# A Study Of The Relative Benefits Of On-Board Diagnostics And Inspection And Maintenance In California

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## ABSTRACT

California is considering adopting an enhanced Inspection and Maintenance (I&M) program (commonly referred to as Smog Check II) beginning with the 1996 calendar year. This program will utilize a targeting scheme to identify vehicles likely to be high emitters and send these vehicles to centralized testing facilities. The remaining fleet of vehicles will be sent to decentralized testing facilities. At these facilities, vehicles will be subjected to steady state loaded mode dynamometer based tests. Simultaneously, all 1996 and later model year passenger cars, light- and medium-duty trucks sold in California will be equipped with an On-Board Diagnostic (OBDII) system. This system is designed to monitor critical emission related components and activate a Malfunction Indicator Light (MIL) when a failure or a drift in calibration is likely to cause emissions to exceed 1.5 times the vehicle certification standards. The main objective of this paper is to ascertain what percentage of the emission benefits are attributable to either I&M or OBDII in order to assist regulators in making near term programmatic decisions. This paper also addresses the potential emission benefits of incorporating a radio transponder into the vehicle's OBDII system that is capable of transmitting fault codes when queried, resulting in prompt identification and repair.

## INTRODUCTION

California's current biennial I&M program utilizes an idle and a no load 2,500 rpm tailpipe tests ("idle tests") to detect Hydrocarbon (HC) and Carbon Monoxide (CO) failures. This program requires mechanics to visually ensure that all the required emission related components are properly connected and functionally verify their proper operation. A vehicle can fail this inspection test either for emissions and/or the visual/functional portions of the test. The current program requires the entire fleet to be tested in order to detect the 30-40 percent of the fleet which is likely to fail. The idle tests were designed in the early to mid-1980's to detect vehicle malfunctions that occur in primarily carbureted vehicles operating at idle. With the introduction of newer technology vehicles, the inability of these tests to detect malfunctions that occur at other operating modes could result in an inefficient I&M program in that the maximum emissions reduction potential of the program would never be realized.

Recognizing the need to improve the current I&M program, California is considering the adoption of an enhanced I&M program beginning in 1996. This program will utilize steady state loaded mode tests* to identify vehicles failing for HC, CO and oxides of nitrogen (NOx). The enhanced I&M program will also use a high emitter profile (developed by the Bureau of Automotive Repair, BAR) to identify vehicles likely to fail and send these vehicles to centralized testing facilities. The remaining fleet of vehicles will be sent for testing to decentralized facilities. As it is currently envisioned, the BAR believes that approximately 30 percent of vehicles will be identified by the targeting profile. Implementation of this program will result in a higher percentage of malperforming vehicles being identified primarily from the use of steady state loaded mode tests. The mechanic repair efficiency (a measure of how effective the mechanic is in correctly diagnosing and properly repairing a vehicle) will also increase since the mechanic will have to ensure that the vehicle is in compliance will all three pollutant standards, thus preventing simple fixes that would only lower HC and CO emissions at idle only, i.e., leaning out the fuel mixture.

Beginning with the 1996 model year, all passenger cars (PCs), light- and medium-duty trucks (LDT & MDT) will be equipped with an OBDII system. This system is designed to activate the MIL when a failure or drift in calibration of an emission related component causes the emissions to exceed 1.5 times the vehicle certification standards. Once the MIL is illuminated, a standardized fault code will be stored in the computer's memory which can be read by an OBDII scan tool.

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* The Bureau Of Automotive Repair is considering using Acceleration and Simulation Mode (ASM) tests (ASM5015 and ASM2525) to identify malperforming vehicles.

The OBDII system incorporates safeguards to prevent false activation of the MIL, i.e., the usage of a two trip algorithm to activate an MIL only when the malfunction is detected twice under the same driving conditions. Implementation of OBDII equipped vehicles will result in a higher identification rate for malfunctions in newer technology vehicles (1996 and later) since the fault code(s) will indicate the nature of the problem to the mechanics. Additionally, the mechanic repair efficiency for OBDII equipped vehicles will also increase since only a correct repair will result in the deactivation of the MIL.

The main focus of this paper is to determine what percentage of the PC emissions benefits are attributable to either I&M or OBDII. Ideally, one would like to have all malfunctions repaired immediately, however, under California's current I&M requirements some vehicles may not undergo repairs for up to two years (the vehicles next scheduled Smog Check). Anticipating the emissions impact associated with this problem, the emissions benefit from implementing a program that would remotely detect malfunctions by incorporating radio transponders into the vehicles OBDII system was also investigated.

## METHODOLOGY

California's Inspection And Maintenance And Emission Factors Model (CALIMFAC) was used in determining the relative emission benefits from I&M and OBD. This model was originally developed by Sierra Research under contract to the California Air Resources Board (CARB) [1]. This model utilizes 20 technology groups* (Table 1), each with it's own set of emission rates, to categorize the fleet.

| T. Group | Emission Control Configurations |
|---|---|
| 1 | Pre-1975, Without Air Injection |
| 2 | Pre-1975, With Air Injection |
| 3 | 1975 & Later, No Catalyst |
| 4 | 1975/76, Oxidation Catalyst, With Air Injection |
| 5 | 1975 & Later, Oxidation Catalyst, Without Air Injection |
| 6 | 1977 & Later, Oxidation Catalyst, With Air Injection |
| 7 | 1977-79, Throttle Body Injection/Carbureted, TWC |
| 8 | 1981 & Later, TBI/Carb., Single-Bed TWC, 0.7 NOx |
| 9 | 1981 & Later, TBI/Carb, Dual-Bed TWC, 0.7 NOx |
| 10 | 1977-80, Multi-Point Fuel Injection, TWC |
| 11 | 1981 & Later, MPFI, TWC, 0.7 NOx |
| 12 | 1981 & Later, TBI/Carb., TWC, 0.4 NOx |
| 13 | 1981& Later, MPFI, TWC, 0.4 NOx |
| 14 | 1980, TBI/Carb., TWC |
| 15 | 1993 & Later, TBI/Carb., TWC, 0.25 HC & 0.4 NOx |
| 16 | 1993 & Later, MPFI, TWC, 0.25 HC & 0.4 NOx |
| 17 | Transitional Low Emitting Vehicles |
| 18 | Low Emitting Vehicles |
| 19 | Ultra Low Emitting Vehicles |
| 20 | Zero Emitting Vehicles |

Table 1 Technology Group Definitions

* Technology groups 17 through 20 were added by Radian Corporation. Four additional technology groups were created by CARB to reflect the implementation of OBDII equipped vehicles.

The model year specific distribution of vehicles is described by using a combination of these technology groups, i.e., the 1980 model year consists of 26.5%, 11.4%, 12.7% and 49.4% of the vehicles from technology groups 5, 6, 10, and 14, respectively. Vehicles in each technology group are further subdived into 5 emission regimes defined as multiples of the vehicle certification standards as measured during the Federal Testing Procedure. Table 2 shows the breakpoints used in defining normal, moderate, high, very high and super emitting vehicles. These breakpoints were defined such that the regimes have stable quantized emissions such that an average emission level could be defined for each emission regime.

| Multiple Of The FTP Standard | | | |
|---|---|---|---|
| Regime | HC | CO | NOx |
| Normal | 1x | 1x | 1x |
| Moderate | 1-2x | 1-2x | 1-2x |
| High | 2-5x | 2-6x | 2-3x |
| Very High | 5-9x | 6-10x | 3-4x |
| Super | >9x | >10x | >4x |

Table 2 Breakpoints Used In Defining Emission Regimes

The model assumes that vehicles in each regime have stable emissions, however, deterioration (with age) or repair (I&M) is simulated within the model by the migration of vehicles from one emission regime to another, i.e., as vehicles age they migrate from the lower emitting regimes (normal-moderate) to the higher emitting regimes (high, very high and super). Figure 1 shows the population fractions for normal, moderate, high, very high and super HC emitters, by odometer for vehicles in technology group 9.

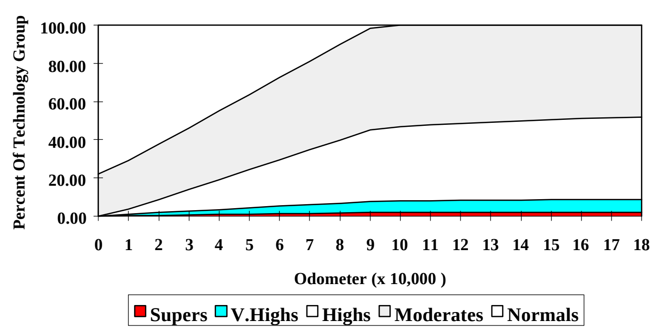


Figure 1 Population Fraction of Normals to Supers HC Emitters In Technology Group 9

For a specific technology group and pollutant, an I&M cycle is simulated by determining the percentage of vehicles identified in each regime by a particular inspection test; repair is then simulated by moving those vehicles to other (ideally) lower emission regimes. The movement of these vehicles is based on the projected repair efficiency of the mechanics and the repair cost limit. The average HC emissions before inspection is calculated by multiplying the percentage of vehicles in each regime by the average regime emission rate. The emissions benefit from one I&M cycle for a particular technology group can be estimated by comparing the average emission rates before and after repair.

The CALIMFAC model was recently modified by the Radian Corporation (under contract to BAR) to estimate the emissions benefit from the 1996 enhanced I&M program. The key assumptions used to model the 1996 I&M program are:

- A vehicle will be tested every two years (biennial program).
- Steady state loaded mode tests will be used to identify malperforming vehicles.
- Usage of a high emitter targeting profile to identify likely failures.
  Approximately 30% of the fleet will be targeted and sent to centralized testing facilities.
- The remaining fleet of vehicles will be sent to decentralized testing facilities.

The 1996 I&M program as modeled by Radian included a 50% repair disbenefit for vehicles going to decentralized test and repair facilities as dictated by the U. S. Environmental Protection Agency. This disbenefit was removed in the following analyses since the baseline emission factors for the current I&M program already implicitly contains a disbenefit. Including this disbenefit would result in double counting the repair disbenefit. Additionally, OBDII vehicles will not realize this disbenefit since these vehicles will be correctly repaired, in order to deactivate the MIL, regardless of whether the vehicles are sent to centralized or decentralized facilities for inspection.

The CALIMFAC model was further modified to account for OBDII vehicles. The key assumptions used in modifying the model were:

- The OBDII system will restrict the growth of high, very high and super emitters for the first 70,000 miles of in use driving since most major emission control components are warranted for this time and owners are more likely to get their vehicles repaired immediately under warranty.
- The OBDII system will identify 95% [2] of the vehicles in the high, very high and super emission regimes since the system is designed to detect malfunctions or a drift in calibrations that will likely cause an increase in emissions 1.5x the vehicle certification standards.
- Malperforming vehicles identified by the OBDII system will be effectively repaired since the fault code will identify the source of the malfunction and the mechanics must correctly repair the vehicle in order to deactivate the MIL. Within the model, this element is reflected by moving those vehicles in the high, very high and super emission regimes in equal proportion to the normal and moderate regimes.
- After the first 70,000 mile of use, the movement of OBDII equipped vehicles from the high, very high and super emission regimes to the moderate and normal emission regimes occurs regardless of whether the vehicle encounters a centralized or decentralized inspection test. This implies that there is no difference in the repair disbenefit for OBDII vehicles.

In determining the emission benefits from the implementation of OBDII vehicles it is assumed that the OBD system will identify 95% of the vehicles that are high, very high and super emitters. To verify this assumption, four FTP tests were performed on a 1995 OBDII compliant vehicle that was equipped with an 8 cylinder, 4.6 liter displacement engine with 3,124 miles on the odometer. Table 3 shows the FTP composite emissions as a result of various defects (listed below) being induced in the vehicle. Table 3 also lists the fault codes that were stored in the vehicle's OBDII computer after each test.

| Defect | HC (g/mi) | CO (g/mi) | NOx (g/mi) | MIL-Status | Codes |
|---|---|---|---|---|---|
| Baseline | 0.101 | 1.059 | 0.089 | OFF | None |
| 1 | 0.439 | 6.896 | 0.166 | ON | P0125/P0155 |
| 2 | 0.095 | 0.756 | 0.188 | ON | P1407 |
| 3 | 0.122 | 1.002 | 0.171 | OFF | None |

Table 3 Composite FTP Results

1 Disconnected two oxygen sensors before the catalyst
2 Blocked off the EGR valve
3 Disconnected the purge flow line, coming from the purge valve control solenoid, at the engine

P0125/P0155 Generic codes indicating a heater circuit malfunction in bank one, sensors one and two.
P1407 Manufacturer specific code indicating that there is no EGR flow.

Although, the testing of the vehicle's OBDII system was not exhaustive, the results indicate that the OBD system performed as required by CARB regulation [3] with the exception of the purge flow monitoring system. Further investigation revealed that the manufacturer had certified this vehicle as being deficient with respect to the purge flow monitoring system. The OBDII system on this vehicle contains a continuity check of the purge flow control valve to ensure it's proper operation, however, the flow itself is not monitored. The current OBDII regulation allows manufacturers to certify their vehicles as being OBDII compliant with one deficiency upto the year 1999, thereafter, the vehicles must be fully OBDII compliant.

## RESULTS

Figure 2 shows the reduction in HC emissions from the 1990 I&M program, with and without the introduction of OBDII equipped vehicles. The emissions benefit is calculated by comparing the with I&M (or with OBDII) emission rates to the without I&M and without OBDII emission rates. Figure 2 shows that the projected percentage emission benefits from the current I&M program without OBDII vehicles will increase with time. This increase in the percentage of emissions reduced is misleading in that it does not represent an actual improvement in the current I&M program, rather it reflects the implementation of zero emission vehicles (electric cars). For example, if the emission benefits from the current I&M program is 20% in the 1997 calendar year, then in the year 2000 the gasoline fueled fleet (approximately 98%) will experience a similar reduction on a g/mi basis. Therefore, the emission reduction on a percentage basis increases since only gasoline fueled vehicles see this benefit. The benefits from implementing OBDII vehicles without an I&M program continue to increase beyond the year 2020 due to the dominance of OBDII equipped vehicles in the future calendar years. The OBDII benefits result from owners of malfunctioning vehicles having them repaired immediately under warranty. The main impact due to the introduction of OBDII vehicles is that it will increase the effectiveness of the current I&M program. The benefits of the I&M program with OBDII are from: detecting malfunctions in older technology vehicles, OBDII benefits from the immediate repair of malfunctions during the first 70,000 miles of use, and the OBDII system identifying malfunctions (after 70,000 miles of use) which are then repaired at the vehicles next Smog Check. Figure 2 shows that the incremental HC emission benefit from implementing OBDII vehicles is 7.4%.

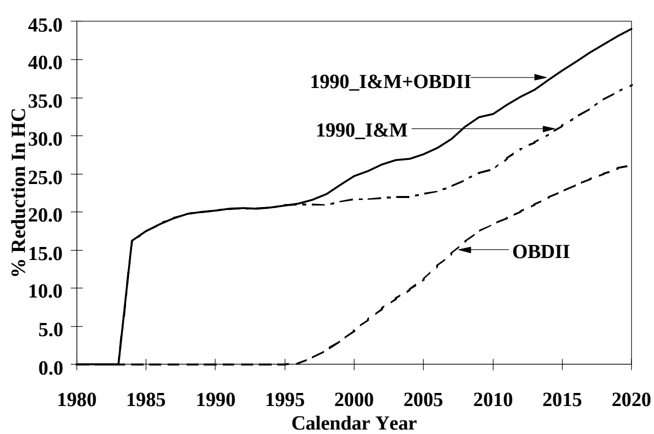


Figure 2 Reduction In HC Emissions From The 1990 I&M Program, With And Without OBDII Vehicles

Figure 3 shows the calendar year specific FTP composite HC emission (g/mi) rates if there is no I&M program, with the implementation of OBDII vehicles but no I&M program, 1990 I&M program and 1990 I&M program with the implementation of OBDII vehicles. This figure shows that the general trend is towards lower calendar year specific HC emission rates due to the phase-in of newer and cleaner (Low Emission Vehicles) technology vehicles. The highest emission rate will result from not having an I&M program and not implementing OBDII vehicles. The lowest emission rate will result from implementing both of these programs.

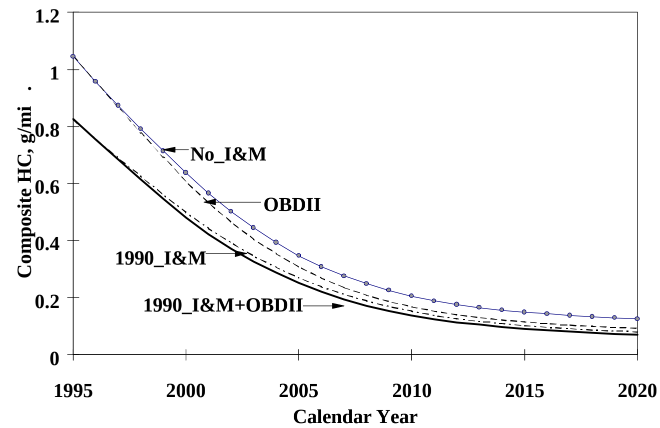


Figure 3 Comparison Of Fleet Average HC Emissions For No_I&M, 1990_I&M, OBDII_Only & 1990 I&M Program With OBDII

Figure 4 shows the reduction in CO emissions from the 1990 I&M program, with and without OBDII. The percent reduction in CO follows trends similar to that observed for HC, however, the incremental benefit from implementing OBDII is less than 1%. This does not imply that the OBDII system is less effective in identifying CO failures rather it reflects how OBDII is currently modeled in CALIMFAC. Within the model it is assumed that the OBDII system will increase the probability of identifying a malperforming vehicle. Rather than increasing the probability of identification it would be more correct to fail a vehicle based on the OBDII fault code which will increase the effectiveness of OBDII.

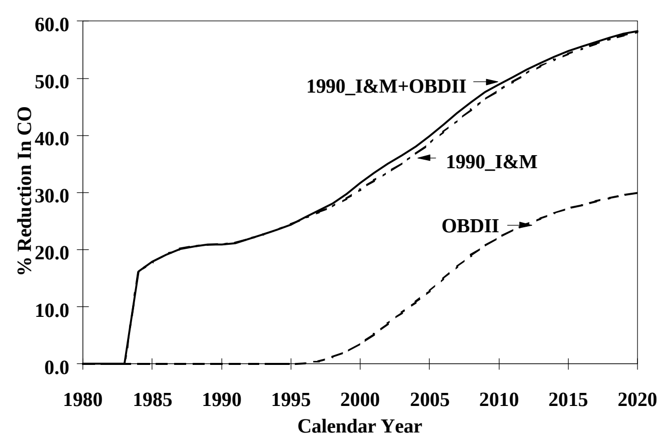


Figure 4 Reduction In CO Emissions From The 1990 I&M Program, With And Without OBDII

Figure 5 shows the reduction in NOx from the 1990 I&M program, with and without OBDII. The NOx emission reduction trends are similar to that observed for HC. The emission reductions for NOx from the current I&M program with OBDII increases sharply with the implementation OBDII vehicles since the system can identify NOx failures more effectively than the current I&M test procedure which simply relies on visual and functional tests of the exhaust gas recirculating (EGR) system to assess if the vehicle is likely to fail for NOx. The incremental NOx emissions benefit from implementing OBDII vehicles is 5.7%.

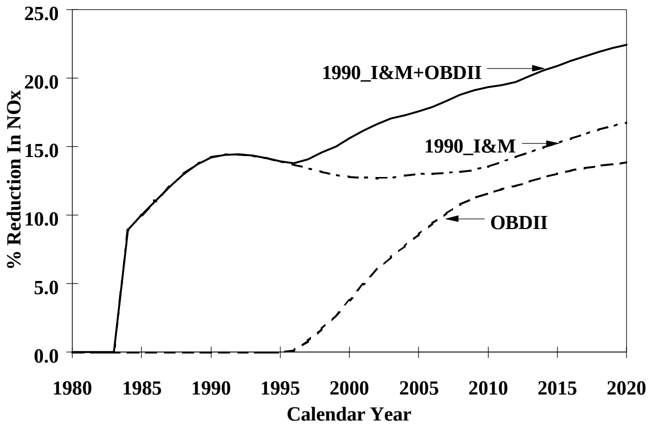


Figure 5 Reduction In Oxides Of Nitrogen From The 1990 I&M Program, With And Without OBDII

Figure 6 shows the incremental HC benefit from the 1996 enhanced I&M program with OBDII compared to the 1990 I&M program with OBDII. The maximum incremental benefit for the 1996 I&M program (compared to the 1990 I&M program) is 4.0% in the year 2005, thereafter, the incremental benefit decreases due to the dominance of OBDII vehicles. The incremental benefits for the 1996 enhanced I&M program result primarily from the higher identification rate of malperforming non-OBDII equipped vehicles. The higher identification rate for these vehicles results from the use of steady-state loaded mode tests to identify and repair failures rather than the current two speed idle tests. The benefits from both programs will eventually converge due to the fleet being dominated by OBDII equipped vehicles at which point the usefulness of the emissions test is negligible since the OBDII system can itself identify malperforming vehicles.

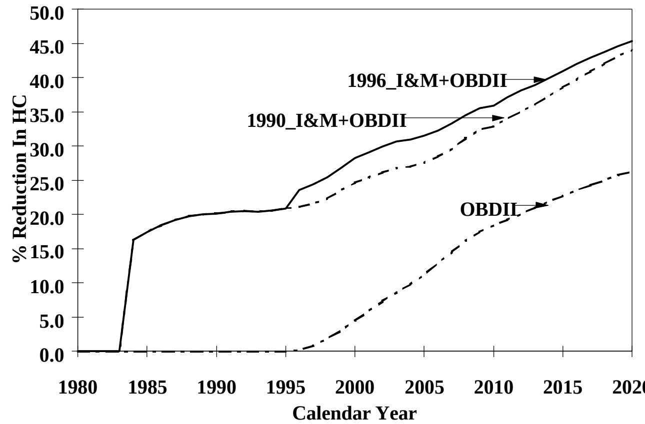


Figure 6 Reduction In HC Emissions From The 1990 And 1996 I&M Programs With OBDII

Figures 7 and 8 show the incremental CO and NOx emission benefits, respectively, from the 1996 I&M Program with OBDII compared to the 1990 I&M Program with OBDII.

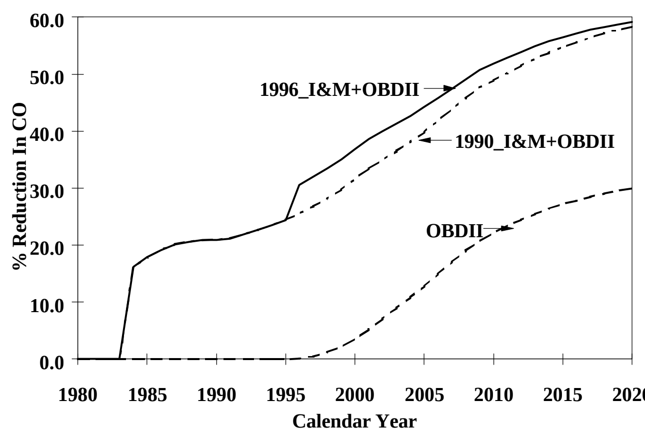


Figure 7 Reduction In CO Emissions From The 1990 and 1996 I&M Programs, With OBDII

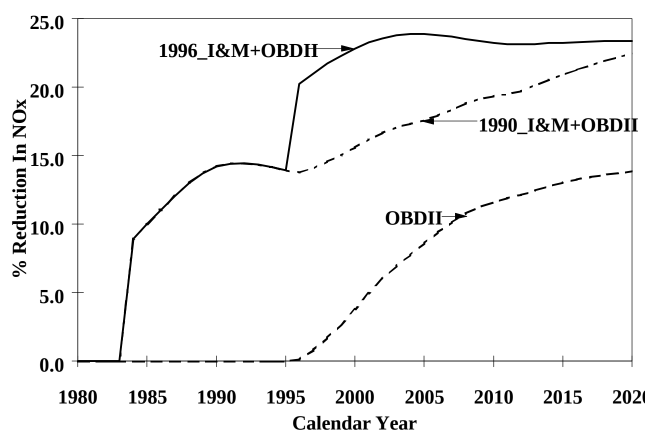

Figure 8  Reduction In NOx Emissions From The 1990 and 1996 I&M Programs, With OBDII

Figure 8 shows that the incremental benefit from the 1996 I&M program with OBDII is more than 7% as compared to the current I&M program with OBDII.  The increase in benefit arises primarily from the ability of steady state loaded mode tests to identify NOx failures better than the current visual/functional tests of the EGR system and catalyst.

Figure 9 shows a comparison of CO emission reductions assuming a 95% and 70% identification rate for the OBDII system. This comparison assumes that a deficiency in one monitoring system will affect the systems ability to detect malfunctions in all three emission regimes.  This figure shows that there will be a 2% loss in benefits if the OBDII system is only 70% as effective in identifying high, very high and super emitting vehicles.

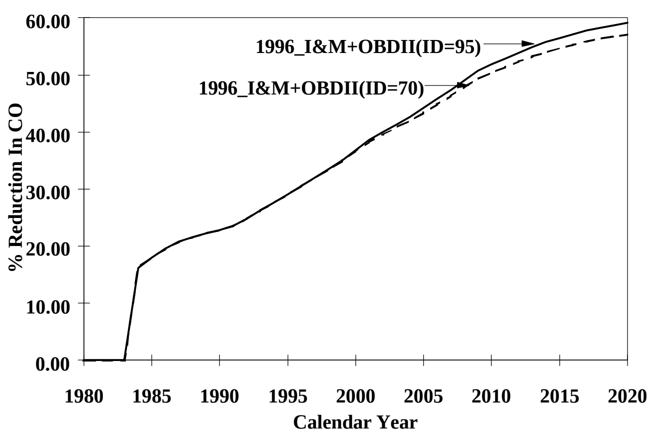


Figure 9  The Effect Of Varying The OBDII Identification Rate

**OBDIII**

The emission benefits from the OBDII system in the first 70,000 miles of in-use is predicated on the assumption that the vehicle owner will repair any malfunctions immediately under warranty.  Thereafter, it is assumed that malfunctions will not be repaired until the vehicle's next scheduled Smog Check.  In reality some owners may get their vehicles repaired immediately and some may wait.  Ideally, all malfunctions would be repaired immediately, however, under California's I&M requirements some vehicles may not undergo repairs for up to two year.  The emissions benefit from implementing a program that would remotely detect malfunctions and require these malfunctions to be repaired in a timely manner was investigated.

The basic concept for OBDIII assumes that all 2000 and later model year PCs,  LDTs and MDTs would by equipped with radio transponders.  The transponder would allow remote query of the vehicle's OBDII system.  On query, the transponder would transmit the vehicle identification number (VIN), system status code (OBDII system is operational or not functioning) and fault code(s).  The OBDIII system could also be designed to transmit a code when it detects malfunctions without query.  The system could be used to inform regulators of malfunctions in real-time who could then require prompt repair, and be assured of proper repair by initiating a subsequent query.

For this analysis, it is assumed that full implementation of OBDIII systems could be achieved for the 2000 and later model year PCs.  This time frame assumes a regulatory change by 1998 and a two year lead-time to incorporate existing transponder technology into the OBDII system.  The implementation of OBDIII would require manufacturers to modify the OBDII system to electronically store the VIN and status or fault code(s) and transmit this information via a transponder when queried.  Figures 10 and 11 show two possible concepts for deploying a transponder based OBDIII system.  Figures 10 and 11 show a cellular based and a roadside based OBDIII transponder systems, respectively.

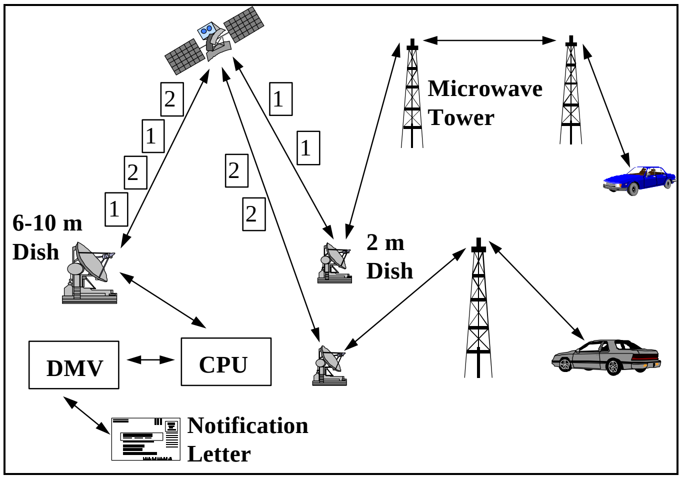


Figure 10  Cellular Based OBDIII System

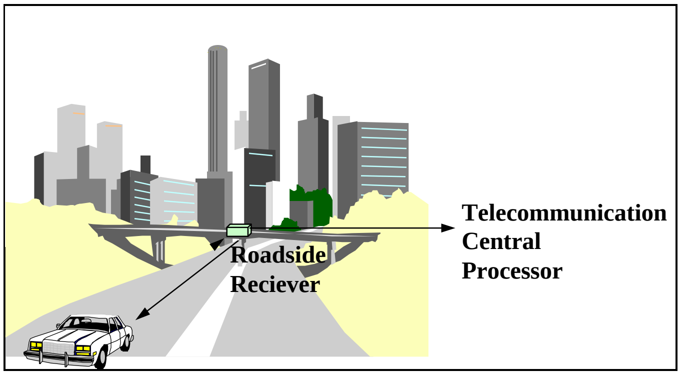


Figure 11  Roadside Based OBDIII system

The cellular based system is similar in concept to that used by Teletrac to locate stolen vehicles by triangulating the position of the radio transponder using up to 40 transmitting and receiving stations.  A malperforming OBDIII vehicle (with the MIL on) would transmit an encoded signal (at a cellular frequency level) which is picked up by the nearest microwave tower. The signal is then routed to the nearest Very Small Aperture Transmitter (VSAT) from where it would be relayed via a satellite to the central dish for signal decoding. The signal from each VSAT to the satellite is relayed using time division multiplexing (shown in Figure 10 as “1” and “2”) to prevent signal collision, and enable the processing of information from multiple VSATs. Once the signal has been decoded, the VIN can be cross-referenced with the Department of Motor Vehicles (DMV) registration database to locate the owner's address. The vehicle owner would then be asked to repair his vehicle in a timely manner. The cellular system allows for two way communication between the central processing center and the vehicle, enabling frequent queries of the vehicle's status.

Another concept that CARB has investigated [4] is the use of a low power in-vehicle transmitter to communicate the vehicle's status to the low power roadside receiver. This system can transmit and receive multiple signals from various vehicles traveling on an 8 lane freeway. The roadside receiver can be used to query the vehicle's OBDIII system and relay (via phone lines) relevant information for central processing.

Figures 12 and 13 show the incremental CO and NOx benefits, respectively, from OBDIII equipped vehicles. The incremental emission benefits from implementing OBDIII vehicles are approximately 3% and 1.5% for CO and NOx emissions, respectively.

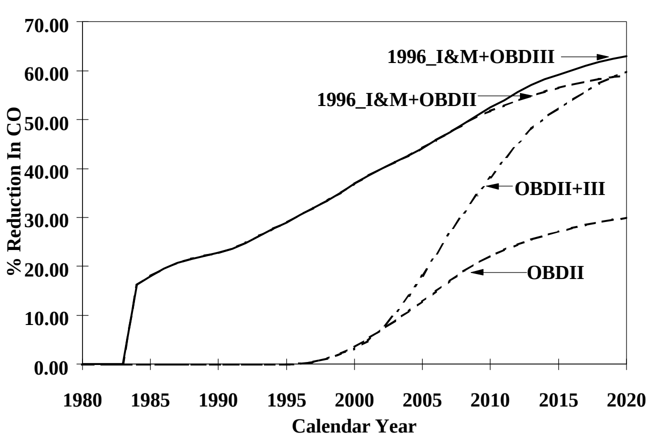


Figure 12 Incremental CO Emission Benefits For OBDIII Vehicles

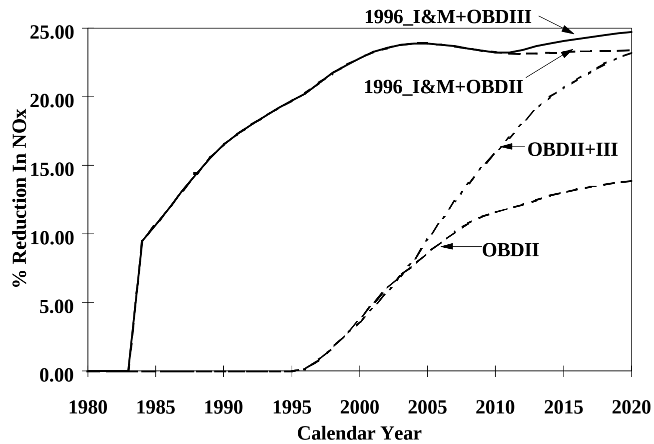


Figure 13 Incremental NOx Emission Benefits For OBDIII Vehicles

The major advantages of OBDIII are financial in that it would eliminate the mandatory testing of the entire vehicle fleet in order to detect the 30-40% of the vehicles which will fail. It will also be more convenient for motorists who will save time and money by not having to pay a $30-40 testing fee even when their car passes the test. The cost effectiveness of the overall program (as measured by the amount of dollars spent to reduce one ton of pollutant) will also increase since only failing vehicles will be tested and repaired. In addition, OBDIII will be a useful tool to CARB’s in-use recall program. In this program, certain engine families are tested to determine their compliance with the 50,000 or 100,000 mile emission standards. If a majority of the vehicles fail these standards due to a particular defect, then a recall is instituted to repair the defect under the manufacturer’s emissions warranty program. OBDIII would be a useful tool to the recall program in that a statistical analyses of the fault codes could be used to identify pattern defects, by engine family and a recall could be based upon these failures.

One of the issues that may have to be resolved pertains to the public’s perception that the OBDIII system may constitute an invasion of privacy. The Fourth Amendment to the U.S. Constitution protects the rights of individuals against unreasonable searches and seizures. CARB has investigated these legal issues [5] and believes that the U.S. Supreme Court has made it clear that vehicles are subject to a diminished expectation of privacy compared to a persons residence or personal effects. In addition, the use of transponder based technology will not enable the state to obtain more information than it could by simply increasing the frequency of inspections. One method of making OBDIII more acceptable to motorists is by asking them to sign a consent form (when purchasing the vehicle) allowing the state to query the OBDIII system, and informing motorists that they would save money by not having to Smog Check their vehicle every two years. This system could also be incorporated into other driver aids, i.e., vehicle navigation or anti theft vehicle location systems.

If the OBDIII system is cellular based then the state would have to obtain a license from the Federal Communications Commission to transmit at a cellular frequency and prove that the communications system will not interfere with the existing cellular network. In order to assure adequate statewide coverage, one would have to determine the number of VSATs for a cellular based system or the number of roadside receivers for a ground based system. Finally, regardless of which system is considered one must determine the cost of each system to demonstrate it's cost effectiveness compared to the current I&M program.

## CONCLUSIONS

The analyses presented in this paper are based on modifications to the CALIMFAC model which was developed in 1990. This version of the model is currently being updated with additional data and the results of the analyses presented here may change.

The projected benefits from the current I&M program will remain constant.

The enhancements planned for the 1996 I&M program will increase the effectiveness of the program since the vehicle will have to pass standards for all three measured pollutants in order to pass the test.

Equipping the fleet with OBDII systems should result in increased identification of failures and facilitate more accurate and effective repair. However, the success of the OBDII system relies heavily upon the driver being motivated to perform timely repairs, and that the repairs are correctly performed.

OBDIII will assist in these areas by remotely informing regulatory officials of the illumination of the MIL and in assessing the effectiveness of repair. Although, the incremental benefits of this concept appear small, the cost effectiveness associated with only requiring tests of those vehicles which are likely to fail make this approach worthy of further investigation.

Finally, the OBDIII system may eventually obviate the need for an I&M program since the fleet can be remotely monitored. This would represent a major cost savings to both the consumer (by not having to pay a testing fee) and the state for administrating an I&M program.

## DISCLAIMER

The opinions, findings, and conclusions expressed in this paper are those of the authors and do not necessarily those of the California Air Resources Board.

## ACKNOWLEDGMENTS

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## REFERENCES

1. Development Of The California I&M Benefits Model (CALIMFAC) by Sierra Research, Inc., under contract (A6-173-64) to CARB, June 1990.

2. Personal Communications between Steve Albu, Chief of Engineering Studies Branch and Mark Carlock, Chief of Motor Vehicles Analysis Branch of the CARB, Entitled "OBDII Emission Benefits In CALIMFAC," July 1995.

3. On-Board Diagnostics (OBDII) System Requirements For 1994 And Later Passenger Cars, Light-Duty Trucks And Medium Duty Trucks Equipped With Feedback Fuel Control Systems, Section 1968.1, Title 13, California Code Of Regulations.

4. Sierra Research, Inc., "Task Order Contract For Emission Inventory Projects" Volume 1 Technical Proposal, September 23, 1991.

5. Macomber, S. Kingsley, Sierra Research, Inc., "Legal Aspects Of Transponder Technology" CARB Contract No. A096-214, January 27, 1994.