Incorporation of Wireless Communications into Vehicle On-Board Diagnostic (OBD) Systems

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ABSTRACT

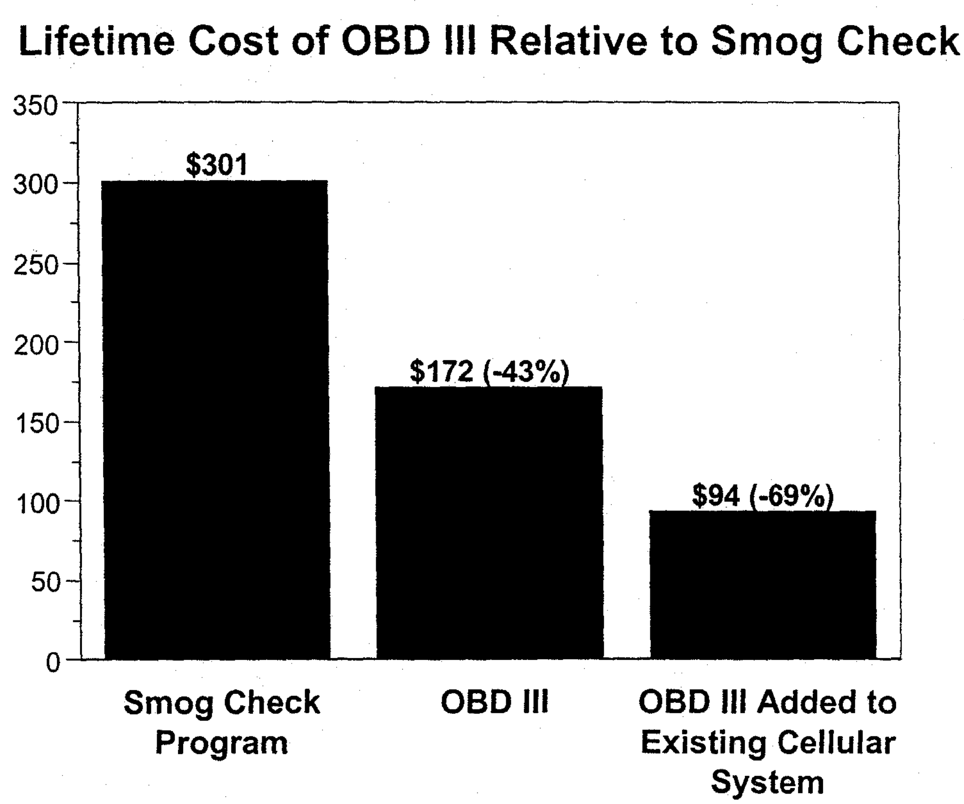
The feasibility of incorporating radio communications into onboard diagnostic (OBD) systems for new cars and light trucks has been demonstrated through the successful completion of a field study using five vehicles equipped with prototype systems. Referred to as "OBDIII", OBD systems interfaced with radio communications would be a cost-effective alternative to the California vehicle inspection and maintenance program (called "Smog Check"). For an initial cost of less than $100 per vehicle and monitoring charges averaging less than $10 per year, the cost of OBDIII would be significantly lower than the cost of biennial Smog Check tests over the life of a vehicle. There would also be substantial value associated with saving the time now spent by motorists who must obtain Smog Check tests on properly maintained vehicles that pass the test. OBDIII is also projected to result in lower emissions due to the earlier detection of emissions-related defects.

Incorporation of Wireless Communications into Vehicle On-Board Diagnostic (OBD) Systems

1. SUMMARY

Incorporation of radio communications into onboard diagnostic systems (OBD) of new cars offers the potential to provide greater emissions reductions than are achieved with the Smog Check program while simultaneously saving motorists time and money. The cost of this third generation of onboard diagnostic equipment (referred to as "OBDIII") is estimated to be $80 per vehicle, plus the cost of cellular service. Using a simplified form of cellular service with all of the vehicles produced by one manufacturer covered by a single account, it is estimated that service costs will be less than one dollar per month. With this type of cellular service, the cost of OBDIII is estimated to be 43% lower than the cost of the Smog Check program, as shown in Figure 1-1. For vehicles that are equipped with cellular phones, less additional hardware is required to implement OBDIII and the cost is projected to be 69% lower than the cost of participating in the Smog Check program.

Figure 1-1



As part of the current study, a demonstration program has been conducted using prototype OBDIII equipment in a fleet of five popular models of cars. The results from the demonstration program and other information collected in the course of this study show that it is possible to fabricate and operate an automated system to communicate changes in OBD fault code status and vehicle identification numbers via wireless cellular communication. Based on the demonstration, it is clear that incorporation of wireless communication capability into OBD systems and the infrastructure to support automated OBDIII communications can be accomplished with currently available technology.

To the extent that OBDIII is needed to achieve and maintain ambient air quality standards in California, there is a legal basis to support OBDIII requirements. However, a mandatory program requiring the implementation of OBDIII systems for all new vehicles in California may face substantial opposition, primarily due to concerns about privacy and undue government intrusiveness. These concerns would be substantially mitigated if the program were voluntary, i.e., if each new car owner were offered the choice either (1) to operate OBDIII and be excused from regular Smog Checks or (2) to forego OBDIII operation and be required to participate in regular Smog Checks. Over time, it is expected that almost all new car owners would choose the less costly and more convenient option of using OBDIII rather than participating in the Smog Check program.

If ARB decides to pursue OBDIII as a mandatory or voluntary program, new regulations will have to be adopted in Title 13 of the California Administrative Code, and substantial coordination will be required with vehicle manufacturers, potential third parties in the communication and vehicle electronics industries, and with the State's Smog Check program authorities.

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2. INTRODUCTION AND BACKGROUND

The state's current motor vehicle inspection and maintenance (I/M) program, commonly referred to as "Smog Check II," requires periodic testing of all vehicles to determine whether they contain emissions-related defects. As a result, each year, millions of vehicles are required to undergo inspection even though they are free from defects. Over the life of the average vehicle, about $300 is spent obtaining emissions tests during which no defects are identified.* The costs are higher if one accounts for the additional vehicle operation and the motorists' time associated with obtaining a Smog Check on a vehicle that is free from defects.

Basing the Smog Check program on periodic, scheduled inspections also introduces other concerns regarding the efficiency of the current program. With a known inspection schedule, owners have the opportunity, if not the incentive, to defer routine maintenance either until the vehicle fails a Smog Check or until just before the vehicle is due for a Smog Check. In the case of defects related to tampering, the owner has the opportunity to correct the problem just prior to Smog Check. Immediately following the test, the vehicle can be restored to a tampered condition. Remote sensing devices (RSDs) are being incorporated into the Smog Check program to help address these concerns; however, "snapshot" measurements of exhaust concentrations are relatively ineffective in identifying most forms of tampering and malmaintenance.[1]**

To overcome the above-described inefficiencies and limitations of the current Smog Check program, the Air Resources Board (ARB) has supported a demonstration of the feasibility and utility of using radio communication equipment to collect information regarding the presence of emissions-related defects contained in OBD systems. Beginning with the 1988 model year, ARB regulations have required the use of OBD systems on gasoline-fueled passenger cars and light trucks. When emissions-related defects are detected by the OBD system, a dashboard-mounted malfunction indicator light (MIL) is illuminated and "fault codes" indicating the location of the defect are available for extraction through a diagnostic port. As described in more detail below, ARB staff believes the latest OBD requirements (OBDII) will be more effective in identifying emissions-related defects than the exhaust emissions testing and other functional test procedures employed during the Smog Check test. By integrating the OBD system with a transponder or other radio communication device, it would be possible to monitor the status of vehicle emissions control systems for all vehicles operating within the range of whatever system is being used to receive information from the vehicle. For vehicles equipped with such a system, the periodic inspection requirement could be eliminated and defective vehicles could be called in for testing

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*Details of the calculation of Smog Check program costs are presented in Section 5.

** Superscripts denote references provided in Section 9.

shortly after defects occur. The designs of many vehicles already incorporate radio communication equipment such as cellular phones. For these vehicles, the incremental cost of providing automated OBDIII communication is greatly reduced. This concept offers the potential to substantially reduce the number of vehicles subjected to testing and to substantially reduce the owners' time and expense of meeting Smog Check requirements, while simultaneously increasing the effectiveness of the state's program for identifying vehicles with emissions-related defects in a timely manner.

Capabilities of OBD Systems

ARB adopted its first OBD regulations in April 1985. Those regulations, which were phased-in over the 1988-1991 model years, required monitoring of "computer-sensed emission-related components," the "on-board processor," and "emissions-related functioning of the fuel metering device or EGR valve on vehicles so equipped." A dashboard "malfunction indicator light" was required to be illuminated when malfunctions were detected, but there were no grams/mile related criteria for determining the occurrence of a malfunction. The initial regulations also required that the systems store "fault codes" indicating the component determined to be defective, and provisions had to be made for fault code extraction without special equipment.

In September 1989, ARB adopted the second generation of its OBD requirements (OBDII). These regulations contained more specific provisions, requiring a 1994-1996 model year phase-in of:

- catalyst efficiency monitoring;
- misfire detection;
- evaporative control system monitoring;
- air injection flow monitoring;
- EGR flow monitoring; and
- more generic requirements for other components.

Since then, several changes to the OBDII regulations have been made that modify the specific requirements for defect identification and extend the schedule for 100% compliance.

In their present form, the OBD regulations require the use of systems that can detect many emissions-related defects that are difficult, if not impossible, to detect with a conventional I/M test. This is especially true in the case of evaporative emissions system monitoring and the monitoring of systems (e.g., air injection) that are functional on most new vehicles only during warm-up.

Low-Cost Radio-Based Communication Technology

OBDII could be modified to include radio-based communication equipment using either one-direction communication (vehicle-to-stationary receiver) or two-way communication. Three broad classes of communications equipment have been identified that appear to be capable of meeting ARB's needs:

1. Short-Range, Ground-Based - Low power (less than 10 mw) or unpowered (backscatter) transponders that communicate with ground-based, roadside receivers;

2. Long-Range, Satellite-Based - Higher power (on the order of 1 watt) transponders or pagers that communicate with a network of receivers in low Earth orbit; and

3. Long-Range, Ground-Based - Cellular data telephony, higher power (on the order of 1 watt) transponders or two-way pagers that communicate with a network of ground-based stations.

Sierra's proposal to ARB envisioned a field demonstration of the short-range, ground-based approach in conjunction with Hughes and Texas Instruments as "cooperating technology providers." However, ARB staff redirected the project towards the demonstration of a longer range, cellular-based system using Hewlett-Packard as a cooperating technology provider. A change in internal priorities resulted in Hewlett-Packard backing out of the project after a substantial amount of time was spent revamping the project plan. Substantial additional time was required for Sierra to recruit a new team of cooperating technology providers, which consisted of Snap-On Diagnostics, American Mobile (operators of the ARDIS network), and Workstat Software. These firms assisted in the development and demonstration of an all-new, cellular-based prototype system from scratch.

Organization of the Report

Following this Introduction, Section 3 of the report provides more detailed information regarding the three radio-based communication technologies described above. Particular attention is focused on the features and applications of long-range, ground-based cellular technology, which is by far the most widely used of the three for mobile two-way communications. Section 4 of the report describes the field demonstration of prototype OBDIII systems developed by Sierra. Section 5 addresses the cost and effectiveness of OBDIII relative to the Smog Check program. Section 6 covers OBDIII implementation issues that ARB should consider. Section 7 describes the short video that has been prepared to explain the OBDIII concept to interested parties. Section 8 contains our overall conclusions and recommendations for future action by ARB. Section 9 contains a list of references cited in this report.

Appendices to the report contain a manual describing the operation of the custom software used in the prototype systems developed by Sierra; a description of the digital cellular system used to communicate with the prototype vehicles during the field demonstration; a list of the disablements used during the field demonstration; a summary of the data collected during the field demonstration; and a legal analysis of both the constitutionality of an OBDIII requirement and ARB's statutory authority.

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3. POTENTIAL OBDIII WIRELESS TECHNOLOGIES

The essence of OBDIII is to enable the vehicle to communicate its status in an automated manner so that expeditious repair can be assured. Radio communication is the medium of choice for this communication, and there are at least three major types of systems capable of meeting ARB's objectives:

1. Short-Range, Ground-Based - Low power (less than 10 mw) or unpowered (backscatter) transponders that communicate with ground-based, roadside receivers;

2. Long-Range, Satellite-Based - Higher power (on the order of one watt) transponders or pagers that communicate with a network of receivers in low Earth orbit; and

3. Long-Range, Ground-Based - Higher power (on the order of one watt) transponders, pagers, or cellular phones that communicate with a network of ground-based receivers.

This chapter provides additional information about each of these alternatives, with particular attention to the third category, which is considered to be the most likely candidate for use in OBDIII systems. It also provides an assessment of the practicality of applying each technology under a phased-in OBDIII program.

Overview of Potential Wireless Technologies

Short-Range, Ground-Based Systems - Prominent examples of short-range transponder and transceiver technology are the small transponders developed by Hughes Electronics, now Raytheon,* that were used by Sierra in the prototype demonstration project conducted for ARB[2]; the TIRIS™ system, which was developed by Texas Instruments and MFS Network Technologies; and the Bluetooth radio transceiver system. The Raytheon and TI systems have been specifically designed to provide reliable vehicle-to-roadside communication for a multitude of purposes including, but not limited to, collecting tolls, providing traffic information to the vehicle operator, and providing vehicle identification and related information, such as truck and cargo data, to private fleet operators or regulatory authorities via a roadside reader(s). Bluetooth is a radio transceiver design for interconnecting various electronic devices in very near proximity (less than 10 meters); it was not designed for vehicle-to-vehicle or vehicle-to-nearby

*The former Hughes Electronics has subsequently been acquired by Raytheon Company.

roadside communication but it is an example of a relatively new technology that may be suited to that purpose.

Raytheon and TI's technologies differ principally in that the Raytheon system contains active radio circuit elements and can be configured to be longer range, although still at relatively low power levels, whereas TI's transponder is relatively simpler than the Raytheon system. TI's transponder modulates and reflects back ("backscatter") the power received from a more closely situated and larger roadside or overhead antenna. The TI system conforms to CalTrans' specifications for automatic vehicle identification equipment, as set forth in Title 21 of the California Code of Regulations.[3]

Whether short-range transponders in vehicles would be effective as a means to obtain timely OBD-related information and vehicle identification number (VIN) depends on many factors, some of which have apparently little or no relationship with OBD. Our discussions with both TI and Hughes about existing and planned installations of their respective technologies and our first-hand experience in testing a Hughes transponder and reader[4] suggest that both technologies are at a sufficiently advanced stage of their technological development as to be capable of transmitting the requisite information over relatively short distances between vehicle and roadside. In addition, both of these short-range transponder systems could be configured, with suitable interfacing hardware and software, to communicate information from the ECU to a roadside unit. However, neither technology has adequate infrastructure in place today to provide for regular, reliable communication with the overwhelming majority of vehicles in California. As a result, the key questions concerning effectiveness for these short-range transponders in their application to OBD appear to center around how many additional roadside readers would be needed to satisfy ARB's objectives, what would be the capital and operating costs for such a network, and who would pay for it.

Bluetooth is a set of hardware, software, and open standards that will allow devices within close range to recognize and connect automatically to one another wirelessly using radio frequency. Bluetooth is supported by the Bluetooth Special Interest Group, a consortium of more than 700 companies, including Ericsson, IBM, Intel, Nokia, and Toshiba. One of the promoters and distributors of Bluetooth technology is Ericsson Components AB, which is also one of the largest cellular phone manufacturers in the world. The Ericsson Bluetooth is a small, potentially low cost, short-range microwave radio (2.4-2.5 GHz) module that is used to connect various mobile electronic devices including portable computers and mobile phone accessories. Ericsson's Bluetooth module is 33 x 17 x 3.65 mm in size, and its line of sight range is about 10 meters, although, according to Ericsson, this range is affected by the type of device in which the module is used and by the device's material of construction. The range can be extended to 100 meters by means of an optional amplifier.[5]

Unless a large number of roadside readers were used (at most or all gasoline service station entrances, for example), it appears that the range for Bluetooth would not be adequate for vehicle-to-roadside communication. However, it is possible to envision a network of vehicles that are linked by short-range, two-way radio communications in which each vehicle not only sends information about its own status but also relays

information about other vehicles. In this way, vehicle data could move over much larger distances across the network. Information provided by Ericsson[6] does not indicate whether vehicle-to-vehicle communication is one of the contemplated uses of Bluetooth, and we are aware of no plans by its promoters or others to consider such an approach. However, it is believed that with careful design and wide-scale implementation, including provisions for retrieving data, perhaps by cell phone (see discussion below on long-range, ground-based systems), such a system might provide cost-effective wide-scale communication. Bluetooth-equipped devices are expected to emerge this year and some small computing devices, including cell phone and personal digital assistants, are expected to have embedded Bluetooth chips in early 2000.[7]

The cost of short-range transponders installed as OEM equipment on most or all new California vehicles is estimated to be no more than $25-50 per vehicle and possibly less.[8] The cost of an infrastructure to support this technology with readers providing adequate coverage and repeat readings for vehicles statewide would be additional. The exact amount would depend on the number of readers and the success in cost-sharing by all who might benefit from a multi-use, vehicle-to-roadside communication system.* As described below, a preliminary estimate of the cost associated with a dedicated network of roadside readers has been developed based on a study[1] performed for the U.S. Environmental Protection Agency during which the cost of unmanned remote sensing devices located at freeway ramps was estimated.

Based on instrumented vehicle data compiled by U.S. EPA[9], 85% of randomly selected vehicles use the freeway system during a one-week period. Over a longer period of time, the percentage of vehicles using the freeway would be expected to increase. Having a receiving station located in the vicinity of each freeway ramp pair therefore provides a first-order approximation of the number of locations needed to provide adequate coverage for a major metropolitan area. There are approximately 2,300 freeway ramp pairs in the four counties comprising the Los Angeles Air Basin.[10] In Sacramento County, 225 ramp pairs serve a population that is approximately 90% smaller. Based on these examples and the 1990 U.S. Census, approximately 230 ramp pairs serve a population of 1 million. Based on statistics compiled by the Federal Highway Administration,[11] the number of registered light-duty vehicles (cars and trucks) per million population is approximately 500,000. Therefore, each roadside receiver could ultimately serve an average of about 2,200 vehicles. (However, only about 200 vehicles would be served by each reader during the initial year that an OBDIII requirement applied to new cars and light trucks.)

The cost of installing receiving stations adjacent to freeway ramps would involve many of the same cost elements considered during Sierra's earlier evaluation of installing

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*In principle, the most efficient uses of a short-range transponder system, or other vehicle communication (or navigation) systems, would be those that simultaneously permit their use for advanced traffic management systems, traveler information systems, vehicle control systems, rural transportation systems, public transportation systems, commercial vehicle operations, and other intelligent transportation systems, of which advanced OBDIII might be one small part. Whether OBD drives the demand, and pays the freight, for such multi-use, vehicle-based communication systems (and navigation systems) may be a major factor in determining the cost and cost-effectiveness of various options for transponder-based OBD, as well as other vehicle-based communication and navigation systems.

unattended remote sensing systems at freeway ramps. Per-unit costs include enclosures, concrete pads, conduit for electrical service, and installation. It was assumed that Caltrans would provide right-of-way at no cost.

Receiving station infrastructure was estimated at one-half of the cost of remote sensing site infrastructure to account for the fact that a separate transmitter and receiver is required for remote sensing, but only a receiver is required for OBDIII. The resultant cost in 1999 dollars was $8,600 per site. Capital costs for the receivers themselves were estimated at $2,000 each (to cover the cost of a computer equipped with an antenna and modem). Maintenance costs were estimated based on one full-time service technician per 200 receivers at a fully burdened annual cost of $100,000 per technician plus annual expenses of $900 per site (20% of the initial equipment cost plus about $40/month for utilities). Initial capital investment for each technician (van, tools, other miscellaneous equipment) was estimated at $50,000.

Assuming a statewide average need for one receiving station per 2,200 vehicles, a total of about 7,300 receivers would be required to serve a population of 16 million light-duty vehicles. Using the above costs, this translates into a capital investment of $63 million for site improvements, $15 million in other capital costs, and $2 million in equipment for a total of 37 technicians. In addition to this initial capital outlay of approximately $80 million, annual operating costs would be $10 million ((37 x 100,000)+(7300 x 900)).

The vehicle price increase necessary to cover these costs has been estimated using a 15% return on investment for invested capital and a 12% profit on recurring annual costs. Amortizing the infrastructure costs over a 15-year period and other initial capital costs over a 5-year period (and assuming the capital investment is made during the three years preceding the sale of the first OBDIII-equipped vehicles) yields an estimated increased price per OBDIII-equipped vehicle of $24. This covers only the operation of the receivers themselves and make no provisions for data retrieval costs and data analysis. As a result, this cost represents the increased costs for a data collection system that does not rely on existing infrastructure. It also should be noted that this was a first-order approximation based on receivers being deployed in the vicinity of each freeway ramp pair. It is possible that significantly fewer receiving stations could adequately serve the vehicle fleet, especially if the receiving stations had sufficient range to pick up signals from vehicles on underpasses or overpasses crossing the freeway.

As discussed below, the estimated cost of the required on-vehicle hardware for cellular systems is similar, so the additional infrastructure cost associated with short-range systems is a disadvantage. However, the uncertainty in both the on-vehicle and infrastructure costs is such that short-range technology could be competitive. Even so, this probably does give the edge to cellular technology because the risk of infrastructure development is eliminated.

Long-Range, Satellite-Based Systems - Direct two-way communication between a satellite and a vehicle-mounted transponder is technologically feasible and, in certain applications, commercially viable. For example, Qualcomm Corporation offers Omnitrac, a satellite-based vehicle transponder system that is currently used to track

vehicles world-wide. The system uses satellites and proprietary software to provide vehicle location and messaging. However, the cost per vehicle, while suitable for commercial, long-haul truck fleets having irregular routes, is, according to Omnitrac, probably not practical for widespread application to noncommercial, light-duty vehicles.[12]

Due to cost, the most important potential applications of direct two-way satellite communications with OBD probably concern the use of low earth orbit (LEO) satellite systems. The significance of low satellite orbits, as compared to geostationary orbits for satellites that are 23,000 miles above earth, is that LEOs are cheaper to launch and, equally important, ground-based transceivers may be relatively low-powered and have unobtrusive omnidirectional antennae. These systems are being developed primarily to meet the demand for two-way voice communication rather than transponders and they are still emerging. However, all of these systems will be digital in nature and could be adaptable to transponder usage.

The major competing satellite systems include ORBCOMM, Iridium (Loral/Motorola), Globalstar (Qualcomm), Ellipsat (Ellipso), Aries (Constellation), Odyssey (TRW), and Project 21 (Immarsat.) All of these companies either have completed or plan to complete soon networks of LEO (or MEO, middle earth orbit) satellites that would provide direct two-way global communication capabilities. A particularly interesting example of this technology is ORBCOMM, which is in commercial service using briefcase-sized (95 lbs) satellites. ORBCOMM's "little LEOs" use very high frequency radio signals to communicate with relatively low power handheld earth-based transponders. The company estimates that the system will permit people to use communicators that cost between $100 and $400, to send small data packets at a cost of a few cents per message.[13] ORBCOMM's technology permits obtaining positional information without requiring the use of a GPS receiver.

Based on the progress in recent years in establishing satellite networks, satellite systems now appear to be capable of providing wide area communications coverage. Furthermore, based on discussions with communications providers,[14] the amount of data traffic that would be generated by OBD communications appears to be within the capability of satellite networks. However, it does not appear likely that they can provide the data communications hardware required by OBD systems in a form that is cost effective compared to shorter range, ground-based communications.

An important caveat regarding satellite vehicle location and communication, perhaps more than any of the other technologies outlined here, is that the ability of this approach to monitor the location of vehicles over a wide area is likely to be viewed by some as overly intrusive of personal privacy and therefore not appropriate for government use. Because of this factor and the higher relative cost of satellite communicators, this approach was dropped from further consideration.

Long-Range, Ground-Based Systems - Two major types of long-range, ground-based systems are described below.

Cellular Telephone Systems - In contrast to the aforementioned categories of communication, long range, ground-based cellular systems are well-established and their use to support portable telephones is widespread. Furthermore, virtually all motor vehicle manufacturers or their suppliers are currently offering[15] or reported to be developing onboard systems for long-range, ground-based cellular communication (commonly called "telematics" in the automotive industry). Such systems are expected to come into widespread use over the next decade.

Based on a survey of wireless users, cellular communications in the U.S. has increased dramatically in recent years. International Data Corporation, which tracks the information technology industry, recently reported the following:[16]

- More than 111 million people in the U.S. subscribed to wireless services in 1998, producing almost $40 billion in revenues. By 2003, there will be nearly 186 million subscribers, generating revenues of almost $69 billion.

- Activity in the cellular/PCS market flourished in 1998. The number of subscribers in this segment increased nearly 24% in 1998, and by 2003, this market will surpass 118 million subscribers.

- Growth in the paging market was slow in 1998. The number of subscribers increased by less than 3% to 42.6 million. By 2003, there will be more than 58 million paging subscribers.

The call volume requirements of OBDIII are insignificant compared to the current levels of cell phone activity. In comparison to cellular phone customers who use their phones 300 to 400 minutes per month on average,[17] with usual call lengths* of several minutes, OBDIII surveillance of emission control systems could be configured to require no more than about four calls per year on average (for a status check on average about every 90 days**) for each light-duty, gasoline-powered vehicle in the fleet. This would result in only about 80 million calls per year in California, with each call lasting less than one

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*One of the major wireless service providers reported the average length of its wireless calls to be more than 140 seconds.

**For example, a vehicle could be set to communicate the status of its emission control system every 90 days or every 2000 miles over its lifetime. Vehicles less than five years old could be checked much less frequently, due to their higher reliability, whereas older, higher-mileage vehicles could be checked with greater frequency, commensurate with the increased likelihood of a defect and of tampering to conceal a defect. In this way, both functioning and non-functioning emission control systems (MIL illuminated) would be detected, and the speed of detecting a faulty system increases in proportion to miles driven.

second.[*] This is a trivial call and data volume compared to that of existing wireless data transfer.

Increasingly, cellular telephones are being offered that have integral paging and messaging services, i.e., data communications involving small packets of data. By one estimate,[18] as many as 6 million of these so-called "smart" phones will be in use in the U.S. by the year 2002. Smart phones provide voice telephony but also have the capability for sending and receiving Internet e-mail, i.e., short paging-type messages, analogous to the short message that could be generated in response to an OBD-detected fault. Interfacing an OBD system to an OEM-installed cell phone to send data over the phone is an approach that is expected to be cost-effective for those vehicles that already have cellular phone and/or data communication technology installed for other purposes. By the year 2005, that may be a significant fraction of the new vehicle fleet. Based on a survey conducted by the National Highway Traffic Safety Administration from November of 1996 through January of 1997,[19] one in seven cell phone owners had phones physically installed in their automobiles. It is not clear, however, whether permanent installations will increase in the future. Increased installations would be expected as costs diminish; however, continuing reductions in the size and weight of cellular phones and continuing increases in battery life are increasing the practicality of carrying cell phones on one's person. For vehicles that are not otherwise cell phone equipped, a dedicated "stripped down" cellular radio that uses cellular "control channels"[**] to transmit fault code status only would be the least cost solution to providing the necessary communication link under this approach. The following discussion pertains to these and other cellular radio based options.

Cellular phones and radios each have a unique identifier consisting of their manufacturer's identification number (ESN) and a mobile ID number (MIN) that associates it with a particular cellular network. As active cellular phones are moved around the network, even when there is no apparent use by the customer, they maintain a regular and frequent communication[***] with cellular networks, using digital control channels to establish the network to which they "belong," as well as seeking credit authorization for calls and setting the power level (i.e., changing cell phone power output to meet power needs while maximally conserving battery strength). All of these communications, which occur automatically and transparently to the cell phone user and are paid for as part of the cellular service, are carried out on the allocated control channels but do not consume all of the available space on those channels.

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[*]The average call could require transferring no more than 100 bytes of information (e.g., 17-digit VIN, current time and date, fault code status, and error checking, and this requirement could be reduced to a single bit if the calling unit is uniquely identified and the message is time and date stamped).

[**]These are the channels that are normally used by cell service manufacturers to keep tabs on the location of cell phones, to arrange for handoffs from one cell to another, to arrange for credit checking so callers don't need to wait when they pick up the phone, to allow for the billing of calls irrespective of from where they are made, as well as other operations that are transparent to users.

[***]This constant communication is what permits cellular system operators to locate cell phones, even when not being used for conversation.

Aeris Communications Inc. (San Jose, California) is the largest vendor that offers systems to provide cost-effective mobile data service through existing cellular networks by taking advantage of available space on unused control channels. Aeris does this using its proprietary technology called "Microburst." This technology utilizes the unused digital control channels in existing cellular networks to allow small packets of data (not in excess of 55 bits) to be transmitted. Vehicle tracking and remote condition monitoring are among the current applications of Aeris technology.

OBDIII communications requirements are, according to Aeris Corporation and Standard Communications,[20] ideally suited to control channel technology.* According to both Aeris and Standard Communications, the cost of a "stripped down" cellular phone to transmit OBDIII information, in the volume of one million units (approximate annual volume projected in 2005 for California implementation), is about $50 today, and less in the future. Standard also consulted with Aeris and provided an estimate of the cost for relatively "high end" cellular service via use of control channels of $24 per year.[21] The level of service associated with this price included monthly polling of all units to check for faults; billing to individual vehicle owners; and real-time reporting of communications to the client (as opposed to daily digests of all communications). Some elements of this level of service (e.g., billing individual vehicle owners) is a significant factor in the total cost. According to Standard Communications, elimination of such features was estimated to reduce the cost to about $18 per year to provide service for one million new vehicles each year.

Several existing systems already use cellular control channels but provide more nearly full-featured systems (at higher cost) including cellular voice communications, vehicle location services, theft deterrence or response, and vehicle condition monitoring.

ATX Corporation's "OnGuard" is a multi-use system that serves the following functions: high-powered cellular phone service, tracking of stolen vehicles, and signaling (with vehicle location) for emergency response. According to ATX,[22] the cost of adding OBDIII to a new vehicle that is equipped with telematics equipment would be small and the cost of locally sending a data packet of 15 bytes or less, using Aeris's Microburst technology, would be less than ten cents (cost including roaming fees will be higher).

In the greater Los Angeles area, AirTouch Communications** offers Teletrac. AirTouch Cellular, a subsidiary of Vodafone AirTouch, is the nation's second-largest[23] wireless provider. "Teletrac," which was formerly operated by Pactel, has been investigated and described by Sierra in previous work focusing on vehicle location systems. Briefly, Teletrac uses a network of about 40 radio transceivers to provide two-way messaging and vehicle location in the greater Los Angeles area and five other major metropolitan areas

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*Microburst data volume is limited to 55 bits. Microburst could support OBDIII by transmitting only one status bit (i.e., emission control system is functioning or not functioning) with each message. VIN could be decoded at a central location from a lookup of ESD and MIN, which would be unique to each hardware installation. All Microburst messages are date- and time-stamped to within a few seconds.

**AirTouch and Aeris have a corporate agreement covering AirTouch's entire network.

of the U.S. A transponder unit, which is slightly larger than a videocassette tape, is located in the vehicle. Vehicle location and other information can be "polled" using a base station computer configured to use software that is licensed for Teletrac. According to Teletrac,[24] the cost of its system could be about $100 to $200 per vehicle, with additional fees for software and a per-message fee.

Both OnGuard and Teletrac use Aeris Microburst technology.

Cellular Data Systems - In addition to voice communication services, a number of technologies exist that provide strictly data (not voice) cellular radio communication services. Included among these are Cellular Digital Packet Data (CDPD) offered by AT&T Wireless Services, ARDIS, RAM Mobile Data, Data over Analog Cellular, ESMR (Geotek), and Metricom. As reflected in the IDS survey data, these data communication services are widespread in the U.S., although not growing as rapidly as cellular telephony systems.

Personal paging systems are probably the most common form of wireless data communication. Paging typically involves only one-way communication from a network of transmitters to portable receivers that can beep or vibrate when triggered and can store and display short digital messages, such as a phone number to call. Using a two-way analog of pager-type technology, several companies offer two-way short message service with or without pager location capability. Two-way paging is not yet widely available.

Another category of long-range, ground-based vehicle communications is that of one-way, alert-type systems. Under this approach, the mobile unit is equipped with only a transmitter and not a receiver. Such systems can be used as emergency locator beacons for ships or aircraft, and they are used routinely with radiosonde balloons, to transmit meteorological data to Earth. In the case of OBD, the concept of an alert transmitter is to have the vehicle broadcast information about its status, including VIN, fault codes, etc., at an appropriate interval, as well as whenever a fault code is detected. Depending on the power and range of the transmitters and the system of receivers that might be used, this might provide many of the advantages of a transponder system without the "overhead," both in cost and in radio traffic, of having to remotely track all vehicles. However, there is not currently an established infrastructure to receive messages of this type from a large number of operating transmitters. A second disadvantage of transmit-only systems is that the option is lost of having the central communication network transmit information back to the vehicle. In two-way systems, such a feature could be used, for example, to illuminate a MIL in order to achieve a more effective recall in the event of a pattern failure of the emission control system.

Summary of Findings Regarding Potential Wireless Systems for OBDIII

Table 3-1 summarizes the potential of the communication technologies discussed above for OBDIII use.

Table 3-1 Summary of Potential Communication Technologies for OBDIII				
Technology	**Potential Effectiveness (Geographic Coverage and Frequency)**	**Availability of Technology and Infrastructure**	**Overall Practicality**	**Potential Technical Obstacles**
Short-Range Ground-Based	Moderate area and frequency of coverage possible	Demonstrated technology; infrastructure feasible but not currently widespread	Moderate	Lack of infrastructure; cost of establishing infrastructure and providing service
Long-Range Satellite-Based	Excellent (comparable to current cell phones)	Apparently adequate satellite infrastructure	Low to moderate	Appears cost prohibitive at present; vehicle location raises privacy concern
Long-Range Ground-Based Alternatives:				
Cellular Telephone Technology	Excellent	Excellent	Moderate to High	Cost, if not integrated with other services
Cellular Control Channel Technology	Excellent	Excellent	Moderate to High	Cost, if not integrated with other services
Two-Way Pager Systems	Moderate	More limited infrastructure than cell phones	Moderate	Cost, if not integrated with other services; limited coverage at present
Transmit-Only Systems	Moderate area and frequency of coverage possible	Potentially as good as other long range systems, but no infrastructure now	Low	Lack of infrastructure; no ability to transmit data to vehicles; high cost because little potential for cost sharing

Short-range vehicle to roadside communication and cellular telephony are found to be the most practical technologies for OBDIII communication for light-duty vehicles in California in the time frame of model year 2005. For these technologies, the principal factor limiting practicality is cost. For short-range communications, lack of existing infrastructure is also a problem.

The practicality of implementation if manufacturers are given about four years lead time is judged to be high if the cost of OBDIII can be minimized by integrating OBDIII into multi-use vehicle communication systems. If communication must be provided to support OBDIII systems, practicality is judged to be moderate due to the added cost of

communications equipment and service. The costs of communications equipment and services can be reduced, however, by using cellular control channel technology.

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4. FIELD DEMONSTRATION

The primary objective of the current study has been to demonstrate the feasibility and utility of using radio communication equipment as a means of improving the effectiveness of the I/M program. This section discusses the demonstration of a prototype OBDIII radio communication system, using a sample of vehicles, defects, and dates selected by ARB staff. The viability of the system was tested by monitoring the test fleet for a one-week period and, at the end of that period, comparing the manually kept record of defects implanted by ARB staff and the records of driving (and malfunction indicator light illumination) with the automated compilation of time and date Internet e-mail messages of changes in fault code status defects as sent by the prototype onboard systems and recorded (blind) at Sierra's recipient e-mail address.

The field demonstration occurred during the week of April 12-16, 1999, in the Sacramento area. Following the field study, one demonstration vehicle, the state-owned Honda, was driven to San Diego by Sierra for public viewing at the CRC Conference on April 19-21, 1999.

Purpose and Overview of the Field Study

The main purpose of the field demonstration was to demonstrate the feasibility of OBDIII systems as a means of quickly identifying and communicating a wide variety of induced emissions-related faults that can be detected by OBD systems. This was accomplished by simultaneously deploying five vehicles, each with a prototype radio-based OBDIII demonstration unit, for a period of up to two weeks. The prototype systems were developed and installed in the vehicles by Sierra Research.

Four of the five demonstration vehicles were rental, light-duty, OBDII vehicles. These four vehicles received temporary installations of OBDIII equipment that were later removed by Sierra. The fifth vehicle was a state-owned 1996 Honda Accord that was permanently retrofit by Sierra. The installation in the Honda has a very unobtrusive appearance for use in public exhibitions of prototype OBDIII equipment, as well as for the video production. The Honda was returned to ARB with the installed OBDIII hardware and software at the conclusion of the current project. The rental vehicles were returned to the vendor in their original, unmodified condition at the conclusion of the field demonstration.

The four rental vehicles were selected from lists of high-volume models for recent years[25] and were chosen to give a representation of various manufacturers. The selection was also constrained by which rental vehicles were available locally. The final model selections were as follows:

1. 1996 Honda Accord,
2. 1998 Chevrolet Lumina,
3. 1998 Ford Taurus,
4. 1998 Chrysler Breeze, and
5. 1997 Volvo S90.

The preliminary and final vehicle selections were approved in advance by ARB staff.

Hardware and Software in the Demonstration Vehicles

Sierra's initial investigation into the availability of off-the-shelf hardware to meet the needs of an OBDIII system identified several brands of cellular telephone that appeared to be modem compatible along with even more modem brands, some of which were advertised to be cell phone compatible. Two brands of cellular phones (Motorola and Nokia) and four brands of PCMCIA modem were obtained (Noteworthy, Megahertz, Practical Peripherals, and TDK) and evaluated for use in the subject application, namely two-way communication from a vehicle to the cellular service provider. The Nokia phone was evaluated along with the Nokia "car kit" (with external antenna.) While essentially all of these products appeared to function as advertised when stationary, no combination was found that provided the level of reliability that was sought for consistent mobile data communication from a moving vehicle. However, as described below, a viable alternative was found in a packet-switched wireless modem that was served by a dedicated wireless network, ARDIS (American Mobile, Lincolnshire, Illinois).

The prototype OBDIII systems used in the field demonstration were cellular radio- and scan tool-based systems (as directed and approved by ARB staff), rather than transponder-based systems, *per se*, as originally contemplated in the RFP. Based on these additional specifications, the field demonstration focused on testing the following four system capabilities:

1. Detecting, in a timely and periodic manner, a change in fault code and sending a radio message containing the VIN, date, time, and new fault code;

2. Sending an aperiodic radio message upon operator command to the vehicle-mounted user interface box (described later) showing VIN, date, time, and any fault codes that are set;

3. Operating all five systems in a substantially simultaneous fashion, i.e., testing for signal collision or interference; and

4. Operating the system to detect fault code changes, even if they occur outside the Ardis radio service area, and to transmit that information after the vehicle returns to the service area. (The Ardis service area for the Sacramento region as well as other major metropolitan areas in California is shown in Appendix B.)

To meet these requirements, each prototype OBDIII system consisted of the following five elements:

1. Toshiba Libretto palmtop computer programmed with custom software (as described later) to communicate periodically or aperiodically with a scan tool and modem;

2. Motorola wireless PCMCIA modem (Model PM100D*) configured to operate with extended battery power and for wireless service using ARDIS;

3. Custom user interface box for driver command entry (discussed in detail in system documentation) and visual confirmation of system activity;

4. Scan tool circuitry** to collect fault codes from the vehicle; and

5. Interconnecting cables and plugs for all of the above, including extended battery capacity for the wireless modems.***

The Toshiba Libretto palmtop computers used the Windows 95 (Microsoft Corporation) operating system, and the principal software used was Outlook (Microsoft Corporation) for communication, Mobile Choice Messenger (Ikon Office Solutions) for the wireless modem interface, and OBDBAS, custom software prepared under subcontract to Sierra by Workstat Software Inc.[26] Additional documentation[27] on the OBDBAS software is contained in Appendix A in the form of a User Manual.

All hardware and software was installed in the demonstration vehicles by Sierra. Installation required connecting to each vehicle's dashboard assembly line data link (ALDL) connector, most of which were located under the dashboard area. Hardware and software, once set up by Sierra, were designed to operate through the end of the

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*Two of the five wireless modems used in the demonstration program were provided through the cooperation of Ardis, whose contribution to this research effort is acknowledged.

**Two of the three scan tools used in the project were provided by Snap-on Diagnostics, whose contribution to this research effort is gratefully acknowledged. Custom OBDII scan tool circuit boards, including OBDII PROM modules, were also provided by Snap-on Diagnostics. A commercial Snap-on scan tool (MT2500) was used by ARB's mechanic to read and clear codes for all the vehicles.

***The wireless modems were approximately the size of a credit card with an attached nine-volt transistor radio battery. However, operation of the modems was found to consume a 9-volt alkaline battery in less than two days when used with the Librettos (software provided with the modems did allow for various methods of low power consumption operation, but that was not compatible with the Librettos due to current limitations of the Libretto's PCMCIA slot.) The battery life problem was resolved by providing six dry cells that powered each of the laptops for more than one week. Additionally, for the permanent installation in the Honda, a DC to DC converter was installed to provide 9 VDC power from the Honda's 12 VDC main battery (only the batteries were used during the field demonstration).

demonstration program with no significant operator intervention. In this mode of unattended use, each palmtop computer, under program control, attempted to command its associated scan tool to poll the vehicle's electronic control unit (ECU), or onboard computer, for a fault code at least once each five minutes and determine if there was any change in fault code status from the last successful polling. If so, the palmtop would attempt to initiate a radio communication via wireless modem to send a message containing the date, time, VIN, and new fault code(s) status (which may be either setting or clearing one or more codes). If the initial radio communication was not successful (because of, for example, being in a shielded basement garage, or being outside of Ardis' service territory), the system would continue to try to send the message.

In addition to the unattended mode of operation, each system could be commanded to attempt to send an immediate message containing the date,* time, VIN, and current fault code status. This was accomplished by pressing the pushbutton on the dashboard-mounted operator interface box (or "dongle") for about one second. This action caused the palmtop to immediately attempt to command the scan tool to poll for fault codes and then initiate a radio message to transmit the code status. As in the mode of unattended operation, communication attempts were repeated automatically until successful. The recipient of the radio messages from the onboard systems was the Ardis wireless network.[28] Ardis responded to received messages by forwarding them via the Internet to the Internet address specified in the outgoing mail message, in this case to Sierra Research. (Thus, there was need for Internet access and a secure address for logging data but no need for a base station as contemplated in the original transponder-based approach.)

All field testing was conducted in the greater Sacramento area, including testing that was deliberately conducted outside of Ardis's Sacramento coverage area. (Appendix B shows maps of the major coverage areas for the Ardis wireless service in California. Additional information about ARDIS can be found at its web site at *www.ardis.com*.)

Prior to the start of the demonstration program, Sierra procured rental vehicles, each for only one day, and attempted inducing a variety of selected disablements. Several suspicions were confirmed from this exercise. First, without service manuals for the test vehicles, it was not possible to identify every candidate sensor disablement on every car, although at least a few disablements and sensors were identified for each car. Second, disconnection of some of the sensors was found to not set OBD codes until 10-20 minutes later. A summary of the results from preliminary testing of candidate disablements is shown in Appendix C. As the list suggests, most of these induced disablements involved simply unplugging one or more sensors. Based on this preliminary testing, Sierra suggested to ARB staff a list of candidate disablements that could be induced safely and relatively easily and could be identified quickly by the vehicle's original equipment manufacturers' (OEM) OBDII systems. As shown later, ARB staff used some of these

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*This is the date and time when the prototype OBDIII system detected the change in fault code status, which would normally be no more than five minutes after the change occurred.

candidate defects as well as other untested* induced defects in the field demonstration, with no apparent problem.

Throughout the demonstration, Sierra maintained a log of messages received from all five demonstration vehicles. Sierra's log of received messages, a copy of which is shown as Appendix D-1, contained a record for each message received at Sierra and included the date and time the message was time-stamped by the on-board palmtop computer, the date and time the message was received at Sierra, and the contents of the message, including the vehicle identification number (VIN) and any fault codes that were retrieved.

During the period of the demonstration, an assigned Sierra employee drove each of the four rental vehicles, and an ARB employee drove the state-owned Honda. A mechanic from ARB's Research Division, Tony Andreoni, performed the vehicle maintenance (implantation of defects, removal of defects, reading of codes, and clearing of codes) and recorded activities in a Mechanic's OBDIII Vehicle Service Log (a copy of which is provided in Appendix D-2). Vehicle usage was recorded by each driver in a usage log that was maintained contemporaneously by each driver (copies of these are compiled in Appendix D-3).

To obtain an accurate comparison of the vehicle usage and maintenance logs with the log of recorded radio messages, clocks in all of the palmtops were synchronized to within one minute by Sierra prior to commencement of the demonstration and were checked at the end and confirmed to be still within one minute. It was likewise necessary for all drivers, including ARB's assigned driver, and ARB's assigned mechanic to synchronize their watches, within one minute, to an onboard clock to ensure accurate timing of the vehicle usage log. Additional details about the study plan and schedule developed by Sierra may be found in Appendices E-1 and E-2, respectively.

Prior to the field study, it was decided, in consultation with ARB staff, to remove from the field study the testing of power-off disablement of the prototype systems, the measurement of emissions effects of induced faults via Smog Check tests, and to focus on cellular radio based technologies. The rationale for each of these decisions is discussed in the following sections.

<u>Removal of Power-Off Disablement Testing</u> - The effectiveness of OBD systems is partially a function of how well they deter or detect tampering. While it was originally considered by ARB staff that a goal of the field demonstration would be to demonstrate a system that could detect tampering due to removal of its external power source, ARB staff tended to agree with Sierra's assessment that the most useful demonstration would be a demonstration of the software's capability to deter power-off tampering. Accordingly, the OBDIII concept and prototype OBDBAS software developed for ARB was designed in such a way that the onboard system sends not only an aperiodic message

*For example, one of the defects that was not tested by Sierra in the subject vehicle but was implanted by ARB was not detected by the OEM OBD system until several drives after the implantation.

when a fault code change occurs (either setting a new code or clearing a previously set code), but also a periodic message (e.g., every 90 days, or whatever interval may be specified by ARB) indicating the presence or absence of fault codes, irrespective of whether there has been a change in fault code status. With this feature, the system manager can routinely check for communications from every registered OBDIII vehicle, and if none is recorded within the specified communications interval, the vehicle would be presumed to have a tampered or otherwise dysfunctional OBDIII system, or be out of state, damaged, etc. Such identification could be used to flag vehicles for further checking prior to registration renewal.*

Removal of Measurement of Emissions Effects of Induced Faults via Smog Check - ARB staff originally contemplated measurement of emissions after tampering as part of the field demonstration for the current program. However, such emissions effects are expected to be particular to the makes and models selected for the study, and the vehicle sample, five, is too small to draw any meaningful results. Accordingly, ARB staff agreed to drop this element and instead provide for a showing of the vehicle and explanation of the OBDIII concept at the Coordinating Research Council's annual meeting in San Diego. Sierra staff made such arrangements and showed the vehicle at the conference. Charts and diagrams that were prepared by Sierra to aid in understanding Sierra's suggested OBDIII concept at the CRC conference are provided later in this report. The concept of a voluntary OBDIII program as an alternative to conventional Smog Check appeared to be well-received by virtually all representatives at the conference.

Exclusion from the Demonstration of Systems Other Than the Primary Cellular Radio-Based Approach - As discussed in the previous chapter, both ARB staff's and Sierra's original concepts for the demonstration were focused on transponders; however, over the course of the initiation of the project, it became apparent that interest in cellular-based mobile communications was growing at a rapid pace. As a result, Sierra was directed by ARB staff to focus on the demonstration of cellular wireless technology and cellular modems such as the one that was ultimately and successfully used for the demonstration program.

Results of the Demonstration Program

For the demonstration program, each of five test vehicles was equipped with a prototype OBDIII system, and an ARB mechanic implanted two different defects in each vehicle over a course of several days. The results are summarized in Table 4-1. The table lists the date and time of each induced disablement; the date and times of each drive during which the respective OEM OBD systems detected the disablement, as evidenced by the

*In principle, this feature could have been used in the demonstration program by setting the time interval very short, e.g., to only one day. In that way, any vehicle that did not report daily, irrespective of change in fault code status, could have been presumed to be tampered or otherwise defective.

Table 4-1
Summary of Results from Field Demonstration
Disablements - Onboard Detection - Remote Detection

System and Vehicle Date, Time, Disablements Planted and Removed by ARB	Detection of Changes Onboard by OEM's OBD System (CEL Illumination)	Detection of Change(s) Onboard by OBDIII System	Logging of Changes at Sierra via OBDIII
L1 Volvo			
4/14 1147 disable MAF	4/14 1745-1822	4/14 1745	4/14 1746 P0102 airflow sgnl vlts lo
4/15 1455 confirm P0102			
4/15 1456 clear code, reenable			
4/15 1459 disable TPS	4/15 1750-1815	4/15 1748	4/15 1748 P0123 TP circuit open
		4/15 1754	4/15 1755 P0120 TPS
L2 Sable			
4/13 1706 disable O2 sens.	4/13 1810-1824	4/13 1815	4/14 1111 P1151 undocumented code
		4/14 0753	4/14 1112 P0155 O2 htr bnk2,snsr1
4/14 1208 cnfrm P0155,P1151			
4/14 1212 clear code, reenable	4/14 1749-1800		
4/14 1215 disable MAF	4/14 1804-1821	4/14 1807	4/14 1807 P0102 airflow sgnl vlts lo
4/14 1442 confirm P0102			
4/15 1449 clear code, reenable	4/15 1734-1738	4/15 1739	4/15 1739 codes clear
4/15 1445 disable TPS	4/15 1751-1808	4/15 1810	4/15 1818 P0122 TP circuit short
L3 Lumina			
4/13 1658 disable TPS	4/13 1735-1745	4/13 1739	4/13 1740 P0122 TP circuit short
4/15 1451 confirm P0122			
4/15 1447 clear code, reenable			
4/15 1452 disable MAF	4/15 1736-1759	4/15 1740	4/16 1153 P0102 airflow sgnl vlts lo P0122 TPS ckt short
L4 Breeze			
4/13 1713 disable EGR vac.vlv.	4/13 1740-1752	4/13 1748	4/13 1750 P0403 EGR sol. ckt
4/14 1150 confirm P0403			
4/14 1153 clear code, reenable		4/14 1130	4/14 1205 codes clear
4/14 1202 disable chrgair/MAP		4/14 1203	4/14 1205 P0113 intake air temp hi
	4/14 1742-1811	4/14 1745	4/14 1747 P0108 MAP/baro ckt hi
4/15 1436 cnfrm P0108,P0013			
L5 Honda			
4/13 0807 disable TPS	4/13 0808-0819	4/13 1635	4/13 1636 no codes present
	4/14 0820-0852	4/14 0821	4/14 0822 P0122 TPS ckt short; P1790 undocumented code
4/14 0856 cnfrm P0122,P1790			
4/14 0857 clear code, reenable	4/14 1129-11:32	4/14 1130	4/14 1205 no codes present
4/14 1536 disable evap/EGR			
4/15 0827 disable evap/sol.	4/15 1324-1413	4/15 1409	4/15 1410 P0441 evap purge flow lo
4/15 1335 no codes			

illumination or extinguishing of the malfunction indicator light (MIL); and the dates and times when the prototype systems detected the disablements and communicated them successfully. (Detailed logs of all disablements, all drives, and all communications can be found in Appendices D-1, D-2, and D-3, respectively.)

The table shows that all ten defects were correctly identified by the OEM's OBD systems and all ten were communicated via wireless e-mail. In some cases, the defect was identified by the OEM's OBD during the drive that occurred immediately after the implantation of the defect and was successfully communicated via e-mail before the drive was completed. In other cases, several drives occurred before the defect was detected by the OEM's OBD system, i.e., before illumination of the MIL, which obviously delayed communication by the OBDIII system. In still other cases, the OEM's OBD system detected the defect relatively quickly, but it was not communicated immediately because the vehicle was at the fringe of the Ardis service area (i.e., the vehicle was somewhere in Rocklin or Davis, which appear to be fringe areas for coverage). Except for the fringe area communications that were obviously delayed, the usual time interval between detection of a defect by the OEM's OBD system and successful wireless communication of that information was less than one hour; in several cases, however, it was as long as a few hours.

Duplicate messages occurred in several cases. Sierra has discussed this problem with Ardis and it has acknowledged that there are times when this problem may have occurred due to Ardis. It is not known whether the problem is entirely due to Ardis. For the limited number of messages logged in the demonstration period, the duplicate messages were not seen to create any significant problem for data analysis.

All five vehicles were operated for about one week in the vicinity of downtown Sacramento (all vehicles included daily commute to and from Sierra's offices) but despite this proximity and the deliberate synchrony of communications, no evidence of "data collision" or interference was observed. (Note, for example, in Appendix D-4, that signals were received on 4/14/99 from the Volvo and the Breeze at 1746 hours and 1747 hours, one minute apart, with no apparent problem.) However, it should be cautioned that such a limited test is insufficient to demonstrate either system capacity or the potential for avoiding interference when a larger population of client systems is served.

The prototype systems were programmed to attempt communication whenever a change occurred in fault code status, i.e., a new fault code was set or fault codes were cleared. While all the setting of fault codes was detected, not all of the code clearings were detected. This is the result of two factors. First, the testing protocol that was used by ARB's mechanic (which was deliberately carried out in a fashion that was blind to Sierra) was to implant the initial defect and deploy the vehicle on one day, and then to service the vehicle on the next day(s). During service, ARB's mechanic read codes, removed any previously implanted defect, cleared codes if necessary, and implanted a different defect, all without any driving. The vehicle was then deployed again for driving. If the second defect was detected by the OEM's OBD system in the first few minutes of driving, it is

likely that the prototype system, which was configured to check fault code status only every five minutes, would never see the vehicle's status in the condition of "codes clear." Instead, the prototype system saw and communicated only the new condition of setting a different code. This is precisely what occurred with the Volvo and the Lumina (which did not report an intervening condition of "codes clear"). For the other three vehicles, the detection of the second defect was sufficiently delayed that the prototype system was able to detect the change to "codes clear" status and communicate that information.

Based on the results from the demonstration program and other information reviewed, it is concluded that it is technically possible to fabricate and operate an automated system to communicate, via wireless cellular communication, vehicle identification numbers and changes in OBD fault code status.

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5. COST, RELATIVE EFFECTIVENESS, AND COST-EFFECTIVENESS OF OBDIII COMPARED TO SMOG CHECK

For the reasons discussed earlier, cellular telephony, especially with control channel utilization, appears to be the most practical technology for OBDIII communication. This chapter analyzes the lifetime costs, relative effectiveness at reducing emissions, and relative cost-effectiveness of these systems in greater detail, using the Smog Check program as a benchmark.

The costs of Smog Check and OBDIII differ principally in that Smog Check has a consumer cost that is a periodic, biennial payment, whereas the cost of OBDIII is primarily an "up front" cost that would be directly paid by the new-vehicle buyer as part of the cost of the vehicle.* To compare these two alternatives, the cost of each is computed and expressed as a present value in a common year. In both cases, a vehicle lifetime of 13 years and a discount rate of 5%/year are assumed. The analysis focuses on new model year 2005 vehicles sold in calendar year 2005** that is subject to either Smog Check or OBDIII, under several different assumptions. For similar comparisons of vehicles that are manufactured in subsequent model years, it is expected that the analysis would be more favorable to OBDIII because of the additional experience gained in manufacturing and deploying OBDIII equipment and in the economies of scale gained in serving such equipment. Conversely, the cost of a conventional Smog Check program would be expected to increase because the number of stations performing Smog Check inspections should decline as a result of the decreasing demand for inspections. (An increase in the price of Smog Check is expected to occur regardless of whether OBDIII is implemented, due to the increasing reliability of new vehicles. However, OBDIII implementation may hasten this change and is likely to result in increased indirect Smog Check costs, as vehicle owners will need to travel further to obtain Smog Check inspections from a dwindling number of stations that provide them.)

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*As discussed later in this section, OBDIII requires a periodic cost element to support the wireless cellular network; however, our assumption is that CARB regulations would require this cost to be paid by the vehicle manufacturer. It would therefore be factored into the price of new vehicles, with appropriate discounting for the time value of money. Advantages of this "up front" payment for lifetime cellular service include lower cost (by eliminating the need for individual accounts) and providing assurance that the system will be available for the expected vehicle lifetime.

**Some MY2005 vehicles will be sold in MY2004; however, to simplify the current analysis, the same model year and calendar year were chosen.

Base Case of Smog Check

The first case examined, which is considered the "base case," is that of continuation of the current Smog Check program. For this case, it is assumed, pursuant to recently passed California legislation (AB 1492, Chapter 803, Statutes of 1997) that new vehicles will be excused from Smog Check requirements for the first five years, unless they undergo change of ownership. For their remaining years, it is assumed that a Smog Check inspection occurs every other year and that two additional inspections are required due to change of ownership, one at about 5 years of age and one at about 11 years of age. Based on survival rates used in ARB's vehicle emissions model, the average vehicle life is just over 13 years. This results in an average of seven initial inspections occurring over the life of the average vehicle. Based on reported Smog Check failure rates, the vehicle is expected to pass six out of the seven tests.* The average cost for Smog Check inspections is estimated to be $50, not including the certificate of compliance fee that covers program administration and enforcement costs (real cost, in 1999 dollars) at the California Bureau of Automotive Repair (BAR) and Department of Motor Vehicles (DMV). This estimate is based on a statewide survey of actual test costs conducted by BAR during 1999 and reported to Sierra.** At $50 per test, $300 is spent over the vehicle lifetime for testing of vehicles that pass the test.

In addition to the direct cost of Smog Check inspections, vehicle owners are subject to indirect costs in the form of inconvenience time and travel associated with getting a vehicle inspection. This includes time spent locating an inspection facility, time and expense of driving to and from the facility, waiting in the queue for a vehicle inspection, and the waiting time during an vehicle inspection. Under a decentralized program, the average inconvenience time spent by a vehicle owner per Smog Check is estimated to be 75 minutes.[25] At an hourly rate assumed to be twice the minimum wage of $5.75/hour, the cost of this time is $14.38. In addition, the average cost of driving to and from the test station is estimated to be $2.07 (6.7 miles average round trip at 20 miles per hour and $.31/ mile). Together, the time and travel amounts to an estimated indirect cost of $16.44 per vehicle inspection.

Adding the direct and indirect costs calculated above gives a total cost for each Smog Check of about $66 (exclusive of certificate fee). Discounting these charges at five percent per year and summing in the base year of 2005 results in a present value of $301

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*According to the "Smog Check Advisory" published by the California Bureau of Automotive Repair in November 1999, the failure rate for the "enhanced" test is approximately 13%.

**Personal communication with Steven Gould, BAR, November 2, 1999. We have rounded the $48.10 test cost reported by BAR up to $50 to partially account for the fact that we are not addressing changes in the certificate fee (currently $8.25) in our cost comparison of OBDIII and Smog Check. As the fraction of OBDIII-equipped vehicles increases, it should be possible for BAR to reduce its enforcement activities and reduce the certificate fee because OBDIII-based inspections are not expected to be as prone to the fraudulent testing that can occur when vehicles are inspected by automotive repair facilities.

for the "Base Case" of Smog Check.* This result, along with the results of other calculations described below, is shown in Table 5-1 (rounded to the nearest dollar).

Table 5-1
Lifetime Costs and Savings for Alternative I/M Approaches for New Model Year 2005 Light-Duty Gasoline-Powered Vehicles

Inspection Alternatives	Lifetime Cost Expressed as Discounted Present Value in Calendar Year 2005	Cost Savings (and percent) Relative to Smog Check
Base Case: Biennial Smog Check costs over the lifetime of a new vehicle, including the inconvenience cost of inspections	$301	-
Biennial Smog Check cost, **excluding** inconvenience cost	$226	$75 (25%)
OBDIII, with dedicated cellular communications hardware	$172	$129 (43%)
OBDIII, incremental cost assuming existing cellular installation	$94	$207 (69%)

Case of Smog Check Without Considering Inconvenience Cost - Although inconvenience cost is a reality of the current Smog Check program, it is quite often not considered when evaluating program cost. To allow such comparisons to be made, Table 5-1 includes an estimate from which the indirect (inconvenience and travel) costs are excluded. As shown, this is a present value cost in calendar year 2005 of $226.

Case of OBDIII with Cellular Telephone Technology - The direct cost for special-purpose OBDIII communication equipment (a system without the ability to provide other functions, such as voice communication) is estimated to be $45-55.[29] Although a detailed cost breakdown was considered proprietary, this estimate was obtained from individuals who are currently supplying communications equipment for cellular-based vehicle communications to fleet operators. It is based on the assumption that market demand will be approximately one million systems per year. (Given the expected implementation

*This cost estimate addresses only the initial inspection requirements. Additional inspection and inconvenience costs occur when a vehicle fails; however, such costs are expected to be approximately equal for OBDIII and non-OBDIII vehicles.

schedule, the lower value of this range, $45, is used for the current estimate.) An additional $10 per vehicle is estimated for an antenna, wiring, and bracketry, and a slight increase in electronic control module memory. Two dollars ($2) per vehicle is also added for additional assembly labor, bringing the total variable costs to $57 per vehicle. Minor design changes to incorporate the technology during a "minor" redesign of the body combined with the cost of developing and testing revised OBD software is estimated at $2 million per engine family. This $2 million engineering and development cost is assumed to be required every five years (and these costs are assumed to occur in the three years prior to the year of production launch).

The $57 in variable costs are marked up 20% to account for manufacturer overhead and profit. An additional 12% is then added to represent dealer margin. Fixed costs (e.g., engineering) are translated into Retail Price Equivalent (RPE) using a 15% return.

Based on the above estimates, the RPE for the OBDIII system is estimated at $80 per vehicle, prior to accounting for the cost of cellular service.

The net cost of providing cellular service may be affected by the added value it offers to the provider of the service. For example, if a manufacturer chooses to install onboard equipment that reports not only when an emissions-related defect occurs, but also what that defect is, such information could provide a substantial marketing benefit. Likewise, if a third party (e.g., a new or existing cellular service provider) were to operate such a system, with access* to the information streams and encoding used by manufacturers, the resulting database of malfunctions could be a saleable commodity to the automotive repair industry. However, commercial use of the information raises privacy issues. For that reason, we have not assigned any commercial value that would defray operating costs.

As described in Section 3, the annual cost of control channel cellular service for OBDIII communications has been estimated at $18 by a major supplier of control channel communications services. However, this estimate was based on California-only economies of scale. As with most other ARB regulatory requirements, adoption of an OBDIII regulation in California would almost certainly spread to many, if not all, other states. Based on independent estimates of the per-message cost for control channel service, greater economies of scale appear to have the potential to significantly reduce the cost of communications service. In addition, no loss in emission benefits compared to the Smog Check program would occur if activation of the cellular communications link was delayed until the vehicle would otherwise be subject to the Smog Check program. Given the time value of money, this change alone would reduce the cost of cellular

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*The value of the resulting database could be substantially determined by whether the precise form of wireless messages is specified by ARB in an open standard (analogous to OBDII) or, alternatively, if only a functional communication requirement were adopted. A functional requirement only would allow manufacturers to control, for their own use or for sale, the resulting database (perhaps defraying the cost of onboard systems), whereas an open standard could potentially allow anyone to use the cellular information.

communications by about half over each vehicle's lifetime. Because of these possibilities, the cost of OBDIII communications was assumed to be half of the $18 per year cost obtained from Standard Communications.

If a cost of cellular service of $9 per year is assumed over the 13-year life of the vehicle, along with the RPE cost of $80 described earlier, the present value in calendar year 2005 would be $172,* which represents a "present value" cost savings compared to Smog Check of $129 or 43% over the life of the vehicle. (Assuming the full $18 per year communication cost applies as soon as the vehicle is put in service, the present value would increase to $264 per year, which is still less than the cost of Smog Check.)

Finally, the last row in Table 5-1 shows the corresponding OBDIII cost if the cost of cellular hardware is not required because the vehicle is assumed to be equipped with a cellular telephone. (The cost of separate cellular service for OBDIII is still assumed to be required.) This saves almost all of the hardware cost associated with OBDIII and leaves only the cost for software development of $2 million dollar per engine family. Lifetime present value savings would be $207, representing a 69% reduction from the cost of Smog Check.

There are additional costs to OBDIII, including the cost of maintaining and analyzing the resulting database and enforcement-related activities. However, most of these activities or corresponding decentralized inspection related activities likewise exist with the current Smog Check program and are covered by the certificate of compliance fee that OBDIII vehicles are also assumed to pay. Accordingly, these costs have not been included in the foregoing comparison with the Smog Check program.

Relative Effectiveness at Reducing Emissions

In theory, the principal emission reduction benefit of OBDIII compared to Smog Check is the more rapid detection and repair of defects. With biennial inspection, defects may occur any time during the two-year interval between inspections but repair is not required and, unless perceived by the owner as damaging to vehicle performance or safety, is likely to be deferred until the next regularly required inspection.** In addition, recent statute changes exempt new vehicles from Smog Check for several years. Depending on the implementation scheme used, OBDIII could be active during this same time period and would identify and report the limited number of defects that occur in relatively new vehicles.

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*Also assumed in this estimate is an "experience curve" cost savings of 1%/year beginning in calendar year 2006.

**At which time the repair of defects is required before registration renewal.

Additional benefits of OBDIII may result from the increased accuracy of inspection. Although the current Smog Check program includes a check of the OBDIII system, it is possible for a known good vehicle to be tested instead of the proper vehicle. It is also possible for the reinspection results to reflect the effect of temporary repairs.

A 1992 evaluation of the Smog Check program resulted in an estimated effectiveness of 18.2% for HC, 15.3% for CO, and 6.7% for NOx. That same evaluation projected that the benefits of Smog Check would reach 19.4% for HC, 26.9% for CO, and 11.4% for NOx by year 2000, assuming a significant increase in the repair cost limit. A Smog Check II type program was estimated to be theoretically capable of achieving reductions of 28.2% for HC, 34.6% for CO, and 22.2% for NOx. Annual inspection frequency was projected to increase the benefits to 36.7% for HC, 41.9% for CO, and 28.6% for NOx.

For a number of reasons (lax emissions standards, continuing problems with falsified test results, etc.) it is clear that Smog Check II is not achieving the theoretical benefits of a biennial I/M program. As a result, the difference between the effectiveness of annual inspections and biennial inspections described above is the <u>minimum</u> expected advantage for OBDIII compared to Smog Check. Since the cost is lower, the cost-effectiveness is <u>negative</u>, i.e., OBDIII reduces emissions while saving money.

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6. IMPLEMENTATION ISSUES

Many different approaches to OBDIII are possible; however, some of these approaches are likely to encounter strong adverse public reaction. This chapter briefly outlines one "Model Approach" for OBDIII. This Model Approach is intended to achieve substantially all of the benefits of OBDIII with the least risk of public rejection. Following the Model Approach, subsequent sections in this chapter address privacy, inclusion vs. exclusion of vehicle location, individual choice for vehicle inspection, and ARB's legal authority to implement OBDIII.

The model OBDIII approach outlined below was, at the request of ARB staff, presented by Sierra at the Coordinating Research Council Conference in April 1999, along with a demonstration of an operating prototype OBDIII vehicle. The presentation received a generally favorable reception.

OBDIII Model Approach

Sierra's general recommendation to ARB for OBDIII, described herein as a "Model Approach," is a voluntary program for vehicle owners in which all new vehicles, beginning with model year 2005,* are mandated to have OBDIII capability but with the decision to deactivate that capability left to each individual vehicle owner and driver. However, deactivation of OBDIII by the owner would mean reverting back into the Smog Check program in the next inspection cycle. Figure 6-1 illustrates the logic of such an onboard OBDIII system.

The figure outlines the major steps and operations that would be made by the onboard computer each time this OBDIII** vehicle is started. After engine start, the onboard system first determines whether OBDIII has been permanently or temporarily deactivated. If so, there is no further program execution and no wireless OBD transmission from the vehicle occurs. In this case, the absence of a signal after some

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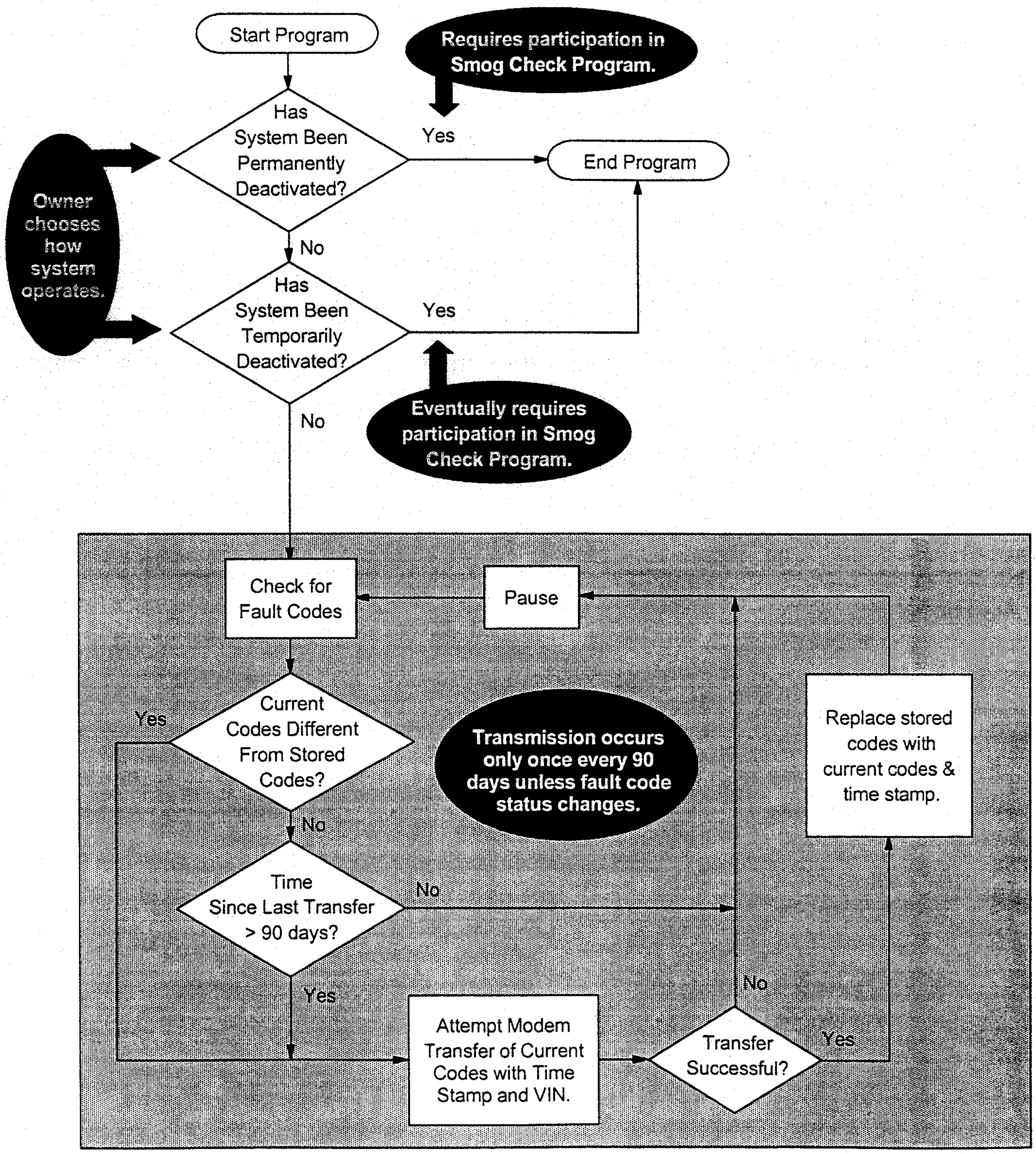
*The feasible implementation date will depend on when manufacturers are given notice that OBDIII will be required and whether a phase-in period is allowed. At least four years lead time combined with a phase-in is likely to be required to minimize costs due to early replacement of current systems.

**It should be emphasized that the figure is only a summary for illustration. Real OBD systems execute thousands of lines of computer code each time a vehicle is started and continuously while the vehicle is operating.

Figure 6-1

Concept for OBD III System Operation



Sierra Research, Inc.

interval, e.g., 90-180 days, triggers the network operator to note that this registered vehicle has apparently opted out of the OBDIII program. Accordingly, the owner is no longer excused from meeting the requirements of the Smog Check program and the owner is reminded when he or she applies for registration renewal in the next renewal cycle that the vehicle must physically be brought to a Smog Check inspection station and pass inspection before vehicle registration can be renewed. Because of the inconvenience and cost associated with the Smog Check program, Sierra believes that most new vehicle owners would not choose this option.[*]

Alternatively, for those owners who do not deactivate their OBDIII systems, either permanently or temporarily,[**] the systems would monitor for emissions-related fault codes in a manner identical to the way OBD systems currently operate, with two exceptions.

First, the OBDIII system would be programmed to constantly check its memory on when it last reported its status over the cellular network. If that status report transmission was more than 90 days old,[***] a new status report would be sent. This update provides a confirmation that the onboard system has not been tampered and is functioning, and it provides a deterrence to tampering, since deactivation of the system would result in no signal being received and reversion of that vehicle to participation in the Smog Check program.

Secondly, for an active OBDIII vehicle, any time that a change occurs in fault code status (e.g., due to a sensor failure), that information would be transmitted immediately and the owner would simultaneously be warned of the problem by illumination of the malfunction indicator light on the dashboard. As in the case with the OBD program now, repair of the problem by the owner would result in clearing of the code and extinguishing of the MIL. In the case of OBDIII, however, clearing of codes also represents a change that would trigger an automatic wireless transmission indicating that the codes are now clear. If the repair occurred promptly, e.g., within 30 days, no further action would occur.

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[*]An additional incentive to remain in the OBDIII program is the fact that while detected faults must be repaired under either Smog Check or OBDIII, Smog Check would require the vehicle owner to return to the service station after repair to obtain a repeat (passing) inspection, whereas OBDIII would automatically detect and transmit information about the code clearing, obviating the need for follow-up physical inspection.

[**]Some time limits would need to be placed on temporary deactivation for the motorist to stay out of the Smog Check program. To minimize the potential for this feature to be abused, the system could be designed to monitor the percentage of driving with temporary deactivation, which could also be electronically reported. Allowing just 10% of driving to be done in the deactivated state would allow motorists the ability to eliminate the possibility of location detection on certain drives while giving CARB assurance that temporary deactivation was not being used to prevent the detection of tampering.

[***]As noted earlier, this interval could be either time- or mileage-based and could vary with the age or mileage of the vehicle to minimize communication requirements consistent with most rapidly identifying those vehicles of such an age or mileage as to have the greatest likelihood of occurrence of a fault.

If the owner were tardy in a repairing an emissions-related defect, however, the system could trigger the sending of a notice advising of the need to effect the repair in a timely fashion. If timely repair still did not occur after a suitable notice and grace period, the vehicle could be transferred out of the OBDIII program and back into the Smog Check program, thus requiring a regular Smog Check inspection before registration renewal would be permitted.

In either of the above two examples, if wireless transmissions were not successful upon the first attempt for whatever reasons,* repeated attempts to communicate would be made until success is achieved or disposition of the vehicle is determined by alternate means, e.g., the vehicle is found to be sold out of state or scrapped.

An additional implementation option, not addressed in the figure, involves the use of a driver-activated switch or button to initiate transmissions. In this mode, the owner would be able to wait until a notice is received from DMV before manually initiating a transmission of OBD system status. This "push button" Smog Check approach would probably eliminate concerns about automated operation of the system interfering with the privacy of the vehicle owner. However, this approach has several disadvantages. Despite the apparent simplicity of operation, it adds cost and clutter to the system by requiring the addition of an activation switch and an additional indicator light to advise the motorist as to whether the transmission was successful. This approach also reduces some of the potential air quality benefits by allowing the identification of defects to be delayed until a Smog Check test would otherwise be required. Under the "model" approach described in the figure, defects would be identified and would require correction soon after they occur.

Privacy

Privacy is potentially a major issue with OBDIII. In designing and implementing an OBDIII program, ARB should take into account that many in California may view governmental electronic surveillance of onboard emission control systems as overly intrusive and an invasion of privacy. One of the principal reasons that Sierra recommended a Model Approach that is voluntary for individuals is to allow motorists to balance their own needs and desires for privacy against the continued inconvenience and cost of participating in the Smog Check program. Sierra further recommends that ARB staff, in developing its own OBDIII proposals, undertake a dialogue with privacy advocate groups and attempt to fashion a proposal that is responsive to their suggestions while still meeting ARB's needs to effect prompt emission defect reporting and repair.

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*An individual attempt at wireless communication could fail because the vehicle is in an underground parking location, out of radio range, in an area with a heavy volume of radio traffic or interference, etc.

Inclusion vs. Exclusion of Vehicle Location Capability

Sierra is not aware of any requirement for vehicle location information as part of an OBDIII program. However, vehicle location relates inextricably to OBDIII in several ways.

Operation of a radio transmitter in a vehicle, even one that is relatively short range and designed for other purposes, means that the vehicle can be located in principle, either by triangulation (timed receipt of the signal at multiple locations) or simply by identification of the receiving cell in a cellular network.

Secondly, the most cost-advantageous implementations of OBDIII provide for OBDIII to be added to onboard systems that provide other services, and vehicle location is one of the prime features being offered by manufacturers of such Telematic systems. Vehicle location systems can provide substantial benefits to vehicle operators in navigation, theft recovery, deterrence, business operations (fleet tracking), etc. Thus, it may be impossible in the near future to avoid installations of OBDIII in vehicles that also have vehicle location systems installed.

Sierra recommends that ARB clearly state that it will not collect or use any vehicle location information as part of any OBDIII program it pursues. However, ARB should likewise be careful not to interfere with the desires by consumers or vehicle manufacturers to enjoy the benefits of vehicle location systems in vehicles into which OBDIII may be cost-effectively integrated.

Individual Choice of OBDIII vs. Smog Check

As noted earlier, Sierra recommends that OBDIII be implemented in such a way that individual new vehicle owners be offered the choice, both when they purchase a new vehicle and each time they operate it, of whether to deactivate the OBDIII system. Permanent deactivation would mean that the vehicle reverts to the Smog Check program. Temporary deactivation of a system by the driver for one drive or a few drives should not cause disqualification from OBDIII and automatic reversion to the Smog Check program. However, longer periods of vehicle use during which the OBDIII system is deactivated by the operator reduces the potential air quality benefits of the system and could therefore be a basis for automatic reversion to the Smog Check program. Under the "push-button Smog Check" approach, ARB would have to accept the loss in air quality benefits associated with less frequent detection of emissions-related defects.

Legal Authority

Sierra believes that a regulation patterned after the previously described Model Approach to OBDIII is legally defensible. If ARB decides to pursue OBDIII as a mandatory or voluntary program, new regulations will have to be adopted in Title 13 of the California Administrative Code.

A detailed memorandum addressing legal and privacy issues related to possible ARB adoption of requirements for an OBDIII* program is presented in Appendix E.

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*"OBDIII" in this context refers to vehicle software and hardware that has the capability of transmitting emissions-related information in the vehicle's OBD system to the state via a wireless link, as an alternative to on-site vehicle inspection under the current Smog Check program.

7. VIDEO PRODUCTION

This task was managed by Sierra and carried out jointly with JHME, which is a professional advertising, design, and public relations firm based in Sacramento.

Under this task, Sierra/JHME produced a short (less than ten minutes) VHS-format video that accomplishes the following:

- Explains OBD I and OBD II system function;
- Explains how OBD I and II are used in the current Smog Check program;
- Points out that over $300 million is spent each year performing Smog Checks on vehicles that pass the test;
- Explains the OBD III concept;
- Presents comments by a Smog Check station owner on the OBD III concept;
- Describes the OBD III Field Demonstration;
- Explains the implementation options; and
- Highlights the fact that OBD III can reduce emissions while saving money.

In preparing the video script, every effort was made to minimize the use of technical jargon and to clearly communicate the advantages of OBDIII in terms that a general viewing audience could understand. The privacy issue is addressed directly by pointing out that motorists could be given the choice of deactivating the system.

The video is provided separately but represents a portion of the final report under the current contract.

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8. CONCLUSIONS AND RECOMMENDATIONS

Based on the results from the demonstration program and other information reviewed, we have drawn the following conclusions:

1. It is technically possible to fabricate and operate an automated system to communicate, via wireless cellular communication, vehicle identification numbers and changes in OBD fault code status.

2. Short-range vehicle-to-roadside communication and cellular telephony are the most practical technologies for OBDIII communication for light-duty vehicles in California. For short-range communications, however, lack of existing infrastructure increases the capital investment required.

3. The cost of OBDIII will be lowest if it can be integrated into multi-use vehicle communication systems. Even without such integration, OBDIII is less expensive than participation in the Smog Check program.

4. Privacy is potentially a major issue with OBDIII and it should be addressed as part of the design and implementation of any OBDIII program.

5. An OBDIII regulation patterned after the previously described Model Approach is, in Sierra's view, legally defensible.

Recommendations

ARB should consider for adoption a voluntary OBDIII program in which all new vehicles, after about four years lead time for manufacturers, are required to have OBDIII capability, but with the decision to deactivate that capability left to each individual vehicle owner or driver; deactivation of OBDIII by the owner should mean automatically reverting back into the Smog Check program in the next inspection cycle.

Making vehicle manufacturers responsible for providing long-term cellular service for OBDIII (possibly through a consortium) would insure long-term service availability and eliminate the relatively high cost of individual customer billings. To address privacy issues, ARB should require manufacturers to disclose any features of systems they develop that go beyond the minimum requirements of the regulation, particularly with respect to vehicle location capability. It may be advisable for ARB to clearly state that it will not collect or use any vehicle location information as part of any OBDIII program it

pursues. However, ARB should be careful not to interfere with the desires by consumers or vehicle manufacturers to enjoy the benefits of vehicle location systems in vehicles into which OBDIII may be cost-effectively integrated.

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APPENDIX A

OADBAS Program Manual

Workstat Software Inc
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TECHNICAL MEMORANDUM

To: Frank DiGenova, Sierra Research
Subject: OBDBAS User Manual
Project: OBD II Emissions Reporting
From: Thomas Hundt, Workstat Software
Date: 22-Feb-99
Cc:

Contents

Introduction

This is the user manual for the ObdBas software developed for Sierra by Workstat Software. It corresponds to version 1.0.7 of obdbas.exe.

Installation

Running Setup

The program is installed on the Libretto from two diskettes. If you have received a CDROM, look for directories DISK1 and DISK2. Files in each of these should be copied to a diskette to create the installation diskettes.

Simply run the Setup program on DISK1, as usual, to initiate installation.

DLL Dependencies

The following DLLs are used by the program (obdbas.exe):

- Direct parallel port i/o (win95io.dll)
- OLE/Messaging 1.0 Object Library (c:\windows\system\mdisp32.tlb)
- Visual Basic runtime (msvbvm50.dll)
- serial port communications (mscomm32.ocx)

System Time

Please be sure the system time and date are correct on the Libretto. It is used for logging and on-screen display purposes.

Windows Messaging

Windows Messaging needs to be properly installed on the host computer. In addition, it needs to have a profile set up to send e-mail over the Ardis network via the Motorola wireless modem. We suggest you use a profile name of "Windows Messaging Settings," as this is the default profile name for ObdBas.

Note: Windows Messaging should not be running while the program is used in unattended operation. It can interfere with message sending. When Messaging is running, the user is required to manually enable transmission of messages via Ardis by "connecting" the wireless modem (by right-clicking on its icon in the tooltray). Obviously, with an unattended machine, there will not be anyone there to do it.

Note: Paul Tarczy reports he is using Outlook 97 v8.03 on all Librettos at this time (1/7/99).

Disable Scandisk on Boot

We recommend that Scandisk be disabled from automatically starting on booting the Libretto, if it was shutdown improperly. (Typically Windows activates Scandisk automatically if the system was not shut down cleanly.) The reason is, there may be dialogs associated with this that cannot be responded to if the Libretto is operated in embedded (no user interaction) mode.

Scandisk auto-start can be disabled using the *Tweak UI* control panel applet, part of the Windows 95 PowerToys collection (available from Microsoft's website).

Tweak has numerous other handy functions, e.g., ability to create the Control Panel as a file (which is useful if placed in the Start Menu folder).

Outlook to be Running

If Outlook is not running, the modem transfer ("connector") program does not reliably pull messages out of the Outbox and send them to the wireless network. If Outlook is running, this works correctly. Therefore we recommend that a shortcut to Outlook be placed in the StartUp folder so that it is run along with ObdBas at system bootup time.

Standard Hardware Configuration

Serial Connection to Scantool

Standard setup is a serial cable (DB-9 male to female) connected to the PC's COM1 port (DB-9 male), going to the black "VT-100" (stamped on DB-25 connector) cable supplied by SnapOn. In between, you need a DB-9 to DB-25 adapter, and, optionally, an "RS-232 Mini Tester" with status LEDs. There are also old-style PC serial cables available that integrate the cable and DB-9/25 adapter, ending in a male DB-25.

The modular end of the "VT-100" cable goes to the scantool's modular connector.

Dongle

The "Dongle" switchbox should be connected to the PC's parallel port (DB-25 female) LPT1.

Setting Libretto's Parallel Port Mode

The Libretto's parallel port should be set to emulate a standard parallel port. This is done via the Control Panel, Toshiba System tool, System Setting tab. Parallel Port is set to ECP by default (this is Enhanced Capabilities Port, for fast bidirectional I/O to printers.

Dongle Debugging

There are two diagnostic screens in the ObdBas program to test the dongle.

Dongle Diagnostics

This is a high-level diagnostic, accessed via the Diag menu, entry Dongle. This brings up a picture of the switchbox, reflecting what the program thinks is the state of each element. If the switches are toggled/pressed, the onscreen pictures should move also. Below the pictures of the LEDs are radio buttons that may be used to turn the LEDs on and off.

If the picture of the switchbox has diagonal lines through it, that means the dongle was not detected to be present. If this is the case and the dongle is in fact plugged in, use the parallel port diagnostics to get further details.

If LEDs don't respond, or the switch diagrams don't respond to switch actions, then it's time to use the low-level parallel port diagnostics to get further details.

Parallel Port Diagnostics

This is a low-level diagnostic, accessed via the Diag menu.

Note that there are tooltips that describe the important elements of this dialog.

Serial Connection Debugging

Hardware

Connect cables according to the "Standard Hardware Configuration" section, including the RS-232 Mini Tester.

Observe the RS-232 Mini Tester:

- Connected only to the scantool cable, with power to the scantool, RD should be glowing red dimly. This indicates the scantool "send data" line is connected properly and that the scantool has power.
- Connected only to the PC cable, with the PC on and with ObdBas in idle mode (running but not retrieving from the scantool), the DTR and TD lights will be red, and the RTS light will be green.
- Connected only to the PC cable, with the PC on and with ObdBas attempting to retrieve from the scantool, the DTR and RTS lights will be green, and the TD light will be red.
- Connected to the PC cable and the scantool, with everything turned on ObdBas in idle mode (not attempting to retrieve from the scantool), the DSR and DTR lights will be red and RTS and CTS will be green (indicating proper handshaking), and TD and RD will be red (indicating no data being sent).
- Connected to the PC cable and the scantool, with everything turned on ObdBas attempting to retrieve from the scantool, the DTR, CTS, RTS, DSR lights will be green (indicating proper handshaking), and the TD and RD lights will be red, flickering sometimes to green when data is sent.

HyperTerminal

Go into HyperTerminal, and set it up for direct connection to serial port COM1, 4800 baud, 8 data bits, no parity, 1 stopbit, no flow control. (4800 8-N-1.) If you go into File>Properties>Settings, set "VT100" emulation. Click "Terminal Setup" and set "Keypad application mode" – this makes the arrow keys send the correct sequences for scantool "VT100" mode operation. (I have saved this configuration on my machine as a file named scantool.ht, for easy access.)

To get the scantool into VT100 mode, power cycle it, then (in Hyperterminal, which you should already have running), hit the "Y" key. (Uppercase or lowercase, doesn't matter.) The scantool should beep and send back a message like "Sun Generic OBDII" or "Select a manufacturer." This will most likely be in some special "large" characters to emulate the LCD on the scantool. (The code to set the mode gets sent on the initial "Sun Generic OBDII" screen.)

Now you should be able to control the scantool using the up and down arrows (to emulate the thumbwheel) and the Y and N keys. If you got this far, then the serial communications hardware is working properly.

When you are finished with HyperTerminal, be sure to power-cycle the scantool, to get it back out of vt100 mode.

If you want to type commands to it that ObdBas uses, these are documented in the file PROTOCOL.TXT.

ObdBas Operation

Logging

A logfile, named by default C:\OBDBAS.LOG, is created and appended to when the program runs. You should not delete/rename/move the file while ObdBas is running. You can, however, view it, provided the tool you use to do so will open the file in shared read mode. Notepad will do this; WordPad will not. The classic DOS "List" program can also do it, if configured properly. You can also copy the file to another file and then open the new one.

Command-line Options

ObdBas recognizes two flags in the command line:

- D sets debugging mode. Enables more detailed logging (to logfile). This mainly applies to scantool communications, where certain intermediate error reports are normally suppressed (the errors are reported anyway, but only once instead of in several places).
- A sets Automatic Run mode (i.e., unattended run mode). Setting this makes the program go into Automatic mode by itself – it is exactly as if you typed the Alt-A command in the main window after you started the program.

Shortcut in StartUp Folder

There should be a shortcut in the Start Menu>Programs>StartUp folder pointing to ObdBas, with the parameter A after the obdbas.exe filename. (So, the shortcut's complete Target field will be something like: "C:\app\obdbas\obdbas.exe A". This will start the program in Automatic mode when the machine boots up.

Main Window

The main window has several buttons and fields that are explained here. Note that each of them has tooltips explaining their functions.

Automatic

This button puts the program in Automatic mode. It sets the countdown values to their starting values and begins counting down to a scantool read. In reporting mode 1 or 3, it will also begin counting down to a sending sequence.

Stop Automatic (mapped to Esc key when in Automatic mode)

This button stops Automatic mode.

Read Now

This button initiates an immediate read of the scantool.

Read+Send Now

This button (only available while in Automatic mode) initiates an immediate read and then report send of the results.

Debugging

This may be checked to enable extensive logging to the logfile, and more messages to be displayed during scantool read.

Logfile

For now, this is permanently turned on (checked), and the name of the logfile is fixed as “c:\obdbas.log”.

Scantool read countdown

This is the countdown, in seconds, until the next scantool read operation. Only in effect in Automatic mode.

Mode 1 time countdown

This is the countown, in seconds, until the next scheduled e-mail report, while in reporting Mode 1 (controlled via setup menu or dongle switch). Note that any change in fault codes cause an immediate report regardless.

Mode 3 miles countdown

This is the countown, in miles, until the next scheduled e-mail report, while in reporting Mode 1 (controlled via setup menu or dongle switch). Note that any change in fault codes cause an immediate report regardless.

Note: This is currently disabled.

Last report status

This is an indicator of the results of the last attempt to queue an e-mail to Ardis. It usually says “OK” and the time of the last scantool report, or an error code. It may also contain different messages when you initiate a diagnostic test message send.

Quit

This button closes the application. Note that you must not be in Automatic mode; hit the Esc key or click Stop Automatic to get out of it.

SimOdo

This is an experimental simulated odometer. After each scantool read, the reported vehicle speed times the time since the last read is computed, yielding a theoretical distance travelled. (It unrealistically assumes the vehicle is always travelling at exactly the same speed.) This is then added to the simulated odometer value.

Last scantool retrieve status

This indicates the results of the last attempt to read the scantool. It will either contain an OK message or an error code (listed elsewhere in this document).

Current Fault Codes

This lists the last set of fault codes read from the scantool.

Current OBD Data

This lists the last set of vehicle realtime data read from the scantool.

Registry Settings

The program saves the user preferences in the Windows registry. The settings appear under this key:

HKEY_CURRENT_USER\Software\VB and VBA Program Settings\Sierra\Obdbas

You can use the RegEdit program (part of Windows) to view them.

One way to reset the program to use known default settings is to delete this key, which deletes all the settings. ObdBas will recreate it the next time you run it.

This section documents the registry settings, which correspond to global variables used to keep the settings internally. A list of these are output to the logfile when the program starts. The global variables and the registry settings have very similar names, e.g., a registry setting named "ComPort" corresponds to a global variable named "g_ComPort".

(*Note: these are all defined in file common.bas.*)

Name	***Default Value***	***Meaning/Interpretation***
PrinterPort	1	LPT port dongle is connected to.
ComPort	1	COM port scantool is connected to.
ComSettings	4800,n,8,1	Settings for COM port baud, parity, databits, stopbits.
TimeoutSecs	60	Timeout in seconds for serial communication w/scantool.
ScanSecs	120	Interval between scantool reads.
MainInterval	500	Main loop activation interval (ms). (Do not change this.)
LogfileName	c:\obdbas.log	Filename for logging.
ReportMode	2	E-mail reporting mode (1=time, 2=faults only, 3=distance).
ReportSecs	86400	(Once/day.) Time between e-mails in Reporting Mode 1.
ReportMiles	20	Miles between e-mails in Reporting Mode 3.
MailTo	thundt@slack.net	Destination for report e-mail (*To:* header).
MailTo2		Secondary destination for e-mail.
MailSubject	[obdbas]	Subject of report e-mails. Timestamp is appended to this string.
MailProfile	Windows Messaging Settings	Windows Messaging profile to send mail via.

MailSendFaults	1	If nonzero send fault codes in report e-mails. (Do not change this.)
MailSendDescrip	False	If true, send fault code descriptions.
MailSendReadiness	0	*Currently unimplemented.*
MailSendData	0	If nonzero, send engine data.
VehVin	(no VIN entered)	Vehicle VIN code.
VehModel	*empty*	Vehicle model.
VehPlate	*empty*	Vehicle license plate.
VehState	CA	Vehicle license plate state abbrev.

Switchbox Dongle Operation

The dongle is intended to be mounted with the red button towards the right. This is merely to provide a frame of reference; it makes no difference to the way it operates. Its DB-25 connector should be connected to the PC's LPT1 parallel (printer) port.

Toggle switch left (away from button): selects reporting Mode 1 ("report by time").

Toggle switch center: selects reporting Mode 2 ("manual mode").

Toggle switch right (towards button): selects reporting Mode 3 ("report by distance").

Press button (until acknowledged by blinking red light): read scantool immediately and send results immediately.

LED Signals

Green light long, then several short flashes: acknowledging user selecting operating mode from toggle switch. Number of short flashes indicates the mode (2 blinks means Mode 2, etc.).

Red light blinking 8 times: acknowledging user pressing pushbutton to retrieve and send immediately.

Steady red light: in process of reading the scantool.

Steady green light: in process of reporting (sending e-mail).

Red and green lights flashing together

Red and green lights flashing alternately:

Dongle-Less Operation

A switchbox dongle is not strictly necessary for operating the program. You can set the reporting mode from the Reporting setup menu. This mode is saved (along with the rest of the settings) when you exit that setup dialog. This will then be the default reporting mode when the program is started.

Automatic Operation

When either the user clicks the "Automatic Mode" button from the main window, or the 'A' command-line option is used, the program goes into automatic retrieve mode. This could also be called "Unattended Operation Mode," because that is its purpose. This means it will periodically read the scantool without user intervention. It will also make use of the switchbox dongle to determine reporting mode and display status.

Operating Flow

**** expand this! ****

Initialization

Load registry settings into global variables.

Interpret command-line options into global variables.

Reporting Modes

Reporting in this context means "sending updates to the monitoring location via e-mail." These are only in effect during Automatic Operation. There are three reporting modes currently defined:

1. Time interval and fault code changes.
2. Fault code changes only.
3. Distance interval and fault code changes.

(Note that one way of thinking about this is that Mode 2 is always in effect.)

Re-sending of E-mail Messages

There is a check-and-resend process in the program's main loop, which is activated every 120 seconds (not counting whatever time is spent doing other thing, like reading the scantool). The purpose of this is to automatically attempt to re-send messages that "bounced" (were unable to be sent) because the modem is out of range of a relay station. Such messages appear in Outlook's Inbox with a subject line that says, "Undeliverable:" followed by the original message's subject line. Sierra reports that it typically takes almost exactly ten minutes for a message to be "bounced". In my experimentation, if the modem is not connected to my development laptop, messages are bounced immediately.

Bounced messages will be re-sent again and again, until the modem is again within range, at which time they will be successfully sent and make their way to Sierra headquarters.

The check-and-resend process operates as follows: It opens the Inbox and looks at each message in turn. If a message has "unread" status, AND has the word "Undeliverable:" at the beginning of its Subject line, it is assumed to be a bounced message. A clone of the bounced message is created and queued using the same sending routine used by the rest of the program. The clone message has the identical recipient(s), subject line (including timestamp), and text body as the original. It appears in the Outbox. The bounced message is then updated to indicate "has been read" status. It stays in the Inbox. Then the program goes on to check the next message in the Inbox.

Note that no check is made that a bounced message is actually from OBDBAS (i.e., has "[obdbas]" in the subject line) nor that the problem causing the bounce was actually the modem (i.e., that a complaint saying so is part of the bounced message). Presumably, messages bouncing due to invalid recipient addresses will be repeatedly resent and will circulate indefinitely.

On the main window, there is a field at the bottom, labelled "Bounce mail check:" that gives the status of the check-and-resend process. It will say "CHECKING..." while it is active, "OK" and a time after successful completion, or "ERROR" and an error code.

Under the Diag menu, there is an option, "Re-send Bounced E-Mails" which causes a check-and-resend immediately.

Program Error Codes

This is a list of error codes, for the most part generated by the scantool reading routines. *(Note: these are in program file autoretr.frm.)* These are reported in the main form status field.

Code	Routine	Interpretation
100	ExpectCommonErrs	User clicked "Cancel"; abort scantool read.
101	ExpectReceiveMsg, ExpectCommonErrs, OpenScantool	Timeout waiting for scantool response.
102	ExpectReceiveMsg	Bad data expecting SOH (^A) char .
103	ExpectReceiveMsg	Bad data expecting hex digit.
104	ExpectReceiveMsg	Bad data receiving checksum.
105	ExpectReceiveMsg	Bad data expecting message string with C43B or C23D header. Didn't receive STX character when we were expecting one.
106	ExpectReceiveMsg	Checksum error in message portion of scantool response.
108	CloseScantool	Bad data expecting 01FE response.
109	GetFaultCodes	Bad data expecting 01FE response.
110	GetFaultCodes	Bad data expecting C2D3 response.
112	GetFaultCodes	"NO RESPONSE FROM VEHICLE" from scantool.
113	GetFaultCodes	Bad data expecting C2D3.
114	GetFaultCodes	Bad message expecting "COMMUNICATION ESTABLISHED" from scantool.
116	GetFaultCodes	Bad data expecting C43B.
117	GetFaultCodes	Bad data expecting C43B
118	GetFaultCodes	Bad data expecting 8679
120	GetRealtimeData	Bad data expecting 01FE.
121	GetRealtimeData	Bad data expecting C23D.
122	GetRealtimeData	Bad data expecting C43B.
123	GetRealtimeData	"NO RESPONSE FROM VEHICLE" from scantool.

124	GetRealtimeData	Bad data expecting 01FE.
125	GetRealtimeData	Bad data expecting 8679.
130	GetFormatStrings	Bad data expecting 01FE.
131	GetFormatStrings	Bad data expecting C43B.
132	GetFormatStrings	"NO RESPONSE FROM VEHICLE" from scantool.
133	GetFormatStrings	Bad data expecting 8679.
140	OpenScantool	Bad data expecting 01FE response.
141	OpenScantool	Bad data expecting 8679 response.
142	CvtRealtimeData	Encountered invalid class code.
143	CvtRealtimeData	Error converting K-class data.
145	OpenScantool	Unknown communications error (COM port in use?)
151	MailSend	Error creating MAPI session object.
152	MailSend	Error during logon to MAPI.
153	MailSend	Error creating message in outbox.
154	MailSend	Error adding recipient to message.
155	MailSend	Error sending message.
156	MailSend	Error closing MAPI control.
157	MailSend	Error adding second recipient to message.
16x	MailBounce	Errors during resend of bounced e-mails.

E-Mail Configuration

The e-mail parameters are configured in the Setup>E-Mail menu item. The most important one of these is the Mail Profile, because if it does not match an available (preferably the default) profile configured on the machine, a dialog box will pop up asking the user to choose one of the valid ones. This will interfere with stand-alone operation!

To test the configuration, use the "Send Test E-Mail" item in the Diag menu. This sends a message using the configuration you set up, and a message body of just the word "TEST". It follows the same process the program normally would when sending vehicle information.

Note the result indicator next to "Last report status:" on the main window.

Messages sent will be visible in the Outbox of Windows Messaging, until they are either sent successfully (and move to the Send Messages folder) or not (and move to the Inbox as "failed" messages).

Format of E-Mail Sent by the Program

The following "pseudocode" with two faultcodes and two realtime data items is the format of the mail file. Note that realtime data and faultcode descriptions are optional. (Configure this on the Setup>Mail menu item.) Note that there are TAB characters between the codes/descriptions and itemnames/values. Note also the marker "RTDATA" indicating the beginning of the realtime data section.

```
From: Frank DiGenova <sierra1@2way.net>
To: "'thundt@slack.net'" <thundt@slack.net>
Subject: [obdbas]
Date: Thu, 10 Dec 1998 08:55:10 -0600
X-Mailer: Internet Mail Service (5.0.1460.8)
```

Vin		
Faultcode1	→"Description"	*Descriptions are only sent if configured.*
Faultcode2	→"Description"	*There could be zero or more of these.*
RTDATA		*This is only sent if realtime data is configured.*
Itemname1	→Data1	*There could be zero or more of these.*
Itemname2	→Data2	*These are only sent if realtime data is configured.*

Weird Glitches and Errors

This section lists some weird problems we've had and what we did about them.

Unexpected Error/Runtime Error 50003

This is a serial port problem. It is in a wedged state and the MSCOMM32 control can't reset it. We were able to clear it by shutting down the machine totally and power-cycling it (not just rebooting). Other symptoms include: the RS-232 tester LEDs all being "green"; Kermit setting them to normal (most of them red); obdcom.exe functioning properly.

Scantool Acts Like It Is Broken

If you get a scantool that acts completely normally except that it won't communicate with the PC, it could have gotten its communications parameters changed. This has been known to happen for no reason. To reset them with a scantool with no LCD panel, you will have to use VT100 mode. (This is initiated by connecting with Hyperterm or other terminal emulator program, set to VT100 emulation, and typing the 'y' key as the very first thing after the scantool is power-cycled.)

Background Technical Information

Pinout of Parallel Port

DB-25 female

Pin	Dir	Assignments	Pin	Dir	Assignments
1	I/O	Strobe *	14	O	AUTOFEED *
2	I/O	Data Bit 0	15	I	ERROR *
3	I/O	Data Bit 1	16	O	INITIALIZE *
4	I/O	Data Bit 2	17	O	SELECT IN *
5	I/O	Data Bit 3	18		Ground
6	I/O	Data Bit 4	19		Ground
7	I/O	Data Bit 5	20		Ground
8	I/O	Data Bit 6	21		Ground
9	I/O	Data Bit 7	22		Ground
10	I	ACKNOWLEDGE *	23		Ground
11	I	BUSY	24		Ground
12	I	PAPER END	25		Ground
13	I	SELECT			

```
* Denotes low true logic.

Data Bit and Strobe signals are 24mA Open-Collector.
Auto Feed, Initialize Printer, Select In are 24mA TTL.
The rest are straight TTL.

Ref: http://dynamik.fb10.tu-berlin.de/manuals/hardware/pp-DB-
25.html
     http://www.radioshack.com (various printer manuals)
```

Pinout of PC Serial Port

This is a DB-9 male connector on the back of the PC. In the Libretto's case, it is on the port expander ("I/O Adapter").

DB-9 male

Pin	Assignments
1	Carrier Detect
2	Receive Data
3	Transmit Data
4	Data Terminal Ready
5	Signal Ground
6	Data Set Ready
7	Request to Send
8	Clear to Send
9	Ring Indicator

DB-25 male

Pin	Assignment	Pin	Assignment
1	GND	13	N/C
2	Transmit Data	14	N/C
3	Receive Data	15	N/C
4	Ready To Send	16	N/C
5	Clear To Send	17	N/C
6	Data Set Ready	18	N/C
7	Signal Ground	19	N/C
8	Carrier Detect	20	Data Terminal Ready
9	N/C	21	N/C
10	N/C	22	N/C
11	N/C	23	N/C
12	N/C	24	N/C
		25	N/C

Pinout of Scantool Vehicle Port

This is a DB-15 male connector recessed in the back of the scantool. The (black) cable going to the vehicle data port connects here.

Pin	*Function*
1	GND
15	VCC (+12V)

I soldered power leads to a DB-15 connector to apply power to the scantool for bench testing. Obviously, it is not connected to the vehicle with this setup, and will consistently return an error to that effect. But, it is useful for development.

Dongle

Schematic Diagram

```
 Signal Wire   DB-25
        Color   Pin
 ------ ------ -----
                                  2.2K
   D1     GRN     3 o________/\/\/\______________
                                              _|_ LED Green
                                              \ /
                                              --- Z
                                        _______|
                                        |
                              2.2K      |
   D0     RED     2 o________/\/\/\_____|_______
                                        |     _|_ LED Red
                                        |     \ /
                                        |     --- Z
                                        x______|
                               10K      |
   D2     BLU     4 o__x____/\/\/\___   |
                       |             |  |
   S3     ORG    15 o__|_____________x__|_________
                       |                |         |
                       |                |         o  Toggle switch
                       |                x_____o---   SPDT ctr-off
                       |     10K        |         o
                       x____/\/\/\___   |         |  (right)
                       |             |  |         |
   S4     YEL    13 o__|_____________x__|_________|
                       |                |
                       |      10K       |
                       x____/\/\/\___   |
                       |             |  |
   S5     WHT    12 o__|_____________x__|_________
                       |                |         |
                       |                |         o  Pushbutton
                       |                |         \
                       |                |          \
                       |                |         o
   GND    BLK    23 o__|________________x_________|
                       |                |
   S7*    BRN    11 o__x              =====
                                        -
```

For signal definitions and i/o details, refer to: http://www.doc.ic.ac.uk/~ih/doc/par/

Front Panel Layout

```
 --------------------------       CASE FRONT PANEL LAYOUT
|--------------------------|         G = green LED
|                          |         T = toggle sw
|  (G)   ( T )  ((B))  (R) |         B = pushbutton sw
|                          |         R = red LED
|                          |
 ----__-------------__----
```

Parts List

```
resistor 10k 1/4W         (3) 271-1335 (pkg 5)
resistor 2k 1/4W          (2) 271-1325 (pkg 5)
DB-25 male solder term    (1) 276-1547
DB-25 "clamshell" hood    (1) 276-1549
project case blk 2x3x1    (1) 270-1801
momentary pushbutton      (2) 275-1547 (pkg 4)
LED panel mount holders   (2) 276-079 (pkg 5)
LED red T-1_3/4           (1) 276-041 (pkg 2)
LED green T-1_3/4         (1) 276-022 (pkg 2)
cable wht tel 8-cond      (10') 278-0876 (roll 100')
toggle sw DPDT ctr-off    (1) 275-664
tie wraps 1/4"            (2) 278-1652 (pkg 30)
drill bit 1/4"            (for drilling appropriate holes)
```

Scantool Serial Cable

This cable has a DB-25 female connector at one end (for connecting to a PC serial port) and a 6-pin RJ-25 modular connector at the other (for connecting to a scantool). The cable is black and has "VT100" stamped on the DB-25 connector.
As noted above under "Standard Hardware Configuration," you will need an adapter to plug it into the Libretto.

Here is a list of the pins and a diagram of the cable:

```
DB9      DB25          Modular
Equiv    ----          -------
3        TD  2 _______  4
2        RD  3 _______  3
7        RTS 4 __
                 |  __  2
8        CTS 5 __| |
6        DSR 6 __  |__  5
                 |              6    1
4        DTR 20 _|           |=''''''=|
5        GND 7 _______  6    |________|
```

Note: The modular connector pins are arbitrarily numbered 1-6 starting from the right, if the connector is pointing toward you, pins side up.

The column labelled "DB9 equiv" is for an equivalent cable having a DB-9 female on the PC end, to plug it directly into the PC. I made up such a cable for testing during development.

Warning: Note the loopback from pins 2-5 on the modular end, so the scantool can tell the cable is connected! It will only erratically send data if this is not present, which will drive you crazy.

Mini Tester LEDs

Please note that depending on what kind of serial mini-tester you have, the polarity of the LEDs will vary. The Radio Shack kind (which has 7 bipolar LEDs) uses green to indicate "ready" state, and red to indicate "not ready." Thus, the data lines (RD and TD) will normally be red (except when they're sending data), and the status lines will be green when communication is in progress. I have another type of tester also, that has 18 LEDs (9 each red and green), which uses red to indicate "ready" and green to indicate "not ready" – the exact opposite of the Radio Shack one.

Note that lines RTS and CTS are tied together by the scantool interface cable, and DTR and DSR are also. This results in a null-modem operation.

You will observe that when ObdBas is in operation, and not communicating with the scantool, the DTR (and DSR) lines are dropped and the their LEDs will appear red.

Scantool VT100 Mode

The scantools have two modes of operation from a PC: using the SnapOn/Balco special protocol (which ObdBas uses and is documented in a couple of memos from SnapOn and Balco) and the VT100 mode (which uses a terminal to emulate the scantool's front panel).

To enter the SnapOn protocol, you send the text characters "951FL" to initiate communications, and "8D27L" to terminate. Each of these results in some acknowledging messages (e.g., ^A 01FE ^A 8679.) The latter command will cause the scantool to reset and beep. In between, there are commands to solicit various types of information from the scantool. Consult the relevant documentation for details.

References

IBM Parallel Port FAQ/Tutorial, http://home.rmi.net/~hisys/parport.html.

IBM-PC Parallel Printer Port Registers & Pinouts, http://www.doc.ic.ac.uk/~ih/doc/par/doc/regpins.html.

A Digital JoyStick for the IBM-PC Parallel Printer Port, http://www.doc.ic.ac.uk/~ih/doc/joystick.html

Interfacing the Enhanced Parallel Port, http://www.geocities.com/SiliconValley/Bay/8302/epp.htm.

Null modem information, http://www.videodatasys.com/null.htm.

Various documents on MAPI, MSCOMM32, etc. in the *MSDN Library*.

WIN95IO package, http://www.softcircuits.com.

OBD-II PC-based scantool info at http://pegasus.acs.ttu.edu/~z7d23, http://www.easesim.com, http://www.interro.com, http://www.carcomp.com.

Libretto info at http://www.csd.toshiba.com.

Snap-On Diagnostics: *PC to Embedded Scanner; OBDII Info Retrieval*, 12/29/96.

Ken Klask and Paul Hlelvinka (Balco): *BAR-90 Host to Scan Tool Communications Protocol, Appendix A/Snap-On's Protocol.*

T. Hundt: *Protocol.txt* (part of ObdBas source code).

Info on MAPI programming in file Valupack\Morehelp\Vbaoutl.hlp on Microsoft Office 97 Professional installation CD-ROM.

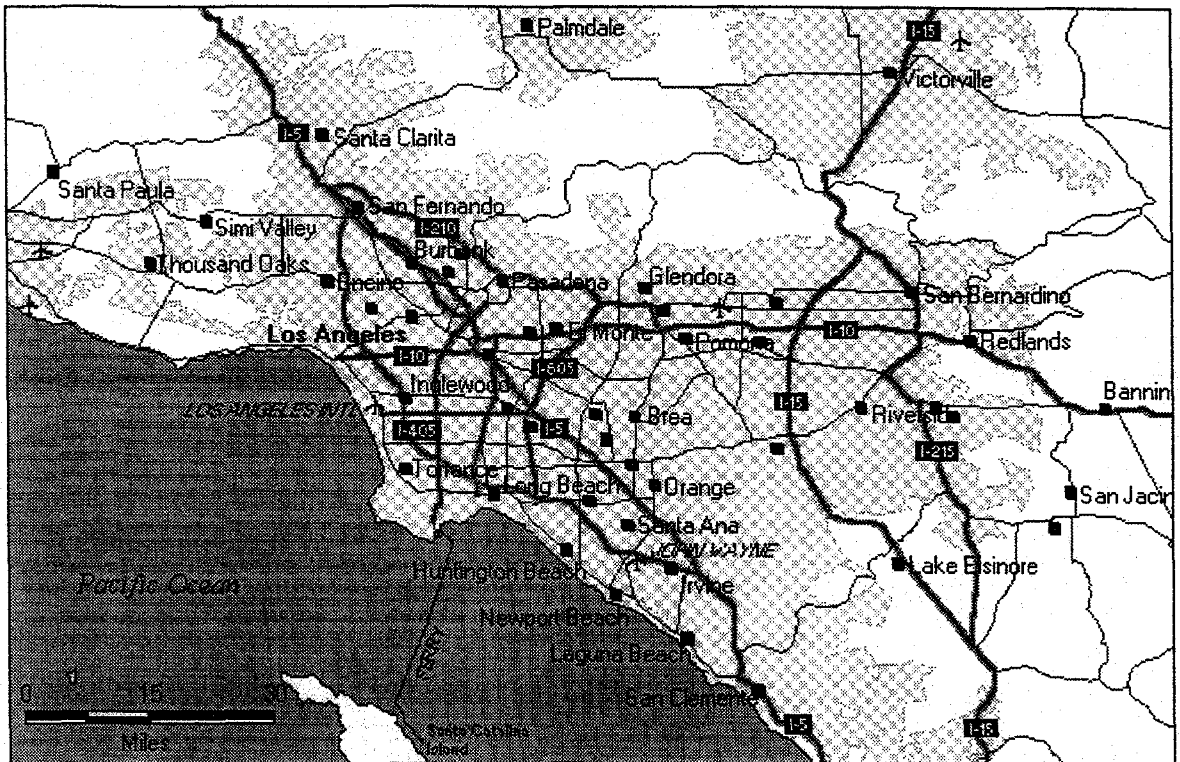
Program Revision History

1.0.4: Added second e-mail "To:" recipient.
Added timestamp to subject of e-mail.
Changed max number of characters in text box using ShowData to 2000.

1.0.3

APPENDIX B

Ardis Description and Coverage Maps



ARDIS
Coverage Atlas

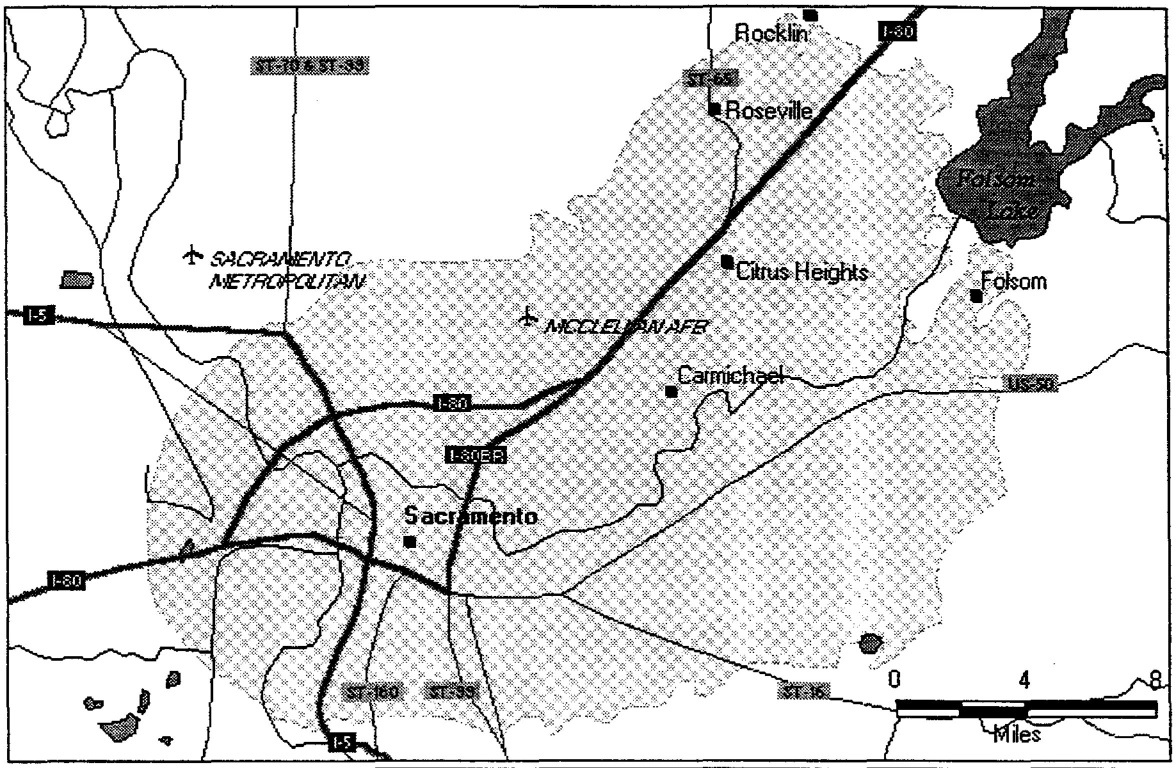
Coverage areas on this map are representative of ARDIS coverage. Actual coverage may vary due to terrain, building density, or other environmental conditions.

N W E S

ARDIS Coverage — Airports
Cities and Towns — U.S. & State Highways
Water Features — Interstate Highways

Choose another State or region

Choose another city



ARDIS

Coverage Atlas

Coverage areas on this map are representative of ARDIS coverage. Actual coverage may vary due to terrain, building density, or other environmental conditions.

N W E S

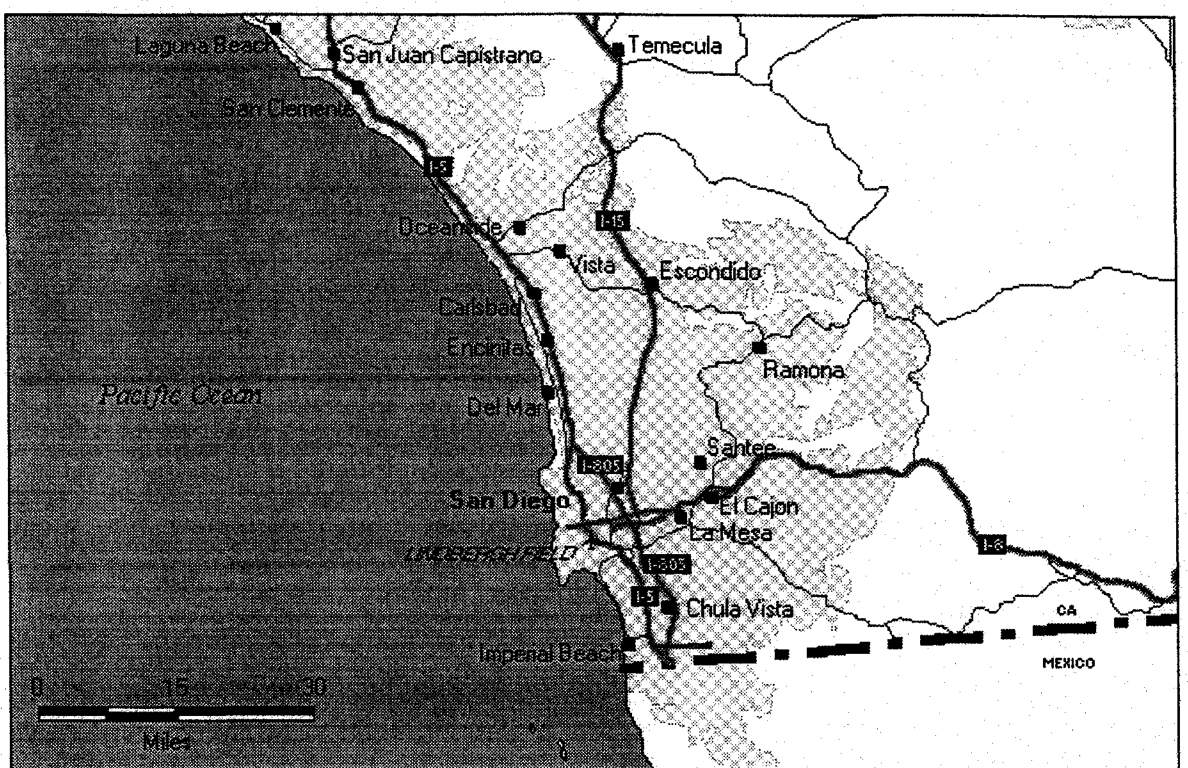
ARDIS Coverage — Airports

Cities and Towns — U.S. & State Highways

Water Features — Interstate Highways

Choose another State or region

Choose another city



ARDIS

Coverage Atlas

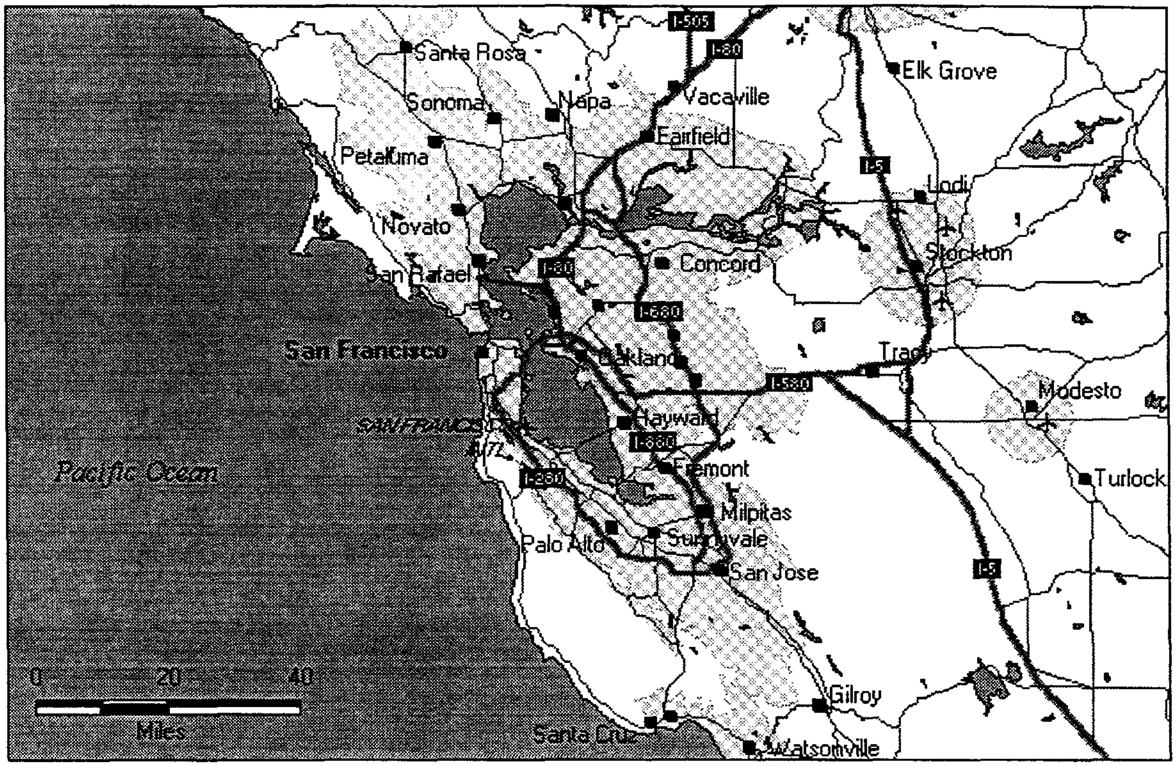
Coverage areas on this map are representative of ARDIS coverage. Actual coverage may vary due to terrain, building density, or other environmental conditions.

N W E S

ARDIS Coverage | Airports | Cities and Towns | U.S. & State Highways | Water Features | Interstate Highways

Choose another State or region

Choose another city



ARDIS

Coverage Atlas

Coverage areas on this map are representative of ARDIS coverage. Actual coverage may vary due to terrain, building density, or other environmental conditions.

N W E S

- ARDIS Coverage
- Airports
- Cities and Towns
- U.S. & State Highways
- Water Features
- Interstate Highways

Choose another State or region

Choose another city

APPENDIX C

Preliminary List of Candidate Disablements

Selected Disablements on Field Test Vehicles as of 4/8/99					
Sensors	96 Honda	98 Chevy Lumina	98 Ford Taurus	98 Chrysler Breeze	97 Volvo S90
Throttle Position	immed. CEL Same time as EGR & Coolant	immed. CEL	~17min - restart engine - Immed. CEL		Immed. CEL
EGR Valve	Undocu-mented Code? Same time as TPS& Coolant	no CEL	~14min - restart engine - Immed. CEL	~ 5min Idle - restart eng. and drove 1 block - CEL	
O2 Sensor		~20min drive after a stop CEL	~10 min - restart engine - Immed. CEL		
Coolant Temperature	immed. CEL Same time as EGR & TPS	~10 min drive CEL			
Evap PurgeControl	No CEL			Immed. CEL	
MAP	immed. CEL			Immed. CEL	
Mass Air Flow		~6 min drive CEL, runs rough	~20min - restart engine - Immed. CEL Runs rough		Immed. CEL

Selected Disablements on Field Test Vehicles as of 4/8/99

Rear O2 Sensor			~12min - restart engine - Immed. CEL		
Both O2 Sensors			~6min - restart engine - Immed. CEL		
Motor Position Sensor/Kickdown Servo					Immed. CEL

APPENDIX D

OBDIII Field Demonstration Data