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Analysis of Evaporative and Exhaust-Related On-Board Diagnostic (OBD) Readiness Monitors and DTCs Using I/M and Roadside Data

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Abstract

Under contract to the EPA, Eastern Research Group analyzed light-duty vehicle OBD monitor readiness and diagnostic trouble codes (DTCs) using inspection and maintenance (I/M) data from four states. Results from roadside pullover emissions and OBD tests were also compared with same-vehicle I/M OBD results from one of the states. Analysis focused on the evaporative emissions control (evap) system, the catalytic converter (catalyst), the exhaust gas recirculation (EGR) system and the oxygen sensor and oxygen sensor heater (O₂ system). Evap and catalyst monitors had similar overall readiness rates (90% to 95%), while the EGR and O₂ systems had higher readiness rates (95% to 98%). Approximately 0.7% to 2.5% of inspection cycles with a “ready” evap monitor had at least one stored evap DTC, but DTC rates were under 1% for the catalyst and EGR systems, and under 1.1% for the O₂ system, in the states with enforced OBD programs. Monitor readiness decreased, and DTC rates increased, as vehicles aged. DTCs were typically limited to a small subset of all possible DTCs for any particular system. For the on-road versus I/M analysis, lower overall readiness rates and higher overall DTC rates occurred during the roadside test than during the I/M test, and the prevalence of roadside DTCs was shown to decrease around the time of the vehicle’s I/M test, possibly indicating some positive I/M influence of reducing on-road DTCs. Roadside Acceleration Simulation Mode (ASM) fail rates also decreased around the time of the I/M test, suggesting a positive influence of I/M programs on reducing vehicle emissions.

Introduction

Under contract to and in collaboration with the United States Environmental Protection Agency (US EPA), Eastern Research Group (ERG) performed analysis of light-duty

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gasoline-powered vehicle On-board Diagnostic (OBD) exhaust emissions control system monitor readiness and diagnostic trouble codes (DTCs) using inspection and maintenance (I/M) program data from the states of California, Georgia, New Jersey, and Colorado. This analysis allowed evaluation of OBD system performance and emission control system malfunction prevalence over a broad range of vehicle types, ages, geographic regions, and also spanning a large range of calendar years. The focus of this analysis was on specific monitored systems, including the evaporative emissions control (evap) system, the catalytic converter (catalyst), the exhaust gas recirculation (EGR) system and the oxygen sensor and oxygen sensor heater (O₂ system). For simplicity, these last three systems (catalyst, EGR, and O₂ system) are generically referred to as “exhaust” monitors and DTCs in this article. In order to allow an evaluation of monitor readiness and the influence of monitor readiness on specific categories of stored DTCs (i.e., the potential for a “not ready” monitor to “hide” certain DTCs), only non-continuous (and component-specific) monitors were considered for this evaluation. In addition, monitors that are less commonly supported, such as secondary air systems, thermostats, positive crankcase ventilation and air conditioning monitors were excluded from this evaluation.

Trends in monitor readiness and DTC rates were evaluated and compared by calendar year, vehicle model year and vehicle age among the four states. Comparisons were also made to determine if the percentages of vehicles with each particular monitor “not ready” were similar among the states. Individual DTCs and DTC combinations associated with each particular emission control component were evaluated to better understand the types and diversity of failure modes according to the type of DTC. Only model year 1996 and newer vehicles were included in this analysis, since OBDII compliance was not federally mandated in the U.S. until model year 1996.

The data from these states spans the calendar years of 2004 through 2012, depending on data available from each state at the time of analysis. Table 1 shows the calendar years of data analyzed for each state as well as each I/M program’s cycle frequency (annual or biennial inspections), model year exemption period for the I/M program during the calendar years of data analyzed for each state. The readiness criteria used by each state was not used in this evaluation (analysis was based on monitor-specific readiness, not I/M-program determined readiness). All four states collect and store DTCs for vehicles regardless of the state’s readiness determination.

The OBD test is not enforced in the Colorado I/M program, but instead the OBD test result is advisory only and not a criterion for passing or failing the I/M inspection in Colorado (Colorado’s I/M test pass / fail determination is based on results of an IM240 exhaust emissions test and a gas cap functionality test). The OBD test is enforced for model year 1996 and newer vehicles in California, Georgia, and New Jersey, so an OBD failure in these three states results in an overall I/M test failure.

As a supplement to this analysis, ERG also analyzed data from the California Bureau of Automotive Repair’s (BAR’s) Roadside Pullover emissions inspection program (Roadside program) in comparison with California’s I/M program in order to gain a better understanding of the differences between I/M and “on-road” readiness and DTC rates and to

help assess the percentage of vehicles with on-road malfunctions that are not identified in I/M programs. For this supplemental analysis, approximately 20,000 matched Roadside and I/M test pairs of model year 1996 – 2008 light-duty gasoline-powered vehicles were analyzed to compare OBD monitor readiness and DTCs associated with the same four systems (evap, catalyst, EGR, and O₂ system). On-road readiness and DTC rates were evaluated as a function of time before and after the I/M test, Roadside Acceleration Simulation Mode (ASM) fail rates were evaluated as a function of time before and after the I/M test, and Roadside ASM emission levels were evaluated in comparison with the presence of catalyst, EGR, and O₂ system DTCs.

Methods

Four-State I/M OBD Analysis Methods

This analysis was based on readiness and DTCs associated with the evap monitor, the catalyst monitor, the EGR monitor, and the O₂ system monitor (which included the oxygen sensor and the oxygen sensor heater monitors). For the combined O₂ system monitor's readiness determination, the O₂ system was considered "ready" if both the O₂ sensor and the O₂ sensor heater were supported and "ready", or if the O₂ sensor was supported and "ready" but the O₂ sensor heater was not supported. The O₂ system was classified as "not ready" if either the O₂ sensor or the O₂ sensor heater had a "not ready" status. DTCs for each of the four monitored systems were selected from SAE J2012 to correspond with the four monitor categories. The complete lists of the DTCs by monitored system are listed in the main study reports.^{1,2}

Since evap monitoring was not fully phased in for all model year 1996–1999 vehicles, evap and DTC rate trends presented herein are based on model year 2000 and newer vehicles. In addition, EGR readiness and DTC rates presented in this article are based only on EGR "supported" vehicles (roughly 2/3 of the fleet were equipped with EGR systems). Consequently, results of EGR system readiness and DTC analysis are based only on the subset of vehicles that were equipped with EGR systems, in order to obtain readiness and DTC rates that are representative of the EGR-equipped fleet. As a result of this data filtering, and because California's I/M program only stores monitor readiness information for supported monitors that are "not ready" (it is not possible to distinguish between "ready" and "unsupported" monitors in the California I/M data), EGR results are not available for California and are therefore only provided for Georgia, New Jersey, and Colorado.

Several steps were taken to prepare the I/M data from the four states for this analysis. ERG screened each state's I/M dataset to eliminate all records for tests not appropriate for this analysis, such as test records of heavy-duty vehicles (those with a gross vehicle weight rating greater than 8500 lbs.); removed inspections of vehicles with a fuel type other than gasoline; removed invalid or unofficial test records; and removed audit test records. Test results for all model year 1995 and older vehicles were removed, and all non-complete OBD tests (such as "aborts" or tests with a "no communication" result) were also removed.

All test records in the filtered dataset were then organized into "inspection cycles," which generally consisted of one or more tests performed within a four-month window, usually

until a pass result was achieved or a waiver was issued. The procedure for determining unique inspection cycles varied from state to state, but typically involved identification of a sticker number, a “pass” inspection result, or the issuance of a waiver, which indicated the conclusion of one cycle. The subsequent inspection would begin a new inspection cycle.

In order to minimize differences in results due to differences in state I/M programs, the OBD readiness determination from each state’s program was excluded from analysis. The results in this article are based on each individual monitor’s readiness status over an inspection cycle, without regard to the state’s I/M readiness determination. Therefore, if a specific monitor was “ready” for at least one test during an inspection cycle, that monitor was classified as “ready” for that inspection cycle. In addition, results in this report are based on the presence (or lack of) monitor-specific DTCs, without regard to malfunction indicator light (MIL) command status or the I/M program’s OBD pass/fail test results. For each system analyzed, for those vehicles with a monitor status of “ready” for at least one inspection during the I/M cycle in each calendar year, the associated DTCs were evaluated by vehicle model year (1996 and newer) and calendar year (calendar years 2004–2012). Vehicles with a “not ready” monitor were not included in the DTC analysis, as these vehicles could provide an artificially low (unrepresentative) DTC rate, since their OBD system had not completed system testing for that monitor.

Since inactive DTCs (DTCs acquired with a Mode \$03 request bit with the MIL commanded off) were included in this analysis, the DTC rates in some states may be higher than they would be if using only I/M fails (Mode \$03 DTCs with MIL commanded on). These inactive DTCs may not represent a current malfunction, but may instead indicate that a malfunction or condition had occurred sometime in the vehicle’s recent past, setting a DTC that had not yet been self-cleared by the vehicle.

Roadside vs. I/M Analysis Methods

The California Roadside test program preferentially selects older vehicles. Because of this, and also due to the California I/M program’s six model-year test exemption, the model year profile of vehicles included in this Roadside vs. I/M analysis is likely older than a “typical” on-road or I/M fleet in California or elsewhere in the country.

Calendar years 2010 through 2012 of California Roadside data and calendar years 2008 through 2013 of California I/M data were used for the analysis. Both data sets contained OBD and ASM test results. Only vehicles with matched test pairs were included in this analysis, and matched test pairs were those for which the Roadside test occurred within 21 months, before or after, of the final test in an inspection cycle.

As with the four-state I/M OBD analysis, ERG screened both the I/M and Roadside datasets to eliminate all invalid tests, using the same criteria for data screening as previously described. The remaining Roadside tests were then matched, by VIN, with the I/M tests to obtain 19,597 matched pairs of Roadside and I/M tests. These 19,597 matched pairs of Roadside and I/M tests contained 13,328 unique VINs, with some VINs associated with Roadside tests both before and after the I/M inspection. Since not all vehicles were equipped with a “supported” EGR monitor and it is not possible to distinguish between unsupported

monitors and supported “ready” monitors in the California I/M data, ERG performed vehicle identification number (VIN) decoding on this 13,328-vehicle dataset to determine whether or not each vehicle had a supported EGR monitor.

Also, as in the four-state I/M OBD analysis, the OBD pass/fail determinations from the Roadside and I/M programs were excluded from this analysis. The results of this comparison were based on each OBD monitor’s individual readiness status (without regard to the program’s overall readiness determination) and the presence (or lack of) monitor-related DTCs (without regard to the vehicle’s MIL command status). DTC rates are provided for each of the monitored systems (evap, catalyst, EGR and O₂ system) by individual monitor readiness status (i.e., “ready” or “not ready”). Also similar to the four-state analysis, since the DTC results are based on all records with associated DTCs (regardless of MIL command status), the DTC rates presented for this California Roadside vs. I/M analysis include inactive DTCs (which are collected in California), and these DTC rates are higher than DTC rates only collected when the MIL is illuminated.

Results

Four-State OBD Monitor Readiness

Tables 2 and 3 list overall and “by vehicle age” readiness rates for each monitored system, for each of the four states. Overall readiness rates shown in Table 2 were based on the number of vehicles with a “ready” monitor at the time of initial and/or re-test inspection within each inspection cycle. Regardless of the details of the I/M program administration or the calendar years of data analyzed, approximately 90% to 93% of the inspections had a “ready” evap monitor for at least one test during the inspection cycle. Overall readiness rates were similar for the catalyst (92% to 95%), but were higher for the EGR and O₂ systems (95% to 98%). The similarity in this percentage for the various monitors across all of the states suggests that these percentages could approximate a national percentage of vehicles in I/M programs with a “ready” monitor during an inspection cycle.

The readiness ranges shown in Table 3 indicate that vehicles in an I/M environment (including Colorado, which is advisory-only for OBD) are more likely to have a “not ready” monitor as they age. As can be seen in Table 3, this effect was most pronounced for the evap monitor, which had a readiness range of up to 12% lower for 9–10 year-old vehicles than the readiness range for 2–3 year-old vehicles. The trend of decrease of readiness by vehicle age for the catalyst monitor was lower than that of the evap monitor, and even less so for the EGR and O₂ systems. This can be seen graphically in Figures 1 through 4. In these figures (as well as in Table 3), data for vehicles still in the new-vehicle exemption age range were likely collected during tests on resale, owners moving into the I/M area, or other “out-of-cycle” inspections.

Four-State DTC Rates

Tables 4 and 5 list overall and “by vehicle age” DTC rates for each monitored system, for each of the four states. Overall DTC rates shown in Table 4 were calculated for each particular “ready” monitor for at least one test during each inspection cycle. Approximately

0.7% to 2.5% of inspection cycles with a “ready” evap monitor for at least one test during the inspection cycle had at least one stored evap DTC (again, for at least one test during that inspection cycle). Inspection cycle-based DTC rates were under 1% for the catalyst and EGR systems, and were under 1.1% for the O₂ system, in the states with enforced OBD programs. Colorado had higher DTC rates, as the OBD test was advisory-only in this state (i.e., vehicles could pass the I/M test with the MIL illuminated). The EGR system DTC rate is unknown in California, since the EGR system is not supported on all vehicles, and it is not possible to distinguish between vehicles with no EGR monitor (unsupported) and those with an EGR monitor (supported and ready) but with no DTCs within the California I/M test record.

The DTC rate ranges shown in Table 5 indicate that vehicles in an I/M environment (including Colorado, which is advisory-only for OBD) are more likely to have a stored DTC as they age. As can be seen in Table 5, this effect was again most pronounced for the evap system. The trend of increase in stored DTCs by vehicle age was similar for the catalyst, EGR and O₂ systems. The trend line plots upon which these numbers are based can be seen in Figures 5 through 8. As with the prior figures, data for vehicles younger than the new-vehicle exemption period were likely collected during tests on resale, owners moving into the I/M area, or other “out-of-cycle” inspections. Figures 5 through 8 also show the strong influence of inactive DTCs (DTCs acquired with an SAE J1979 Mode \$03 request but for which the MIL is commanded off). These are DTCs that were previously active but no longer represent an active DTC. On average, for vehicles at 10 years of age, inactive DTCs comprised from as much as 60% of all DTCs (for O₂ system DTCs in California) to as little as 20% (for EGR DTCs in California). For evap systems, on average approximately 30% to 50% of all evap DTCs were Mode \$03 DTCs without a MIL commanded on³. Note that these do not include pending DTCs (collected using SAE J1979 Mode \$07 requests), which are not collected in I/M programs. It should also be noted that if multiple DTCs are recorded from a vehicle with the MIL commanded on, some of these DTCs may no longer be active (it is not possible to distinguish between active and inactive DTCs collected for vehicles with the MIL commanded on). Therefore, the actual percentages of inactive DTCs may be higher than the percentages previously cited.

Only the test data from California and Colorado contained DTCs with the MIL commanded off. Georgia and New Jersey only collect and store DTCs when the MIL is commanded on, so Georgia and New Jersey results include fewer inactive DTCs than California and Colorado results (the only inactive DTCs in California and Colorado are those for which the MIL is commanded on, multiple DTCs are present, and some of those have turned inactive, as previously described).

Modes of Failure for the Four Systems

As noted previously, DTCs for each of the four monitored systems were selected from SAE J2012 to correspond with the four monitor categories, resulting in 75 “evap” DTCs, 34 “catalyst” DTCs, 41 “EGR” DTCs, and 141 “O₂ system” DTCs. However, for most systems, the majority of DTCs were limited to a small subset of DTCs. For the evap monitor, fewer than 20 different individual and combinations of evap DTCs (out of 75 possible) comprised

more than 90% of all evap DTCs in the data. Common evap DTCs primarily fell into two categories, leaks or purge flow. The leak DTCs, including P0442, P0455, P0456, and P0457, comprised more than 50% of all evap DTCs, while purge flow DTCs P0441 and P0443 comprised an additional 18%. For the catalyst, P0420 through P0422 (catalyst and warm up catalyst efficiencies for bank 1) comprised roughly 81% of all catalyst DTCs in the four states, while P0430 through P0432 (catalyst and warm up catalyst efficiencies for bank 2) comprised the remaining 19% of the catalyst DTCs. A very small number of other catalyst DTCs were also present. For the EGR system, DTCs in the range of P0400 through P0406 comprised nearly 100% of all DTCs in the four-state dataset. Approximately 88% of all EGR DTCs were flow related (P0400 through P0402), with the remaining DTCs pertaining to the EGR's control circuit or sensor. For the O₂ system analysis, a wide range of O₂ system DTCs were present in the data for each I/M program, and "common" DTCs were not as limited to a small number of DTCs as they were for the evap, catalyst, and EGR systems. However, of the 141 possible O₂ system DTCs considered for this analysis, 90% of the DTCs occurring in the four states (in terms of frequency of occurrence) were limited to 18 DTCs. Approximately 58% of all O₂ system DTCs were associated with the O₂ sensor activity, response or circuit, while another 32% of the O₂ system DTCs pertained to the O₂ heater or heater circuit.

California Roadside vs. I/M Analysis Results

The following subsections provide results of the roadside versus I/M analysis. A primary objective of this evaluation was to better understand the readiness and DTC rates in an I/M program (Smog Check) versus "on-road" readiness and DTC rates (Roadside), keeping in mind the bias that may be introduced by preferential selection of "older, higher emitting vehicles,"⁴ as well as California's exemption of the six newest model year vehicles. Also, as many vehicles in the California fleet may have been certified to different new vehicle certification standards than other 49-state vehicles, emissions and OBD results could differ somewhat from those that would occur in other states, although general I/M versus on-road trends are likely relatively consistent among states with enforced I/M programs.

Roadside vs. I/M Readiness and DTC rates

Tables 6 and 7 summarize readiness and DTC rates for each of the systems evaluated for this analysis. From Table 6, it can be seen that the evap monitor had a 6.5% lower readiness rate during the I/M test than during the Roadside test. In comparison, the differences in readiness rates between the I/M and Roadside tests were 2.4% for the catalyst monitor and 0.7% for the EGR and O₂ system monitors. For the Roadside test, the catalyst monitor had a lower readiness rate than any of the other monitors (including the evap monitor), but for the I/M test, the evap monitor had the lowest readiness rate. The I/M readiness rate was lower than the Roadside readiness rate for each of the four monitors evaluated. Table 7 shows that the evap system had higher DTC rates than the other systems that were analyzed, for both the Roadside test and the I/M test. These readiness and DTC rates could be influenced somewhat by the fact that the sample of vehicles used for this analysis is biased toward older vehicles, as previously described, in particular since model year 1996 through 1998 vehicles have exhibited a higher incidence rate of readiness issues⁵.

In terms of DTC rates, Table 7 shows that 5.3% of the total number of vehicles tested had evap DTCs during the Roadside test, while only 1.4% of these same vehicles had evap DTCs during the I/M test. This 3.9% difference in DTC rates between the two tests was only slightly larger than for the other monitors, which had DTC rate differences between the two tests ranging from 2.8% to 3.4%. As with readiness, DTC rates were always higher during the Roadside test than during the I/M test. The overall range of Roadside DTC rates (which ranged from 3.7% to 5.3%) was three to five times higher than the I/M DTC rates (0.8% to 1.4%) for each of the four test groups. Although this could be due to certain monitors not being “ready” at the time of the I/M test (and hence “concealing” OBD-identifiable malfunctions), it could also be due in part to intermittent malfunctions or repaired malfunctions (which later reoccurred). Further, this analysis was based only on the presence of DTCs, without regard to MIL illumination, and therefore included both active and inactive DTCs. As shown in Table 8, 12% to 25% of the Roadside tests had DTCs with no MIL illumination. DTCs without MIL illumination would not be sufficient to fail either the I/M or Roadside tests. Table 8 totals include all Roadside tests, regardless of monitor readiness status.

To further explore the relationship between roadside and I/M test results, DTC percentages were binned according to test type (Roadside vs. I/M) and monitor-specific readiness for all test pairs, as shown in Tables 9 through 12. The “Roadside DTCs Only” column in these tables is shown in bold font, as this represents counts of test pairs that had DTCs during the Roadside test, but not during the I/M test. The results in red font indicate the subset of vehicles with Roadside DTCs that may have been “masked” by a “not ready” monitor during the I/M test. For each of the four monitors, between 10% and 17% of the test pairs had a “not ready” monitor (and no DTCs) during the I/M test but had DTCs and a “ready” monitor during the Roadside test. Also, for each of the four monitors, an additional 2.5% to 3.0% of the vehicles had a “ready” monitor for both tests, but only had DTCs during the Roadside test. DTCs that are only present during the Roadside test (with that monitor “ready” for both tests) may be due to intermittent malfunctions or malfunctions that were corrected because of the I/M test. For these test pairs in which each specific monitor was “ready” for both tests, all systems were found to have slightly higher rates of Roadside DTCs present when the Roadside test was performed AFTER (rather than before) the I/M test, which suggests the OBD-detected malfunctions were either intermittent in nature or repairs performed were not durable (resulting in a reappearance of the DTCs after the I/M test).

The overall trends were also found to be relatively consistent across monitor groups. It does appear “not ready” monitors may be concealing DTCs on some vehicles during the I/M test. The amount of time a monitor takes to achieve readiness likely has an influence on this effect.

Time-based comparison of Roadside vs. I/M readiness and DTC rates

For each of the monitors, an evaluation was performed of Roadside test monitor readiness status and DTC rates as a function of time before and after the I/M test for all matched vehicles in the study. When evaluating readiness as a function of time before or after the I/M inspection, no strong consistent trends were seen among all the monitors in terms of the rate

of monitor readiness before and after the I/M test. However, for all four monitors, a small decrease in the percentage of tests with DTCs associated with each specific monitor was seen around the time of the I/M test, as shown in Figures 9 through 12. Figures 9 through 12 were created by grouping all data pairs into bins of 150 observations according to time (roughly four to seven-days) since the I/M inspection had been performed. Days to the left of the chart (with negative values) represent Roadside tests that occurred prior to the I/M test. Green trend lines showing trends in system DTC rates before and after the I/M test are shown and can be compared with the overall average DTC rate (shown as a dashed horizontal black line).

Figures 9 through 12 all show the pattern of increasing DTC rates until the I/M test, with a drop around the time of the I/M test. This could be due in part to repairs performed on vehicles in preparation for or as a result of the I/M inspection, although to a lesser extent it could also be due in part to evap DTCs being “masked” by “not ready” monitors.

Comparison of roadside tailpipe emissions and DTCs

Similar to the evaluation of readiness and DTC rates as a function of time before or after the I/M test, Roadside emission test results (acceleration simulation mode, or ASM, pass/fail rates) were evaluated as a function of time before and after the I/M test. In general, Roadside emission test fail rates tended to decrease around the time of the I/M test, suggesting the I/M program does have an influence on these emission results (and hence pass/fail rates). This is shown in Figure 13. In Figure 13, the tests are grouped in the same manner as for Figures 9 through 12. Before / after trend lines again show a gradual increase in Roadside ASM fail rates until the I/M test, at which time the ASM fail rates decrease.

A comparison was also performed of average Roadside ASM emission concentrations between vehicles with no DTCs and vehicles with catalyst, EGR or O₂ system DTCs. Although average emission concentrations were higher for vehicles with catalyst or O₂ system DTCs than for vehicles with no DTCs, for the most part these emission differences were not statistically significant, with the exception of NO_x emission concentrations for model year 1996 – 1999 vehicles (and the magnitude of the difference is very small even for these vehicles). Again, these were DTCs without regard to MIL command status, so these DTCs included some inactive DTCs and did not all necessarily represent a current malfunction. Overall, no strong trends were seen between these types of DTCs and ASM emissions during the Roadside test.

Summary / Conclusions

This analysis provided a comparison of light-duty gasoline-powered vehicle evap system, catalyst, EGR system and O₂ sensor system readiness monitors and DTCs using data from I/M programs in California, Georgia, New Jersey, and Colorado. Additional OBD monitor readiness and DTC rate analysis was performed on vehicles that had received both I/M and Roadside tests in California (these vehicles had received a Roadside test within 21 months of an I/M test). Also, for these same vehicles, Roadside ASM fail rates were evaluated as a function of time before and after the I/M test, and Roadside ASM emission levels were evaluated in comparison with catalyst, EGR, and O₂ system DTCs.

Readiness and DTC rates were fairly consistent by monitor among the four states, with the exception of Colorado, which had lower overall average readiness rates and higher overall average DTC rates than the other states, likely a result of Colorado's unenforced OBD program (pass/fail is based on IM240 and gas cap test results, and OBD results are provided only on an advisory basis). As Tables 2 and 4 show, the evap system had lower readiness rates overall and slightly higher DTC rates than the "exhaust" related monitors.

For all systems, analysis results indicated that as vehicles age, they tend to be more likely to have a "not ready" monitor during an I/M cycle, although the rate of decline of readiness by vehicle age varied by monitor. This can be seen in Table 3 and Figures 1 through 4. Among the four systems evaluated, the evap monitor readiness rates showed the strongest dependence on vehicle age (older vehicles are less likely to have a "ready" evap monitor than newer vehicles). The O₂ system monitor showed the least dependence of monitor readiness as a function of vehicle age.

Similarly, as vehicles age, they tend to be more likely to have DTCs (as presented in Table 5 and shown in Figures 5 through 8). This trend was most pronounced for the evap system. In general, readiness rates are higher, and DTC rates are lower, for vehicles subjected to an enforced OBD test program. The rate of decrease of readiness by vehicle age and increase in DTCs by vehicle age is also lower for vehicles subjected to an enforced OBD test program (when compared to vehicles not in an enforced OBD test program).

For most systems, the majority of DTCs were limited to a small subset of all possible DTCs. For the evap monitor, DTCs primarily fell into two categories, leaks or purge flow. Six DTCs pertaining to catalyst and warm up catalyst efficiencies comprised nearly all catalyst DTCs, and seven DTCs which were either related to EGR flow or the EGR control system comprised nearly all the EGR DTCs. The O₂ system DTCs were more diverse, although only 13% of all possible O₂ system DTCs comprised 90% of all O₂ DTC occurrences in the data. These DTCs pertained to both the O₂ sensor and the O₂ heater system.

When evaluating the subset of vehicles in California that received both Roadside and I/M tests within a 21-month period, all four monitors showed a slight decrease in the percentage of Roadside tests with DTCs associated with each specific monitor around the time of the I/M test. The changes in Roadside test readiness rates around the time of the I/M test were mixed (readiness decreased for the evap monitor, increased for the catalyst, and changed little for the EGR and O₂ system monitors). For all four monitors, the overall average I/M readiness rate was lower, and the overall average DTC rate was higher, for the Roadside test than for the I/M test (Tables 6 and 7). Tables 9 through 12 show additional detail on the prevalence of Roadside vs. I/M DTC and readiness rates, and from this table it can be seen that between 10% and 17% of the test pairs had a "not ready" monitor (and no DTCs) during the I/M test but had DTCs and a "ready" monitor during the Roadside test. The number of DTCs recorded during Roadside tests decreased around the time of the I/M test, and Roadside test ASM fail rates also decreased around the time of the I/M test, suggesting the I/M program does have an influence on DTCs and ASM emission rates. However, no strong overall trends were seen between the four categories of DTCs considered in this analysis and

ASM emissions during the Roadside test. Again, these are DTCs collected without regard to MIL command status (and therefore may include some inactive DTCs).

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Definitions/Abbreviations

ASM	acceleration simulation mode
CA	California
CO	Colorado
DTC	diagnostic trouble code
EGR	exhaust gas recirculation
Evap	evaporative emissions control system
GA	Georgia
I/M	inspection and maintenance program
MIL	malfunction indicator light
NJ	New Jersey
NR	not-ready (OBD monitor)
OBD	on-board diagnostic
O₂	oxygen sensor
RS	roadside
U.S.	United States
U.S. EPA	United States Environmental Protection Agency
SAE	Society of Automotive Engineers
VIN	vehicle identification number

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Figure 1:
Readiness Trends by Vehicle Age for the Evap Monitor

Figure 2:
Readiness Trends by Vehicle Age for the Catalyst Monitor

Figure 3:

Readiness Trends by Vehicle Age for the EGR Monitor (Note: EGR readiness cannot be evaluated for California I/M Data)

Figure 4:
Readiness Trends by Vehicle Age for the O₂ System Monitor

Figure 5:
DTC Trends by Inspection Cycle for the Evap Monitor

Figure 6:

DTC Trends by Inspection Cycle for the Catalyst Monitor

Figure 7:
DTC Trends by Inspection Cycle for the EGR Monitor

Figure 8:

DTC Trends by Inspection Cycle for the O₂ System Monitor

Figure 9:
Time-based Trends in Roadside Evap DTC Rates

Figure 10:
Time-based Trends in Roadside Catalyst DTC Rates

Figure 11:
Time-based Trends in Roadside EGR DTC Rates

Figure 12:
Time-based Trends in Roadside O₂ System DTC Rates

Figure 13:
Time-based Trends in Roadside ASM Fail Rates

Table 1.Summary of I/M Data Analyzed¹

State	Calendar Years of Data Used	OBD Inspection Frequency	Exemption Period
CA	2004–2010	Biennial	First 6 MYs ²
GA	2007–2012	Annual	First 3 MYs
NJ	2005–2009	Biennial	First 4 MYs
CO	2004–2011	Biennial	First 4 MYs

¹Program criteria during calendar years when data was collected²First 4 MYs on Resale

Table 2.

Overall Monitor Readiness Rates across Four States

System	Overall “Ready” Rates by State ¹			
	CA	GA	NJ	CO
Evap	89.6%	92.1%	92.8%	91.4%
Catalyst	91.7%	94.9%	94.5%	92.1%
EGR	N/A	97.8%	97.7%	94.6%
O₂ System	97.2%	98.3%	97.7%	95.2%

¹ Overall “ready” rates are based on monitor-readiness by inspection cycle for all vehicles / years of analysis.

Table 3.

Monitor Readiness Rates across Four States by Age

System	Readiness Ranges by Age Range ²	
	2–3 Years	9–10 Years
Evap	90% – 98% (CO is $\cong$ 95%)	86% – 90% (CO is $\cong$ 89%)
Catalyst	96% – 100% (CO is 97% – 98%)	93% – 96% (CO is 92% – 93%)
EGR	Nearly 100% (CO is 98% – 99%)	98% – 99% (CO is 95% – 96%)
O₂ System	97% – 100% (CO is 97% to 98%)	97% – 99% (CO is 95% – 96%)

²Readiness ranges are based on linear regression trend lines of data by vehicle age for model-year 2000 and newer vehicles. Colorado is listed separately as the OBD program is not enforced.

Table 4.

Overall Monitor DTC Rates across Four States

System	Overall DTC Rates for Vehicles with a “Ready” Monitor, by State ^I			
	CA	GA	NJ	CO
Evap	1.6%	0.7%	0.9%	2.5%
Catalyst	0.8%	0.6%	0.8%	1.7%
EGR	N/A	0.8%	0.9%	2.3%
O ₂ System	1.1%	0.4%	0.8%	2.1%

^I Overall DTC rates are based on inspection cycles for all vehicles (with that monitor “ready”) and across all years of analysis.

Table 5.

Monitor DTC Rates across Four States by Age

	DTC Rate Ranges by Age Range²	
	2–3 Years	9–10 Years
Evap	0.0% – 0.6% (CO is 0.7% – 1.1%)	1.0% – 2.6% (CO is 3.8% – 4.2 %)
Catalyst	0.0% – 0.2% (CO is $\cong$ 0.2%)	0.8% – 1.4 % (CO is 3.0% – 3.5%)
EGR	0.1% – 0.2% (CO is $\cong$ 0.4%)	0.7% – 1.1% (CO is 2.6% – 3.0%)
O₂ System	0.0% – 0.3% (CO is 0.3% – 1.1%)	0.4% – 1.2% (CO is 2.0% – 2.3%)

²DTC rate ranges are based on linear regression trend lines of data by vehicle age for model-year 2000 and newer vehicles. Colorado is listed separately as the OBD program is not enforced.

Table 6.

Roadside vs. I/M Readiness Summary

System	Count of Test Pairs	Overall “Ready” Rates	
		Roadside	I/M
Evap	19,597	92.4%	85.9%
Catalyst	19,597	90.8%	88.4%
EGR	13,721	96.7%	96.0%
O ₂ System	19,597	96.4%	95.7%

Table 7.

Roadside vs. I/M DTC Summary

System	Count of Test Pairs	By-Vehicle Occurrence of DTCs ^I	
		Roadside	I/M
Evap	19,597	1031 (5.3%)	283 (1.4%)
Catalyst	19,597	828 (4.2%)	163 (0.8%)
EGR	13,721	503 (3.7%)	107 (0.8%)
O₂ System	19,597	806 (4.1%)	244 (1.3%)

^I Indicates percentage of per-vehicle test pairs with DTCs (active and inactive) present in the Roadside or Smog Check I/M tests, regardless of that monitor's readiness

Table 8.

Roadside Test DTC Rates by MIL Command Status

System	# of Tests with DTCs and MIL Commanded On	# of Tests with DTCs and MIL Commanded Off	Total Tests With DTCs
Evap	814 (79.0%)	217 (21.0%)	1031
Catalyst	704 (85.0%)	124 (15.0%)	828
EGR	443 (88.1%)	60 (11.9%)	503
O₂ System	605 (75.1%)	201 (24.9%)	806

Table 9.

Summary of Evap Monitor DTCs by Test Type and Monitor Readiness

Evap Readiness by Test Type ¹	Test Pairs	No DTCs	Roadside DTCs Only	I/M DTCs Only	DTCs in Both Tests
Both Tests Rdy	16,047 (81.9%)	15,304 (95.4%)	487 (3.0%)	113 (0.7%)	143 (0.9%)
RS is Rdy I/M is NR	2,064 (10.5%)	1755 (85.0%)	303 (14.7%)	3 (0.1%)	3 (0.1%)
RS is NR I/M is Rdy	788 (4.0%)	738 (93.7%)	40 (5.1%)	7 (0.9%)	3 (0.4%)
Both Tests NR	698 (3.6%)	645 (92.4%)	42 (6.0%)	1 (0.1%)	10 (1.4%)

¹RS = Roadside, Rdy = Evap monitor ready, NR = Evap monitor not ready

Table 10.

Summary of Catalyst Monitor DTCs by Test Type and Monitor Readiness

Catalyst Readiness by Test Type¹	Test Pairs	No DTCs	Roadside DTCs Only	I/M DTCs Only	DTCs in Both Tests
Both Tests Rdy	16,325 (83.3%)	15,693 (96.1%)	474 (2.9%)	65 (0.4%)	93 (0.6%)
RS is Rdy I/M is NR	1476 (7.5%)	1227 (83.1%)	249 (16.9%)	0 (0.0%)	0 (0.0%)
RS is NR I/M is Rdy	995 (5.1%)	981 (98.6%)	9 (0.9%)	5 (0.5%)	0 (0.0%)
Both Tests NR	801 (4.1%)	798 (99.6%)	3 (0.4%)	0 (0.0%)	0 (0.0%)

¹RS = Roadside, Rdy = Catalyst monitor ready, NR = Catalyst monitor not ready

Table 11.

Summary of EGR Monitor DTCs by Test Type and Monitor Readiness

EGR Readiness by Test Type¹	Test Pairs	No DTCs	Roadside DTCs Only	I/M DTCs Only	DTCs in Both Tests
Both Tests Rdy	12,859 (93.7%)	12,446 (96.8%)	317 (2.5%)	43 (0.3%)	53 (0.4%)
RS is Rdy I/M is NR	411 (3.0%)	339 (82.5%)	68 (16.5%)	2 (0.4%)	2 (0.5%)
RS is NR I/M is Rdy	313 (2.3%)	271 (86.6%)	41 (13.1%)	0 (0.0%)	1 (0.3%)
Both Tests NR	138 (1.0%)	117 (84.8%)	15 (10.9%)	0 (0.0%)	6 (4.3%)

¹RS = Roadside, Rdy = EGR monitor ready, NR = EGR monitor not ready

Table 12.Summary of O₂ System Monitor DTCs by Test Type and Monitor Readiness

O ₂ Readiness by Test Type ¹	Test Pairs	No DTCs	Roadside DTCs Only	I/M DTCs Only	DTCs in Both Tests
Both Tests Rdy	18,189 (92.8%)	17,483 (96.1%)	486 (2.7%)	112 (0.6%)	108 (0.6%)
RS is Rdy I/M is NR	697 (3.6%)	618 (88.7%)	71 (10.2%)	5 (0.7%)	3 (0.4%)
RS is NR I/M is Rdy	569 (2.9%)	443 (77.9%)	117 (20.6%)	5 (0.9%)	4 (0.7%)
Both Tests NR	142 (0.7%)	125 (88.0%)	10 (7.0%)	0 (0.0%)	7 (4.9%)

¹ RS = Roadside, Rdy = O₂ system monitor ready, NR = O₂ system monitor not ready