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Final Technical Support Document for "Amendments to Vehicle Inspection Maintenance Program Requirements Incorporating the Onboard Diagnostic Check"

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1.0 Overview

On September 20, 2000, EPA proposed to revise existing Motor Vehicle Inspection/Maintenance (I/M) requirements related to the incorporation of Onboard Diagnostic (OBD) checks into such programs. Among other things, the proposed regulatory revisions -- once adopted -- will accomplish the following:

1) Allow the OBD-I/M check to replace tailpipe and evaporative system testing on OBD-equipped vehicles (with the exception of the gas cap evaporative system test); and

1) Revise the failure and rejection criteria for the OBD-I/M check.

This Technical Support Document (TSD) provides EPA's technical justification for these amendments, based upon the Agency's findings gathered during three separate OBD-I/M pilot studies. These three pilot studies focused on the following aspects of OBD-I/M testing: 1) OBD-I/M's effectiveness as compared to existing exhaust emission testing; 2) OBD-I/M's effectiveness in identifying faults in the evaporative system; and 3) the unique implementation issues associated with incorporating checks of the OBD system into a traditional I/M setting. The results of EPA's pilot testing were shared while still in progress with members of the OBD workgroup of the Mobile Source Technical Review Subcommittee established under the Federal Advisory Committee Act (FACA). The OBD workgroup's membership includes representatives from the testing and repair industries, vehicle manufacturers, the states, EPA, scan tool manufacturers, the academic community, private consultants, and providers of OBD technician training. Feedback from the workgroup was used to help guide the progress of the pilots, to interpret the results along the way, and to develop the proposed amendments to the rule's existing OBD-I/M requirements.

This TSD is divided into four main sections. Following the overview section are three main sections that coincide with the three pilots identified above.

2.0 OBD-I/M Pilot 1: OBD Checks and Tailpipe Testing

2.1 Summary of Goals and Conclusions

Between September 1997 and October 1999, EPA recruited 201 in-use MY 1996 and newer OBD-equipped vehicles and performed an IM240 transient test, an OBD-I/M inspection, and an abbreviated version of the vehicle certification test known as the Federal Test Procedure (FTP) on each vehicle[1]. Vehicles identified as needing repairs were repaired after this initial test

[1] Because the focus of this pilot was comparing OBD-I/M checks to more traditional, tailpipe-based I/M tests, only the tailpipe portion of the FTP was performed for this pilot study. The evaporative emission portion of the FTP was performed on a smaller sample of vehicles included in the separate, OBD evaporative pilot discussed in section 3 of this TSD.

sequence and then subjected to the same sequence again, after repairs. The goal of this test program was to answer the following question:

> ***Is it necessary to conduct both an OBD-I/M check and the IM240 (or some other tailpipe test) on OBD-equipped vehicles?***

To answer this question, EPA had to determine if the OBD-I/M check: 1) failed vehicles it should have passed; 2) passed vehicles it should have failed; and 3) whether the rate at which it did either of these was higher than, lower than, or the same as the IM240. Since it is widely considered the most accurate tailpipe-based I/M test available, the IM240 was used to represent the "best case" scenario with regard to tailpipe testing in general.

Based upon the test results detailed in this TSD, EPA concluded that it should not require both an OBD-I/M check and the IM240 (or other tailpipe test) on MY 1996 and newer OBD-equipped vehicles[2]. Specifically, EPA found that while the OBD-I/M check did falsely pass and falsely fail some vehicles, in both cases the percentage of vehicles impacted was smaller than would be the case with the IM240 and other tailpipe tests. Furthermore, even though the IM240 caught some of the very few vehicles missed by the OBD-I/M check, the additional cost that would result from subjecting OBD-equipped vehicles to two tests instead of one will likely outweigh any additional benefit that may be achieved. Lastly, the emission reductions available from basing repairs on the OBD-I/M check appear to be at least as large as the emission reductions obtained from IM240-triggered repairs on OBD-equipped vehicles.

2.2 Background

Under the Clean Air Act as amended in 1990 (CAA), EPA was required to promulgate two categories of regulations related to OBD. The first regulated vehicle manufacturers and required the installation of the OBD system on all new light-duty vehicles and light-duty trucks. The second regulated state I/M programs and required that all such programs – whether basic or enhanced – include an inspection of the OBD computer for vehicles so equipped. In 1992, when EPA published its original I/M rule, federal OBD certification requirements were still being developed, and so sections were reserved in the I/M rule to address the OBD-I/M testing requirement at a later date. Since the 1992 I/M rule was published, EPA has amended it twice to address OBD-I/M testing requirements – first, on August 6, 1996, and again on May 4, 1998.

In the 1996 amendments, EPA described how OBD was to be addressed as part of the basic and enhanced I/M performance standards and established OBD-I/M SIP requirements. The 1996 amendments also specified data collection, analysis, and summary reporting requirements for the OBD-I/M testing element; established OBD test equipment requirements and the OBD test result reporting format; and identified those conditions that would result in either an OBD-

[2] Although EPA does not intend to require dual testing of OBD-equipped vehicles for reasons detailed in this TSD, states wishing to dual test MY 1996 and newer vehicles may do so. EPA will work with individual states to determine whether or not additional credit is warranted on a case-by-case basis.

I/M failure or rejection. Lastly, the 1996 amendments established January 1, 1998 as the deadline by which most I/M programs were to begin OBD-I/M checks, though vehicles were not required to be failed based upon the OBD-I/M check until January 1, 2000[3]. The data gathered by state programs between January 1, 1998 through December 31, 1999 was to be used to assess the effectiveness of the OBD-I/M check relative to the IM240.

Subsequent to the 1996 amendments, the I/M test environment changed significantly, with the result that use of the IM240 was not as prevalent as had once been expected. In the same time frame, EPA discovered that the IM240 test as originally designed might lead to false failures for some vehicles due to insufficient preconditioning[4], and as a result the test itself might not be as effective as once thought. This latter issue suggested that evaluating the OBD-I/M check based upon a comparison to the IM240 could unfairly penalize the OBD-I/M check. Members of the OBD workgroup[5] (established under the Federal Advisory Committee Act) raised similar concerns regarding the appropriateness of comparing the OBD-I/M check to a “hot start” test like the IM240 as opposed to the FTP, which is a “cold start” test and the standard to which new cars are certified. Furthermore, OBD design requirements are based in part on detecting emission failures which are directly related to the FTP[6].

As a result of these changing conditions and concerns, EPA revisited its original plans for evaluating the effectiveness of OBD-I/M testing by comparing it to state-gathered IM240 inspection lane data. Instead, EPA decided to pursue the test program described here, in order to alleviate the need for states to run dual tests (tailpipe and OBD) in their I/M lanes merely as a form of data gathering[7]. The May 4, 1998 amendments to the I/M rule addressed this change by delaying the date by which I/M programs were to begin OBD testing to no later than January 1, 2001[8]. To generate the necessary data for comparison, EPA and its research partners conducted sample testing at four different labs: the National Vehicles and Fuels Emissions Laboratory (NVFEL) in Ann Arbor, Michigan; the Automotive Testing Laboratory (ATL) in Mesa, Arizona; the Colorado Department of Health Laboratory (CDH) in Aurora, Colorado; and the California Air Resources Board (CARB) test facilities in El Monte, California.

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[3] Programs qualifying for the Ozone Transport Region (OTR) low enhanced performance standard were allowed to postpone mandatory OBD-I/M testing until January 1, 1999.

[4] SAE paper 962091, “Preconditioning Effects on I/M Test Results Using IM240 and ASM Procedures,” Heirigs, Philip; Gordon, Jay.

[5] The OBD workgroup is a subgroup of the Mobile Sources Review Subcommittee, which was itself formed under the Federal Advisory Committee Act (FACA) in order to advise the Agency on technical matters.

[6] The exhaust standards for OBD require that a dashboard light be illuminated under circumstances which could lead the vehicle to exceed its certification standards by 1.5 times the standard.

[7] Federal Register Volume 61, No. 152; August 6, 1996; page 40940.

[8] In its September 20, 2000 notice of proposed rulemaking, EPA proposed to extend this deadline to January 1, 2002 in addition to the other revisions discussed in this TSD -- in part due to the proximity of the current deadline to the release of these findings and the proposed amendments.

2.3 Vehicle Sampling

2.3.1 Methodology

Based upon advice from the Mobile Source Review Subcommittee, EPA decided to conduct an FTP-based test program with a minimum of 200 vehicles[9]. The goal of the test program was to determine how well OBD-I/M testing compared to tailpipe I/M testing. Because the IM240 is generally accepted as the most accurate tailpipe test available for use by I/M programs, EPA decided that a comparison to the IM240 would be considered a "best case" comparison for establishing relative tailpipe test effectiveness[10].

The recruitment of vehicles for pilot testing was controlled by the need to answer two basic questions concerning the effectiveness of OBD-I/M testing relative to traditional tailpipe tests: 1) Do vehicles identified by the OBD-I/M check actually need repair, and 2) Does the OBD-I/M check miss high emitters that would be caught by traditional tailpipe testing? To address the first question, EPA recruited vehicles identified by OBD as possible high emitters in need of repair (i.e., vehicles with the malfunction indicator light -- or MIL -- illuminated). To address the second question, EPA focused on those vehicles that failed a properly preconditioned IM240, but for which no MIL was illuminated.

Concern about the relatively small sample size and the degree to which it would represent the fleet at large led EPA to weight its sample based upon manufacturer production for the six largest producers. The remaining manufacturers represent a small percentage (<10%) of the entire fleet and are represented by the category "other." The sample was also weighted to account for the growing fraction of light-duty trucks (LDTs) in the fleet. Table 1 below was developed to act as a target for the 200 vehicle sample based on 1997 vehicle sales[11].

Table 1: Procurement Goals Based on Production

MFR	GM	Ford	Daimler-Chrysler	Toyota	Honda	Nissan	Other	Total
LDV	35	21	10	11	11	7	10	105
LDT	27	29	20	5	1	3	10	95
Total	62	50	30	16	12	10	20	200

[9] Mobile Source Review Subcommittee meeting of 7/16/97.

[10] Sierra Research Report under EPA Contract 68-C4-0056; WA 2-03; "Development of a Proposed Procedure for Determining the Equivalency of Alternative Inspection and Maintenance Programs," page 7.

[11] Automotive Industries; February, 1998, page 17.

For vehicles with the MIL illuminated, any vehicle with a non-evaporative, emissions-related trouble code commanding the MIL on was accepted into the program[12]. These vehicles were selected without knowledge of their tailpipe emissions. However, because misfire codes are relatively common among the MILs observed in the field, an upper limit of 25% was established for misfire codes per manufacturer represented in the overall sample. This 25% limit was derived from a fleet survey of over 160,000 vehicles in Wisconsin and represents the relative occurrence of misfire diagnostic trouble codes (DTCs) seen in the I/M lane[13].

The pilot study also called for the recruitment of vehicles with (potentially) high emissions and no MIL illumination. These no-MIL/high-emitter vehicles were identified and recruited based upon two primary criteria: 1) High LANE240[14] test results or 2) other characteristics which experience suggested would result in high emissions (i.e., high mileage, and/or driveability problems). Using the first criteria, the most stringent IM240 standards[15] were applied even though the actual state I/M program did not fail vehicles based on those values.

Additional, potential high emitters were recruited based upon very high mileage, or a mechanic's report that a particular vehicle was running poorly. Because NVFEL is not located near an operating I/M program, the Ann Arbor lab used this secondary method as its primary means for identifying and recruiting no-MIL/high-emitter vehicles for subsequent testing. ATL and CDH also attempted to find additional no-MIL/high-emitter vehicles based upon these more qualitative (as opposed to quantitative) criteria. On the vehicles with suspected high emissions but no lane-based tailpipe data, the LAB240 was again used to screen which vehicles were kept in the sample and which were released from further participation in the pilot study.

2.3.2 Results

201 vehicle test slots were filled during the program versus the 200-vehicle target (2 vehicle slots were filled by the same vehicle, which was recruited twice, six months apart, with different problems each time). Table 2 represents the breakdown of this sample by manufacturer and is also segregated into cars (LDVs) versus trucks (LDTs). The category of "other" is made up of the following manufacturers followed by the number of sample vehicles

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[12] "Recommended Practice for Diagnostic Trouble Code Definitions," SAE J2012, Society of Automotive Engineers, Inc., revised March 1999.

[13] "Analyses of the OBDII Data Collected from the Wisconsin I/M Lanes," Trimble, Ted, Environmental Engineer, U.S. EPA, August 2000.

[14] EPA distinguishes between "LANE240" tests (i.e., those conducted by a commercial testing contractor as part of the routine operation of an existing program) and "LAB240" tests (i.e., those conducted under controlled, laboratory conditions for test type comparison and evaluation purposes). More information concerning the differences between "LANE" and "LAB" IM240s is available in Appendix 3.

[15] "EPA I/M Briefing Book: Everything You Ever Wanted to Know About Inspection and Maintenance," EPA-AA-ESPD-IM-94-1226, Section 4, page 10. U.S. EPA, Office of Air and Radiation, February 1995.

from each: Mazda (2), Volkswagen (3), Isuzu (2), Hyundai (3), Kia (1), Saab (1), Volvo (1), and Suzuki (3). Of the 201 vehicles in the sample, 193 were recruited as MIL-on vehicles, while the remaining 8 were recruited as no-MIL/high-emitter vehicles.

Table 2: Description of Sample by Manufacturer and Type

MFR	GM	Ford	Daimler-Chrysler	Toyota	Honda	Nissan	Other	Total
LDV	*45 **(128%)	31 (148%)	22 (220%)	5 (45%)	8 (73%)	7 (100%)	14 (140%)	132 (126%)
LDT	18 (66%)	28 (96%)	16 (80%)	1 (20%)	0 (0%)	4 (133%)	2 (20%)	69 (73%)
Total	63 (102%)	59 (116%)	38 (127%)	6 (38%)	8 (67%)	11 (110%)	16 (80%)	201 (100%)

* = number procured ** = percent of goal

The sample breakout by model year and by minimum, maximum, and average odometer readings are listed in tables 2a and 2b, respectively.

Table 2a: Breakout by model year

	1996	1997	1998	1999	2000
LDV	28	33	38	32	1
LDT	27	22	14	6	0

Table 2b: Odometer readings

	LDV	LDT
MINIMUM	29	3,981
AVERAGE	26,440	54,505
MAXIMUM	93,575	245,000

As the results of these procurement efforts are considered, it is important to keep in mind the relatively low age of the fleet of vehicles being evaluated (i.e., MY 1996 and newer). The relatively low age (four years old or newer) and mileage (average = 37,000 miles) of the vehicle population targeted by the study led to fewer MIL illuminations in the general fleet than would be expected. We do not believe, however, that the relative newness of the vehicles that participated in this pilot will change the direction of the conclusions drawn from this study. Specifically, we do not believe that OBD systems will prove somehow less effective at identifying vehicles in need of repair as the OBD-equipped population ages. This is because the OBD system itself (as opposed to the hardware the OBD system monitors) is primarily a self-contained, software-based system and not likely to be subject to substantial degradation due to aging. The practical impact of the newness of these vehicles was the limited exposure of the hardware being monitored to the real world effects of heat, cold, water, salt, etc. However, because the possibility exists that multiple-component aging may have a negative, synergistic effect on OBD's ability to detect vehicles which have high emissions in the future, continued study of the OBD-equipped fleet as it ages and accumulates mileage seems warranted[16].

2.4 Vehicle Testing

2.4.1 Methodology

During the two-year period from September 1997 through October 1999, EPA and its research partners conducted sample testing at four different laboratories across the country: the National Vehicles and Fuels Emissions Laboratory (NVFEL) in Ann Arbor, Michigan; the Automotive Testing Laboratory (ATL) in Mesa, Arizona; the Colorado Department of Health Laboratory (CDH) in Aurora, Colorado; and the California Air Resources Board (CARB) test facilities in El Monte, California. FTP testing was performed using the methods described in CFR 86.130-96 with the exception that no diurnal heat build or SHED testing was conducted[17]. IM240 testing was done in accordance with EPA Technical Guidance EPA-AA-RSPD-IM-98-1. OBD information was gathered using scan tools from various manufacturers complying with the standards established by SAE 1978. Maintenance was performed at either the original manufacturer's dealership or by mechanics following the manufacturer's available service information.

MIL-on vehicles were inspected when they first arrived at the lab using the LAB240 procedure and the fuel that was already in the vehicle's tank. The tanks were then drained of in-use fuel and refilled with indolene test fuel. The vehicles then received a standard FTP and a second LAB240. This provided the "As-Received" emissions profile of the vehicle. The FTP was the standard for comparing actual emissions reductions; the IM240 and the OBD-I/M test results were only used to identify vehicles as either "pass" or "fail," relative to the respective I/M test type. Vehicles identified as "failures" based upon either their tailpipe or OBD-I/M results were then sent for repairs, after which they were again tested on the FTP to determine their "after repair" emission levels. Any difference measured between the two FTPs represented the air quality improvement[18] or emission benefit. Most maintenance was performed following original equipment manufacturer (OEM) published procedures, while in some cases, this information was supplemented through consultation with OEM engineers. In cases where DTCs were present but

[16] In recognition of the potential impact of high mileage on OBD effectiveness, EPA recently completed testing and has begun analyzing the results from a study of 43 OBD-equipped vehicles with mileages of approximately 100,000 miles to as high as 273,000 miles. Early indications suggest that high mileage does not have a noticeable impact on the effectiveness of the OBD system to detect needed repairs. With regard to the impact of simple aging, EPA recognizes the value of gathering additional information on the durability of OBD systems as they age, and stands ready to revise the OBD-I/M requirements should future study suggest such is warranted.

[17] Sealed Housing for Evaporative Determination (SHED) testing was conducted on a different subset of vehicles, as part of the evaporative system pilot, which is addressed in section 3.0 of this TSD.

[18] Two vehicles were too dirty and/or running too poorly to test on the FTP. Since it was not possible to establish an accurate "before repair" emission measurement for these vehicles, no air quality benefit was assigned to them. (See discussion in Table 10, and Appendix 4).

the mechanics could find nothing in need of repair or replacement, the OBD system was allowed to reset and was then monitored to verify the absence of any OBD- or emission-related problem. (See Appendix 1 for additional test sequence details.)

2.4.2 Results

Table 3 shows the number of MIL-on vehicles with initial FTP readings exceeding 1 and 1.5 times the applicable certification standard (the latter being a subset of the former). One and a half times the standard was chosen as a criterion for comparison because the certification requirements for OBD specify that the MIL is to be illuminated if a problem is detected that could result in emissions exceeding 1.5 times the exhaust certification standard. Table 3 also shows the subset of MIL-on vehicles for which the MIL cleared on its own, after being recruited but before any repairs could be attempted[19].

Table 3: MIL-On Vehicles vs. FTP and 1.5 Times FTP

	MIL on	MIL self-cleared	FTP > 1 times cert.	FTP > 1.5 times cert.
LDV	128	5	40	21
LDT	66	6	18	10
Total	194	11	58	31

As noted in footnote 18, Table 3 includes two vehicles which are assumed to have failed their as-received FTP at over 1.5 times the applicable tailpipe standards. These vehicles could not be driven on the FTP trace and therefore no tailpipe readings are available. A description of these two vehicles is included in Appendix 4.

EPA also recruited vehicles with suspected high emissions but no MIL illumination. Using the screening methods discussed earlier, 8 vehicles qualified to represent this category. Table 4 shows the number of MIL-off vehicles with initial FTP readings exceeding 1 and 1.5 times the applicable certification standard (the latter being a subset of the former).

Table 4: MIL-Off Vehicles vs. Certification and 1.5 Times Certification Standard

	MIL-off	FTP > 1 times cert.	FTP > 1.5 times cert.
LDV	4	2	1
LDT[20]	4	3	3
Total	8	5	4

[19] MIL self-clearing is a design feature of OBD systems, and is the way the system accounts for intermittent problems (like misfire) that may occur once under atypical vehicle operation, but then seem to disappear during more normal driving. This aspect of OBD is discussed in more detail in section 2.4.2.2, “OBD and Preventative Maintenance.”

[20] All three figures in this row include vehicle CDH04, which was recruited with no MIL but is considered an accurate OBD identification (see Appendix 4).

The ability of OBD to correctly identify vehicles which are emitting at levels significantly over their applicable certification standard (2 times or higher) was also investigated. The subgroup of vehicles making up this sample is listed in Table 5 below.

Note that OBD-I/M missed two of a total of 21 vehicles identified as gross emitters with FTP scores of two or more times their certification standards (i.e., OBD successfully identified 90% of these gross emitters). Note further that the LAB240 missed four times as many vehicles from this category, and identified only 62% of the grossest emitters. The two vehicles missed by OBD-I/M -- one LDV (CDH03) and one LDT (CDH33) -- were correctly failed by the LAB240, while the eight LDVs missed by the LAB240 were correctly failed by OBD-I/M.

Table 5: Vehicles with FTP Results Over 2 Times the Certification Standard

	As measured by FTP	Identified by OBD	Identified by LAB240
LDV	15	14	7
LDT	6	5	6

EPA also collected data on the degree to which repairing vehicles solely to turn the MIL off resulted in emission reductions that changed FTP-failing vehicles into FTP-passing vehicles. Of the 15 LDVs with emissions over twice their standard (>2xFTP), 12 (or 80%) were repaired to below certification levels by targeting repairs solely at correcting the conditions that led to the MIL being on. All 14 of the >2xFTP LDVs identified by OBD-I/M that were repaired based upon OBD-targeted repairs tested below 1.5 times the applicable standard after those repairs (i.e., below the minimum required detection threshold for OBD). The two vehicles that remained above the FTP standard (but below 1.5 times that standard) after repairs to turn off the MIL are discussed in section 2.4.2.3 of this TSD (Table 9).

2.4.2.1 Emission Reductions

The emissions reductions attributable to OBD- and LAB240-triggered repairs performed as part of this pilot are presented in Table 6 below. Vehicles which failed both the LAB240 and OBD-I/M tests are included in both the IM240 and OBD categories of repair data presented below. Nevertheless, vehicles that failed both the LAB240 and OBD-I/M tests were repaired based mainly on the OBD codes and therefore the IM240 repair data are not completely independent of OBD effects. Wholly separate from its use in the I/M arena, OBD is a powerful tool for diagnosing and repairing vehicles in the real world, and more and more repair technicians are using the OBD scan as their starting point for diagnosing vehicles prior to repair. Although EPA could have required technicians to ignore OBD when attempting to fix vehicles identified by IM240 for repair, we believe that such a restriction would be artificial and unnecessarily limiting.

The varying sample sizes listed above for non-methane hydrocarbon (NMHC), total hydrocarbon (THC), and CO2 are due to the fact that while NVFEL and ATL measured all five pollutant categories for the pilot vehicles they tested, the CDH did not measure NMHC and CARB did not measure THC or CO2 for their respective vehicles. The THC and NMHC averages quoted below are therefore based upon the subset of vehicles for which those emissions were measured. LDV and LDT data are presented separately because of significant differences in their certification standards and control strategies.

Table 6: Average Reductions and Fuel Economy Improvement from OBD vs. IM240 Repairs

LDV	THC (gpm)	NMHC (gpm)	CO (gpm)	NOx (gpm)	CO2 (gpm)	FE Increase (mpg)
Avg. OBD n=126	0.138 n= 114	0.1 n= 111	2.4 n= 126	0.1 n=126	6.47 n=114	0.53 n=114
Avg. IM240 n=7	1.04 n=7	0.9 n=5	15.4 n=7	0.6 n=7	14.71 n=7	2.36 n=7
LDT						
Avg. OBD n=65	0.11 n= 65	0.05 n= 49	1.56 n=65	0.13 n=65	-2.66 n=64	0.03 n=64
Avg. IM240 n=7	0.84 n=7	0.37 n=5	10.47 n=7	0.60 n=7	8.27 n=7	0.79 n=7

Another way to look at the same repair reductions is to quantify the total grams per mile (gpm) reduced over the course of the study as opposed to average gpm reductions. Table 7 below quantifies the total gpm reductions attributable to repairs triggered by either OBD or IM240, per pollutant category and segregated by LDVs and LDTs. If a vehicle failed both the LAB240 and the OBD tests, the gpm reductions resulting from repairs were counted under both categories. Note that with the exception of fuel economy improvement on LDTs, OBD-triggered repairs consistently produced more total reductions and fuel economy improvement than did the IM240-triggered repairs.

Table 7: Summation of Reductions Associated with OBD vs. IM240 Triggered Repairs

LDV	THC (gpm)	NMHC (gpm)	CO (gpm)	NOx (gpm)	CO2 (gpm)	FE Increase (mpg)
OBD reductions	15.7	11.1	298	12.1	737	60
IM240 reductions	10.0	4.9	277	5.4	25	27
LDT						
OBD reductions	7.5	2.6	101	8.2	43	2
IM240 reductions	6.4	1.9	90	7.1	61	6

It should be pointed out that in its comparison of the emission reductions attributable to the OBD-I/M check versus the IM240, the OBD tailpipe study was biased in favor of the IM240 to ensure that the conclusions drawn regarding the OBD-I/M check's relative effectiveness were conservative. Specifically, when a vehicle was identified as a likely IM240 false failure based upon a comparison of LANE240 and LAB240 test results, that vehicle was then dismissed from further participation in the study. As a result, the gpm emission reductions attributed to IM240 were not "watered down" down by the false failures noted between the LANE- and LAB240s. Conversely, potential OBD-I/M check false failures were included in the sample and were actively recruited. Therefore, the gpm reductions attributed to either test based upon this pilot really do represent the “best case” scenario for the IM240 and the “worst case” scenario for the OBD-I/M check.

2.4.2.2 OBD and Preventative Maintenance

As a matter of design, OBD should be able to identify the need for repairs and/or maintenance prior to actual increased emissions. This is because OBD monitors the performance of individual emission control components, several of which may need to fail in sequence, or over a period of time before the problem shows up at the tailpipe. For example, a periodic misfire might not lead to immediate increases in emissions, but eventually can destroy the catalyst, at which time tailpipe emissions will increase substantially (as will the likely cost of repairs). Traditional tailpipe tests are less capable of identifying this kind of preventative repair, because such tests rely exclusively upon measurement of post-catalyst tailpipe emissions. Therefore, with traditional tailpipe tests, a relatively inexpensive problem to begin with may become critical before it can be detected.

The tailpipe pilot evaluated this aspect of OBD, and Table 8 lists the results of maintenance performed on vehicles with tailpipe emissions below the applicable certification standards. Vehicles for which EPA was unable to identify or reproduce the condition that led to the original MIL illumination are designated below as MNR (for “Malfunction Not Reproduced”). Vehicles for which the MIL went out on its own after procurement but prior to attempted repair are designated below as “MIL self-cleared.” See Appendix 2 for a list of the parts replaced on these vehicles OBD identified as needing maintenance.

Table 8: Maintenance aspect of OBD MIL illumination identification

	MIL on/FTP pass	Broken part(s) found	MNR	MIL self-cleared
LDV	88	63	25	3
LDT	48	34	14	6
Total	136	97	39	9

In considering these results, it is important to understand that a MIL going out on its own is considered a part of the normal operation of the system; it is not necessarily an indication that the OBD system itself is having a problem. Every mechanic knows that vehicles are complex systems and can experience intermittent or transient problems that seem to go away on their own. And most motorists have had the experience of having a problem that mysteriously “goes away” the second they take it into the shop. Perhaps the vehicle has been put under an unusually high load, the fuel quality is below par, or the vehicle is otherwise being operated under atypical conditions. The OBD system is designed to account for intermittent problems by setting a code when a problem is first detected (for example, a misfire) and then to monitor the vehicle to see if the problem recurs after a certain number of key-on/key-off cycles. If the problem does not recur, the system is allowed to extinguish the MIL, though a record of the problem is recorded and retained by the OBD system for a certain period of time after the MIL is turned off, depending upon the nature of the code. The last column of Table 8 above – “MIL self-cleared” – represents this particular subset of MNR vehicles recruited as part of the tailpipe pilot. Given the difficulty EPA had in finding MY 1996+ vehicles with the MIL on for recruitment, we may have tended to procure vehicles as soon as the MIL turned on (and before the OBD system had a chance to clear itself if the problem detected was an intermittent or transient condition), which does not reflect the anticipated experience of an OBD-I/M program. As a result, EPA believes its sample may have been biased in the direction of recruiting vehicles with MILs lit for intermittent problems.

2.4.2.3 OBD and Errors of Omission (“False Passes”)

During the pilot program, 4 vehicles were found with no MILs illuminated or DTCs set, but which nevertheless had tailpipe emissions exceeding both their certification standards and the 1.5 times the certification level at which OBD is supposed to command the MIL to illuminate and set relevant DTCs. A fifth vehicle was also found to have high emissions and no visible MIL illumination, though when this vehicle was scanned, it was found that the MIL was, indeed, commanded on, but had not illuminated due to a short in the system. All 5 of these vehicles are listed in Table 9 below along with a brief summary of the cause(s) of their high emissions.

The first two vehicles (CDH03 and CDH33) had high emissions and no MIL or pending DTCs prior to repair, while the next two vehicles (ATL120 and ATL130) arrived with the MIL on. In the case of ATL120, the MIL was extinguished by repairs, but the vehicle still produced high emissions after these repairs. In the case of ATL130, a diagnostic scan revealed nothing to fix and the MIL did not re-light after being cleared by the scanner, even though the vehicle’s emissions were still high after the MIL was cleared. And the last vehicle (CDH04) could not be driven on the FTP because it stalled in third gear, but was assumed to be a high emitter due to the fact that it produced a plume of black smoke when tested on the LAB240.

CDH03 is considered an OBD error of omission due to its emission levels and the lack of MIL illumination and DTCs. The repair of the oxygen sensor returned this vehicle to acceptable emissions level. Further investigation of this problem by Daimler-Chrysler engineers found an unanticipated failure mode of the rear oxygen sensor. Daimler-Chrysler found that this failure mode would be detected by all later OBD systems in their product line. No additional examples of this type of oxygen sensor failure mode were located in this test program.

Table 9: Discussion of Specific Vehicles

Vehicle	FTP Emissions	Problem found
CDH03: 1996 Chrysler Neon; 86,236 miles; LANE240 failure	(As received) THC/NMHC/CO /NOx FTP: 1.73/xx/52.0/0.25	OBD error of omission; unanticipated oxygen sensor failure; problem fixed for later model years.
CDH33: 1997 Daimler-Chrysler 1500 Pick-up truck, odometer 113,543; LAB IM240 failure	(As received) FTP: 0.55/xx/12.8/2.9 Standard: xx/0.4/5.5/0.97	THC was < 1.5 times standard (NMHC unknown) but CO and NOx > 1.5 times. See catalyst monitor discussion below.
ATL120: 1997 GM Grand Am; 47,173 miles; MIL extinguished after diagnostics.	(Post diagnostics; no repair) FTP: 0.14/0.12/1.6/0.97 Standard: xx/0.25/3.4/0.4	No problem found during diagnostics and MIL did not reset after clearing, even though NOx was above OBD trigger level. (HC and CO remained below the OBD trigger level.)
ATL130: 1996 Isuzu Hombre (GM system); 235,000 miles; MIL extinguished after diagnostics.	(Post repair) FTP: 0.5/0.39/17.1/0.6 Standard: xx/0.31/4.2/0.6	On post-repair FTP with MIL off, CO was still > 1.5 times standard, while HC fell below the OBD trigger level. See catalyst monitor discussion below.
CDH04: 1996 GM S10 Pickup Truck; 27,063 miles; LANE240 failure	Could not be driven on FTP; projected failure (See Appendix 4)	MIL commanded on, but electrical short prevented illumination; would be caught by OBD-I/M scan.

The issue with CDH33, ATL130, and ATL120 seems to be a matter of timing and the way that catalyst efficiency losses are monitored by OBD[21]. Currently, catalyst monitors only target HC to establish catalyst efficiency[22] based on the fact that the vast majority of possible failure modes leading to increased CO and NOx emissions from the catalyst will also eventually lead to increased HC emissions -- at which time a DTC will be set and the MIL illuminated. While CDH33, ATL130, and ATL120 showed high emissions for NOx and/or CO, the malfunction in question simply had not had time to lead to excessive HC emissions.

Lastly, CDH04 is not considered an OBD error of omission because the computer was commanding the MIL on, but the nature of the problem (a short in the electrical system) prevented the MIL from illuminating. This type of problem would be identified as a failure in an OBD-I/M program and would be required to be repaired. This vehicle helps illustrate why a simple pass-fail visual check for MIL illumination is not enough on which to base an I/M inspection; a scan of the onboard computer is also needed to help determine if there is a problem with vehicle readiness, a malfunctioning MIL, a short in the wiring, et cetera.

[21] EPA did not perform a detailed analysis of the entire emissions systems on these vehicles. Therefore, we cannot say for certain that these CO and NOx problems are exclusively due to loss of catalyst efficiency, though it is our engineering judgment that catalyst efficiency is a significant, contributory cause of the results observed.

[22] California Air Resources Board Regulation, "Malfunction and Diagnostic System Requirements, 1968.1(b)(1.2.1-1.2.4).

2.4.2.4 OBD and Errors of Commission ("False Failures")

Of the 194 vehicles that were accepted into the program with the MIL on, 43 or 22% were sent home without a repair identified because repair technicians were unable to replicate the cause of MIL illumination. Ten of these vehicles were sent home because the light went out before initial testing was completed; this was attributed to OBD's ability to self-clear non-recurring, intermittent fault codes (as discussed above). Because the repair goal of the tailpipe pilot was to extinguish the MIL, no repairs were attempted on these self-clearing vehicles and they were dismissed without further testing.

Of the 33 remaining vehicles, 30 had FTP measurements at or below the applicable certification standards, 2 (ATL120 and ATL94) had FTP scores below the OBD threshold of 1.5 times the certification standard, and 1 (ATL120) was a gross emitter which EPA was unable to fix based upon OBD diagnostics. Based upon engineering judgment, EPA believes that the majority of these vehicles had intermittent problems that for one reason or another were not manifesting themselves at the time repairs were being attempted. Almost half (15) had misfire codes, while an additional 11 had fuel trim OBD codes for which OEM diagnostics failed to identify a specific cause. Misfires, it should be noted, are notoriously intermittent. In some of these cases the repair technicians were able to reproduce the misfire by spraying the engine compartment with water. In at least one case, however, the repair technicians were unsuccessful with this technique even though they could plainly see where the misfire was occurring from a plug wire that was not routed correctly. In one case where the repair technicians were unable to reproduce the misfire on their own, the owner took technicians out on the road to demonstrate when the misfire occurred (e.g., at high rpm and load, off the FTP cycle). This was a case where EPA was able to convert a vehicle that seemed like a potential false failure into one where the OBD system successfully identified a vehicle in need of repair. It is possible that other pilot vehicles identified as potential OBD false failures based upon the repair technicians' inability to identify a fixable problem could have been successfully repaired if EPA had access to the vehicle owners. Such access was the exception rather than the rule during the tailpipe pilot study, because in many cases the "owners" of the vehicles were actually car rental agencies or dealerships without practical knowledge of the individual vehicles in their fleets. In a real world I/M program, the repair technician would be able to consult with the vehicle owner concerning the conditions under which the MIL was illuminated, and as a result, the incident of unfixable OBD failures should be lower than suggested by the pilot sample.

2.5 Conclusions

Based upon the results of the OBD tailpipe pilot, EPA concluded that OBD scanning and repair is a viable basis for I/M testing for MY 1996 and newer, OBD-equipped vehicles. The emission reductions attributable to OBD-triggered repairs appear to be at least as large as those attributable to repairs triggered by the most accurate, traditional I/M tailpipe test (i.e., the IM240). In direct comparison to the IM240, OBD-I/M checks identified more vehicles with tailpipe emissions exceeding their certification standards. With few exceptions, OBD-I/M checks identified the same true failures as did the IM240, while also providing diagnostic information for repairing those vehicles. Furthermore, OBD-I/M checks: 1) identified vehicles that were falsely failed on the IM240 as clean; 2) identified high emitting vehicles missed by the IM240; and 3) identified vehicles with broken or worn components that needed replacement or repair prior to the actual development of emissions problems (thereby providing additional air quality benefits in the form of pollution prevention). Additionally, EPA found that OBD-triggered repairs effectively returned vehicles to their proper operating conditions and that tailpipe emissions returned to below certification levels in the majority of cases.

3.0 OBD-I/M Pilot 2: OBD-I/M Checks and Evaporative Emission Testing

3.1 Summary of Goals and Conclusions

From April 1999 through May 2000, Automotive Testing Laboratories, Inc. (ATL) in Mesa, Arizona conducted pre- and post-repair evaporative system emission testing on 30 OBD-equipped vehicles under contract to EPA. Unlike the tailpipe pilot described in section 2, the evaporative pilot did not use vehicles with naturally occurring system failures. Instead, specific purge system malfunctions and evaporative system leaks were induced to see whether or not the vehicles' OBD systems were capable of detecting a range of evaporative system problems. After the failures were induced, the vehicles were then tested using the evaporative portion of the FTP. Once OBD's ability to detect these induced evaporative system failures was established along with the vehicles' pre-repair FTP scores, ATL technicians then repaired the vehicles, and a second round of FTP testing was conducted. The goal of this pilot test program was to answer the following question:

> ***Can the OBD-I/M check accurately detect evaporative system purge malfunctions and leaks on OBD-equipped vehicles and, once these failures are repaired and the codes cleared, does the OBD system respond correctly by leaving the MIL extinguished?***

Unlike the tailpipe pilot, the OBD evaporative pilot did not focus on comparing the OBD-I/M check to traditional I/M tests like the purge and pressure tests. The reason for this is because OBD-equipped vehicles with enhanced evaporative system monitoring are largely considered untestable using traditional I/M program evaporative system tests[23]. In many cases, the intrusive nature of the traditional I/M evaporative system tests could easily compromise the evaporative control systems on these vehicles, which, for example, frequently have hard lines that cannot be crimped without causing damage to the vehicle. In other cases, the lines are simply inaccessible, or cannot be disconnected as required by some of the traditional evaporative system test procedures.

Based upon the test results detailed in this TSD -- and given the impracticality of using traditional purge and pressure checks on most OBD-equipped vehicles -- EPA concluded that

[23] A notable exception is the gas cap pressure test (see section 4). Another exception is OBD-equipped vehicles that have been built with special evaporative system service ports. However, because such service ports are not required on these vehicles -- and EPA has no reliable data on how many vehicles are so equipped -- it is difficult to imagine basing a program of evaporative system testing upon the presumption that such ports will be generally available to facilitate testing.

OBD-based evaporative emissions checks are a suitable replacement for traditional evaporative emission I/M tests on OBD-equipped vehicles. This conclusion is based upon the following observations made during the OBD evaporative system pilot:

1) OBD evaporative system monitors appear to operate within their design specifications in the majority of cases. When evaporative system failures of the type found in traditional I/M test programs were induced, in most cases the OBD system responded correctly by lighting a MIL and setting an evaporative system DTC. Furthermore, once these failures were corrected and the codes cleared, the OBD system again responded correctly by not resetting the DTCs and re-lighting the MIL.

2) The emission reductions associated with performing repairs triggered by OBD-based evaporative system testing appear to be substantial. In general, vehicles with evaporative emission DTCs and lit MILs were found to substantially exceed their FTP evaporative emission standards, while repaired vehicles fell well below those standards.

3.2 Background

In addition to monitoring components the failure of which could lead to exhaust emissions exceeding their FTP standards by 1.5 times the standard, OBD certification requirements also phase-in separate standards for monitoring the evaporative control systems on OBD-equipped vehicles. The first of these OBD evaporative system standards is phased in with the 1996 through 1999 model year and applies to those vehicles which meet the enhanced evaporative emission certification standards. Vehicles built to meet the enhanced evaporative emission standard must limit running losses to less than 0.05 gpm and hot soak/diurnal losses on the FTP to no more than 2.0 grams. Beginning with MY 1998, and phasing in through MY 2006, OBD-equipped vehicles must also meet the Onboard Refueling Vapor Recovery (ORVR) standards, which prohibit vehicles from emitting more than 0.02 grams per gallon of fuel dispensed during vehicle refueling.

To determine whether vehicles built to meet these requirements were operating as required in the field, EPA contracted with ATL to conduct a pilot study of OBD evaporative monitor effectiveness. As previously stated, the pilot testing ran from April 1999 to May 2000 and included a mix of 30 LDVs and LDTs from MY 1996 through 2000[24]. The goal of this pilot was to determine whether OBD reacted correctly to evaporative system malfunctions and to the repair of those malfunctions, as well as to determine the degree to which either condition (i.e., malfunctioning vs. repaired) affected FTP evaporative emissions. This pilot did not examine the issue of OBD evaporative emission readiness under in-use driving conditions, nor did it address whether the gas cap test is a suitable supplement to OBD-I/M evaporative system testing. Those issues were addressed as part of EPA's analysis of OBD test results from the Wisconsin I/M program and will be discussed in section 4 of this TSD.

[24] Data gathered for EPA under Work Assignments 3-12 and 0-4, SHED Tests on OBD II Evap Vehicles, EPA Contract No. 68-C99-241 - Automotive Testing Laboratories; 1999-2000.

3.3 Vehicle Sampling

3.3.1 Methodology

Unlike the OBD tailpipe pilot, the vehicles used in the OBD evaporative pilot were not recruited from operating I/M lanes, and recruitment was not based upon naturally occurring, pre-existing evaporative system failures. This decision was based upon prior attempts to recruit natural OBD-I/M failures which showed that the majority of such failures with evaporative system DTCs set were the result of gas caps that had not been tightened properly (this issue is discussed further under section 3.4.1, which addresses vehicle testing methodology). Instead, the majority of vehicles for the OBD evaporative pilot were recruited from fleet owners in the Mesa, Arizona area, including both commercial rental agencies and local auto dealerships with which ATL had a standing arrangement for procuring test vehicles. Only one vehicle involved in the pilot was a privately owned vehicle recruited from an ATL employee. Though every effort was made to recruit as diverse a sample as possible, no attempt was made to weight the vehicle sample by vehicle type and manufacturer. This was due largely to limitations resulting from the small sample size (less than one-sixth the size of the OBD tailpipe sample) which, in turn, was the result of the high cost and time requirements associated with FTP evaporative system testing, where a single test can take several days to complete.

3.3.2 Results

A complete description of the 30 vehicles participating in the OBD evaporative pilot can be found in Table A-1 of Appendix 6. The descriptive details identified include vehicle make, model, model year, mileage, engine family, evaporative system family, chassis dynamometer testing parameters, and whether the vehicle was designed to comply with ORVR and/or enhanced evaporative control standards. A snapshot of the 30-vehicle OBD evaporative test sample is provided below:

Manufacturers represented: 8

Ford (7), GM (7), Honda (3), Isuzu (1), Mazda (2), Mitsubishi (1), Nissan (4), Toyota (5)

Model years represented: 5

1996 (2), 1997 (1), 1998 (9), 1999 (16), 2000 (2)

Lowest mileage: 5,259 miles — Highest mileage: 116,730 miles

Light-duty vehicles: 20 — Light-duty trucks: 10

Enhanced evap system *only*: 14 — Enhanced evap *and* ORVR: 16

Fleet vehicles: 29 — Privately owned vehicles: 1

As discussed in section 3.3.1, the 30-vehicle sample was not sales weighted among manufacturers; neither was it weighted based upon car versus truck sales. Most of the vehicles in the sample were of relatively low mileage, with only 5 exceeding 50,000 miles, while the sample average was just over 31,000 miles. As can be seen from the above manufacturer summary, Chrysler vehicles are not represented in the 30-vehicle sample. This is because Daimler-Chrysler used an alternative Federal OBD certification provision available for MY 1996-99 vehicles which allowed manufacturers to postpone use of OBD evaporative emission monitors in their Federally certified vehicles until MY 2000.

3.4 Vehicle Testing

3.4.1 Methodology

Prior to being accepted into the OBD evaporative pilot study, candidate vehicles were evaluated to ensure that there were no driveability, braking, or exhaust leak problems. Once a vehicle was accepted, its OBD emission control system was then checked for readiness status and the presence of a lit MIL and/or DTCs. Unlike the OBD tailpipe pilot, the pre-existence of naturally occurring system failures was not one of the criteria for participation in the OBD evaporative pilot. Instead, EPA opted to use induced failures.

Induced failures were used due to the difficulty EPA had in finding MY 1996 and newer OBD-equipped vehicles with naturally occurring evaporative system problems, which, in turn, was due to the relative newness of the vehicles in question. Unlike tailpipe problems which are largely a function of mileage accumulation and general wear-and-tear, evaporative system problems tend to be a function of vehicle age, as the components of the system lose elasticity and become brittle and more leak-prone. Furthermore, when naturally occurring evaporative system DTCs were found, the vast majority turned out to be due to gas caps that had not been properly tightened after refueling. EPA decided to use induced evaporative system failures to more thoroughly investigate the effectiveness of OBD systems in detecting a wide variety of potential in-use failures, above and beyond loose gas caps. Table A-2 in Appendix 6 provides a vehicle-by-vehicle account of the induced failures that were used in the 30-vehicle sample, the resulting DTCs, and the drive cycles required to satisfy the readiness criteria for both “failure” and “repair” sequences. Table A-2 also includes a comment field for more detail on specific vehicle test issues. A summary of the induced failures used in the pilot is provided in Table 10 below:

Only one failure was induced per vehicle. The failures used were not meant to represent the variety of real world failures, nor were they necessarily representative of the range of excess emissions which results from real failures. Rather, the failures used were selected because they are reproducible, easy to repair, and are the sorts of failures properly functioning OBD evaporative system monitors should detect. Following the induced failures, vehicles were then given the evaporative portion of the FTP to help estimate the mass of excess evaporative emissions associated with these failures.

Table 10: Summary of Induced Evaporative System Failures

Type of Failure	Number of Instances in Sample
Missing gas caps	3
Loose gas caps	2
0.040 inch leaks in gas caps, vent lines (initial OBD leak detection threshold)	11
Disabled canister fresh air inlet	1
Disconnected purge lines	8
0.020 inch leaks in gas caps (stricter OBD leak threshold, begins phasing-in MY 2000)	5

Two varieties of small orifice leaks were induced under the OBD evaporative pilot -- a 0.040 inch leak and a more stringent 0.020 inch leak. Under California and Federal OBD requirements, MY 1996 and newer vehicles equipped with OBD II evaporative system monitors are required to detect leaks from a hole 0.040 inches in diameter or larger, and must also detect and identify a malfunctioning purge system[25]. Beginning with MY 2000, LDVs and LDTs must begin phasing in a more stringent leak detection threshold of 0.020 inches in diameter. Under the OBD evaporative pilot, 5 vehicles were tested with 0.020 inch diameter leaks to examine the robustness of the current systems (i.e., whether or not they can detect leaks below the level minimally required), as well as to estimate the incremental emission impact from identifying vehicles which pass the 0.040 inch limit while failing the more stringent 0.020 inch limit. Gas caps with 0.040 and 0.020 inch diameter leaks were supplied by Stant Manufacturing Corporation and were built with flow tested, precision machined, square-edged orifices.

Once a failure was induced, the impact on the vehicle's evaporative emission system was verified by performing functional "pressure" and "purge" tests on the vehicle in question. These traditional evaporative system tests were conducted by experienced ATL laboratory technicians[26] who were not under the time constraints that make such testing impractical in most high volume I/M test lanes. For vehicles with service ports, the tests were conducted by measuring pressure loss and purge system vacuum through the service port. For vehicles without service ports, the ATL technicians used test procedures designed for pre-OBD-equipped vehicles. These pre-OBD test procedures consisted of measuring pressure loss by pressurizing the evaporative system from the fill-pipe and then monitoring the loss of pressure with time. Purge system failures were verified by using a roto-meter to check for the presence (or lack) of purge flow.

After a failure condition was induced, the vehicle's OBD computer was then reset to clear codes so that all monitors registered as "not ready." The vehicles were then operated in a manner that would exercise the monitors and -- if the OBD system was functioning properly -- a DTC would be set and the MIL illuminated. Typically, "exercising the monitors" meant driving

[25] Not all MY 1996-99 vehicles are equipped with OBD evaporative system monitors. Manufacturers were allowed to phase-in the use of such monitors from MY 1996 through MY 1999.

[26] We stress that the repair technicians were "experienced" because many manufacturers have opposed the intrusive nature of EPA's original evaporative system tests, particularly in high volume I/M lanes. Particular care was taken during this pilot to conduct these tests in a manner that did not adversely influence the evaporative emission results.

the vehicle on a dynamometer prior to formal FTP testing. The only exception to this practice was when a dynamometer was not available, at which time "exercising the monitor" was achieved by operating the vehicle over a local surface street, following a route approximating the speed-time relation of the drive cycle used in the FTP (also known as the LA-4). Following FTP testing of vehicles with OBD-confirmed, induced failures, the vehicles were then repaired by ATL technicians. After repairs, the OBD system was again reset to clear the fault code and return the readiness status to "not ready." The vehicle was then driven to exercise the monitors to determine if the OBD system responded correctly (i.e., by not setting a DTC or commanding the MIL to light).

The FTP evaporative emission test selected for this study was the 3-day diurnal procedure with running loss test. An abbreviated flowchart of the test procedure for the FTP evaporative test is presented in Figure A-1 in Appendix 6. In general, tests were conducted in accordance with 40 CFR Part 86, Subpart B, as revised July 1, 1998[27]. The test fuel used in this pilot was indolene, as specified by the FTP.

3.4.2 Results

The 30-vehicle sample was divided into two groups, based upon detection threshold. The first is a group of 25 vehicles, 9 with purge system failures, and 16 with leaks greater than or equal to 0.040 inches in diameter (i.e., vehicles with induced failures within the required detection range of current OBD evaporative system standards). The second group consists of 5 vehicles with induced leaks produced by a 0.020 inch diameter hole in the gas cap (i.e., vehicles with induced failures falling below the currently required detection threshold for OBD evaporative systems). The two groups were separated so as not to "penalize" the overall sample for vehicles in the second group which failed to find leaks more stringent than their design requirements. Table 11 below looks at each subset separately.

Table 11: DTC and MIL-on Rates After Induced Failures

	DTC Registered	MIL Illuminated
25 Vehicle Sample (purge, 0.040 leaks)	22	The same 22
5 Vehicle Sample (0.020 leaks)	3	The same 3

Emission results for 22 vehicles repaired as part of the OBD evaporative pilot are summarized in Table 12 below. Only 22 of the 30-vehicle sample are included in the repair results summary because not all vehicles registered DTCs, and valid "repair" results were not accomplished for all vehicles. Vehicles without a complete set of "fail" vs. "repair" data were excluded from the analysis used to prepare Table 12.

[27] Some minor deviations from Subpart B were allowed during pilot testing, including the use of: 1) external fuel tank temperature measurement (on steel fuel tanks) as a surrogate for installing internal thermocouples, 2) the vehicle's fuel pump to drain the tank instead of installing a drain(s) at the lowest point in the tank, and 3) a greater than +/- 3 degree F disagreement between measured and target temperatures on the running loss test for a small number of vehicles. Table A-5 in Appendix 6 lists all target vs. actual temperature differences observed during pilot testing (see Appendix 7 for further discussion).

The summary results presented in Table 12 are stratified as a function of evaporative emission control design (i.e., whether enhanced evap or ORVR designs). Of the 22 vehicles included in the sample, 11 were certified to the enhanced evaporative standard and 11 were designed to comply with ORVR requirements. Table 12 divides the evaporative emission results into these strata because the design of ORVR systems (larger canisters, larger vapor lines, other unique components to control refueling loss) may lead to lower overall evaporative emission losses in the case of a leak or other malfunction. Because ORVR designs are manufacturer and vehicle design specific and the sample size used in the pilot was too small to be representative across manufacturers and models, an investigation into how and why ORVR compliant vehicles seem to have inherently low evaporative emissions was not performed as part of the OBD evaporative pilot. Nevertheless, the data in Table 12 suggest that when compared to vehicles designed to only meet the enhanced evaporative emission requirements, ORVR-controlled vehicles have significantly lower evaporative emissions, even when leaks or other malfunctions have been introduced into the system.

To get an idea of the impact on the mean and standard deviations when the subsets of enhanced evap and ORVR vehicles are averaged together, see Table 13 below. Complete evaporative emission results for all 30 vehicles are presented in Table A-3 in Appendix 6, while FTP exhaust results for these same vehicles are summarized on a bag-by-bag basis in Table A-4.

Table 12: Summary Statistics for 11 Enhanced Evap and 11 ORVR Vehicles

	Enhanced evap fails	Enhanced evap repairs	ORVR fails	ORVR repairs
Running Losses (gpm)	x = 7.86	x = 0.02	x = 4.51	x = 0.02
	s = 7.89	s = 0.01	s = 5.29	s = 0.01
1 hour Hot Soak Loss (grams)	x = 10.74	x = 0.13	x = 2.89	x = 0.14
	s = 16.12	s = 0.08	s = 3.20	s = 0.07
High 24 hour Diurnal Loss (grams)	x = 20.83	x = 0.95 (N=10)[28]	x = 12.31	x = 0.87
	s = 17.77	s = 0.87	s = 12.00	s = 0.51

x = mean; s = standard deviation

Table 13: Average Emission Reductions From Sample of 22 Repaired Vehicles

Running Losses (gpm)	x = 6.17	s = 6.78
1 hour Hot Soak Loss (grams)	x = 6.68	s = 12.04
High 24 hour Diurnal Loss (grams)	x = 14.18 (N=21)[29]	s = 14.54

In addition to the summary results presented in Tables 12 - 13 above, EPA wishes to highlight the following findings made as a result of the OBD evaporative pilot study:

[28] One of the 11 enhanced evap vehicles had to be returned to its owner prior to post-repair evaporative system testing.

[29] See explanation in footnote 28 above.

1) 88% of OBD-equipped vehicles (22 of 25) set DTCs and lit MILs when evaporative system failure conditions were induced and subsequently showed no DTCs and MILs when the vehicles were repaired. This suggests that OBD evaporative system monitors are working as designed in the vast majority of cases. EPA considers these results impressive, compared to the existing purge and fill-neck pressure tests, which both suffer from relatively low testability rates -- approximately 70% for pre-OBD-equipped vehicles and less than 15% for OBD-equipped vehicles.

2) Of the 3 vehicles that did not light a MIL or set a DTC during ATL testing, 2 were Mazda 626s, which represents 100% of that manufacturer's fraction of the 30-vehicle sample. To see whether there was a possible design problem with this particular make and model, EPA procured two "sister" vehicles in Ann Arbor, and found them to be functioning properly. EPA is pursuing a resolution regarding the third vehicle's results with the manufacturer.

3) 60% of OBD-equipped vehicles tested (3 of 5) identified a 0.020 inch diameter leak (i.e., a leak below the required leak detection threshold for the OBD-equipped vehicles in the sample) by setting a DTC and lighting the MIL. This suggests that the majority of OBD systems are quite robust and have leak detection capability well below the minimum requirement.

4) Three OBD-equipped vehicles which set MILs for evaporative system problems (different from the 3 of 5 listed in item # 3 above) produced FTP evaporative emissions less than half the levels of the enhanced evaporative emission standards. This suggests that "maintenance" problems are being identified by OBD even though they result in emission levels below FTP standards.

5) 95% of repaired OBD-equipped vehicles (21 of 22) had FTP-measured running loss emissions that were actually below the certification standard for enhanced running losses. 95% of repaired OBD-equipped vehicles (20 of 21) had FTP-measured diurnal plus hot soak emissions that were below the certification standards for those categories of evaporative emissions. The running loss and diurnal plus hot soak emissions for ORVR vehicles with induced failures averaged approximately half the levels measured for comparable, enhanced evap-only vehicles.

6) The average emission reductions for repairing OBD-identified DTCs is substantial: 6.17 gpm for the running loss test, 6.7 g for the hot soak test, and 14.2 g for the high 24 hour result for the diurnal loss test.

3.5 Conclusions

In the majority of cases, OBD evaporative emission monitors appear to be operating as designed, and, in some cases, better than required. This conclusion is based upon an admittedly small sample of OBD-equipped vehicles with induced failures specifically aimed at triggering the evaporative system monitors. Nevertheless, the majority of OBD-equipped vehicles in the test sample correctly set evaporative DTCs and lit the MIL when evaporative system failures were induced, while also successfully showing no MILs or DTCs when those failures were removed. An analysis of the FTP mass emissions data before and after these induced failures suggests that the emission reductions attributable to OBD-triggered evaporative system repairs is substantial, with pre-repair vehicles registering evaporative emissions well above the applicable FTP standards and post-repair vehicles having evaporative emissions well below those standards. Based upon these observations -- and given the impracticality of using pre-OBD-style purge and pressure checks on most OBD-equipped vehicles -- EPA believes that OBD-I/M evaporative emissions checks are a suitable replacement for the traditional purge and fill-neck pressure tests for MY 1996 and newer, OBD-equipped vehicles.

Neverthless, EPA still recommends that states continue to perform gas cap pressure tests on OBD-equipped vehicles. Unlike other, traditional evaporative system tests, the gas cap test does not suffer from the material composition and accessibility problems that make many OBD-equipped vehicles untestable using the purge and fill-neck pressure tests. Furthermore, the failure threshold for the gas cap pressure test is more stringent than even the most stringent OBD-based evaporative emission standards. As will be shown in section 4, which details EPA's analysis of Wisconsin's operating OBD-I/M program data, EPA believes that there is real-world data to suggest that additional evaporative system failures can be identified by performing a separate gas cap pressure test in conjunction with the OBD-I/M check (see Table 19, "Gas Cap vs. OBD Evaporative System Failure Rates" later in this document).

4.0 OBD-I/M Pilot 3: Analyzing the Wisconsin OBD-I/M Program Experience

4.1 Summary of Goals and Conclusions

The last of the three OBD-I/M pilot studies was aimed at identifying the real-world implementation issues associated with OBD-I/M testing and was conducted using data gathered from the Wisconsin enhanced I/M test lanes, where OBD checks are being implemented voluntarily by the state. The analysis of Wisconsin's operating program data for OBD-equipped vehicles was conducted in two stages, the first performed by Sierra Research in 1998 under contract to EPA and the second in 1999-2000, performed by EPA staff from the Office of Transportation and Air Quality (OTAQ) in Ann Arbor, Michigan.

Although the original focus of the Sierra study was intended to be broader, flaws in Wisconsin's I/M contractor's OBD hardware and software limited the scope of the analysis to identifying physical aspects of the OBD-I/M testing process that could lead to implementation difficulties. Specifically, the Sierra study provided an estimate of the time needed to perform a typical OBD-I/M inspection (on average, about 31 seconds) and also identified atypical data link connector (DLC) location as a potential bottleneck in high-volume I/M test lanes. In response to this latter issue, EPA has developed a database of DLC locations based upon the Wisconsin data and manufacturer-supplied information. Electronic copies of this database are available on

EPA's web site at http:\\www.epa.gov\OMSWWW. EPA has found that the development of this database and increased inspector experience has eliminated DLC location as a problem area in the Wisconsin program. While a period of introductory learning will be necessary, we do not believe that DLC location will be a significant problem for future, OBD-based I/M efforts.

Separate from the Sierra Research analysis, EPA looked at data from Wisconsin's I/M program for the last eight months of 1999, by which time the OBD software and hardware problems mentioned above had been corrected. The program data EPA analyzed included IM240, gas cap, and OBD MIL illumination and readiness data for over 116,000 MY 1996 and newer vehicles.

Using the above database, EPA compared evaporative system failure rates for vehicles based upon the OBD evaporative system test and the separate gas cap check and found that the gas cap test identified significantly more evaporative system leaks than were identified based upon the OBD evaporative system monitors alone. EPA believes this demonstrates the complementary nature of these two tests -- not an unanticipated conclusion, given the different standards and stringencies involved. We believe that these findings support our recommendation that states continue gas cap evaporative system testing on OBD-equipped vehicles in conjunction with OBD-I/M testing (as mentioned earlier, in section 3 of this TSD).

In analyzing Wisconsin's OBD-I/M data, EPA also looked at MIL illumination and monitor readiness results and concluded that there is a small fraction of vehicles that arrive for testing with one or more of their OBD readiness codes unset, although the problem seems largely limited to the earliest of the OBD-equipped vehicles (i.e., MY 1996). Looking at the raw data, EPA found a 5.8% not-ready rate among MY 1996 vehicles. However, when we excluded vehicles for which corrective measures are being taken by the manufacturers, the not-ready rate for MY 1996 dropped to roughly 3%. By MY 1998, the OBD not-ready rate dropped even further -- to below 1%. EPA believes that offering states the ability to waive vehicles with one or two unset readiness codes instead of rejecting them (as currently required) will go a long way toward eliminating vehicle readiness as an obstacle to smooth implementation.

Because the two-staged analysis of Wisconsin's OBD-I/M data has three separate points of focus – DLC location, vehicle readiness, and the relative effectiveness of the gas cap test – each will be dealt with individually below, identified by focus.

4.2 DLC Location

4.2.1 Background

In 1998, EPA contracted with Sierra Research to gather information on approximately 2,500 OBD-equipped vehicles upon arrival at the I/M test lanes in Wisconsin[30]. Parallel IM240 and OBD-I/M testing was conducted in the Wisconsin test lanes by Envirotest Systems

[30] Under Purchase Order No. 7CS124NTSA, "Status of OBD Systems Upon Arrival at I/M Lanes." Report No. SR98-10-02, "Summary of Test Results from Wisconsin EPA OBD Project," October 16, 1998.

Corporation (under subcontract to Sierra Research, Inc.). The original purpose of the study was to conduct testing of OBD systems on MY 1996 and newer vehicles, with the intent to:

- Gain practical experience in conducting OBD-I/M tests;
- Use this experience to develop guidance on how to perform OBD-I/M tests properly;
- Estimate the average time required to perform an OBD-I/M test;
- Determine the frequency of readiness for each OBD system monitor;
- Determine the reliability of the MIL as an identifier of vehicles likely to fail other I/M tests;
- Determine the frequency and nature of DTCs stored in OBD computers; and
- Identify any problems among OBD-equipped vehicles that could interfere with proper testing, including those specific to particular vehicle models.

4.2.2 Results

Between May 20, 1998, through July 25, 1998, 2,583 paired OBD/IM240 test records were collected. Only initial tests were used because Wisconsin does not currently fail vehicles on the basis of the OBD-I/M check[31]. Information was gathered concerning test time, OBD readiness, DTC and/or MIL frequency, etc. However, due to problems with the OBD software and hardware used by Wisconsin's testing contractor at the time of the Sierra study, no useful information was gathered by Sierra concerning OBD readiness or DTC and/or MIL-on rates. Nevertheless, useful information was gathered concerning test time and the general ability of inspectors to locate difficult-too-find DLCs. Table 14 below provides a summary of the data gathered, divided by make, model, and vehicle type.

As can be seen from Table 14, the average OBD-I/M test time was roughly 31 seconds, including the time to locate the OBD connector, connect to the system, interrogate it, and download the resulting information[32]. Care should be taken in interpreting the test time estimates, however, due to possible variance in how inspectors conducted the test. Envirotest's inspectors were instructed to locate the OBD connector as soon as they were prompted to do so

[31] While Wisconsin does not fail vehicles on the basis of OBD (yet), the State does fail vehicle based upon their IM240 results. The Sierra study focused on initial tests only to avoid double counting vehicles which failed their initial IM240 and then returned for a retest.

[32] It should be noted that these test time calculations do not include the time needed to record vehicle information, such as VIN, license plate number, etc. Such information was gathered as part of the overall testing process, which also included performance of an IM240, as previously discussed. No vehicle in the Wisconsin program received just the OBD test. The test times discussed here, therefore, reflect only the time spent conducting the OBD-I/M portion of the overall test process.

estimates, however, due to possible variance in how inspectors conducted the test. Envirotest's inspectors were instructed to locate the OBD connector as soon as they were prompted to do so by the test system. The system tracked the time from when the inspector prompt appeared to when the connection to the OBD system was established. However, it is obvious from the short connect times recorded for some vehicles (e.g., 1-2 seconds) that certain inspectors were locating the connector in advance of the prompt. Actual connect times (and thus overall test time as well) may therefore be slightly longer than the data in Table 14 suggest. However, given how the test is structured, it is believed that this would add only about five seconds at most to some of the recorded OBD-I/M test times.

The time it takes to locate the DLC is a relevant variable in assessing the time it takes to perform an OBD-I/M inspection because DLC location varies from manufacturer to manufacturer, and from model to model. Attempts to standardize DLC location are reflected in the Society of Automotive Engineers (SAE) Recommended Practices J1962, which specifies the following with regard to DLC location:

> ***3.1 Consistency of Location*** - *The vehicle connector shall be located in the passenger compartment in the area bounded by the driver's end of the instrument panel to 300 mm beyond the vehicle centerline, attached to the instrument panel, and accessible from the driver's seat. The preferred location is between the steering column and the vehicle centerline. The vehicle connector shall be mounted to facilitate mating and unmating.*
>
> ***3.2 Ease of Access*** - *Access to the vehicle connector shall not require a tool for the removal of an instrument panel cover, connector cover, or any barriers. The vehicle connector shall be fastened and located so as to permit a one-handed/blind insertion of the mating test equipment connector.*
>
> ***3.3. Visibility*** - *The vehicle connector should be out of the occupant's (front and rear seat) normal line of sight but easily visible to a "crouched" technician.*

Even with this guidance, however, vehicle manufacturers have been anything but consistent with regard to where they place the DLC.

Table 14: Summary of Wisconsin Data, 5/20/98 to 7/25/98

Make	Type	Number Tested	Connect Time (sec)	Comm Time (sec)	Total OBD Time (sec)
Acura	LDGV	19	28.9	13.3	42.2
Audi	LDGV	3	6.0	14.0	20.0
BMW	LDGV	23	25.3	14.7	40.0
Buick	LDGV	117	12.8	12.8	25.6
Cadillac	LDGV	41	23.5	17.3	40.8
Chevrolet	LDGV	182	14.8	15.0	29.8
	LDGT1	101	12.4	15.8	28.2
	LDGT2	75	12.6	13.9	26.5
	HDGT	6	24.0	5.8	29.8
Chrysler	LDGV	42	14.9	18.0	32.9
	LDGT1	25	11.6	18.2	29.8
Datsun	LDGV	105	15.9	16.7	32.6
	LDGT1	17	29.3	18.6	47.9
Dodge	LDGV	88	16.5	15.6	32.0
	LDGT1	115	10.7	16.0	26.7
	LDGT2	30	14.4	16.1	30.5
	HDGT	6	19.5	12.7	32.2
Eagle	LDGV	3	18.3	16.0	34.3
Ford	LDGV	144	13.5	13.7	27.2
	LDGT1	117	18.6	15.7	34.3
	LDGT2	44	16.6	13.0	29.7
	HDGT	10	36.7	13.2	48.9
Geo	LDGV	23	16.0	14.3	30.3
	LDGT1	2	5.5	17.0	22.5
GMC	LDGT1	21	11.8	14.4	26.2
	LDGT2	17	10.7	15.2	25.9
	HDGT	5	19.4	13.8	33.2
Honda	LDGV	127	12.8	16.9	29.7
	LDGT1	20	33.5	15.9	49.3
Hyundai	LDGV	4	2.7	15.7	18.3
Infiniti	LDGV	2	1.5	16.5	18.0
Isuzu	LDGT1	15	9.8	13.8	23.6
	LDGT2	2	24.5	15.0	39.5
Jaguar	LDGV	4	21.3	14.3	35.5
Jeep	LDGT1	80	17.1	21.3	38.4
Lexus	LDGV	14	13.2	18.1	31.3
Lincoln	LDGV	26	17.3	13.2	30.5
Landrover	LDGT2	5	19.5	14.0	33.5
Mazda	LDGV	33	17.1	14.1	31.2
	LDGT1	2	23.0	27.0	50.0
Mercury	LDGV	98	15.3	13.4	28.6
	LDGT1	33	11.7	17.1	28.8
Mercedes	All	15	22.2	15.1	37.3
Mitsubishi	LDGV	14	19.7	15.9	35.6
	LDGT1	3	32.3	14.3	46.7
Oldsmobile	LDGV	56	18.1	14.7	32.8
	LDGT1	11	16.0	14.0	30.0
Other	LDGT1	1	40.0	12.0	52.0
Plymouth	LDGV	32	14.2	16.1	30.3
	LDGT1	48	9.6	15.4	25.0
Pontiac	LDGV	168	15.8	14.2	29.9
	LDGT1	13	8.9	14.8	23.8
Porsche	LDGV	1	80.0	14.0	94.0
Saab	LDGV	7	20.6	14.6	35.1
Sterling	LDGV	61	13.5	17.8	31.3
Subaru	LDGV	9	53.7	15.4	69.1
Suzuki	LDGT1	2	31.5	11.5	43.0
Toyota	LDGV	199	12.2	15.7	27.9
	LDGT1	45	22.0	14.8	36.8
	LDGT2	4	32.0	18.0	50.0
Volkswagen	LDGV	45	18.2	18.4	36.6
Volvo	LDGV	5	14.2	15.0	29.2
TOTAL		**2,583**	**15.6**	**15.6**	**31.2**

Table 15: DLC Location Problems in the Sierra Wisconsin Data

Make	Total in sample	# DLC location problem	% DLC location problem in sample of make
Acura	19	14	11.8%
Audi	3	3	100%
BMW	23	18	78.3%
Buick	117	2	1.7%
Cadillac	41	3	7.3%
Chevrolet	364	2	0.6%
Chrysler	67	1	1.5%
Datsun	122	1	0.8%
Dodge	239	3	1.3%
Ford	315	7	2.2%
Geo	25	1	4%
GMC	43	1	2.3
Honda	147	69	46.9%
Hyundai	4	1	25%
Isuzu	17	2	11.8%
Lexus	14	1	7.1%
Mazda	35	1	2.9%
Mercury	131	3	2.3%
Mercedes	15	12	80%
Mitsubishi	17	7	41.2%
Oldsmobile	67	3	4.5%
Pontiac	179	1	0.6%
Subaru	9	1	11.1%
Suzuki	2	2	100%
Toyota	248	20	8.1%
Volkswagen	45	25	55.6%
Volvo	5	4	80%
TOTAL	2,583	208	8.1%

Ultimately, OBD-I/M test times were found to be highly dependent on the ease with which the inspector located the DLC, which was itself found to vary greatly among the various makes and models included in the Sierra Research study. During the first phase of the Wisconsin analysis, Sierra Research found that it took considerably longer to locate the DLC on some makes and models than it did for others. Apparently, despite attempts to standardize DLC location, some manufacturers have interpreted SAE J1962 more broadly than originally anticipated. In fact, many vehicles were identified by inspectors as "untestable" because they could not locate the DLC in a timely manner. Out of the 2,583 vehicles involved in the test program, 208 or 8.1% were identified as “untestable,” largely because the inspector was unable to locate the connector within a time period that was commensurate with the throughput demands of the test network. In fact, DLC location is not so much an issue of “testability” as it is an issue of throughput. Table 15 above provides a breakdown of these so-called “untestable” vehicles by manufacturer.

Designating a given vehicle as “untestable” proved to be highly subjective. While nearly all of the test records represented in Table 15 contain a connector location of “99” (signifying a location other than somewhere under the front dashboard), many of the records also contain inspector comments indicating they were either unable to find the connector or it was found in an abnormal location. Some inspectors were apparently able to test them, while others could not locate the connectors, and still others could locate the connectors but indicated it was too much effort to do so. For example, on the BMW 318i a cover panel must be removed with a screwdriver before the OBD connector can be accessed.

4.2.3 Conclusions

In general, the OBD connector was located by one or more inspectors on a very high fraction of test vehicles. However, without further efforts, the difficulty in accessing some of the connectors could have a significant impact on the future success of large-scale OBD-I/M testing. Accessibility time is particularly an issue in a high-volume test-only I/M environment. Inspectors are under continuous pressure from both motorists and management to be as fast and efficient as possible in completing required inspection procedures. Any connectors that take over 15-30 seconds to locate and access are a problem in this environment. While it is expected that inspectors will quickly learn the abnormal DLC locations for higher volume makes and models (e.g., behind the ash tray on Honda passenger cars), EPA believes that the potential for start-up problems is nevertheless significant. To address this issue, EPA has therefore developed a database of atypical DLC locations based upon the Wisconsin data, as well as manufacturer-supplied information. This database is available electronically at: www.epa.gov/otaq/regs/im/obd/obd-im.htm

4.3 Vehicle Readiness

4.3.1 Background

The OBD system monitors the status of up to 11 emission control related subsystems by performing either continuous or periodic functional tests of specific components and vehicle conditions. The first three testing categories – misfire, fuel trim, and comprehensive components – are continuous, while the remaining eight only run after a certain set of conditions has been met. The algorithms for running these eight, periodic monitors are confidential to each manufacturer and involve such things as ambient temperature as well as driving times and conditions. Most vehicles will have at least five of the eight remaining monitors (catalyst, evaporative system, oxygen sensor, heated oxygen sensor, and exhaust gas recirculation or EGR system) while the remaining three (air conditioning, secondary air, and heated catalyst) are not necessarily applicable to all vehicles. When a vehicle is scanned at an OBD-I/M test site, these monitors can appear as either "ready" (meaning the test in question has been run), "not ready" (meaning the test has not been run yet), or "not applicable" (meaning the vehicle is not equipped with the components in question).

Current Federal regulations for OBD-I/M testing require that I/M programs reject from further testing any MY 1996 or newer OBD-equipped vehicle that is found to have one or more unset readiness codes. It is important to note that "rejection" is distinct from "failure." In the context of the OBD-I/M check, rejection is triggered by a vehicle's readiness status while failure is related to the presence of DTCs that command the MIL to be lit. If DTCs are present and the MIL is commanded on, the vehicle is failed, the initial test process is considered complete, and an official test report is generated. If, on the other hand, unset readiness codes are present, the vehicle is rejected and the test process is aborted until such time as all readiness codes are set.

The reason vehicles with unset readiness codes are rejected but not failed is because an unset readiness code is not necessarily an indication of an emission problem. Rather, it is an indication that certain monitor(s) that are intended to determine whether or not there may be an emission problem have not been run to evaluate the system. In the case of rejection, the issue of whether or not the vehicle requires repairs is deferred until the readiness code(s) have been set and the monitor(s) run.

There are many reasons why a readiness code may not be set when an OBD-equipped vehicle arrives at the I/M test site – some of them wholly legitimate and beyond the control of the motorist. For example, if the battery is disconnected during servicing or the monitors are turned off with a scan tool, it takes a varying amount of time for the monitors to reset, and some may still not be ready when the vehicle shows up for its I/M inspection. It is also possible that the battery was disconnected on purpose in an attempt to fraudulently extinguish the MIL and clear DTCs prior to OBD-I/M testing. While it is true that disconnecting the battery will temporarily clear any DTCs that are present, many of these will be quickly reset (in particular, the continuous monitors discussed above). In fact, readiness codes were developed specifically to prevent vehicle owners from evading the OBD-I/M test by disconnecting their batteries just prior to testing. In many cases, exercising the monitors to set a readiness code may be as simple as operating the vehicle on a dynamometer or on the highway for a certain amount of time, while in other cases, readiness is more difficult to establish because of design issues with certain makes and models of vehicles.

To determine the extent to which vehicles may be appearing for their OBD-I/M check with unset readiness codes in the real world, EPA looked at OBD readiness data from Wisconsin's I/M program for the last eight months of 1999. The program data EPA analyzed included IM240, gas cap, and OBD MIL illumination and readiness data for over 116,000 MY 1996 and newer vehicles. The data was analyzed to determine the size of the readiness problem, the number of model years affected, and the approximate percentage of vehicles that would be rejected under a variety of possible readiness criteria. EPA also looked at the frequency of MIL illumination across model years and vehicle types, and compared the relative failure rates of the OBD-I/M check versus lane-based IM240s.

4.3.2 Results

4.3.2.1 Readiness

Since August 1998, Envirotest Systems Corporation (the I/M contractor in Wisconsin) has been sending EPA staff OBD-I/M check and IM240 test data collected on MY 1996 and newer vehicles coming through the Wisconsin test lanes. The data provided by Envirotest included vehicle identification numbers (VIN), and IM240, OBD-I/M, and gas cap test results (for a full list of the 40 data fields included in the Wisconsin data, see Appendix 8). Because of the OBD software and hardware problems discussed earlier, EPA limited its analysis to data gathered beginning with May 1999, by which time the software and hardware issues had been resolved.

Table 16 below provides the average mileage accumulation for MY 1996 and 1998 vehicles from the Wisconsin data set. Because Wisconsin did not include odometer data until recently and only tests vehicles every other year, the data EPA has available for MY 1997 vehicles does not include odometer readings. However, because the data we have for MY 1998 and 1997 represents vehicles that are being tested at the same age (i.e., when they are one year old) we can assume that the average mileage accumulation for MY 1997 vehicles at the time of their first test is similar to that of MY 1998 vehicles at the time of their first test (i.e., between 20,000 to 22,000 miles, depending upon vehicle class).

Because of the different emission standards for LDVs versus LDTs, these vehicle classes were analyzed separately. Looking at the three model years and two vehicle classes represented in the Wisconsin data therefore forms six vehicle categories: 1996, 1997, and 1998 LDVs and LDTs. There is one caveat concerning these groupings, however. Because Wisconsin used the same IM240 cutpoints for some light trucks as it did passenger cars (mostly four cylinder S10s, Rangers, etc.) these LDTs were listed as LDVs for these analyses (see Appendix 8 for a discussion of EPA's analysis methodology).

Table 16: Average Mileage Accumulation, by Model Year and Vehicle Type

Vehicle class	1996	1998
LDVs	45,385	20,745
LDTs	51,018	22,962

Table 17 below presents the "not ready" status for MY 1996-98 LDVs and LDTs in the Wisconsin data set. Note that the majority of the "not ready" vehicles are MY 1996 LDVs (6.9%) and that the majority (77%) of all "not ready" MY 1996 LDVs were not ready for the catalyst monitor, while MY 1998 LDVs were more frequently "not ready" for the evaporative system monitor. Note further that by MY 1998, the "not ready" rate for LDVs dropped over five-fold – from 6.9% to 1.3% – while the overall "not ready" rate for MY 1996 vehicles (5.8%) dropped more than four-fold by MY 1998 – to 1.4 %.

We can speculate that this difference in "not ready" rates among the three model years reflects a maturation curve for OBD technology, with the systems improving as manufacturers gained experience with what did and did not work in the real world. By the same token, however, it is also possible that the lower occurrence of readiness problems among the newer model years could be the result of differences in relative age and/or mileage accumulation. A test of this latter hypothesis would be to look at vehicles from different model years when they are at the same age and have accumulated comparable mileage. As discussed above, the Wisconsin data includes test results from MY 1997 and MY 1998 vehicles that were receiving their first tests on their one-year anniversary of purchase. Unfortunately, as we also discussed above, EPA does not have mileage accumulation data for MY 1997. Nevertheless, in the absence of any compelling reason to assume that MY 1997 vehicles were driven more or less than their MY 1998 counterparts in their first year of operation, we believe it is reasonable to assume that MY 1997 and MY 1998 vehicles exhibited comparable, accumulated mileage. The fact that the data in Table 17 still shows a significant decline in "not ready" rate from MY 1997 to MY 1998 – from an overall average of 2.3% to 1.4% – suggests that manufacturer learning curve is at least a likely explanation for the significant trend toward improvement in observed "not ready" rates.

As discussed in the background section above, some instances of vehicle unreadiness are due to vehicle design issues which EPA and CARB are still working with vehicle manufacturers to resolve. In the interim, it does not seem right to penalize motorists for something that is beyond their control. One logical solution is to allow states the flexibility (and the discretion) to not reject certain vehicles if the only problem is that they have unset readiness codes. The natural question then is, how do you allow these exemptions from the readiness criteria without opening the door to motorist fraud? In discussing this issue with the states and other interested OBD and I/M stakeholders, EPA concluded that the key is to limit the use of readiness exemptions – first, by model year, and secondarily, by the number (and possibly category) of unset readiness codes allowed.

Table 17: "Not Ready" (NR) Status for MY 1996-98

	Total Tested	Not Ready (NR)	One NR	Two NR	Catalyst	Evap	O2	Heated O2	EGR valve
96 LDV	27,313	1,873	1,155	884	1,435	475	826	880	1,041
%		6.9%	4.2%	3.2%	5.3%	1.7%	3.0%	3.2%	3.8%
96 LDT	16,423	651	169	64	471	184	74	186	72
%		4.0%	1.0%	0.4%	2.9%	1.1%	0.5%	1.1%	0.4%
96 Total	43,736	2,524	1,324	948	1,906	659	900	1,064	1,113
%		**5.8%**	3.0%	2.2%	4.4%	1.5%	2.1%	2.4%	2.5%
97 LDV	14,946	360	58	30	87	209	38	102	33
%		2.4%	0.4%	0.2%	0.6%	1.4%	0.3%	0.7%	0.2%
97 LDT	7,656	171	34	14	88	77	11	31	18
%		2.2%	0.4%	0.2%	1.1%	1.0%	0.1%	0.4%	0.2%
97 Total	22,602	531	92	44	175	286	49	133	51
%		**2.3%**	0.4%	0.2%	0.8%	1.3%	0.2%	0.6%	0.2%
98 LDV	27,615	361	101	61	105	287	59	61	55
%		1.3%	0.4%	0.2%	0.4%	1.0%	0.2%	0.2%	0.2%
98 LDT	22,716	350	69	32	221	182	32	55	17
%		1.5%	0.3%	0.1%	1.0%	0.8%	0.1%	0.2%	0.1%
98 Total	50,331	711	170	93	326	469	91	116	72
%		**1.4%**	0.3%	0.2%	0.6%	0.9%	0.2%	0.2%	0.1%
TOTAL	116,669	3,766	1,586	1,085	2,407	1,414	1,040	1,313	1,236
%		**3.2%**	1.4%	0.9%	2.1%	1.2%	0.9%	1.1%	1.1%

Determining the optimum combination of limiting factors, however, required real-world data. Therefore, in performing its analysis of the Wisconsin data, EPA also looked at the impact of adjusting “not ready” rates based upon a variety of possible readiness waiver scenarios. For example, does it make more sense to exempt vehicles based upon a certain number of “not ready” codes? Or would it be better to limit the exemptions to vehicles presenting as “not ready” for specific OBD monitors? In Table 17 above, the column headed “One NR” reflects the “not ready” rate by model year and vehicle type adjusted to reflect a waiver of the “not ready” rejection requirement if only one monitor is listed as “not ready.” The column headed “Two NR” reflects a similar adjustment of the “not ready” rate, but this time assuming a waiver of the rejection requirement if up to two monitors are listed as “not ready.” Table 17 also breaks out the readiness status of the vehicles in the Wisconsin data by monitor.

Table 17 shows that if any one monitor is allowed to be “not ready” the overall rejection rate among MY 1996-98 vehicles goes from 3.2% to 1.4%. If exemptions are allowed for vehicles with up to two unset readiness codes, the overall rejection rate goes down even further – to 0.9%. Because Wisconsin did not fail vehicles on the basis of the OBD-I/M check – which was being conducted on a purely advisory basis at the time this data was collected – vehicles were also not being rejected for unset readiness codes. As a result, no attempt was made at the test lanes to exercise these monitors prior to continuing the test. EPA therefore believes that the relative “not ready” rates reflected in Table 17 represent the worst-case scenario for these model years, and that the frequency of unresolved “not ready” codes in a fully implemented OBD-I/M program will be even lower.

4.3.2.2 MIL-on and IM240 Failure Rates

Table 18 below compares the relative failure rates for the OBD-I/M check versus the IM240 test observed in Wisconsin, and the degree to which the test results overlap. As can be seen from the data, the OBD-I/M check almost always fails slightly more vehicles than does the IM240 (MY 1998 LDVs are the only exception). There are several obvious reasons for the marginal difference in failure rate between these two tests:

1) The cutpoints for OBD are more stringent than the IM240 (i.e., 1.5 vs. 2 times the certification standard);

2) The IM240 only monitors vehicle performance for approximately 4 minutes over a limited number of operating modes, while OBD performs ongoing monitoring of vehicle performance over the full range of operating conditions; and

3) OBD monitors individual systems and components for any sign of degradation thus allowing it to identify necessary maintenance prior to the vehicle’s producing high emissions, while the IM240 can only identify vehicles which have already become high emitters (see discussion on “OBD and Preventative Maintenance” in section 2).

Table 18 also makes clear that the agreement between IM240 and the OBD-I/M check is exceedingly low for all model years and vehicle types. What is not clear from this data is which of the two tests is more beneficial to the environment. Traditionally, relative failure rate has been used as a crude indicator of test effectiveness in I/M programs, with the assumption being that the more vehicles that are failed, the more emission reductions are being achieved. Using simple, relative failure rates, Table 18 suggests that the OBD-I/M check is the more effective test, environmentally, because it has the greater overall failure rate.

When we use gross failure rate as our indicator of environmental effectiveness, however, we are ignoring one very important factor: false failures. After all, any test can be made to have a high failure rate – up to and including 100% – if one just makes the cutpoints tight enough and does not choose to worry about false failures and their impact on overall program acceptance. And, as indicated above, the OBD-I/M check does have more rigorous cutpoints than does the IM240. However, as suggested by the data presented in section 2 of this TSD, substantial evidence suggests that lane-based IM240s can produce false failure rates at least as high as that resulting from OBD-I/M testing on OBD-equipped vehicles, due to improper preconditioning, infrequent and/or inadequate quality assurance, etc. Conversely, section 2 also suggests that the vast majority of OBD-identified failures did trigger needed repairs and/or maintenance. Finally, manufacturers have an incentive to minimize MIL illumination when no detectable problem exists. Therefore, we expect false MIL illumination to be a decreasing problem. Taken together, these findings suggest that comparing the two tests – the OBD-I/M check versus IM240 – the OBD-I/M check will have no higher and perhaps less of a false failure rate than the IM240. The OBD-I/M check may therefore have a marginally higher absolute failure rate and ability to identify problem vehicles when compared to the IM240.

Table 18: OBD vs. IM240 Fails

MY/Class	Total Tested	OBD Fail (number)	OBD Fail (percent)	IM240 Fail (number)	IM240 Fail (percent)	Failed Both (number)	Failed Both (percent)
1996 LDV	27,313	645	2.4%	569	2.1%	59	0.2%
1996 LDT	16,422	436	2.7%	383	2.3%	100	0.6%
1996 Total	43,735	1,081	2.5%	952	2.2%	159	0.4%
1997 LDV	14,944	91	0.6%	71	0.5%	7	0.2%
1997 LDT	7,656	66	0.9%	51	0.7%	0	0.0%
1997 Total	22,600	157	0.7%	122	0.5%	7	0.0%
1998 LDV	27,616	118	0.4%	223	0.8%	7	0.0%
1998 LDT	22,716	123	0.5%	47	0.2%	0	0.0%
1998 Total	50,332	241	0.5%	270	0.5%	7	0.0%

4.3.3 Conclusions

Based upon its analysis of the Wisconsin lane data, EPA has concluded that although readiness seems to be a concern among the earliest OBD model years, flexibility in the form of readiness-based exemptions can go a long way toward minimizing the problem in the short term, while improvements in OBD implementation by the manufacturers will likely eliminate or greatly minimize the problem in the long run. To provide the needed flexibility to states to ensure smooth implementation of their OBD-based I/M programs, EPA is taking action to allow states to complete the testing process on MY 1996-2000 vehicles with two or fewer unset readiness codes; for MY 2001 and newer vehicles, the testing process can still be considered complete provided there is no more than one unset readiness code. This does not mean that these vehicles are exempt from the OBD-I/M check. The complete MIL check and scan must be run in all cases, and the vehicle still must be failed if the MIL is commanded on. The vehicle should continue to be rejected if it is MY 1996-2000 and has three or more unset readiness codes or is MY 2001 or newer and has two or more unset readiness codes. This allowance is consistent with a FACA OBD workgroup recommendation. It is intended to reduce the potential for customer inconvenience during this start-up phase of the transition to OBD-I/M testing. We believe that the environmental impact of this exemption will be negligible, given the small number of vehicles involved, the likelihood that at least some of these readiness codes will have been set in time for subsequent OBD-I/M checks, and the fact that an unset readiness code is not itself an indication of an emission problem.

4.4 Gas Cap Testing vs. OBD-I/M

4.4.1 Background

Unlike the OBD exhaust test versus the IM240, where the failure criteria for OBD are tighter than the failure criteria for the IM240, the OBD failure criteria for leak detection are known to be more lenient than the gas cap pressure test currently in use in several states. Although in theory this difference in test stringency should result in a greater number of failures for the gas cap test than for the OBD-based evaporative system test, it is not obvious that vehicles actually develop such “in between” leaks in the real world (and, if so, whether the frequency of such leaks is significant enough to warrant recommending the continuation of the gas cap test in conjunction with OBD-based testing).

To shed light on this issue, EPA decided to look at the Wisconsin data, focusing on the relative failure rates for the OBD-based evaporative system test versus the gas cap pressure test. Unlike the previous discussion concerning the use of gross failure rates as an indicator of test effectiveness when it comes to analyzing tailpipe tests, comparative failure rate is a fairly reliable index of a leak detection test’s relative effectiveness -- even when the failure criteria of the two tests being compared are different. Compared to tailpipe tests which are dynamic and relatively complicated, leak detection tests aimed at identifying leaks in the gas cap are straightforward. Whereas vehicle operation (i.e., whether steady-state, transient, loaded or unloaded), vehicle preconditioning, fuel composition, tire inflation, and multiple-instrument test equipment calibration can all have a considerable impact on the pass-fail decisions made by a traditional tailpipe test, none of these factors will have much effect on the traditional gas cap pressure test.

4.4.2 Results

Table 19 below compares the relative number and percentage of OBD evaporative system failure rates found in the Wisconsin vehicle sample versus the gas cap pressure test failure rate. Note that the gas cap failure rate is several orders of magnitude higher than the OBD failure rate for the entire evaporative emission system. Clearly, some of this is due to the fact that enhanced OBD evaporative system monitoring was phased in over the model years being looked at in this sample[33]. Furthermore, as described in our earlier discussion on OBD readiness, the overall OBD readiness on MY 1998 LDVs was dominated by vehicles which showed up at the test lane without their evaporative system monitors having run. Even with these caveats taken into consideration, however, EPA believes that the difference in failure rates is pronounced enough to warrant consideration of retaining the gas cap pressure test as a complement to OBD-I/M testing in those areas needing VOC reductions to attain and/or maintain their clean air goals.

Table 19: Gas Cap vs. OBD Evaporative System Failure Rates

MY/Class	Total Tested	Gas Cap Fail (number)	Gas Cap Fail (percent)	OBD Evap Fail (number)	OBD Evap Fail (percent)
1996 LDV	27,313	291	1.1%	7	0.03%
1996 LDT	16,422	245	1.5%	3	0.02%
1996 Total	43,735	536	1.2%	10	0.02%
1997 LDV	14,944	83	0.6%	2	0.01%
1997 LDT	7,656	48	0.6%	1	0.01%
1997 Total	22,600	131	0.6%	3	0.01%
1998 LDV	27,616	170	0.6%	6	0.02%
1998 LDT	22,716	155	0.7%	1	0.004%
1998 Total	50,332	325	0.6%	7	0.01%

4.4.3 Conclusions

For the reasons discussed above, EPA believes that separate pressure testing of the gas cap test using the test procedures currently employed in many I/M programs should be continued in conjunction with OBD-I/M testing on MY 1996 and newer OBD-equipped vehicles. Retention of the gas cap pressure test is the only exception to EPA's standing recommendation regarding the dual testing of MY 1996 and newer, OBD-equipped vehicles.

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[33] The phase-in requirements for MY 1996, 1997, 1998, and 1999+ are 20%, 40%, 90% and 100%, respectively.

Appendix 1: Test Sequence Used at Laboratories

1) Procurement and acceptance into the program
2) LA-4 cycle (preconditioning for IM240 test)
3) IM240 test
4) Drain in-use fuel
5) Fill with indolene (40% fill)
6) LA-4 cycle (preconditioning for FTP test)
7) 12 hour soak (no diurnal heat build)
8) FTP test (no evaporative test)
9) IM240 test
10) Repair if necessary
11) OBD Readiness codes cleared thru operation of vehicle
12) Repeat starting at step 4

Appendix 2: Breakdown of the broken parts found for FTP-passing, MIL-on vehicles

Systems/Components	LDV	LDT
O2 Sensor	3	24
EGR_Valve	4	6
Ignition System (spark plugs, ignition wires, other)	9	0
Transmission components	3	5
PCM, Reprogram or Replace	4	3
Miscellaneous Wires	3	0
Engine, Mechanical (cylinder head, harmonic balancer, valve springs)	2	1
Vacuum Leaks	1	1
Thermostat, Cooling System	1	0
Fuel Pump	0	1
Transmission Unit	0	1
Cam Sensor	1	0
Secondary Air Combo Valve	1	0
Throttle Position Valve	0	1
Exhaust Leak	0	1
Catalyst	0	1

Appendix 3: Lane IM240 vs. Lab IM240

There are a number of differences between the way an IM240 test is conducted in an inspection lane and the way that the test is conducted in an emissions laboratory. Some of them are:

1) quality of the test equipment

2) frequency of calibration of test equipment

3) skill of technician

4) control of ambient conditions

5) control of tire pressure

6) operating temperature of the vehicle

The first five items are of critical importance for a certification test in the laboratory but it is our opinion that they not crucial for the I/M function. By far the greatest importance is item six. There is a large variation in emissions between a partly warmed vehicle and a fully warmed vehicle. In the laboratory an LA4 (1372 seconds)test cycle is run before the LAB240 test to assure that the engine is fully warmed up and the catalyst hot. Vehicles arriving at I/M inspection lanes are assumed to be at operating temperature due to the driving prior to arrival at the lane (this may or may not be true). Attempts have been made in I/M systems to address this preconditioning problem through various methods.

Appendix 4: Description of Vehicles/Trucks Assumed to Fail FTP

CDH4, 1996 S-10 Pickup MIL off (computer commanding MIL "On")	Truck could not accelerate and would stall in 3rd gear on FTP	Lab IM240 results: (THC/CO/NOx) 11.8/147/0.02 Black plume of smoke from tailpipe
ATL78, 1999 Malibu MIL illuminated 74,000 miles	IM240 test of the vehicle caused closure of test cell due to hydrocarbon contamination of instruments. Decision made to not run FTP.	Lab IM240 results: 32.1/45.6/0.14 Raw fuel out of the tailpipe

Appendix 5

Raw Data – OBD/Tailpipe Pilot

Appendix 6

Detailed Data From The 30-Vehicle OBD Evaporative Pilot Study

Appendix 7

This section will primarily discuss issues with the Mazdas (150, 182), Hondas (153, 188), and Fords (155, 194). Reports and data are still pending from Honda and Ford, respectively.

Use of external mounted thermocouples instead of installing internal thermocouples is a common EPA practice for in-use evaporative emission testing. Without this simplification, instrumenting the vehicle in strict accordance with the EPA certification requirements for locating thermocouples and fuel drains can require cutting access panels through the floor of the vehicle's trunk compartment. ATL's practical experience in using surface mounted thermocouples is that this thermocouple location does not compromise testing accuracy because accurate measurement of the internal liquid temperature at the mid-point of the 40% fuel level is achieved. Vehicles with plastic fuel tanks used thermocouple probes installed through the bottom of the fuel tank. Any fuel tank modification that comprised the integrity of the OEM tank was resolved by installing a new fuel tank or fuel sending unit before the vehicle was returned to the owner.

The FTP evaporative emission running loss test requires that the measured fuel tank temperature track the target temperature within 3 degrees F over the dynamometer driving portion (Urban Dynamometer Driving Schedule (UDDS), New York City Cycle (NYCC), NYCC, UDDS) of the running loss test. In general, the measured fuel tank temperatures denoted as "Actual F" (failed) or "Actual R" (repaired) in Table A-5 in the Appendix indicate close agreement with the vehicle manufacturer supplied fuel tank temperature profile. Manufacturer supplied fuel tank target temperatures and ATL measured temperatures for starting and ending segments of the running loss test are summarized in Table A-5 in the Appendix.

Exceptions to meeting the 3 degree tolerance were observed for vehicles 150, 154, 184, and 189. The 3 degree tolerance is not straightforward to meet for in-use evaporative emission testing. The deviations for vehicles 150, 154, 184, and 189 range from slightly over 3 degrees F to about 7 degrees F. Not withstanding test work with vehicle 188, a 1999 Honda Accord (discussed below), these deviations from the target temperature profile and the short time of the excursion are not thought to be important because their effect on running loss results is judged to be minor.

<u>Appendix 8: Wisconsin I/M and OBD Data Fields</u>

Date/time	Date and time the vehicle was tested
Mod yr.	Model year
Make	Make
Model	Model
Vin	Vin number
Test	Test number, 1 for the first time vehicle has been tested in this test cycle, 2 for the first retest. A very few vehicles have been retested four times.
HC Stan	Final cutpoints, 0.6 grams per mile for cars
Co Stan	Final cutpoints, 1.5 grams per mile for cars
NOx	Final cutpoints 0.7 grams per mile for cars, Wisconsin does not fail for NOx
HC	Actual emissions total grams divided by the total miles, at the time the test was terminated
Co	Actual emissions total grams divided by the total miles, at the time the test was terminated
NOx	Actual emissions total grams divided by the total miles, at the time the test was terminated
Em fsec	Number of seconds that the test ran. (“0” for the full 240 second test)
Em res	P or F, pass or fail the 240 tailpipe test
Pr cap Stan	Pressure cap standard, inches of water
Pr cap ini	Initial pressure, inches of water
Pr cap	Final pressure, inches of water
Pr cap res	P or F, pass or fail pressure cap test
Onboard	Whether the technician could find the OBD connection. No cases where he could not after October 98
Obd res	Pass or fail, if MIL was illuminated. Should correspond to column AM
Tr no	Number of codes present (sum of V through AA) but is sometimes wrong
Code1	The next six columns list the OBD trouble codes, if any
Code2 - 6	(Blank)
Ready misfire	The next 11 columns list the readiness codes. 0 means that the monitor is not fitted. 1 means that the monitor is fitted but not ready. 2 means that the monitor is ready
Fuel	Fuel trim
Comp	Various circuits necessary for the other monitors to work
Cat	Catalyst
Hcat	Heated catalyst

Evap	Evaporative system
Sair	Secondary air
Acsys	Air conditioning
Oxy	Oxygen sensor
Hoxy	Heated oxygen sensor
Egr	Exhaust gas recirculation sensor
Obd Mil	Mil light, 1 if lighted, 0 if not. Should be same as column T
Odo	Odometer reading to nearest 1,000 miles (truncated)