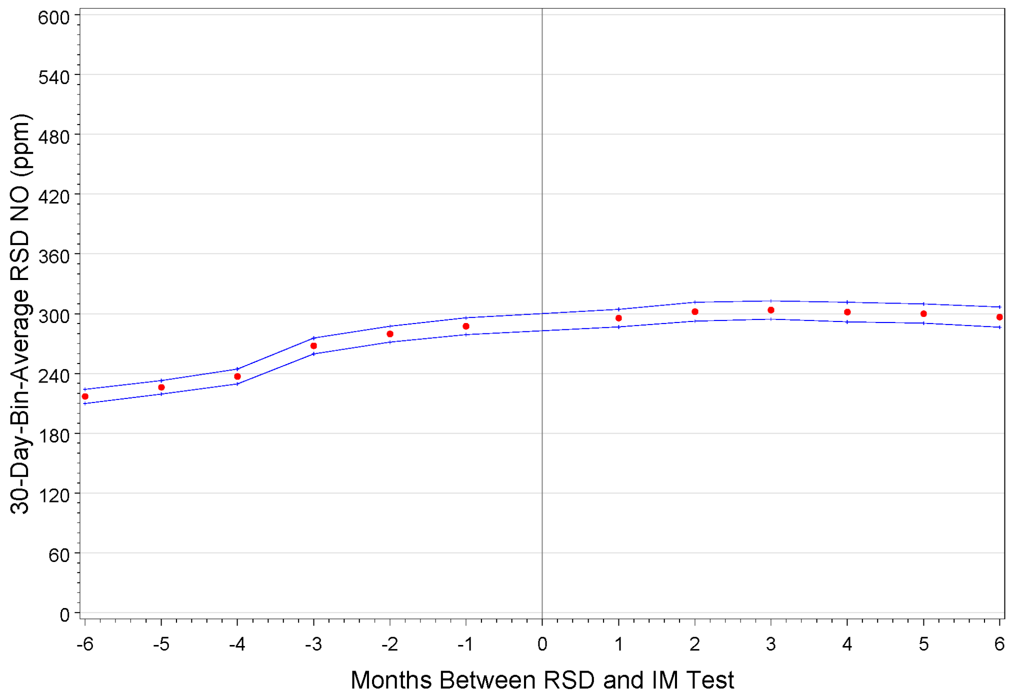
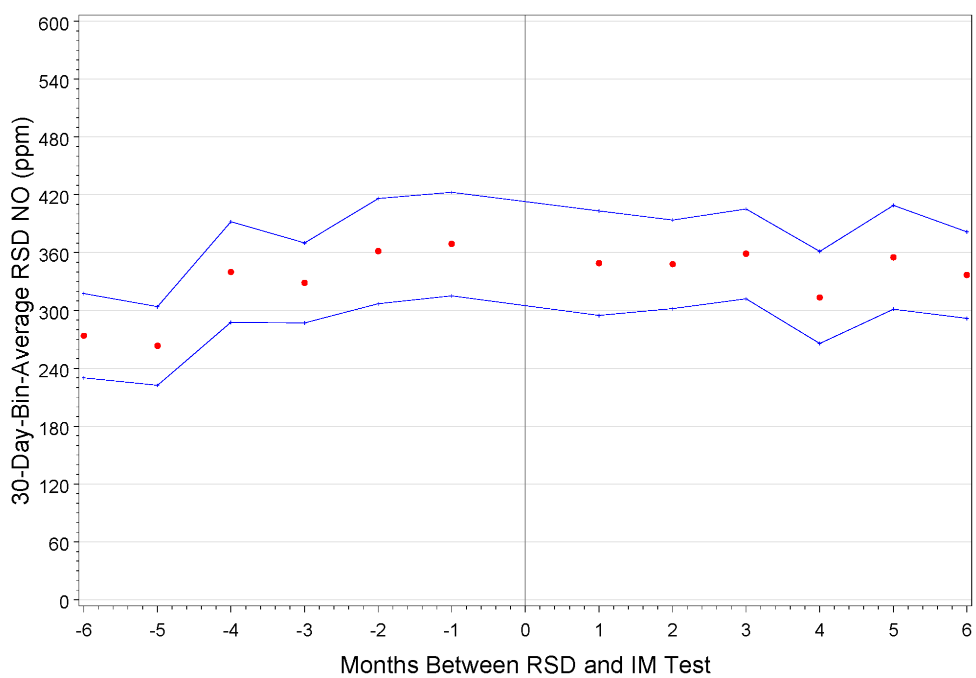


Figure V-12. Average RS NO_x vs. Month After the I/M Test for HGB Vehicles with I/M Sequence Category = FP



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.

It is important to note again that the RS data for this analysis of 2014-2015 TIMS data was largely collected toward the end of 2013. Therefore, when RS/I/M pairs are limited to those with the RS and I/M observations within three months of each other, the dataset size is greatly reduced. There are about one third as many observations to work with in this analysis, as there were the last time this analysis was done in 2014 for 2012-2013 TIMS data.

The calculations for the before and after I/M RS averages were done for the entire RS matched TIMS 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 matched set of RS vehicles, 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 program areas in Figures 5-13 through 5-24. The bars show the mean emissions levels and the error bars show the 95% confidence level uncertainties for the respective averages.

The plots for the FP vehicles show that in most cases the emissions of FP vehicles decrease, especially for the older model year groups; however, in many cases the decrease is not statistically significant – even with thousands of RS observations in the FP category. The plots for the 1P vehicles 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 tens of thousands of RS observations in the 1P category.

Figure V-13. Average 1P RS HC by Model Year Group Before and After I/M Test for HGB Vehicles

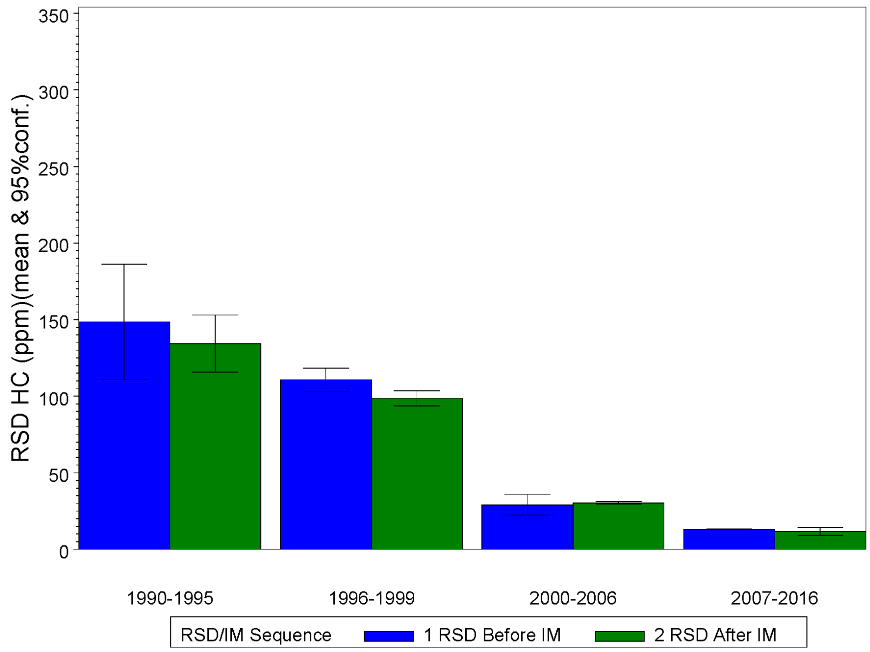


Figure V-14. Average 1F RS HC by Model Year Group Before and After I/M Test for HGB Vehicles

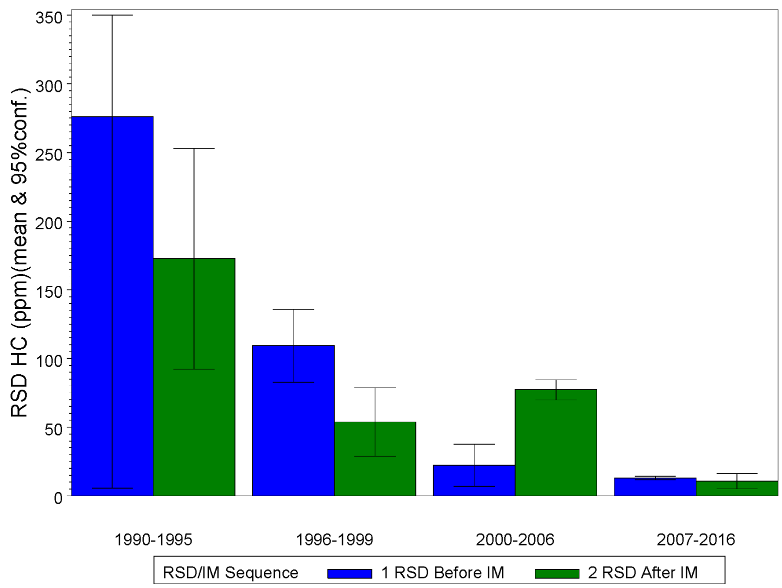


Figure V-15. Average 1P RS HC by Model Year Group Before and After I/M Test for DFW Vehicles

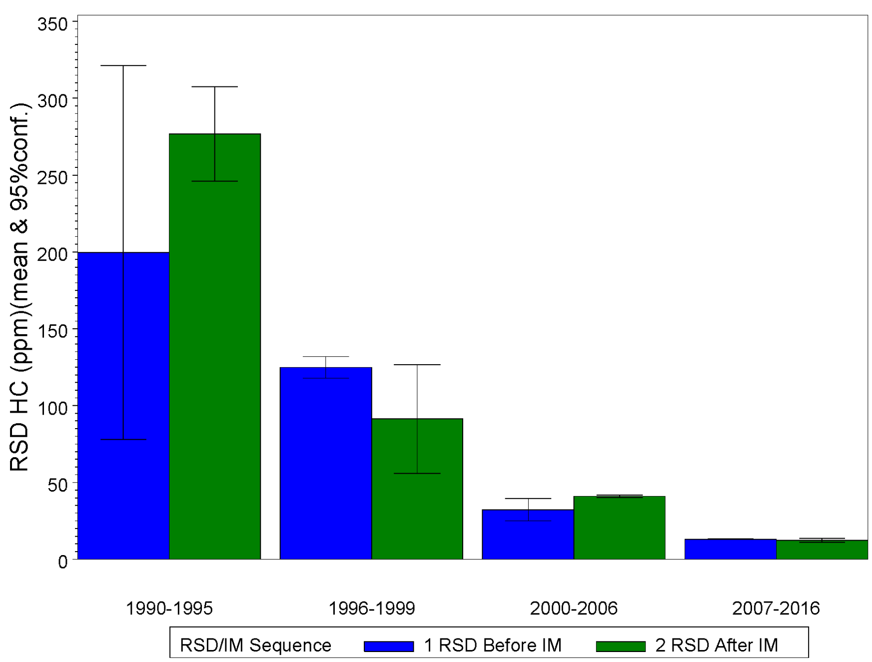


Figure V-16. Average FP RS HC by Model Year Group Before and After I/M Test for DFW Vehicles

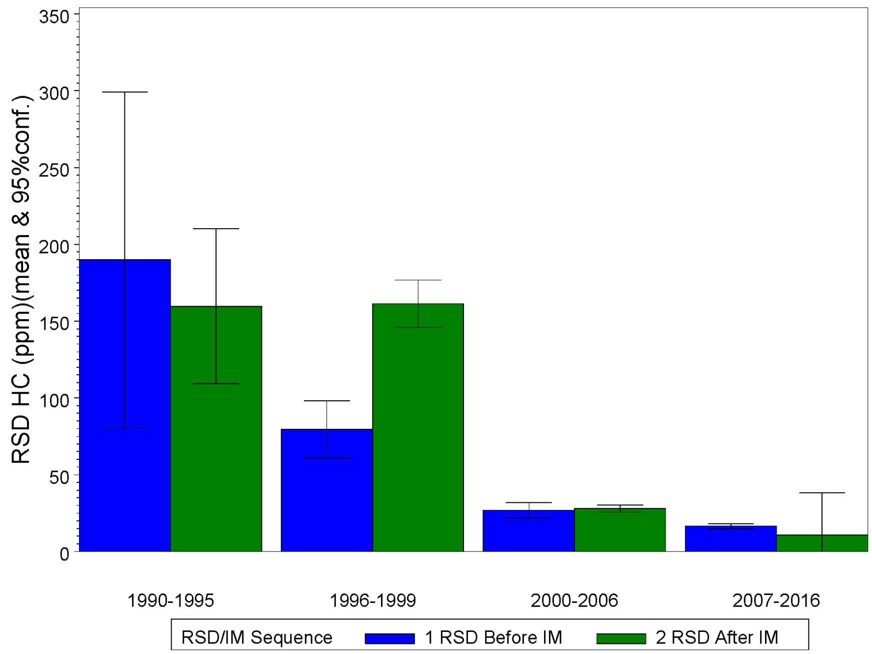


Figure V-17. Average 1P RS CO by Model Year Group Before and After I/M Test for HGB Vehicles

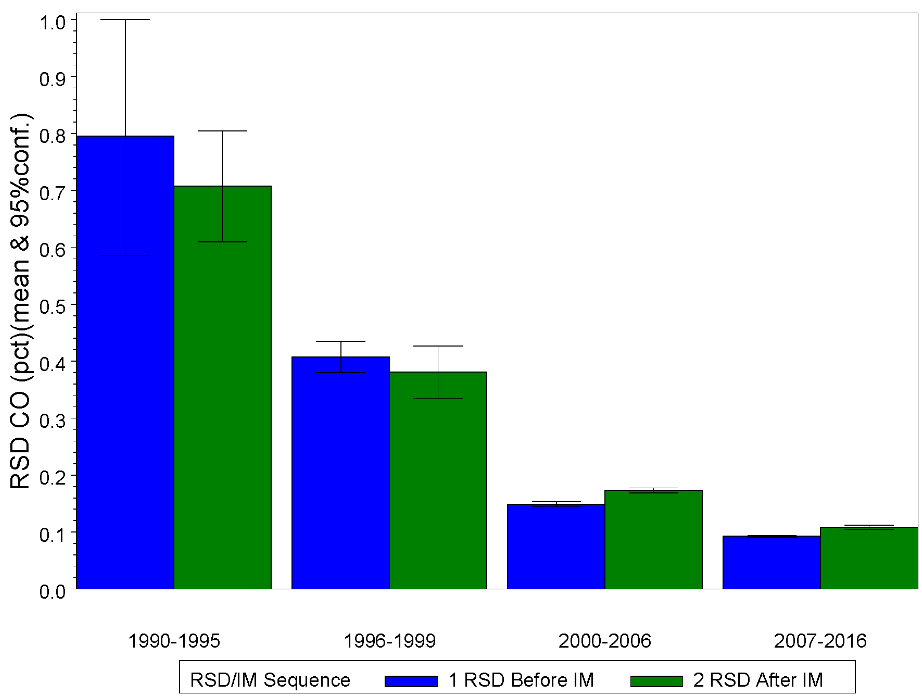


Figure V-18. Average FP RS CO by Model Year Group Before and After I/M Test for HGB Vehicles

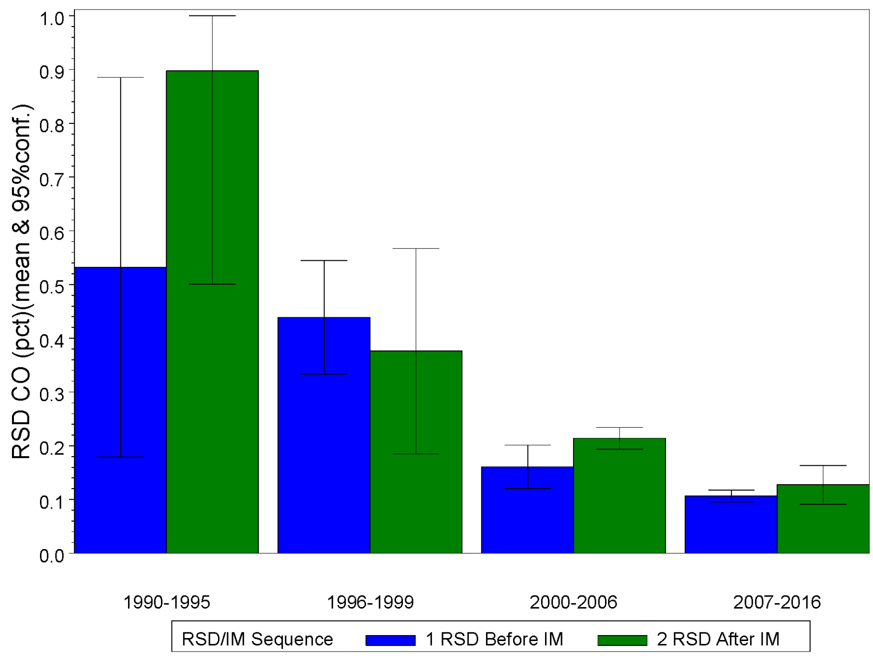


Figure V-19. Average 1P RS CO by Model Year Group Before and After I/M Test for DFW Vehicles

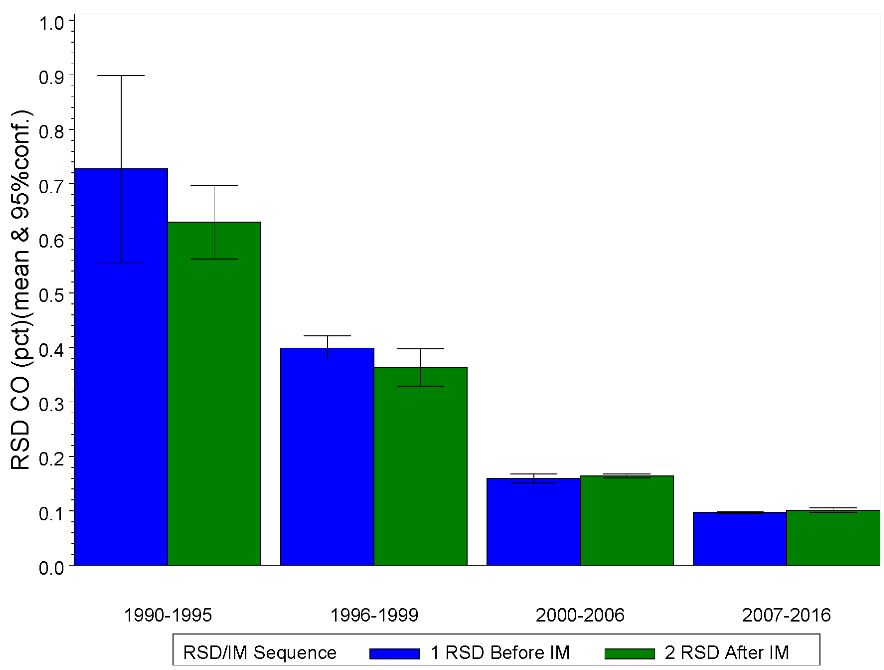


Figure V-20. Average FP RS CO by Model Year Group Before and After I/M Test for DFW Vehicles

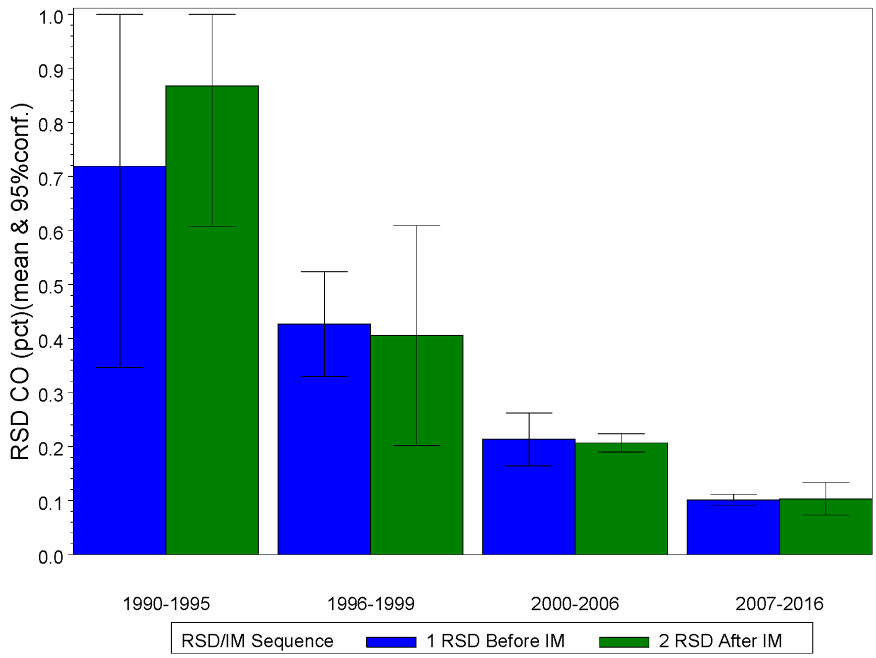


Figure V-21. Average 1P RS NO_x by Model Year Group Before and After I/M Test for HGB Vehicles

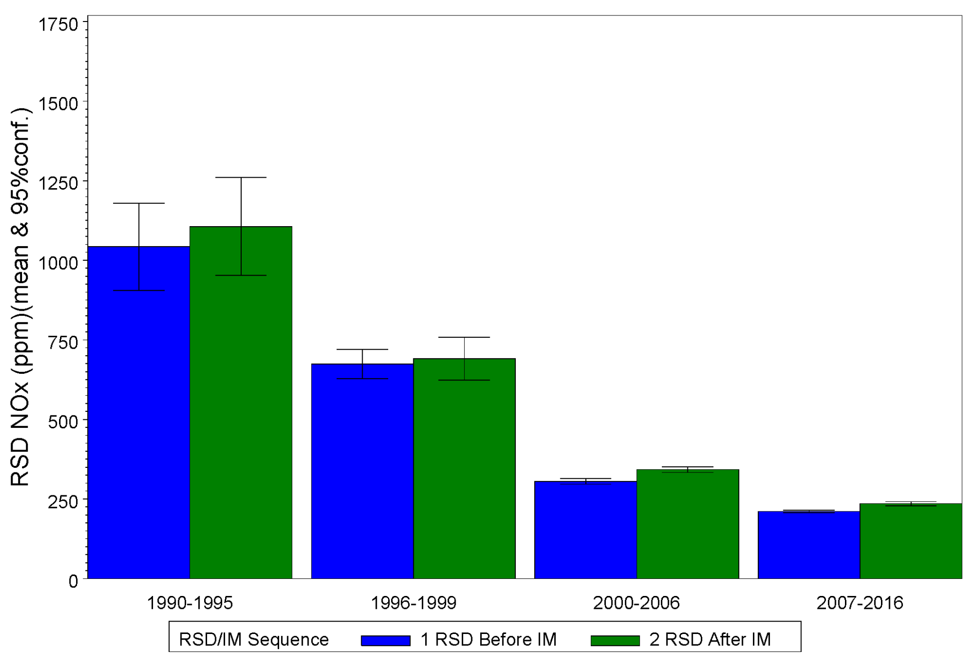


Figure V-22. Average FP RS NO_x by Model Year Group Before and After I/M Test for HGB Vehicles

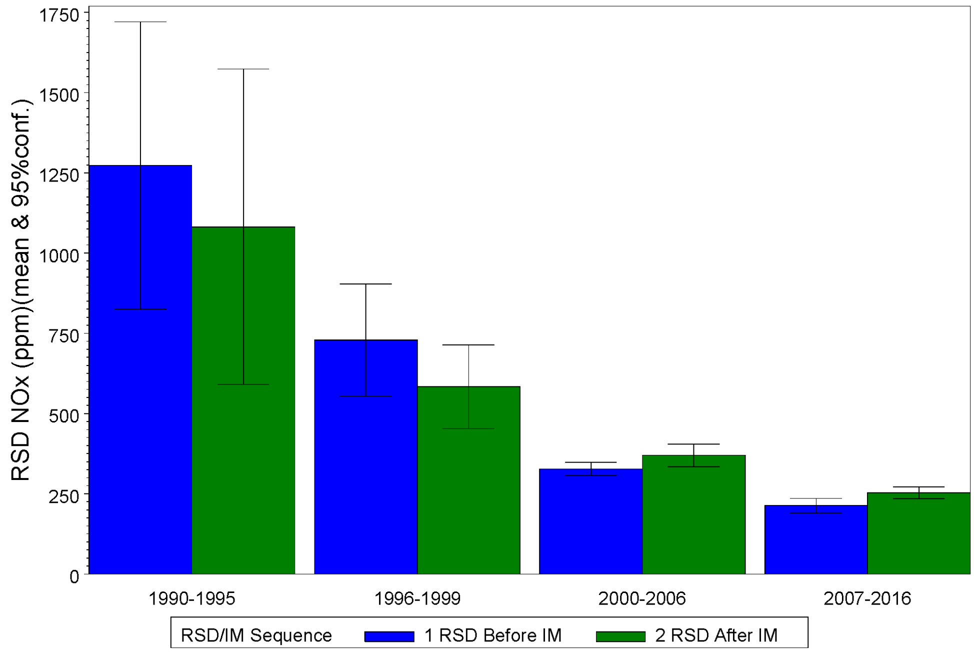


Figure V-23. Average 1P RS NO_x by Model Year Group Before and After I/M Test for DFW Vehicles

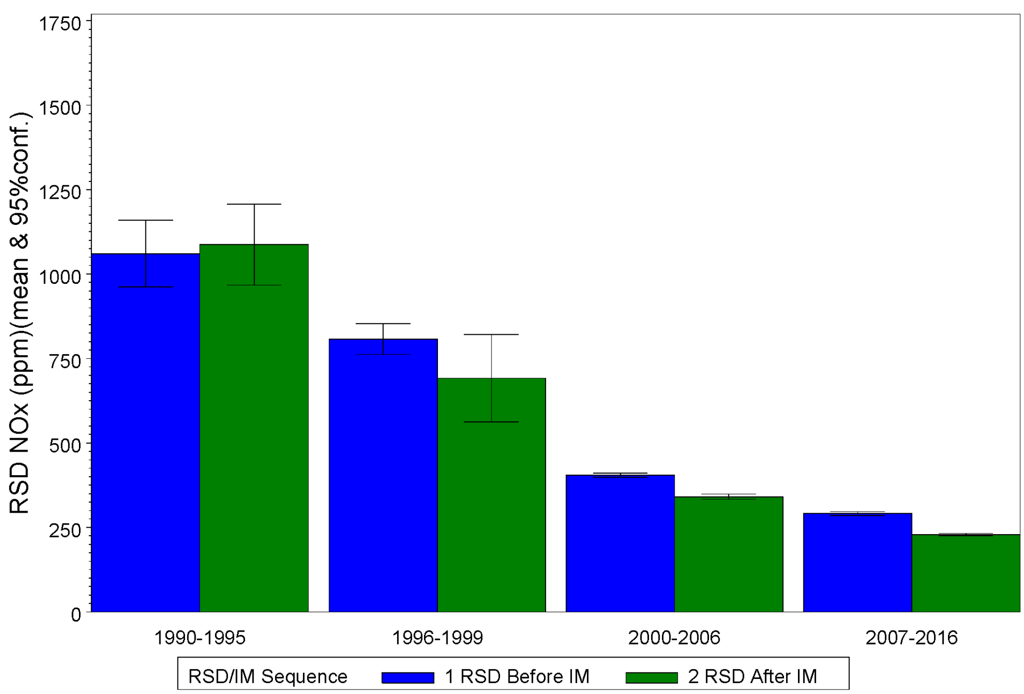
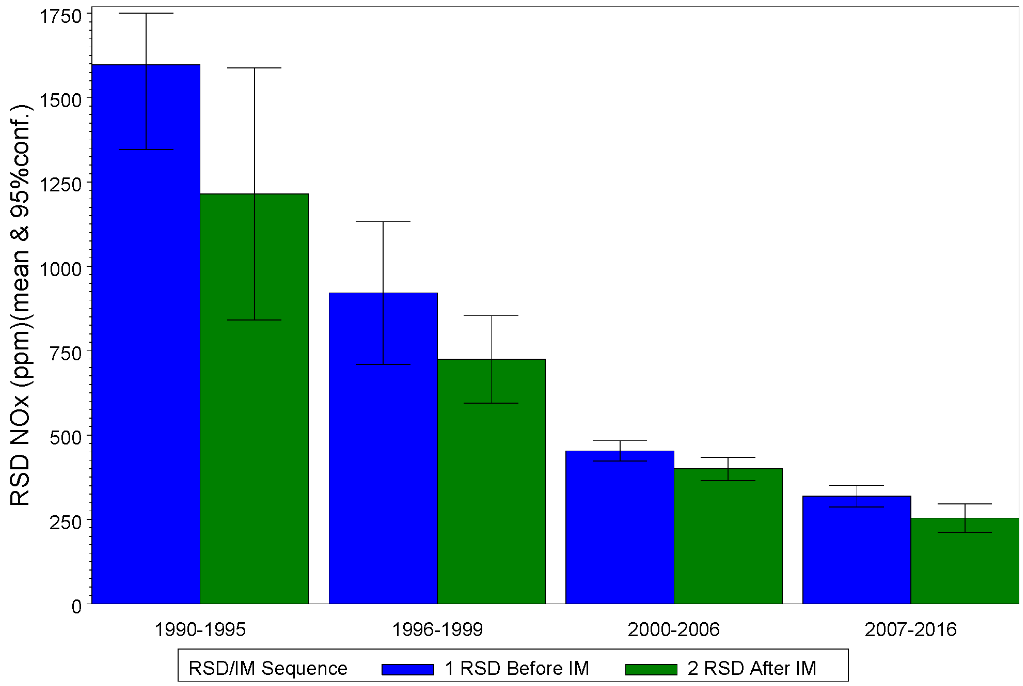


Figure V-24. Average FP RS NO_x by Model Year Group Before and After I/M Test for DFW Vehicles



4

The RS average concentrations shown in the figures above are summarized in Tables 5-10 and 5-11. The values in Table V-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 V-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 5-18, it can be seen that the changes are almost always within the error bars, and therefore, not statistically significant.

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

HGB Program 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
1990-1995	276	173	0.53	0.90	1273	1082
1996-1999	109	54	0.44	0.38	729	584
2000-2006	22	77	0.16	0.21	327	370
2007-2016	13	11	0.11	0.13	213	253
DFW Program 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
1990-1995	190	160	0.72	0.87	1597	1214
1996-1999	80	161	0.43	0.41	921	725
2000-2006	27	28	0.21	0.21	453	399
2007-2016	17	11	0.10	0.10	319	254

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

HGB Program 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
1990-1995	148	134	0.80	0.71	1043	1107
1996-1999	111	99	0.41	0.38	675	691
2000-2006	29	30	0.15	0.17	306	343
2007-2016	13	12	0.09	0.11	211	235
DFW Program 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
1990-1995	200	277	0.73	0.63	1060	1087
1996-1999	125	91	0.40	0.36	808	692
2000-2006	32	41	0.16	0.16	405	341
2007-2016	13	12	0.10	0.10	291	229

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. These results are then combined to calculate the net overall effect on emissions of the I/M program. 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 V-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. The overall fleet results for the annual I/M benefit are shown in Table V-13. In Table V-13, the following abbreviations are used:

- wrt- with respect to
- Obs- observations
- CLM- confidence limit

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

Model Year Group	DFW Program Area				HGB Program 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	%
1990-1995	4,340	1.5%	186,644	2.9%	2,888	1.3%	163,727	2.8%
1996-1999	17,069	6.0%	528,052	8.3%	11,935	5.3%	473,320	8.0%
2000-2006	103,014	36.3%	2,422,791	38.1%	74,168	33.1%	2,206,585	37.2%
2007-2016	159,667	56.2%	3,219,494	50.6%	134,959	60.3%	3,092,461	52.1%
Total	284,090	100.0%	6,356,981	100.0%	223,950	100.0%	5,936,093	100.0%

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

I/M Program Area	I/M Sequence Category	RS wrt I/M	Number of Obs	RS HC (ppm)				RS CO (%)				RS NOx (ppm)			
				Mean	Upper CLM	Lower CLM	Change (%)	Mean	Upper CLM	Lower CLM	Change (%)	Mean	Upper CLM	Lower CLM	Change (%)
DFW + HGB	1P + FP	Before	41,343	27.2	29.6	24.9		0.14	0.15	0.14		333	337	329	
		After	47,064	28.2	30.6	25.8	3.5%	0.15	0.16	0.15	5.6%	309	313	306	-7.0%
DFW + HGB	1P	Before	37,687	26.9	29.3	24.5		0.14	0.14	0.14		328	333	324	
		After	42,820	27.5	29.8	25.1	2.1%	0.15	0.15	0.14	5.4%	306	310	302	-6.9%
	FP	Before	1,828	34.1	41.8	26.5		0.19	0.22	0.16		424	448	399	
		After	2,122	42.7	60.7	24.7	25.2%	0.21	0.23	0.18	8.1%	382	402	361	-9.9%
DFW	1P + FP	Before	23,126	29.1	32.5	25.6		0.15	0.15	0.14		378	384	372	
		After	25,906	31.6	35.3	27.9	8.6%	0.15	0.16	0.14	1.4%	315	320	310	-16.7%
HGB	1P + FP	Before	18,217	24.9	28.0	21.9		0.14	0.14	0.13		277	282	271	
		After	21,158	24.2	27.1	21.3	-3.0%	0.15	0.16	0.14	11.4%	303	308	297	9.4%
DFW	1P	Before	21,096	28.9	32.5	25.3		0.15	0.15	0.14		373	379	367	
		After	23,594	31.3	35.1	27.4	8.3%	0.15	0.15	0.14	1.4%	311	316	305	-16.7%
	FP	Before	1,015	33.8	42.7	24.9		0.21	0.25	0.16		489	524	454	
		After	1,156	38.6	53.9	23.4	14.4%	0.21	0.25	0.18	1.6%	408	437	378	-16.6%
HGB	1P	Before	16,591	24.5	27.6	21.3		0.13	0.14	0.13		273	279	268	
		After	19,226	23.0	25.5	20.6	-5.9%	0.15	0.16	0.14	11.0%	300	305	295	9.8%
	FP	Before	813	34.6	47.6	21.5		0.17	0.21	0.14		344	378	311	
		After	966	47.4	81.9	12.9	37.3%	0.20	0.24	0.17	17.9%	352	380	323	2.1%

VI. 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 VI.A)
    - VIN from vehicle doesn't match OBD-downloaded VIN (VI.A.1)
    - Powertrain Control Module (PCM), Parameter ID (PID), VIN, and/or readiness status changes between inspections (VI.A.2)
  - Tailpipe Inspection Manipulation (Section VI.B)
    - Clean-piping: a passing re-test follows a failed inspection within only a few minutes (VI.B.1)
    - Switching vehicle from ASM to TSI in order to pass inspection (VI.B.2)
    - Switching from LD (<8,500 GVWR) to HD (>8,500 GVWR) in order to pass inspection (VI.B.3)
    - Stations with a very high or very low ASM or OBD fail rate (VI.B.4)
- Errors of Omission:
  - Use of analyzers of less-than-optimal functionality (Section VI.C)
  - Performing inspections on analyzers with a high degree of drift (VI.C.1)
  - Performing inspections right before failing a span gas audit (VI.C.2)
  - Performing only one of the four calibrations that are required every 72-hours, instead of all four (VI.C.3)
- Data entry issues (Section VI.D)
  - Consistently entering repair type as "Misc" (VI.D.1)
  - Consistently entering repair cost as $0 (VI.D.2)
  - VIN Check digit errors (VI.D.3)
  - Anomalous inspection sequences (other than 1P or FP) (VI.D.4)

- — Anomalous test results (Section VI.E)
- — ASM or TSI Inspection results with greater than 16% CO_2 (VI.E.1)
- — ASM or TSI Inspection results with greater than 20.5% O_2 (VI.E.2)
- — ASM or TSI inspections with high DCF values (VI.E.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 in the previous 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 VI.F.

Inspection stations that are operated by the state tend to exhibit a substantially different range of results than the majority of privately-operated stations, skewing the distribution of the results. These stations may be identified by the "G" within the station identification number, and were excluded from all of the following analysis.

A. 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. Information downloaded from the OBD system during an inspection may be used to identify possible clean-scanning activities. Parameters collected during an OBD inspection establish an electronic signature. If test parameters do not match the parameters expected for the vehicle under test, it's possible that clean-scanning has occurred.

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

A majority of the vehicles receiving OBD tests report the vehicle identification number (VIN) electronically. These VINs are referred to as eVINs. All 2005 and newer vehicles are required to report eVINs; a large number of 2004 and older models also report eVINs. 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 (or "eVIN") are recorded in each vehicle inspection record of the TIMS.

For this analysis, all 14 million OBD inspection records for the 2-year evaluation period were used. For each of these remaining records, the OBD-downloaded eVINs were compared with VINs entered (either via keyboard or barcode scan) during the vehicle inspection. Of these, about 29%, or 4 million records, contain no valid eVIN (either the eVIN is entirely blank, is entered as "N/A", or is less than 17 digits long). Of the remaining 10 million, approximately 1.2% of these records (123,794 records) were found to have VIN-to-eVIN discrepancies. Manual investigation of these records showed a number of the OBD eVINs or entered VINs were invalid (for example, the VIN contained characters that are not allowed in a VIN, or combinations of characters not expected to be in a VIN, such as "XXXX"), and some mismatches were also due to VIN errors in the vehicle test record. An investigation of the VIN discrepancies, shown in Table VI-1, revealed that vehicles from the early years of OBD (1996-1999) had very high rates of discrepancies, with as many as 89% 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 eVIN 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.

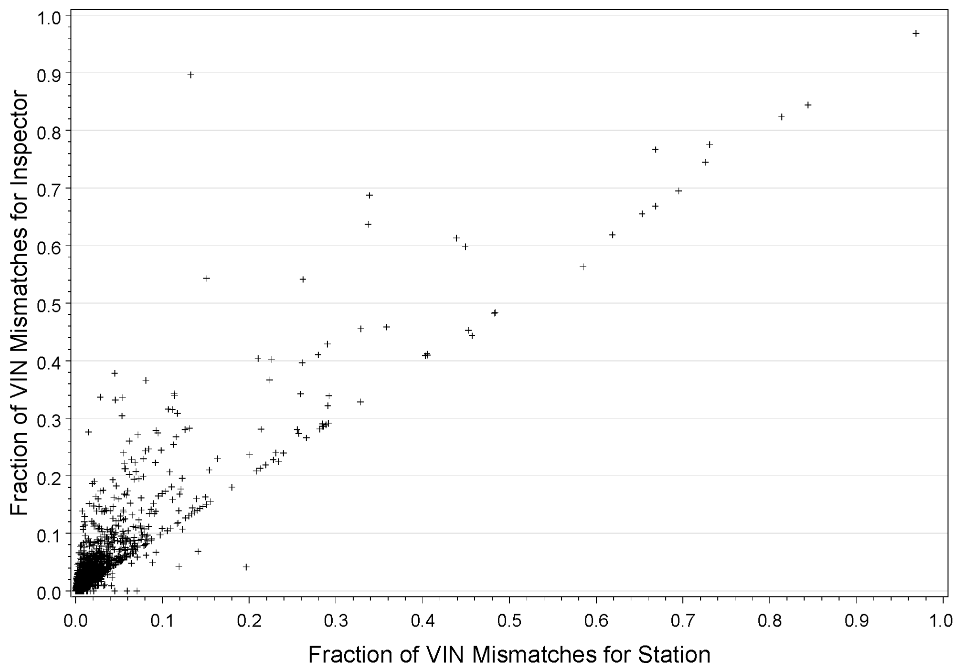
Table VI-1. Rates of OBD-Downloaded and Inspector-Entered VIN Discrepancies, by Model Year

Model Year	Number of OBD Inspections with VIN Mismatch	Percent of OBD Inspections with VIN Mismatch	Total Inspections With OBD VINs
1996	2,166	89.2%	2,427
1997	2,928	87.9%	3,331
1998	3,440	87.9%	3,913

Model Year	Number of OBD Inspections with VIN Mismatch	Percent of OBD Inspections with VIN Mismatch	Total Inspections With OBD VINs
1999	4,335	75.9%	5,714
2000	8,996	13.2%	68,260
2001	10,800	4.7%	232,237
2002	12,069	4.0%	300,582
2003	12,681	3.5%	361,045
2004	13,294	2.8%	467,007
2005	11,162	1.3%	828,588
2006	9,220	1.0%	919,145
2007	8,315	0.8%	1,089,658
2008	6,495	0.6%	1,102,695
2009	3,536	0.5%	739,822
2010	3,497	0.4%	890,804
2011	3,626	0.4%	1,006,966
2012	3,970	0.3%	1,166,572
2013	2,496	0.3%	818,345
2014	627	0.3%	189,662
2015	137	0.6%	24,337
2016	4	0.6%	668
ALL	123,794	1.2%	10,221,778

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 VI-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 VI-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 eVIN 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 VI-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 VI-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:				
1P48430	96.9%	159	148	100.0
1P43010	84.4%	1,175	979	100.0
2P48396	81.4%	204	82	100.0
1P43184	74.1%	108	42	99.9
2P39821	73.1%	2,066	822	99.9
1P46146	72.6%	241	64	99.9
2P48665	69.5%	187	108	99.9
2P48302	68.6%	118	28	99.8
1P45988	66.9%	356	119	99.8
1P45307	66.8%	2,102	1,389	99.8

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 re-tests 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 re-test were used, and only records where monitor readiness values were non-missing were used, reducing the dataset from 14 million OBD inspections to 1.4 million inspections. This includes 680,000 initial inspections, and 750,000 re-tests.

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 63% of the test records. The OBD VIN or the manually entered VIN was null in the remaining 37% 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 ID: The PCM ID was available in all but 18 of the test records. 46 unique PCM IDs were seen, but 48% of all PCM IDs had a value of "10". One other PCM ID

represented another 31% of records, three other PCM IDs each comprised an additional 2 to 4% of the test records, and the remaining test records were distributed among the other 41 PCM IDs. Because of this, as with the OBD VIN, use of PCM 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 most common PCM IDs).

- PID Count: 93 unique PID Count values were seen, and all but 311 OBD test records contained a value for PID Count. Six PID Count values were seen in 50% of all OBD test records, while the remaining test records contained one of the remaining 87 PID Count values.
- When the PCM ID and PID Count are looked at in combination, the three most common combinations comprise 12, 8, and 7% of inspections, with 813 combinations making up the remainder of inspections. Thus the combination of PCM 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: 41% not monitored, 59% monitored;
- Evaporative systems: 5% not monitored, 95% monitored;
- heated O2 systems: 3% not monitored, 97% monitored;
- secondary air systems: 93% not monitored, 7% monitored; and
- When the status of the four monitors is looked at together, two combinations of monitor status dominated the dataset, with 53% and 35% of vehicles. Smaller numbers of vehicles comprised the remaining 14 combinations and 12% 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 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 re-test 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 680,000 initial inspections and 750,000 re-tests. Retests that took place on an analyzer from a different manufacturer than the initial test were excluded from the results, leaving 670,000 re-tests for analysis. The results of the analysis were:

- 597,292 (89.2%) of re-tests had matches for both the electronic profile and the readiness profile between initial test and subsequent re-tests on the same analyzer. These tests very likely indicate compliant testing.
- 30,593 (4.6%) of re-tests had a mismatch for both the electronic profile info and the readiness profile, between the initial test and at least one re-test 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).

- 1,513 (0.2%) of re-tests had a "readiness profile" mismatch between the initial test and at least one re-test on the same analyzer, but the electronic profile matched between the initial test and all subsequent re-tests 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.
- 40,265 (6.0%) of re-tests had an electronic profile mismatch info between the initial test and at least one re-test on the same analyzer, but the "readiness profile" matched between the initial test and all subsequent re-tests on the same analyzer. Since the computer ID serves as a unique identifier for any vehicle, this information should always match for re-tests on the same vehicle. A mismatch could occur only in the following scenarios:
  - if another vehicle was substituted for a re-test (clean-scanning)
  - if an anomaly in the analyzer software interpreted the computer ID info two different ways on subsequent re-tests 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.

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

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

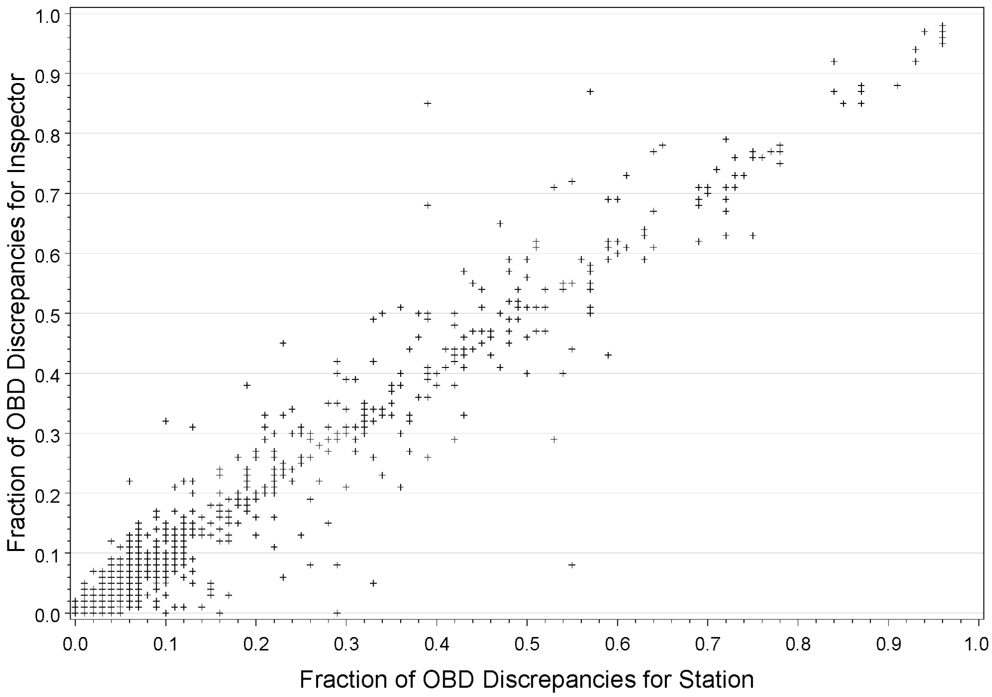
Re-test Match Scenario	Re-test-only Dataset
All match (compliant)	89.2 %
Readiness mismatch (ambiguous)	0.2 %
PCM ID info mismatch (fraud likely)	6.0 %
Both mismatch (fraud very likely)	4.6 %
Estimated % of clean-scanning	4% to 10%

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, 73% of the 5,011 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 re-test records for any one station was 1,232 records over the two-year period, and another 34 stations had more than 200 records with a mismatch. Some stations had mismatch rates as high as 90%.
- Over the two-year audit period, 34% of the 28,293 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 re-test records for any one inspector was 630 records over the two-year period, while an additional 18 inspectors had more than 200 mismatch re-test records. Inspector mismatch rates as high as 90% were seen.

The distribution of station and inspector mismatch rates is shown in Figure VI-2. The horizontal axis shows the fraction of re-test 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 re-test 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 VI-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 re-test inspections performed at that station that included both an electronic profile mismatch and a readiness profile mismatch. Stations with fewer than 100 OBD re-test 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 VI-4. Some electronic profile and/or readiness mismatches are to be expected, and as mentioned above, more than 73% of stations had at least one case of a mismatch. However, most of those stations had only one or a few mismatches. Overall, about 4.6% of re-test inspections resulted in a readiness profile and electronic profile mismatch. When stations with a mismatch in as many as 90% of their inspections are seen, one can start to suspect that something beyond the expected occasional difference is taking place.

Table VI-4. Stations with Highest Percent 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:			
1P44804	90.6%	192	100.0

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	89.2%	204	100.0
2P34213	86.2%	210	99.9
2P44831	83.4%	211	99.9
1P42519	76.7%	120	99.8
2P45301	75.0%	164	99.8
2P45651	71.8%	1,279	99.7
2P40511	69.4%	206	99.7
1P38625	67.5%	212	99.6
1P45442	64.6%	127	99.6

B. 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 re-test 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.

Short Time Interval Between Inspections

For inspection cycles that begin with a failing inspection, a re-test (or re-tests) 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 re-test. The dataset shows that many stations have one or a few cases of a passing re-test 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 OBD, TSI, and ASM inspections were considered. This left 14.9 million observations in the dataset. In addition, only time differences on re-test inspections that were conducted at the same inspection station as the initial inspection were used. This resulted in a dataset of about 656,672 re-test observations.

The distribution of the number of times that a failed initial inspection was followed by a passing re-test within 15 minutes at a given station over a 2-year period is listed in Table VI-5. The table shows that this happened rarely or never for most stations. However, for 64 stations, it happened 20 or more times (up to 99 times for the highest station, not shown in the table).

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

Number of Close-In-Time Retests	Number of Stations	Percent of Stations
0	1,780	35.7
1	969	19.4
2	639	12.8
3	396	7.9
4	300	6.0
5	200	4.0
6	170	3.4
7	109	2.2
8	72	1.4
9	79	1.6
10	49	1.0
11	37	0.7
12	24	0.5
13	17	0.3
14	15	0.3
15	23	0.5
16	14	0.3
17	4	0.1
18	9	0.2
19	7	0.1
20 or more	64	0.2
Total	4,973	100.0

The ten stations with the highest rate of close-in-time re-tests are listed in Table VI-6. The percentage was calculated from the number of close-in-time re-tests and the total number of re-tests, at that station. Stations that performed fewer than 100 re-test inspections over the 2-year period are excluded from the results. From the table, the highest ranked stations performed more than a third of their re-test inspections within the short time period of 15 minutes or less after the initial passed inspection.

Table VI-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
2P42264	43.8	88	201	100.0
1P00804	34.0	53	156	99.9
2P04162	33.5	87	260	99.9
1P32476	29.0	63	217	99.8
2P42938	27.8	30	108	99.8
1P35099	25.0	33	132	99.7
2P32413	22.8	38	167	99.7
1P37988	18.9	47	249	99.6
1P28958	17.6	29	165	99.6
2P42851	17.4	77	443	99.5

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 ASM inspection measures NO_x, but the TSI inspection does not, 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 490,000 observations in the dataset. Only inspection cycles where the initial inspection and the re-test inspection were conducted at the same station were used. This left about 52,000 re-tests 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, 2.1% of re-tests were TSI instead of ASM. For ASM inspections that included a NO_x failure, 2.3% of re-tests 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 VI-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 re-test inspections were excluded from the results. The table shows that this happened 11 times at the station with the highest frequency of occurrences. The stations in Table VI-7 had rates of 2-11% of all re-tests being switches from ASM to TSI inspections.

Table VI-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
1P41802	10.8%	11	102	100.0
2P40629	7.5%	8	106	98.9
1P38484	5.0%	5	100	97.8
1P35729	4.6%	6	130	96.7
1P39751	3.5%	6	170	95.6
2P42273	2.8%	3	108	94.5
1P32478	2.2%	3	135	93.4
2P31529	2.0%	3	147	92.3
1P44250	1.8%	3	166	91.2
1P37169	1.8%	2	114	90.1

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 15 million inspection records. Only inspection cycles where the initial inspection and the re-test inspection were conducted at the same station were used. This left 660,000 re-test inspections in the dataset.

Overall, it was found that only 0.34% of inspections that were initially failed as a light-duty vehicle were followed by a passing re-test as a heavy-duty vehicle. However, these inspections were clustered at a handful of stations, shown below in Table VI-8. The table shows the ten inspection stations with the highest frequency of re-tests that involved a vehicle that failed as a light-duty vehicle on the initial inspection, followed by a passed re-test of the same vehicle as a heavy-duty vehicle. At the first station on the list, about 28% of vehicles that failed as a light-duty vehicle were switched to a heavy-duty vehicle, and then passed.

Table VI-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
2P42851	28.2%	125	443	100.0
2P02227	18.5%	39	211	99.9
2P38602	15.7%	47	299	99.9
2P40519	12.3%	37	302	99.8
1P40404	10.7%	23	215	99.8
1P35260	10.6%	17	160	99.7
2P22729	9.2%	17	185	99.7
1P05586	8.7%	28	323	99.6
1P43253	7.6%	22	290	99.6
2P33890	6.3%	8	127	99.5

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 VI-9, with failure rates for OBD and ASM inspections listed separately. The lowest failure rate stations are listed in Table VI-10, with failure rates for OBD and ASM inspections listed separately. Stations with fewer than 100 inspections are excluded from the results.

Table VI-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:				
1P45916	36.4%	538	1,480	100.0
2P32154	33.2%	909	2,735	99.9
2P44826	23.8%	31	130	99.9
1P48484	23.8%	31	130	99.8
1P39655	22.2%	296	1,334	99.8
2P36730	21.8%	244	1,121	99.7
1P35240	21.7%	231	1,066	99.7
2P48676	21.6%	38	176	99.6

Station ID	Failure Rate (%)	Number of Failed Inspections	Total Number of Inspections	Percentile Rank for Station
1P19453	21.1%	458	2,168	99.6
1P45047	21.1%	35	166	99.5
ASM Inspection Results:				
1P39751	21.1%	43	204	100.0
1P45927	19.2%	24	125	98.2
2P02227	18.6%	24	129	96.4
1P37865	18.3%	21	115	94.6
1P41802	17.6%	21	119	92.9
2P40519	16.9%	34	201	91.1
2P38027	16.8%	35	208	89.3
2P30388	16.4%	19	116	87.5
1P35758	16.2%	18	111	85.7
2P27469	16.2%	17	105	83.9

Table VI-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:				
2P48716	0.0%	0	409	100.0
1P49033	0.0%	0	219	100.0
1P48969	0.0%	0	158	99.9
1P48963	0.0%	0	287	99.9
1P48906	0.0%	0	295	99.9
1P48229	0.0%	0	172	99.8
1P48121	0.0%	0	111	99.8
1P46234	0.0%	0	303	99.8
1P46055	0.0%	0	186	99.7
1P44243	0.0%	0	421	99.7
ASM Inspection Results:				
2P45733	0.0%	0	162	100.0
1P48201	0.0%	0	199	98.5
1P44433	0.0%	0	127	97.0
1P41206	0.0%	0	205	95.5
1P44321	0.2%	1	405	94.0
2P42111	0.5%	1	185	92.5
1P38625	0.5%	2	368	91.0
2P40629	0.6%	3	535	89.6
1P44764	0.8%	3	365	88.1
2P33169	0.9%	1	116	86.6

C. 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.

High Degree of Drift

In Section III.D, 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 VI-11 had almost all calibrations on out-of-tolerance analyzers.

Table VI-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
2P45222	ES212768	100.0%	48	48	100.0
1P47887	ES213634	100.0%	44	44	99.9
1P41687	ES922010	100.0%	106	106	99.9
1P41676	ES112430	100.0%	49	49	99.8
1P39749	ES213634	100.0%	73	73	99.8
1P19749	ES315097	100.0%	127	127	99.7
1P42816	ES112528	99.1%	111	112	99.6
1P29075	ES212685	99.0%	98	99	99.6
2P02270	ES212592	97.7%	43	44	99.5
1P37809	ES419646	97.6%	41	42	99.5

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 III.D. 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 VI-12.

Table VI-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
2P48510	ES212600	100.0%	6	6	100.0
2P04215	ES520343	90.9%	10	11	99.9
2P47662	ES417526	85.7%	6	7	99.8
2P45980	ES112541	85.7%	6	7	99.7
1P44081	SE910126	85.7%	6	7	99.6
2P42377	ES922340	83.3%	5	6	99.5

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
2P12202	ES112553	83.3%	5	6	99.4
1P48288	ES317060	83.3%	5	6	99.3
1P44539	ES316100	82.4%	14	17	99.2
2P32746	ES315079	81.8%	9	11	99.1

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 III.D, 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 VI-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 VI-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
1P44433	SE120139	53.2%	1,141	2,146	100.0
1P37088	WW510166	42.6%	1,449	3,405	100.0
1P45567	SE140541	41.6%	948	2,278	99.9
1P41797	SE052530	37.0%	606	1,637	99.9
2P12105	WW510185	37.0%	604	1,634	99.8
1P39123	WW510214	35.5%	857	2,417	99.8
1P27010	WW510601	33.9%	966	2,847	99.8
2P39487	WW510697	32.8%	746	2,275	99.7
1P48872	SE052530	31.3%	63	201	99.7
1P44629	SE460168	31.1%	606	1,949	99.7

D. 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.

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 42% 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 VI-14. Stations that performed fewer than 100 inspections following repairs are excluded from the results.

Table VI-14. Miscellaneous Repair Percentage

Station ID	Percent of "Misc" repairs	Number of "Misc" repairs	Total Repairs	Percentile Rank for Station
2P38584	100.0%	138	138	100.0
1P39423	100.0%	235	235	99.9
1P38521	100.0%	164	164	99.9
1P44393	99.4%	162	163	99.8
1P45853	99.0%	102	103	99.8
2P12877	99.0%	501	506	99.7
2P40123	99.0%	195	197	99.7
1P45102	98.8%	171	173	99.6
1P44250	98.7%	458	464	99.6
1P42969	98.5%	327	332	99.5

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 VI-15 below. Stations that performed fewer than 100 inspections following repairs are excluded from the results.

Table VI-15. Zero-Cost Repair Percentage

Station ID	Percent of $0 Repairs	Number of $0 Repairs	Total Number of Repairs	Percentile Rank for Station

2P45155	100.0%	144	144	100.0
2P42090	100.0%	427	427	99.8
2P41654	100.0%	160	160	99.6
2P41331	100.0%	153	153	99.4
2P41318	100.0%	256	256	99.2
2P41047	100.0%	398	398	99.0
2P40495	100.0%	132	132	98.8
2P40123	100.0%	197	197	98.5
2P39828	100.0%	144	144	98.3
2P39001	100.0%	331	331	98.1

VIN Check Digit Errors

In the 2009 Texas I/M Program 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 and 2014 reports, fewer than 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 or 2014 analysis. For the same reason, this metric was not used in the 2016 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.

Anomalous Inspection Sequences (other than 1P or FP)

Each vehicle that participates in the Texas I/M program produces a brief history when it is inspected, repaired, and retested. 99.5% of the vehicles that participate in the program have a repair sequence of either pass (P) or fail-repair-pass with three or fewer re-tests before the ultimate pass (FP group). The remaining portion of the fleet consists of vehicles with histories that contain multiple passes or fails. Table VI-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 VI-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
1P48443	11.4%	15	132	100.0
1P48176	10.0%	24	241	100.0
1P47684	7.1%	9	126	100.0
1P47917	7.0%	7	100	99.9
2P47742	6.8%	9	132	99.9
1P01288	6.7%	7	105	99.9
1P35041	6.2%	25	404	99.9
2P48427	5.8%	7	120	99.8
1P47919	5.6%	7	126	99.8

Station ID	Percent of Inspections with Odd Sequence	Number of Inspections with Odd Sequence	Total Inspections	Percentile Rank for Station
1P47683	5.5%	10	181	99.8

E. ANOMALOUS TEST RESULTS

In Section III.D, 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 DCFs. In this section the rate of each of these anomalies by station is investigated.

Tailpipe Inspections with CO_2 Greater Than 16%

Table VI-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 VI-17. Percent of Inspections with CO_2 Greater Than 16%

Station ID	Percent of Inspections with CO_2 Greater Than 16%	Number of Inspections with CO_2 Greater Than 16%	Total Number of Inspections for Station	Percentile Rank for Station
1P39100	80.2%	625	779	100.0
2P04215	58.4%	181	310	99.9
2P26640	48.7%	263	540	99.8
1P44251	46.8%	188	402	99.7
2P32603	46.1%	129	280	99.7
1P42718	36.8%	95	258	99.6
2P35737	35.0%	42	120	99.5
1P39564	24.1%	104	432	99.4
2P36725	22.9%	25	109	99.3
1P39855	22.2%	49	221	99.2

Tailpipe Inspections with O_2 Greater than 20.5%

Table VI-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 VI-18. Percent of Inspections with O_2 Greater Than 16%

Station ID	Percent of Inspections with O_2 Greater Than 20.5%	Number of Inspections with O_2 Greater Than 20.5%	Total Number of Inspections for Station	Percentile Rank for Station
2P38596	100%	786	786	100

2P30874	98.9%	373	377	99.9
1P35639	98.1%	265	270	99.8
2P33043	97.6%	286	293	99.7
1P37583	97.4%	190	195	99.7
1P04303	97.3%	219	225	99.6
1P45853	96.6%	198	205	99.5
1P41797	96.4%	586	608	99.4
2P10346	95.8%	482	503	99.3
2P12507	95.6%	667	698	99.2

F. TAILPIPE INSPECTIONS WITH HIGH DCF DIFFERENCES

Table VI-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 VI-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
2P38596	100.0%	786	786	100.0
2P30874	98.9%	373	377	99.9
1P35639	98.1%	265	270	99.8
2P33043	97.6%	286	293	99.7
1P37583	97.4%	190	195	99.7
1P04303	97.3%	219	225	99.6
1P45853	96.6%	198	205	99.5
1P41797	96.4%	586	608	99.4
2P10346	95.8%	482	503	99.3
2P12507	95.6%	667	698	99.2

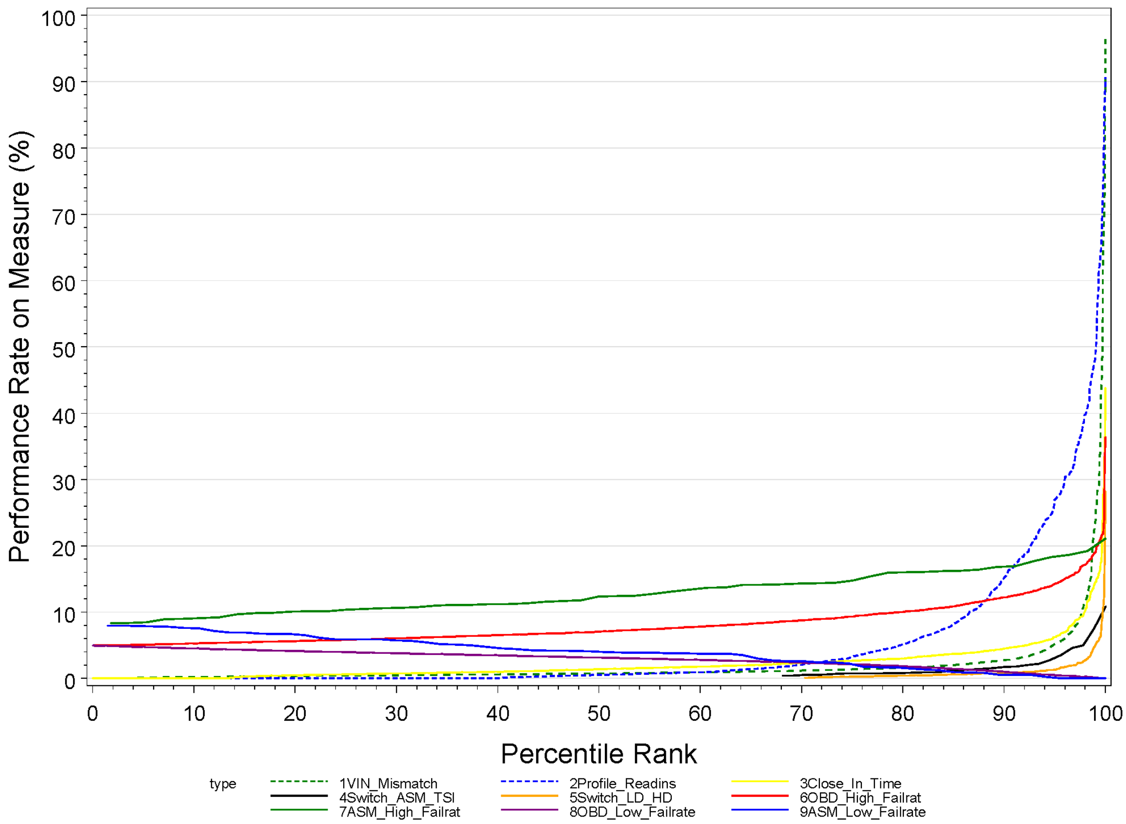
G. COMPILATION OF PERCENTILE RANKINGS

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 re-tests, 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 85% of stations had very low VIN mismatch rates. The remaining 15% had VIN mismatch rates that might be cause for concern, or about the top 15 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 VI-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 the OBD electronic readiness profile shows that stations up to the 75th percentile had a low rate of mismatches. For the other measures, the rate of overly close in time inspections, re-tests switched from ASM to TSI, and re-tests switched from light-duty to HD, the stations below about the 90th percentile had very low results. Above the 90th percentile, the rate of potentially fraudulent results rapidly increases. 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 VI-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 VI-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 VI-20. Table VI-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 first station, 2P02227 had a very high rate of OBD VIN mismatches, and high rates of OBD readiness and electronic profile mismatches. This indicates a high possibility of OBD inspection fraud. However, this station also had a high rate of close-in-time retests, switches from LD to HD, plus a very high OBD failure rate for initial inspections. These results do not guarantee that this station is intentionally causing OBD vehicles to fail an initial inspection and performing unnecessary repairs, but the results do c indicate that 2P02227 would be a good candidate for an audit. By contrast, in the fourth line, 2P42264 had high rates of OBD VIN mismatches, OBD readiness mismatches, and OBD electronic profile mismatches. This station also had a very low OBD failure rate. This station is likely to be clean-scanning and would also be a good candidate for an audit. 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 VI-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 VI-4, the "break" percentiles were assigned at the 80th percentile for analyzers out of tolerance, the 80th percentile for span gas audit failures, the 90th percentile for performing inspections when analyzer is not fully calibrated and should be locked out, the 95th percentile for inspections with unusual pass/fail sequences, the 60th percentile for stations entering repair types as "Misc", the 30th percentile for stations entering repair costs as $0, the 90th percentile for inspections with CO_2 greater than 16%, the 80th percentile for inspections with O_2 greater than 20.5%, and the 60th 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 VI-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.

Finally, one new investigation for this section is a comparison of the potential-fraud rates in by I/M program area. If fraud rates were higher in one area than the other, it might be possible that this would result in the Texas I/M program having a different degree of impact in the two program areas. The result of the investigation is shown below in Figure VI-5. Each of the nine different types of errors of commission is shown on the plot (this is the same group of categories as was shown in Figure VI-3). However, the plot now shows the fraction of stations that are from the DFW program area, for each decile of the ranks. For example, looking at the green dots on the dashed green line (VIN/eVIN mismatch), we can see that at the zero percentile group, the fraction of stations in that group is 56% DFW (and by inference, 44% HGB). At the 10^{th} decile group, we see about 59% of stations are from the DFW program area (and so 41% from the HGB program area). By contrast, at the 90^{th} and 100^{th} decile groups, the percentage of stations from the DFW program area is 46 or 44% (so the HGB program area would be 54 or 56%). This indicates that at the low end of the ranks (where fraud of this type is unlikely), there are more DFW stations, and at the high end of the ranks (where fraud of this type is much more likely) there are more HGB stations. A similar, and even more significant, trend can be seen for the squares on the blue dashed line, for the OBD electronic profile comparisons. For the other measures, it is much more difficult to see any sort of meaningful trend. However, it does appear that for the two major OBD fraud checks, the VIN/eVIN and the electronic profile, more stations are potentially committing fraudulent inspections in the HGB program area than in the DFW program area. Since OBD vehicles now dominate the fleet, fraudulent OBD inspections could significantly undermine the Texas I/M program's effectiveness.

Table VI-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
2P02227	6	99.9	96.2	86.5	97.8	.	99.9	97.8	96.4	.	.
1P39751	4	100.0	87.2	74.5	47.8	95.6	92.0	87.4	100.0	.	.
1P41802	4	100.0	43.3	81.9	95.7	100.0	71.7	.	92.9	22.5	.
2P42264	4	100.0	88.4	97.9	100.0	.	63.6	.	.	93.0	.
2P45733	4	100.0	41.2	95.2	94.2	.	94.0	.	.	61.4	100.0
2P38602	4	99.9	86.3	75.4	98.5	.	99.9	3.5	.	.	.
1P32476	4	99.8	98.3	95.1	99.8	.	96.3	10.4	.	.	.
2P22729	4	99.7	85.3	82.4	96.1	.	99.7	33.2	.	.	.
2P09323	4	99.5	95.4	94.3	99.5	.	90.2	.	.	40.0	.
2P45169	4	99.4	93.4	89.0	99.4	.	97.9	27.3	.	.	.
2P39800	4	99.2	99.2	89.3	97.2	.	58.0	97.4	.	.	.
2P41322	4	99.1	94.0	85.3	98.4	.	99.1	24.5	.	.	.
2P44814	4	98.6	96.3	88.9	98.6	.	95.6	35.6	.	.	.
2P41602	4	98.6	97.4	97.1	98.6	.	98.6	38.0	.	.	.
2P30447	4	98.5	87.5	79.4	91.5	.	98.5	35.3	.	.	.
1P45927	4	98.2	88.9	77.6	75.8	.	93.3	62.7	98.2	.	.
2P38998	4	97.9	94.0	90.1	97.9	.	56.5	.	.	92.9	.
2P29353	4	97.8	92.3	96.1	92.4	.	97.8	76.5	.	.	.
2P44931	4	96.8	94.8	87.4	96.8	.	95.5	6.0	.	.	.
2P35738	4	95.8	92.7	83.5	94.7	.	95.8	32.2	.	.	.
1P32785	4	93.5	91.0	88.1	26.5	.	93.5	90.5	.	.	.
2P42851	3	100.0	81.6	77.2	99.5	.	100.0	45.1	.	.	.
1P00804	3	99.9	99.3	98.7	99.9	.	0.5	88.2	.	.	.
2P04162	3	99.9	98.0	82.1	99.9	.	79.1	.	.	55.8	.
2P40519	3	99.8	15.0	36.0	93.1	.	99.8	21.9	91.1	.	.
2P42938	3	99.8	99.7	99.5	99.8	.	65.2	.	.	26.3	.
1P35099	3	99.7	96.4	86.6	99.7	.	12.6	37.4	.	.	.
1P35260	3	99.7	76.2	90.8	95.0	.	99.7	.	.	73.6	.
2P36730	3	99.7	98.6	79.1	0.0	.	53.1	99.7	.	.	.

Table VI-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
2P32413	3	99.7	77.4	85.7	99.7	.	46.0	.	.	97.4	.
1P37988	3	99.6	95.5	98.8	99.6	.	17.6	.	.	47.1	.
1P38625	3	99.6	64.1	99.6	.	.	.	.	.	94.1	91.0
1P43253	3	99.6	90.6	82.2	66.4	.	99.6	30.8	.	.	.
1P32638	3	99.5	56.6	77.5	95.0	.	99.5	.	.	12.8	.
2P38070	3	99.4	54.4	99.4	94.4	.	92.2	.	.	43.7	.
2P42042	3	99.4	81.5	92.2	99.1	.	99.4	82.5	.	.	.
1P41687	3	99.3	97.5	97.7	99.3	.	25.0	.	.	83.9	71.6
1P33253	3	99.2	89.4	81.3	99.2	.	10.7	.	.	48.2	.
1P38525	3	99.0	72.1	86.1	93.7	.	89.4	99.0	.	.	.
1P45531	3	99.0	96.7	94.8	99.0	.	71.9	60.0	33.9	.	.
1P29906	3	98.9	98.9	93.4	84.2	.	98.1	83.0	60.7	.	.
2P40629	3	98.9	92.1	90.6	63.5	98.9	59.5	.	.	85.2	89.6
1P41801	3	98.8	92.6	86.7	36.1	.	98.8	44.0	.	.	.
2P44409	3	98.8	98.8	94.0	82.4	.	90.7	85.8	.	.	.
1P45528	3	98.8	98.8	94.0	91.0	.	33.0	64.4	.	.	.
1P38316	3	98.8	90.8	85.0	98.8	.	18.1	34.2	.	.	.
2P33665	3	98.6	98.6	90.7	60.2	.	98.2	31.4	.	.	.
2P12681	3	98.5	95.4	92.9	98.5	.	85.6	14.4	.	.	55.2
2P45659	3	98.4	92.9	70.7	33.1	.	98.4	90.8	.	.	.
2P41861	3	98.4	95.8	98.4	.	.	.	.	.	96.4	.

Table VI-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
2P11492	0	80.5	1.9	51.8	80.5	.	38.4	.	.	16.8	.
1P38501	0	80.5	80.5	.	.	.	.	.	.	58.2	.
2P41749	0	80.5	59.8	.	.	.	.	.	.	80.5	.
1P45085	0	80.5	78.3	.	.	.	.	80.5	.	.	.
1P34632	0	80.5	72.6	69.9	80.5	.	76.0	.	.	44.2	.
2P41760	0	80.5	19.4	36.7	47.9	.	80.5	.	.	51.8	.
1P42437	0	80.4	75.1	18.8	14.2	.	26.8	80.4	.	.	.
2P19612	0	80.4	51.8	67.5	47.7	.	80.4	.	.	66.3	.
1P48638	0	80.4	.	.	.	.	.	.	.	80.4	.
2P12918	0	80.4	65.3	71.5	80.1	.	80.4	80.1	.	.	.
2P38604	0	80.4	30.4	45.3	80.4	.	55.9	15.4	.	.	.
1P42697	0	80.4	71.1	19.3	0.0	.	27.3	80.4	.	.	.
2P07458	0	80.4	80.4	.	.	.	.	14.1	.	.	.
2P34300	0	80.4	24.2	.	.	.	.	.	.	80.4	.
2P35137	0	80.3	80.3	.	.	.	.	.	.	30.5	.
1P48403	0	80.3	76.3	.	.	.	.	80.3	.	.	.
1P39514	0	80.3	23.7	.	.	.	.	.	.	80.3	.
2P45621	0	80.3	80.3	68.0	37.6	.	68.4	19.4	.	.	.
1P40551	0	80.2	65.0	55.4	80.2	.	22.4	10.1	.	.	.
1P45640	0	80.2	32.5	.	.	.	.	80.2	.	.	.
2P35699	0	80.2	18.2	42.6	48.4	80.2	78.7	25.9	.	.	.
2P45318	0	80.2	80.2	.	.	.	.	.	.	4.4	.
1P38721	0	80.2	41.8	.	.	.	.	.	.	80.2	.
2P44453	0	80.2	80.2	.	.	.	.	.	.	25.2	.
2P02270	0	80.2	9.1	46.4	67.0	.	80.2	9.4	.	.	.
2P33879	0	80.2	80.2	30.0	30.7	.	48.2	.	.	63.7	.
2P44513	0	80.2	14.5	.	.	.	.	.	.	80.2	.
1P36031	0	80.1	59.4	47.0	57.1	.	80.1	.	.	15.2	.
1P41795	0	80.1	80.1	52.0	0.0	.	25.4	44.1	.	.	.

Table VI-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
2P46074	0	80.1	80.1	.	.	.	.	35.5	.	.	.
1P31734	0	80.1	14.9	6.4	44.7	.	8.7	.	.	80.1	.
2P35076	0	80.1	80.1	.	.	.	.	.	.	61.1	.
2P42750	0	80.0	16.7	.	.	.	.	.	.	80.0	.
1P26129	0	80.0	26.4	42.7	62.0	.	80.0	9.9	.	.	.
2P09655	0	80.0	16.3	.	.	.	.	.	.	80.0	.
1P32815	0	80.0	80.0	.	.	.	.	.	.	24.2	.
1P33301	0	80.0	39.7	.	.	.	.	.	.	80.0	.
1P45686	0	80.0	16.0	23.4	80.0	.	33.6	.	.	20.7	.
2P40948	0	80.0	80.0	53.8	0.0	.	60.0	54.5	.	.	.
1P44257	0	79.9	5.7	.	.	.	.	.	.	79.9	.
2P35077	0	79.9	79.9	65.3	53.5	.	50.5	43.1	.	.	.
2P48159	0	79.9	79.9	.	.	.	.	.	.	27.8	.
1P47668	0	79.9	38.1	57.0	33.2	.	79.9	.	.	35.0	.
1P31408	0	79.9	4.2	51.9	67.6	.	8.2	79.9	.	.	.
2P41876	0	79.9	79.9	.	.	.	.	62.5	.	.	.
1P45814	0	79.9	79.9	.	.	.	.	.	.	18.5	.
2P32415	0	79.9	24.7	29.4	32.6	.	46.1	.	.	79.9	.
1P35639	0	79.9	47.6	46.7	17.7	.	79.9	.	.	6.1	.
1P38326	0	79.9	79.9	.	.	.	.	.	.	43.0	.
2P25661	0	79.9	79.6	.	.	.	.	79.9	.	.	.

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

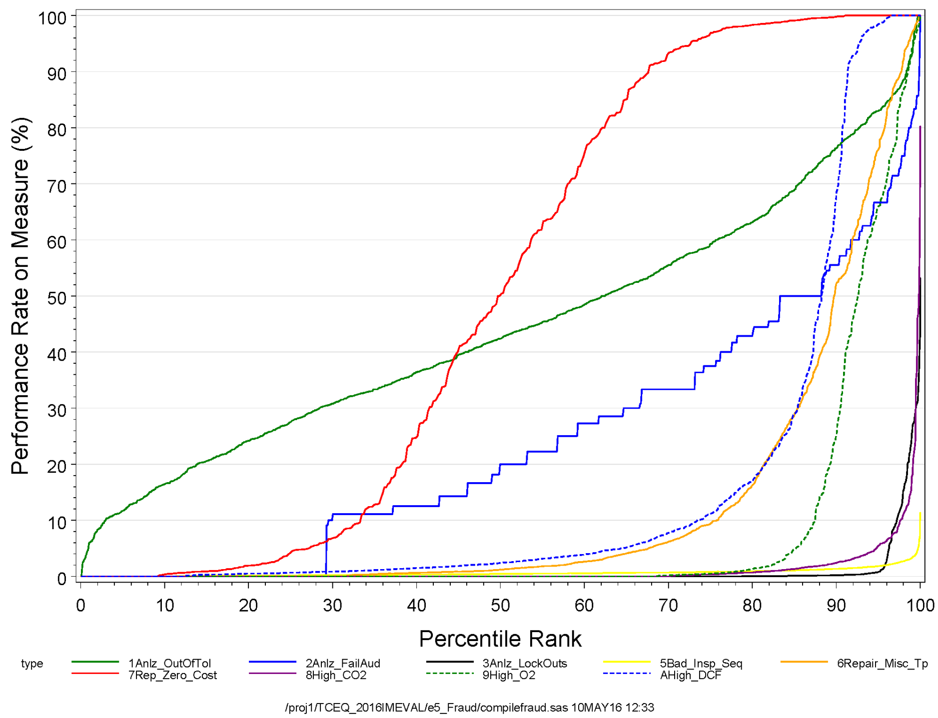


Figure VI-5. Fraction of Stations from the DFW Program Area, by Rank Decile, for Errors of Commission

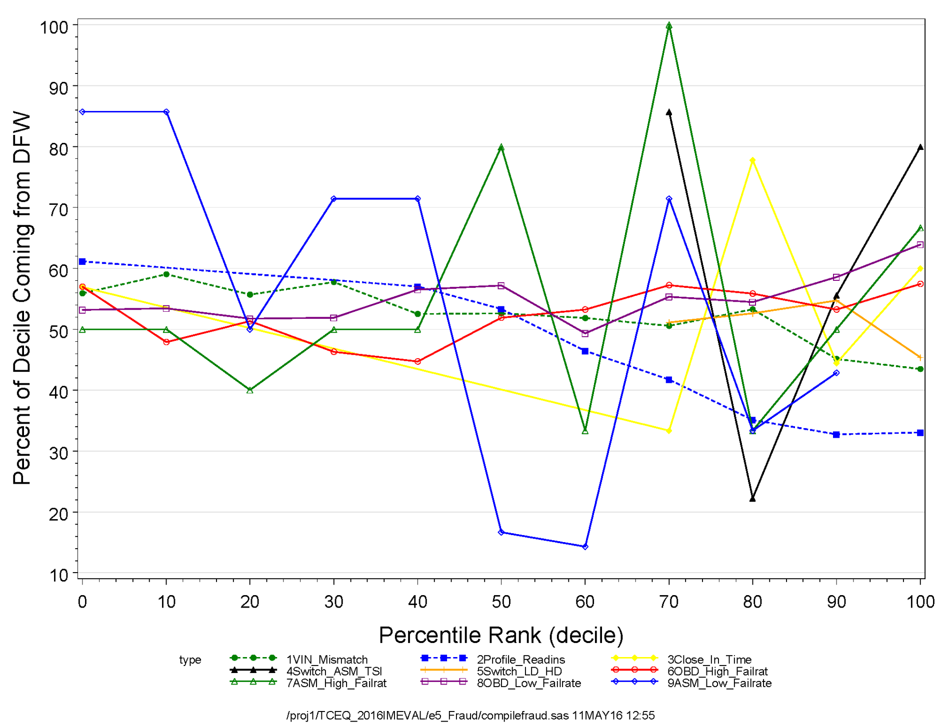


Table VI-22. Top 50 Stations with Errors of Omission

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	CO_2 gt 16%	O_2 gt 20.5%	DCF Disagreement
1P39100	5	100.0	39.5	78.5	23.8	100.0	22.6	90.2	.	79.4	81.7
1P39100	5	100.0	39.5	78.5	99.1	100.0	22.6	90.2	.	79.4	81.7
1P41797	5	99.9	73.7	.	99.9	28.7	99.4	97.5	.	2.5	89.7
2P33043	5	99.7	25.5	.	54.3	97.8	99.7	99.0	.	41.2	84.3
2P33043	5	99.7	25.5	.	54.3	97.8	99.7	99.0	.	41.2	84.3
1P04303	5	99.6	13.4	57.0	91.3	1.7	99.6	96.6	.	97.1	85.1
2P12905	5	99.3	39.0	.	99.3	99.1	41.5	81.5	.	96.8	85.0
2P12686	5	99.0	5.3	.	46.5	43.6	41.0	33.1	.	95.3	93.9
2P12686	5	99.0	71.6	.	92.8	43.6	41.0	33.1	.	95.3	93.9
2P12686	5	99.0	71.6	.	99.0	43.6	41.0	33.1	.	95.3	93.9
2P41047	5	99.0	48.0	98.5	92.6	96.1	69.4	44.1	.	11.1	98.9
2P33162	5	99.0	87.9	99.0	54.5	50.8	70.9	77.3	.	72.0	94.5
2P33162	5	99.0	87.9	99.0	94.6	50.8	70.9	77.3	.	72.0	94.5
2P02227	5	98.9	51.7	17.8	93.3	98.9	38.4	73.1	.	95.5	68.2
1P25039	5	98.6	98.6	92.0	80.7	5.5	89.8	86.3	.	69.5	87.9
2P37909	5	96.4	83.5	.	63.7	96.4	57.1	61.8	.	71.4	62.7
2P37909	5	96.4	83.5	.	94.3	96.4	57.1	61.8	.	71.4	62.7
2P44078	5	96.0	93.1	91.0	73.0	83.3	96.0	95.5	.	13.9	29.8
2P44078	5	96.0	93.1	91.0	91.4	83.3	96.0	95.5	.	13.9	29.8
1P44433	4	100.0	60.5	96.8	100.0	78.6	31.7	75.1	.	3.4	92.7
2P38596	4	100.0	18.9	.	64.8	81.9	100.0	99.6	.	14.8	75.2
2P30874	4	99.9	20.2	.	51.6	48.7	99.9	98.9	.	63.0	77.7
2P12105	4	99.8	17.7	.	94.7	76.7	40.4	81.6	.	96.8	20.2
2P12105	4	99.8	44.1	.	99.8	76.7	40.4	81.6	.	96.8	20.2
1P39123	4	99.8	14.9	12.0	23.9	95.6	22.7	66.8	.	31.3	83.1
1P39123	4	99.8	35.0	12.0	99.3	95.6	22.7	66.8	.	31.3	83.1
1P39123	4	99.8	35.0	12.0	99.8	95.6	22.7	66.8	.	31.3	83.1
2P42090	4	99.8	71.3	81.9	71.2	66.2	94.1	95.1	.	19.9	97.7
1P42718	4	99.6	94.2	.	30.7	99.6	73.7	84.8	.	55.4	76.3
1P42718	4	99.6	94.2	.	30.7	99.6	73.7	84.8	.	55.4	76.3

Table VI-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	CO_2 gt 16%	O_2 gt 20.5%	DCF Disagreement
1P42718	4	99.6	94.2	.	92.9	99.6	73.7	84.8	.	55.4	76.3
2P35146	4	99.2	17.1	.	58.0	54.4	95.1	99.2	.	34.5	79.1
2P10957	4	98.8	75.1	82.8	45.0	83.8	39.9	59.4	.	59.9	95.0
2P10957	4	98.8	75.1	82.8	98.8	83.8	39.9	59.4	.	59.9	95.0
1P31834	4	98.8	28.7	.	98.8	79.3	96.9	91.9	.	60.8	5.0
1P38571	4	98.7	53.2	57.9	98.7	96.1	21.9	41.0	.	30.9	97.9
1P26542	4	98.7	98.7	90.4	79.7	6.8	70.7	80.7	.	75.5	95.6
1P36276	4	98.6	13.6	32.6	98.6	19.0	17.2	41.5	.	98.5	87.0
1P17052	4	98.6	54.9	2.8	90.0	98.6	77.4	77.0	.	97.6	94.8
1P45923	4	98.6	52.5	.	37.8	37.9	98.6	95.7	.	11.5	98.1
1P40608	4	98.4	75.7	84.8	26.2	98.4	77.0	86.8	.	36.8	68.0
1P36932	4	98.3	10.0	61.9	92.7	98.3	18.6	63.0	.	82.6	90.5
1P00274	4	98.3	91.1	30.0	98.3	0.3	0.3	41.8	.	92.5	98.0
1P28265	4	98.2	85.3	5.1	7.8	89.1	69.7	61.1	.	97.2	98.2
2P27849	4	98.2	66.4	92.4	90.4	98.2	44.1	75.7	.	64.3	94.3
2P10331	4	98.0	85.7	.	44.9	76.3	98.0	93.5	.	32.9	81.4
2P10331	4	98.0	85.7	.	44.9	76.3	98.0	93.5	.	32.9	81.4
1P32646	4	97.7	65.2	80.6	11.8	12.3	97.7	97.0	.	78.0	65.3
1P37988	4	97.7	82.3	97.7	21.7	85.1	95.0	92.5	.	34.7	38.2
1P38625	4	97.2	94.4	33.4	23.2	81.1	97.1	97.2	.	1.7	67.5

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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

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

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

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`
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

[7] Includes oxygen sensor and oxygen sensor heater

Table A-4. O_2 System DTCs[7]

DTC	DTC Description	DTC	DTC Description
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-5. 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