Eastern Research Group, Inc.

Review of Literature on Remote Sensing Devices

REPORT

For peer review and public comment

Prepared for:

California Air Resources Board
and
California Bureau of Automotive Repair

Prepared by:

Eastern Research Group, Inc.

August 26, 2004

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Prepared for:

California Air Resources Board
Haagen-Smit Laboratory
9528 Telstar Avenue
El Monte, CA 91734

California Bureau of Automotive Repair
10240 Systems Parkway
Sacramento, CA 95827

Prepared by:

Tom Austin
Sierra Research

Andrew D. Burnette
Eastern Research Group, Inc.

Rob Klausmeier
de la Torre Consulting, Inc.

Bob Slott
Consultant

August 26, 2004

Disclaimer

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Purpose

The purpose of this literature review is to assess what is known about the ability of remote sensing devices (RSD) to do the following:

1. Identify high emitters for immediate testing;
2. Exempt vehicles from I/M testing (i.e., "clean screening);
3. Identify candidate vehicles for subsidized scrappage programs;
4. Improve the high emitter index model (HEI) used in California to select vehicles for testing in test-only stations;
5. Evaluate the overall effectiveness of Smog Check program; and
6. Characterize emissions in subcategories of the California fleet.

This report is intended to fulfill one objective (i.e., Task 2) of the Pilot Remote Sensing Study, specifically, to "provide an organized synthesis and critical assessment of previous and current studies on relevant remote sensing programs. The information obtained from this task would be used to help answer the questions identified in Task 1, define research gaps, establish the need for further studies, and resolve controversies, if any." If possible, the research gaps, controversies, etc. would be resolved by performing the rest of the Pilot Remote Sensing Study.

The literature reviewed for this report included several studies reporting the results of relatively large-scale testing programs as well as several papers and reports providing analyses of the capabilities and limitations of remote sensing. Generally, we limited our review to more recent studies that used more reliable equipment, measured vehicle speed and acceleration, and used improved quality assurance procedures relative to earlier studies. A detailed description of the studies that were reviewed follows the conclusions.

Based on our review of the available literature, the authors have determined that:

1. RSD could be used to "clean screen" vehicles. It has the advantage of providing an on-road measurement (which gives a "tangible" reason for the clean screen): however; it is costly and complex compared to alternative clean screen methods that are similarly effective.
2. RSD has potential for the following tasks:
    a. Identifying high emitters for immediate testing;
    b. Identifying vehicles for scrappage programs;
    c. Evaluating the overall effectiveness of the Smog Check program;
    d. Improving the accuracy of the "high emitter index" used to identify vehicles that are likely to fail the Smog Check test; and

e. Characterizing emissions from subcategories of the California fleet.

Additional details regarding the capabilities of RSD are discussed in the rest of this report. Following is an overview of the current state of RSD technology. Then, conclusions about the ability of RSD to address each of the six objectives are presented. Recommendations are also made on how the Pilot Remote Sensing Study can be used to more completely address these objectives for the situation in California. Summaries of the major studies follow the conclusions.

State of Remote Sensing Device (RSD) Technology

Before we present our conclusions on what existing studies say about the six objectives of the project, we will discuss how they illuminate the overall state of RSD technology. The following issues will be addressed:

- Accuracy of Remote Sensing
- Representativeness of Remote Sensing Measurements
- Ability of Remote Sensing to Cover the Vehicle Fleet

Although these issues were not necessarily the object of the studies we reviewed, they were addressed in various ways. After having reviewed the studies, we were able to summarize these overarching issues.

Accuracy of Remote Sensing – Accuracy is a complex issue for remote sensing because of the following variables that go into emissions measurements:

a) instrument accuracy/error;

b) ambient variability and its impact on accuracy (e.g., turbulence, changes in relative humidity and/or temperature);

c) vehicle variability (poorly controlled vehicle operating conditions);

d) the ability to link speed and acceleration measurements to the vehicle operating condition that created the exhaust plume; and

e) transitional conditions causing the plume to have been created under more than 1 operating mode

There may be additional errors that have not been fully quantified, such as the effects of water in real vehicle exhaust versus dry gases used for calibration and audits. In addition, some researchers believe that there may be a "wake effect" causing the CO2 concentration to change in the wake of larger vehicles, affecting the ratio measurement.

It is the total of all of the above impacts that determine the accuracy of a particular test. Available literature indicates that remote sensing systems can measure HC, CO, and NOx emissions in a homogeneous and relatively static plume with error levels similar a garage analyzer. However, instrument error probably has the least impact on the overall error in RSD measurements. How the vehicle is driven has a major impact on accuracy. In RSD measurements, vehicle operating conditions are not controlled, except by limiting where the measurements are taken (e.g., certain lane configurations that limit driving behavior) and by post processing the data and eliminating data from vehicles under apparently extreme operating conditions and taking into account multiple RSD measurements on a given vehicle. I/M tests attempt to control the operating conditions of the vehicle and measure much more than the one-second of emissions that RSD measures. Therefore, I/M results on a given vehicle will tend to have less variability than RSD results.

Although current RSD technology can accurately measure speed and acceleration (see Appendix C), RSD systems cannot yet reliably determine the speed and acceleration of an individual vehicle *at the moment it produced the measured emissions*. It is important to know the speed and acceleration (which are used to determine the operating conditions of the vehicles engine) at the moment it produced the measured pollutants. At many RSD measurement sites operating conditions can change very rapidly and they greatly influence emissions. ,The current RSD systems do not account for the variable time lag between when emissions occur and when speed is measured. This transport time is a function of exhaust system volume and engine load. A system that captures a high-resolution speed profile just before the remote sensing measurement and accounts for a specific exhaust gas transport time for each vehicle test (by post-processing vehicle weight from a look-up table and the speed profile) would probably substantially improve our ability to interpret remote sensing data.

RSD studies can accurately estimate the average emissions of a group of vehicles (or one vehicle that has been measured several times) because, when the emissions of a group are averaged together, the random variability of individual measurements is cancelled-out. For example, when RSD measures a group of very clean vehicles, whose average hydrocarbon emissions are slightly above zero, many of the individual measurements will be below zero. Since those negative measurements are somewhat outnumbered by the positive measurements from the group, the average result for the group is positive. Again, the variability of these measurements is not because of the instrument, but because of the natural variations in ambient conditions around vehicles traveling in the roadway and how vehicles are driven.

When accurate emissions for a single measurement on a vehicle are required, the operating conditions of that vehicle at the moment the emissions were created in its engine are critical. When RSD is used to estimate emissions for groups of vehicles, better knowledge of operating conditions of individual vehicles would help the data analyst tighten the confidence limits around the average emissions estimates.

The concentration measurements made via remote sensors can be converted to a mass emissions rate based on an estimate of the fuel consumption associated with the operating mode under which the measurement was made. As mentioned above, however, These results are best used as averages from groups of vehicles. We cannot determine the vehicle speed and acceleration associated with the measured exhaust plume with sufficient precision to ensure accurate estimates of mass emissions rates for individual measurements.

Representativeness of Remote Sensing Measurements – Average emissions in "real-world" service are the result of a multitude of vehicle operating conditions including cold start and warm-up, idle, a wide range of accelerations and decelerations, a wide range of quasi-steady-state cruising, and low speed "creeping" in bumper-to-bumper traffic. In addition to exhaust emissions of HC, CO, and NOx, evaporative HC emissions occur both during vehicle operation and when the vehicle is parked. Because of the extreme variation in emissions as a function of operating mode, the test procedures used to determine whether vehicles meet applicable emission standards, and the test procedures used to determine the average emissions of vehicles in customer service, involve measuring emissions under a very wide range of operating conditions. In the case of the Federal Test Procedure ARB now uses for setting new car standards and for emissions inventory purposes, exhaust emissions are characterized under a range of speeds from 0 to 67 mph with acceleration rates ranging from decelerations to accelerations of up to 3 m/s^2. The complexity associated with these procedures is necessary because there is no single mode of operation, or narrow range of operation, that accurately represents average emissions. RSD measurement conditions typically are dominated by moderate loads because to improve measurement accuracy, sites are selected to maximize the number of observations at moderate loads. Therefore, average RSD emissions must be grouped and averaged by vehicle specific power (VSP)[1] (which requires sufficient measurements be made throughout the VSP range) to obtain a "representative" inventory estimate. Also, there is no remote sensing technology currently available that can measure evaporative emissions, crankcase emissions and liquid leaks, so emissions inventories of hydrocarbons based upon RSD measurements must use similar estimates for these emissions as are used for current inventory methods to estimate a complete HC inventory.

Notwithstanding the inability to characterize average emissions of a vehicle fleet with one or two operating modes, it was demonstrated during the development of the emissions test used in the Smog Check program that one or two light acceleration modes could reliably separate vehicles with low exhaust emissions from vehicles with serious exhaust emissions defects.[2] In addition, it is possible to establish correlations with average exhaust emissions in "real-world" service based on tests of large numbers of vehicles under narrowly defined acceleration modes. Therefore, it should be possible to use RSD for similar purposes. However, as noted above, this

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[1] Vehicle Specific Power (VSP) is an estimate of the load on a vehicle's engine. It is calculated from the speed and acceleration fo the vehicles and the slope of the roadway the vehicle is traveling along.

[2] Austin, Thomas C. et al, "An Evaluation of Loaded Mode I/M Testing at Service Stations," prepared for the California Bureau of Automotive Repair by Sierra Research, Sierra Report No. SR88-12-02, December 7, 1988.

is complicated by the limitation that current speed measurement systems used with RSD are not capable of determining the individual vehicle speed and load associated with the instant at which the exhaust plume was created.

Ability of Remote Sensing to Cover the Vehicle Fleet – Based on the requirements of remote sensing systems described above and based on the vehicle operating conditions that generate reasonable correlation with average emissions in urban driving, representative remote sensing measurements must be made at locations where vehicles are traveling single file and accelerating under a light load. Although certain freeway ramps are well-suited for remote sensing measurements, it is not currently feasible to deploy remote sensing systems or to collect representative emissions measurements at the following:

1. multi-lane ramps;
2. single-lane ramps where there is no space available for the safe deployment of remote sensing systems;
3. straight off-ramps or curved off-ramps with a down grade (that result in no significant vehicle operation with loads representative of mild accelerations);
4. on-ramps that routinely produce acceleration rates in excess of those well-correlated with average emissions in customer service;
5. on-ramps with a physical configuration (e.g., steep upgrade or short length after a sharp turn) that routinely results in engine load in excess of that which is well-correlated with average emissions in customer service; and
6. ramps that are routinely so congested that there is insufficient spacing between vehicles to obtain reliable remote sensing measurements.

Surface streets can also be used for remote sensing; however, suitable locations have relatively low traffic volume and do not service a significant fraction of the motor vehicle fleet. High volume, multilane roadways are not practical, at least during the peak travel periods. These restrictions limit the ability of RSD to get valid measurements on a majority of the vehicle fleet. The Virginia Pilot RSD study projected that to get at least one measurement on about 70% of the fleet, RSD must move from site to site and measure about double the number of vehicles that are in the entire fleet (i.e., many vehicles will have more than one measurement). Other researchers believe that a greater number of observations are needed to cover a majority of the fleet. In the reviewed literature no RSD program, including the two-year old, full-scale program in Missouri, had achieved 70% coverage. Between 5% and 20% of the fleet will never be measured by RSD, because they do not typically travel past sites that are suitable for the technology. For example, older vehicles tend not to travel on the highway as often as newer vehicles. Also, motorists can easily avoid RSD sites if they wish.

Conclusions on How RSD Can Meet Project Objectives

Based on past studies, we can draw the following conclusions concerning the ability of RSD to meet the different objectives of this study.

Identify high emitters for immediate testing/ Identify candidate vehicles for subsidized scrappage programs – Remote sensing measurements can be used to identify some of the vehicles with excessive tailpipe emissions that should receive a Smog Check in the near future. Since whether a vehicle can be classified as a “high emitter” or not depends upon the standards it was designed to meet, a “high emitter” manufactured recently may actually emit much less than an older high emitter. Below certain emission levels, RSD’s ability to distinguish between a “normal” emitter and a “high” emitter is greatly diminished, so newer vehicles may be difficult for RSD to identify as being high emitters.

Recent studies (see Appendix A) found that using RSD results in conjunction with other indicators can double the probability that a vehicle classified as a high emitter is indeed a high emitter. Researchers speculate that the pass/fail decision would be enhanced if it is based on emissions measured during a specific vehicle speed and load condition for which correlations with the Federal Test Procedure have been established. Practical constraints on RSD site locations limit fleet coverage, thereby limiting the ability of remote sensing systems to identify a majority of vehicles with excessive emissions. Also, a portion of motorists driving high emitting vehicles will likely avoid RSD once they know it will cause them an inconvenience. These same fleet coverage constraints limit the ability of RSD to identify candidate vehicles for scrappage programs (because RSD cannot identify them if it does not see them). However, if a program’s design does not require coverage of all or most of the fleet, then RSD will probably be adequate for identifying high emitters for immediate testing or scrappage, especially for Tier 1 and older vehicles.

Research Recommendation:

Future research could investigate the importance of precisely determining the operating conditions of a vehicle on the precision of RSD results. It this is found to be of practical importance, future research should investigate ways to improve the effectiveness of high emitter identification programs through better measurement technology (e.g. improved speed/acceleration measurements) and innovative RSD sites, such as unmanned bunkers and vertical laser beams for multi-lane measurements. It could also attempt to quantify RSD’s ability to identify recently manufactured vehicles as being high emitters.

Exempting vehicles from I/M testing (i.e., "clean screening) – Remote sensing measurements do not improve our ability to select candidates for exemption from I/M tests ("clean screen"). Studies find that clean screening based on model year or emissions index (e.g. HEI) has less emissions impact than clean screening based on RSD[3]. The HEI model ranks vehicles according to their probability of failing Smog Check. Furthermore, clean screening on the basis of model year or with the HEI can be done for minimal cost. None of the existing studies report the actual costs of using RSD to clean screen vehicles, but these costs should be available from the administrators of these programs.

In addition to being relatively expensive for this purpose, current remote sensing technology is not capable of detecting the following:

1. evaporative emissions defects,
2. many defects that are identified by OBDII systems (see end of Appendix A):
    a. defects related to evaporative system or cold start and warm-up,
    b. defects that cause a vehicle to be moderate emitters (>1.5 to 3 x stds), and
    c. defects in the monitoring system.

These defects can be detected in a conventional I/M test that includes OBDII inspections and functional evaporative emission system checks. As the vehicle fleet becomes lower emitting, this limitation of RSD will become greater unless new RSD technologies are developed which address this issue.

Many of the problems identified by OBDII inspections are component failures that may lead to high emissions later, but at the time of inspection the catalytic converter masks the problem. Like other emissions tests, RSD cannot identify vehicles with problems that are temporarily masked by the catalytic converter. By the time most vehicles show high enough emission levels to register a high RSD reading, they will likely have serious emission related problems. These vehicles should not be clean screen candidates.

The literature review did not produce enough information about the use of Smart Signs (devices which tell motorists the result of an RSD measurement on their vehicle as they drive past) to include an informed summary of their utility in attaining the goals of this study.

[3] Profiling and Prediction of Individual Virginia Vehicle ASM Pass/Fail Results, TECHNICAL NOTE, Prepared by ERG, December 24, 2003.

Research Recommendation:

Future research should quantify the actual costs of operating an RSD based clean screen program, based on programs in Colorado and Missouri program results. Also, methods to remotely monitor OBDII system status should be investigated.

Improve the high emitter index model (HEI) used in California to select vehicles for testing in test-only stations – Remote sensing measurements provide an independent indicator of which vehicles are likely to be high emitters. Currently, the primary input into the HEI is failure probability (Fprob) based on Smog Check results. This statistic can be biased based on where the vehicle is tested. Developing Fprobs based on RSD test results could probably improve the accuracy of the HEI.[4] Using RSD Fprobs to improve the HEI does not depend upon the ability to cover a majority of the vehicle fleet, unlike using RSD to identify a high emitter for immediate testing. Many RSD test results (probably a few million) should suffice for improving Fprobs. In addition to developing RSD based Fprobs for the HEI, emission measurements on vehicles that are seen by RSD can improve the HEI in the same way that they can improve our ability to select high-emitting vehicles for off-cycle testing. Whether the degree of improvement will be significant or cost effective is not clear.

Research Recommendation:

Future research can develop and test new HEI approaches that use Fprobs which have been augmented by RSD measurements.

Evaluate the overall effectiveness of Smog Check program – Remote sensing can be used to estimate step changes in vehicle emissions before and after I/M. The inability of remote sensing systems to precisely measure emissions from *individual* Low Emission Vehicles does not necessarily limit the ability of remote sensing measurements to determine fleet average impacts. It is, however, important that a sufficiently large and representative sample of the fleet be measured to ensure that the emissions averages have low enough uncertainty levels.

Variations in emissions caused by differences in gasoline specifications and vehicle operation will impact the extent to which remote sensing can be used to compare average emission levels for I/M and non-I/M communities. Currently, methodologies have not been developed to account for differences in fuel specifications and operational variables. This is a concern because these factors can impact vehicle emissions as much as or more than an I/M

[4] RSD Fprobs along with Fprobs based on Smog Check results would be used along with other parameters in the HEI to select vehicles that must receive inspections at designated testing facilities.

program. Outside of California, fuel specification differences limit the ability of remote sensing to evaluate I/M program performance using the so-called "Reference" method (described in EPA guidance), because most areas without I/M programs do not require the use of reformulated gasoline while areas with I/M programs often do require reformulated gasoline. Since the theoretical benefits of I/M are in the same range as the theoretical benefits for reformulated gasoline[5], the potential for fuel specification differences to confound the comparison of remote sensing data is considerable. Similarly, relatively small changes in vehicle operation can cause differences in emissions that exceed the potential changes caused by an I/M program. As with gasoline specification differences, no quantitative method has yet been developed to account for differences in average vehicle speeds and acceleration rates occurring between sites.

Research Recommendation:

Future research could evaluate ways to adjust readings to account for differences in fuels and vehicle operating conditions. In addition, future research could investigate the ability of RSD to evaluate I/M effects on LEVs

Characterize emissions in subcategories of the California fleet – With appropriate weighting by VSP, remote sensing measurements can be used to estimate average exhaust emissions from a population of vehicles. If RSD systems are improved to enable determination of vehicle operating conditions at the moment the measured exhaust was created, the confidence limits on those averages will be improved (i.e., narrowed). Concerns have been raised that remote sensing systems cannot accurately measure the fleet emissions of Low Emission Vehicles, where total emissions are dominated by cold start conditions. However, most researchers agree that RSD can be used to estimate the percent of gross polluting LEVs, which will be a useful parameter when estimating fleet emissions. To more accurately identify vehicles with high emissions, RSD should be improved to determine the operating conditions of the vehicle at the moment it created the measured pollutants.

Research Recommendation:

Future research could determine the feasibility of estimating California fleet emissions with RSD systems that include higher resolution speed measurement, the estimation of exhaust transport time in the exhaust system, and the development of correlations for the specific vehicle speed and load condition associated with the plume being measured.

[5] The EPA regulation describing the performance standard for reformulated gasoline specifies emissions reductions of more than 25% for HC and 5% for NOx. The California reformulated gasoline specifications provide for even greater control.

Summary of Major RSD Studies and Projects

Following is a summary of major RSD reports and projects. Appendixes A through C provide new analysis of previously collected data. Appendix D presents an annotated bibliography of major RSD reports.

Table 1 summarizes the major RSD studies and projects that were reviewed as part of this task. This table indicates which objectives were addressed by each project and whether the study supported the application of RSD for this purpose. Summaries of each individual study follow the table.

Table 1 – Summary of Major RSD Studies and Projects

Study	Objectives Addressed (Various uses of RSD)
1. The Denver Remote Sensing Clean Screening, ESP, CDPHE	**1. Identify high emitters for immediate testing:** Supported application of RSD for this purpose. **2. Exempt vehicles from I/M testing (i.e., clean screening):** Supported application of RSD for this purpose.
2. Infrared Remote Sensing Of On-Road Motor Vehicle Emissions In Washington State, WA Dept of Ecology	**1. Identify high emitters for immediate testing:** Did not address except for projecting coverage. **2. Exempt vehicles from I/M testing (i.e., clean screening):** Did not support application of RSD for this purpose.
3. Oregon Remote Sensing Study, OR DEQ	**5. Evaluate the overall effectiveness of Smog Check program:** Did not feel RSD worked well enough to evaluate I/M program.
4. Virginia Remote Sensing Device Study, ESP/VA	**1. Identify high emitters for immediate testing:** Supported application of RSD for this purpose. **2. Exempt vehicles from I/M testing (i.e., clean screening):** Not addressed but provided data. **4. Improve the high emitter profile (HEI) used in California to select vehicles for testing in test-only stations:** Supported application of RSD for this purpose. **5. Evaluate the overall effectiveness of Smog Check program:** Supported application of RSD for this purpose.
5. Evaluation of On-Board Monitoring Devices for Qualifying Taxis, CA ARB	**1. Identify high emitters for immediate testing:** Supported application of RSD for this purpose (1996+ only). **2. Exempt vehicles from I/M testing (i.e., clean screening):** Supported application of RSD for this purpose.

Table 1 (continued) – Summary of Major RSD Studies and Projects

Study	Objectives Addressed (Various uses of RSD)
6. Gateway Clean Air Program, ESP/MO	**1. Identify high emitters for immediate testing:** Not addressed but provided data. **2. Exempt vehicles from I/M testing (i.e., clean screening):** Supported application of RSD for this purpose. **5. Evaluate the overall effectiveness of Smog Check program:** Not addressed but provided data. **6. Characterize emissions in subcategories of the California fleet:**
7. Remote Sensing Device High Emitter Identification With Confirmatory Roadside Inspection, CA BAR	**1. Identify high emitters for immediate testing:** Supported application of RSD for this purpose.
8. On-Road Remote Sensing of Automobile Emissions in the Chicago Area, Univ. of Denver	**1. Identify high emitters for immediate testing:** Not addressed but provided data.
9. Evaluation of Remote Sensing in AZ, ERG/AZDEQ	**1. Identify high emitters for immediate testing:** Did not support application of RSD for this purpose. **4. Improve the high emitter profile (HEI) used in California to select vehicles for testing in test-only stations:** RSD helped refine HEI for dirty screen but not clean screen.
10. Using Remote Sensing Devices (RSD) to Evaluate the California Smog Check Program, Radian/BAR	**5. Evaluate the overall effectiveness of Smog Check program:** Quantified I/M reductions using RSD.
11. On-Road Emissions Changes Due to IM240 Inspection/Maintenance and Oxygenated Fuel Program, CDPHE	**5. Evaluate the overall effectiveness of Smog Check program:** Supported application of RSD for this purpose.
12. Analysis of Data from the California I/M Pilot Program/Assessment of RSD, Sierra/EPA	**1. Identify high emitters for immediate testing:** Did not support application of RSD for this purpose. **2. Exempt vehicles from I/M testing (i.e., clean screening):** Did not support application of RSD for this purpose. **5. Evaluate the overall effectiveness of Smog Check program:** Did not support application of RSD for this purpose.

Detailed Tables on RSD Projects

The following tables provide details on the major studies reviewed in this task.

1. The Denver Remote Sensing Clean Screening Pilot. Prepared for: The Colorado Department of Public Health and Environment, Prepared by: Peter M McClintock, Ph.D., Applied Analysis, 891 Tiburon Blvd., Tiburon CA 94920, (415) 435-8301, December, 1999
• **Purpose:** The purpose of the Denver Remote sensing clean screen pilot was to determine the feasibility and the technical parameters for using remote sensing in the Denver metro area to identify vehicles that are low in emissions and waive them from I/M inspection.
• **Conclusions Relative to 6 CA Pilot RSD Study Objectives:** **1. Identify high emitters for immediate testing:** Although the project concentrated on clean screen, the benefits of high emitter identification were investigated. Requiring high emitters to pass an unscheduled IM240 inspection would result in emission reductions that more than offset the loss of benefit from clean screen. **2. Exempt vehicles from I/M testing (i.e., clean screening):** The study demonstrated that about half of the vehicles could be clean screened with 10% loss in program benefits for HC, CO, and NOx. If profiling were combined with clean screening the benefit loss would drop to 5%. The study did not investigate profiling alone as a clean screen tool. **3. Identify candidate vehicles for subsidized scrappage programs:** Not addressed. **4. Improve the high emitter profile (HEI) used in California to select vehicles for testing in test-only stations:** Not addressed. **5. Evaluate the overall effectiveness of Smog Check program:** Not addressed. **6. Characterize emissions in subcategories of the California fleet:** Not addressed.
• **Did study demonstrate a cost-effective and practical application for RSD?** The study concluded that clean screen was feasible. The cost-effectiveness of clean screen was not evaluated, but the State expects that the fee will need to be increased to cover clean screen costs.
• **Were program options implemented?** The State of Colorado is in the process of implementing an RSD based clean screen program in the Denver metropolitan area.
• **Peer Review Process:** None known
• **Data Collection Protocols:** ESP protocols, Certification with audit vehicles having known gases: Calibration at beginning of day and every two hours
• **Equipment:** RSD3000
• **Data Availability:** Contact CDPHE, Rick Barrett
• **Measurement:** CO2, CO, NO, HC, speed & acceleration, road grade, vehicles linked with IM240 data; Ambient data (temperature, humidity, pressure) from April 16, 1999. Over 150,000 on-road remote sensing records were collected between December 1998 and October 1999. Of these, 103,000 had readable Colorado plates with valid emissions measurements and 94,000 were matched to current registrations. For comparative analysis, 13,600 initial IM240 inspections were identified that occurred some time after an on-road remote sensing measurement. Additional matched IM240 results will accumulate over time as vehicles measured by remote sensing continue to come in for their scheduled I/M inspections. In addition, 1900 vehicles were measured by remote sensing on inspection station entrance roads so the remote sensing measurement could be compared to an IM240 inspection following within a very short time.
• **Comparisons:** Greeley and Denver pilot programs

1. The Denver Remote Sensing Clean Screening Pilot. Prepared for: The Colorado Department of Public Health and Environment, Prepared by: Peter M McClintock, Ph.D., Applied Analysis, 891 Tiburon Blvd., Tiburon CA 94920, (415) 435-8301, December, 1999
• **Data Collection Dates and Locations:** December 1998 to October 1999; 6 carefully selected sites used. Locations described in the report
• **Other --** Description of Sample Site Characteristics: Site selection is critical to obtaining remote sensing measurements that are representative of vehicle operation. Recommended site attributes include: (1) Absence of cold start vehicle operating conditions; (2) Sites where vehicles will be accelerating or driving at a steady speed uphill; to avoid the highly variable tailpipe emissions that can occur under deceleration; (3) Absence of enrichment due to high load conditions; (4) Single lane operation; (5) High volume traffic; (6) Unobtrusive siting of the remote sensing equipment; (7) Adequate median space for safe operation of the RSD equipment. Report includes an appendix with derivation of VSP and calculation of the VSP in the IM240 commenting on difference in rolling resistance on dynamometers compared to on-road experience

2. Infrared Remote Sensing Of On-Road Motor Vehicle Emissions In Washington State, March, 1999, Kerry L. Swayne, Air Quality Program Washington State Department of Ecology, Northwest Regional Office, 3190 160th Ave. S.E., Bellevue, WA 98008-5452, 425-649-7101, kswa461@ecy.wa.gov, Publication #99-204
• **Purpose:** The Washington State Department of Ecology conducted a pilot study to evaluate the usefulness of remote sensing as a compliment to its existing I/M program.
• **Conclusions Relative to 6 CA Pilot RSD Study Objectives:** **1. Identify high emitters for immediate testing:** The effectiveness of RSD in identifying high emitters was not addressed. However, Ecology projected that 35 million readings would be needed to get RSD results on the 800,000 now being inspected annually. **2. Exempt vehicles from I/M testing (i.e., "clean screening"):** Reducing model year coverage and test frequency was deemed to be a better method than RSD to improve customer convenience. **3. Identify candidate vehicles for subsidized scrappage programs:** Not addressed. **4. Improve the high emitter profile (HEI) used in California to select vehicles for testing in test-only stations:** Not addressed. **5. Evaluate the overall effectiveness of Smog Check program:** Not addressed. **6. Characterize emissions in subcategories of the California fleet:** Not addressed.
• **Did study demonstrate a cost-effective and practical application for RSD?** Ecology concluded that remote sensing would provide no practical benefit to Washington's emission check program. The cost to collect enough valid observations exceeded the cost of testing the vehicles in conventional I/M facilities.
• **Were program options implemented?** No
• **Peer Review Process:** None known
• **Data Collection Protocols:** Unknown
• **Equipment:** Hughes Smog Dog
• **Data Availability:** Unknown
• **Measurement:** Valid measurements required CO2, CO, NO, HC, speed, acceleration. VSP was not calculated study; was done in 1996). No evidence of ambient measurements. 201,581 total readings taken; 137,523 (68% of the total) of these readings were valid. A reading was invalid if it lacked any of the following: License plate number, Any of the pollutants measured, Speed or acceleration within the specified range. 64,028 (32% of the total) of the readings met the study's requirement that the measured vehicle appear on record as having had an Emission Check inspection within the previous two years. 4,539 vehicles had three or more valid readings. The ratio between readings taken and vehicles with at least three valid readings was: Two percent of all readings taken, Three percent of the valid readings, Seven percent of the readings that met the study requirements.
• **Comparisons:** None
• **Data Collection Dates and Locations:** August and September of 1996. 6 freeway ramp sites with single traffic lane, slight incline, traffic mainly in light acceleration, and moving at 25-35 mph,

3. Vehicle Emission Testing using a Remote Sensing Device (RSD), Demonstrating the Value of Routine Vehicle Maintenance & Providing Initial Quantification of Vehicle Emissions in Pendleton, Bend and LaGrande, Oregon, September 2003, Vehicle Inspection Program Report, State of Oregon, Department of Environmental Quality
• **Purpose:** The purpose of this study was to quantify differences in emission levels for I/M and non-I/M areas.
• **Conclusions Relative to 6 CA Pilot RSD Study Objectives:** **1. Identify high emitters for immediate testing:** Not addressed. **2. Exempt vehicles from I/M testing (i.e., "clean screening"):** Not addressed. **3. Identify candidate vehicles for subsidized scrappage programs:** Not addressed. **4. Improve the high emitter profile (HEI) used in California to select vehicles for testing in test-only stations:** Not addressed. **5. Evaluate the overall effectiveness of Smog Check program:** The study was unable to collect enough valid observations to project any significant differences between I/M and non-I/M areas. **6. Characterize emissions in subcategories of the California fleet:** Not addressed.
• **Did study demonstrate a cost-effective and practical application for RSD?** No
• **Were program options implemented?** No
• **Peer Review Process:** None known
• **Data Collection Protocols:** Unknown
• **Equipment:** MDLaserTech
• **Data Availability:** Unknown
• **Measurement:** DEQ tested 19,630 vehicles during this study to achieve the 2805 useable vehicle tests. This is an effectiveness rate of just over 14 percent. A good effectiveness rate is approximately 40 percent. The low effectiveness rate may be a result of testing at locations that did not provide for proper vehicle speed and acceleration. Instrument measured HC, CO, CO2, NO. Speed and acceleration were measured.
• **Comparisons:** None
• **Data Collection Dates and Locations:** The testing occurred in the Pendleton area during May 14-24, 2003, in the Bend area during June 4-14, 2003 and in the LaGrande area during August 6-17, 2003. Seven different locations in Pendleton, four locations in Bend and ten locations in LaGrande.
• **Other --** DEQ reported results of the study to the EPA in November 2001, in a report titled Voluntary Vehicle Emission Testing by Remote Sensing with Repair Incentives, Does It Work? (November 2001). This report concludes that an RSD testing program with an on-road visual display of vehicle pollution levels coupled with voluntary repairs may be able to achieve a "4 percent reduction in overall fleet emissions" in the Bend area. This compares to an estimated 20 percent reduction that can be achieved with a mandatory "basic" test program (examines vehicles only at idle) and a 30 percent reduction for an "enhanced" test program (examines vehicles while under load on a treadmill). The report also concluded that a "voluntary RSD program is less cost-effective than a mandatory I/M program in reducing vehicle emissions."

4. Virginia Remote Sensing Device Study – Final Report, Prepared for: Virginia Department of Environmental Quality February 2003, Peter McClintock and Rob Klausmeier, for ESP, 2002 North Forbes Blvd., Tucson, AZ 84745

• **Purpose:** DEQ intends to use information gathered during this study to:

1. Compare the emission test results from the existing I/M program area with the emissions as measured by remote sensing,
2. Determine the overall feasibility and cost effectiveness of operating a future comprehensive remote sensing program in the Northern Virginia Enhanced I/M Program area,
3. Determine the percent of "transient vehicles" not registered in the I/M program area and determine which of these are habitual commuters,
4. Assess fleet emissions in the existing northern Virginia I/M area,
5. Draw conclusions as to the effectiveness of the existing I/M program, and
6. Assess the vehicle miles traveled (VMT) distribution of vehicles within the I/M area by vehicle age and body style.

• **Conclusions Relative to 6 CA Pilot RSD Study Objectives:**

1. Identify high emitters for immediate testing: By combining remote sensing results with the high emitter index, it is possible to identify a relatively small fraction of the fleet (15%) that contains approximately 60% of the excess HC and NOx emissions.

2. Exempt vehicles from I/M testing (i.e., "clean screening"): Not directly addressed by report. The Virginia study collected data that can be used to evaluate the feasibility of exempting vehicles from I/M testing based upon RSD results and vehicle profile.

3. Identify candidate vehicles for subsidized scrappage programs: Not addressed.

4. Improve the high emitter profile (HEI) used in California to select vehicles for testing in test-only stations: Analysis of data in the Virginia program found that remote sensing significantly improves the ability of high emitter index model to identify new high emitters (see Appendix A).

5. Evaluate the overall effectiveness of Smog Check program: Emission levels recorded in I/M areas were much lower than those recorded in non-I/M areas. Even after correcting for differences in fleet composition (e.g., model year), emissions from I/M vehicles were 20 to 30% lower than emissions from non-I/M vehicles.

6. Characterize emissions in subcategories of the California fleet: Not addressed.

• **Did study demonstrate a cost-effective and practical application for RSD?** Cost-effectiveness was not specifically addressed. Subsequent analysis of the data indicates that using RSD to identify high emitting vehicles can reduce the cost per ton of pollutant removed compared to testing all vehicles.

• **Were program options implemented?** Virginia is in the process of implementing a program to identify high emitters registered in and outside the I/M program area and require that they pass an emission test.

• **Peer Review Process:** None known

• **Data Collection Protocols:** Audit and calibration protocols described in detail, similar to OREMS. Calibration once in the morning and at mid-day if conditions warrant. Audit trucks checked quarterly.

• **Equipment:** RSD4000

4. Virginia Remote Sensing Device Study – Final Report, Prepared for: Virginia Department of Environmental Quality February 2003, Peter McClintock and Rob Klausmeier, for ESP, 2002 North Forbes Blvd., Tucson, AZ 84745
• **Data Availability:** Contact Virginia DEQ, Rich Olin
• **Measurement:** Over 900,000 measurements were made. Fuel specific concentrations of HC, CO, CO_2, NOx and smoke are measured in vehicle exhaust plumes based on their absorption of IR/UV light in the dual beam path. The data-recording device captures an image of the rear of the vehicle, while the Speed & Acceleration Detector measures the speed of each vehicle. Meteorological measurements are not mentioned.
• **Comparisons:** None
• **Data Collection Dates and Locations:** In total, 87 sites were used, 59 sites in northern Virginia and the Fredericksburg area, 23 sites in the Richmond area and 5 sites in Washington DC.
• **Other --** The agreed site visit strategy was to visit each site on two successive days twice during the data collection phase for a total of four collection days per site. This provided a good balance of general fleet coverage as well as a significant number of vehicles with multiple measurements that have been used to assess the effectiveness of alternative high emitter and low emitter identification protocols. 7 sites had two RSD units measuring vehicles on one date at the same time. The high emitter index in this analysis was based upon ASM tests conducted in the northern Virginia I/M program. Vehicles falling into the high emitter index were those that had high failure rates in the northern Virginia program.
• Post data processing: ESP applied the following screening checks to the RSD measurements to ensure the data used for fleet evaluation and fleet comparisons are reasonable and consistent: Screening of exhaust plumes; Screening of hourly observations to check for cold starts; Screening of high values; Screening of day-to-day variations in emissions values; Screening for Vehicle Specific Power (VSP) range

5. Evaluation of On-Board Monitoring Devices for Qualifying Taxis, Networkcar, Inc. February 28, 2003
• **Purpose:** The purpose of this study was to evaluate the feasibility of remotely monitoring OBD status by using the Networkcar system to continuously record OBD faults.
• **Conclusions Relative to 6 CA Pilot RSD Study Objectives:** **1. Identify high emitters for immediate testing:** The study demonstrated the feasibility of identifying vehicles with OBD faults. Overall emissions were reduced by more than 50% by fixing these vehicles. **2. Exempt vehicles from I/M testing (i.e., "clean screening"):** The study demonstrated that it is feasible to exempt vehicles from I/M testing as long as they do not have any continuous faults in the system. **3. Identify candidate vehicles for subsidized scrappage programs:** Not addressed. **4. Improve the high emitter profile (HEI) used in California to select vehicles for testing in test-only stations:** Not addressed. **5. Evaluate the overall effectiveness of Smog Check program:** Not addressed. **6. Characterize emissions in subcategories of the California fleet:** Not addressed.
• **Did study demonstrate a cost-effective and practical application for RSD?** The study did not demonstrate that the Networkcar device is a cost-effective alternative to periodic I/M test.
• **Were program options implemented?** The Networkcar device continues to be installed on taxis and other high mileage vehicles. Some municipality, for example Oakland, require that taxis and similar vehicles have these devices if they are to serve airports.
• **Peer Review Process:** None known
• **Data Collection Protocols:** Data were collected from 691 vehicles and stored in Networkcar's database. In addition, FTPs were performed at ARB's laboratory in El Monte.
• **Equipment:** Networkcar OBDII monitoring device was installed in participating vehicles.
• **Data Availability:** Contact ARB.
• **Measurement:** OBDII codes, ASM results and FTP results.
• **Comparisons:** None performed
• **Data Collection Dates and Locations:** December 2002 to present.
• **Other**

6. Gateway Clean Air Program, Annual RapidScreen Report, January – December 2002; ESP Missouri, Inc., Prepared for: Missouri Department of Natural Resources, Prepared by: Peter M McClintock, for ESP, July 2003.
• **Purpose:** The Gateway Clean Air Program includes a remote sensing triggered clean screen option. The purpose of the study was to evaluate the emissions impact of clean screen.
• **Conclusions Relative to 6 CA Pilot RSD Study Objectives:** **1. Identify high emitters for immediate testing:** Although the report did not directly address identifying high emitters, data from the Gateway Clean Air Program can assess the feasibility of using remote sensing to identify high emitting vehicles, including vehicles equipped with OBDII systems. **2. Exempt vehicles from I/M testing (i.e., clean screening):** The study demonstrated that even with clean screening, the Gateway Clean Air Program retained 97% of the HC tailpipe reductions, 85% of the gas cap related HC reductions, 98% of the CO reductions, and 92% of the NOx reductions. **3. Identify candidate vehicles for subsidized scrappage programs:** Not addressed. **4. Improve the high emitter profile (HEI) used in California to select vehicles for testing in test-only stations:** Not addressed. The study developed the low emitter index, which is a table indexed by vehicle model year, make and model. It contains estimates of failure rates and repairable emissions for each make/model based on the results of recent IM240 tests. **5. Evaluate the overall effectiveness of Smog Check program:** Data from the Gateway Clean Air Program can be used to evaluate the impact of I/M on vehicle emissions. **6. Characterize emissions in subcategories of the California fleet:** Not addressed.
• **Did study demonstrate a cost-effective and practical application for RSD?** Currently, motorists pay the same fee to opt for clean screening as they would if they showed up for emission testing at a stationary test lane. The study did not demonstrate that clean screen overall could be done for less cost than testing all vehicles.
• **Were program options implemented?** The Gateway Clean Air Program with Rapid Screen is underway.
• **Peer Review Process:** None known
• **Data Collection Protocols:** ESP Missouri subcontracted Remote Sensing Air to provide RSD data management and quality assurance functions for the RapidScreen program. Procedures include dry gas audits of RSD units, tracking measurements, tag editor training and review.
• **Equipment:** RSD3000
• **Data Availability:** Contact Missouri DNR, Haskins Hobson
• **Measurement:** Over 4.9 million on-road measurements were made in the January-December 2002 period, 65% (3.2 million) had Missouri plates entered and 56% (2.7 million) were matched to Missouri registrations. RSD Unit, road grade, Date and Time, Vehicle Plate, HC, CO, CO2, NOx, speed and acceleration. Meteorological measurements do not appear to have been made but should be available from the St. Louis airport.
• **Comparisons:** Similar reports in 2001 and 2000 on the Missouri RapidScreen program

6. Gateway Clean Air Program, Annual RapidScreen Report, January – December 2002; ESP Missouri, Inc., Prepared for: Missouri Department of Natural Resources, Prepared by: Peter M McClintock, for ESP, July 2003.
• **Data Collection Dates and Locations:** 71 sites were used in and around St. Louis, MO, in the January-December 2002 period
• **Other --** The low emitter index is a table indexed by vehicle model year, make and model. It contains estimates of failure rates and repairable emissions for each make/model based on the results of recent IM240 tests. It was initially developed using results from two million tests performed during 1999 in Colorado and Illinois. The low emitter index was updated in January 2002 using results from Missouri and Colorado tests performed in 2001. No sites had two RSD units measuring vehicles on one date at the same time.
• **Post data processing:** VSP outside of the 3 to 23 kW/t range only produces higher emissions.

7. Remote Sensing Device High Emitter Identification With Confirmatory Roadside Inspection, Bureau of Automotive Repair Engineering and Research Branch, August 2001
• **Conclusions Relative to 6 CA Pilot RSD Study Objectives:** **1. Identify high emitters for immediate testing:** BAR concluded that vehicles with ASM emissions levels can be identified by RSD. Over 80% of the vehicles identified as having high RSD emissions failed ASM standards when tested immediately after being observed by RSD. **2. Exempt vehicles from I/M testing (i.e., clean screening):** Not addressed. **3. Identify candidate vehicles for subsidized scrappage programs:** Not addressed. **4. Improve the high emitter profile (HEI) used in California to select vehicles for testing in test-only stations:** Not addressed. **5. Evaluate the overall effectiveness of Smog Check program:** Not addressed. **6. Characterize emissions in subcategories of the California fleet:** Not addressed.
• **Did study demonstrate a cost-effective and practical application for RSD?** No.
• **Were program options implemented?** No.
• **Peer Review Process:** Reviewed by BAR staff.
• **Data Collection Protocols:** Beginning on May 23, 2000, BAR's air quality representatives (AQRs) used RSD to identify and a portable BAR-97 EIS to inspect targeted vehicles. During the study, BAR visited several Southern California enhanced area sites. The typical lane configuration included two Fuel Efficiency Automobile Test (FEAT) remote sensing devices, placed upstream of the roadside inspection equipment. Upon viewing emission readings exceeding pre-determined levels, the RSD operator radioed the California Highway Patrol (CHP) officer to pull over each high emitting vehicle for immediate roadside inspection.
• **Equipment: Two** University of Denver FEAT devices.
• **Data Availability:** Contact BAR
• **Measurement:** 18,476 valid RSD records (HC, CO and nitric oxide (NO) in percent) and 326 vehicles had RSD and ASM records.
• **Data Collection Dates and Locations:** Data collected in Southern California in a two month period during beginning May 2000.
• **Post data processing:** Analysis of cutpoints.

8. On-Road Remote Sensing of Automobile Emissions in the Chicago Area: Year 4; Sajal S. Pokharel, Gary A. Bishop and Donald H. Stedman; August 2001, Prepared for: Coordinating Research Council, Inc., Contract No. E-23-4. Similar CRC E-23 reports released as of January 2004 include: 5 from Chicago (1997, 1998, 1999, 2000, 2002), 4 from Denver (1999, 2000, 2001, 2003), 3 from LA Riverside (1999, 2000, 2001), 1 from LA La Brea (2001), and 4 from Phoenix (1998, 1999, 2000, 2002)

• **Purpose:** The purpose of this study was to determine trends in vehicle emissions over a four-year period.

• **Conclusions Relative to 6 CA Pilot RSD Study Objectives:**

1. Identify high emitters for immediate testing: Although this study did not investigate the effectiveness of remote sensing in identifying high emitters, subsequent studies of remote sensing emissions in Illinois (and Indiana) found that vehicles failing remote sensing tests are three times more likely to fail an I/M test, including an OBDII test.

2. Exempt vehicles from I/M testing (i.e., clean screening): The study provided data for clean screen, but the effectiveness of clean screen was not evaluated.

3. Identify candidate vehicles for subsidized scrappage programs: Not addressed.

4. Improve the high emitter profile (HEI) used in California to select vehicles for testing in test-only stations: Not addressed.

5. Evaluate the overall effectiveness of Smog Check program: Not addressed.

6. Characterize emissions in subcategories of the California fleet: Not addressed.

• **Did study demonstrate a cost-effective and practical application for RSD?** No

• **Were program options implemented?** None were recommended, but RSD continues to be used in the Chicago area to chart trends in vehicle emissions.

• **Peer Review Process:** CRC Real World Vehicle Emissions and Emissions Modeling Group

• **Data Collection Protocols:** CRC E-23 Protocol; described in Appendix B of "Remote Sensing Measurement of Real World Vehicle High Exhaust Emitters," Interim Report, R. S. Slott, April 2002, Prepared for: Coordinating Research Council, Inc., Contract No. E-23.

• **Equipment:** DU remote sensors

• **Data Availability:** All data and all reports are available at http://www.feat.biochem.du.edu/reports.html

• **Measurement:** 22,065 records with make and model year information and valid measurements for at least CO and CO2. Measurements made include CO2, CO, HC, NO, speed, acceleration, road grade. Temperature and humidity recorded hourly.

• **Comparisons:** Four other reports on remote sensing in Chicago (1997, 1998, 1999, 2000)

• **Data Collection Dates and Locations:** Measurements were made on four consecutive weekdays, from Monday, September 11 to Thursday, September 14 between the hours of 8:30 am and 7:00 pm. The measurement location used in this study was the on-ramp from Algonquin Rd. to eastbound I-290 (S.H. 53) in northwest Chicago. The setup of the cones and equipment was kept as close to that of the previous years.

8. On-Road Remote Sensing of Automobile Emissions in the Chicago Area: Year 4; Sajal S. Pokharel, Gary A. Bishop and Donald H. Stedman; August 2001, Prepared for: Coordinating Research Council, Inc., Contract No. E-23-4. Similar CRC E-23 reports released as of January 2004 include: 5 from Chicago (1997, 1998, 1999, 2000, 2002), 4 from Denver (1999, 2000, 2001, 2003), 3 from LA Riverside (1999, 2000, 2001), 1 from LA La Brea (2001), and 4 from Phoenix (1998, 1999, 2000, 2002)
• **Other --** Two remote sensing instruments were used to measure the same vehicles at the same site at the same time in the report "On-Road Remote Sensing of Automobile Emissions in the Phoenix Area: Year 3," Sajal S. Pokharel, Gary A. Bishop and Donald H. Stedman, May 2002, Prepared for: Coordinating Research Council, Inc., Contract No. E-23-4. The two units were placed at two different distances apart on different days. "Quality Assurance Narrative, Standard Operating Procedures, Help Notes, Roadside Check List," for the DU remote sensors , Updated November 2003, is available at http://www.feat.biochem.du.edu/
• **Post data processing:** Comparisons to previous measurements at the same site were made with and without adjusting the VSP distribution of the vehicles measured.

9. Evaluation of Remote Sensing in AZ, ERG, Prepared for: Arizona Department of Environmental Quality, June 27, 2002.
• **Purpose:** The purpose of the remote sensing evaluation that was performed as part of AZACTS was to evaluate RSD was a strategy to further reduce vehicle emissions in Arizona.
• **Conclusions Relative to 6 CA Pilot RSD Study Objectives:** **1. Identify high emitters for immediate testing:** The study concentrated on how to improve the accuracy of remote sensing, and included comparisons of emission levels reported by different remote sensing systems. This study did not specifically address identifying high emitters for immediate testing. Previous studies by ERG for Arizona found that remote sensing had to be combined with vehicle emission profiling to be able to identify high or low emitting vehicles with any degree of precision. **2. Exempt vehicles from I/M testing (i.e., "clean screening"):** Not addressed. **3. Identify candidate vehicles for subsidized scrappage programs:** Not addressed. **4. Improve the high emitter profile (HEI) used in California to select vehicles for testing in test-only stations:** Previous studies found that remote sensing improves the accuracy of the high emitter index model in identifying vehicles that should be tested at test-only stations. **5. Evaluate the overall effectiveness of Smog Check program:** Not addressed. **6. Characterize emissions in subcategories of the California fleet:** Not addressed.
• **Did study demonstrate a cost-effective and practical application for RSD?** No.
• **Were program options implemented?** RSD based high-emitter program was cancelled.
• **Peer Review Process:** None known
• **Data Collection Protocols:** Three contractors, ESP, MD-LaserTech, and Denver University, each used their own data collection protocols.
• **Equipment:** ESP - RSD3000, MD-LaserTech - Inspector IV, DU FEAT
• **Data Availability:** Contact AZDEQ
• **Measurement:** 170,000 measurements, 110,000 had valid NO, CO, CO2, HC, speed and acceleration measurements, and 77,000 were matched with Arizona license plates. Meteorological measurements (temperature, humidity) were apparently not measured. DU had high noise and an offset in its HC channel. MD-Laser Tech had a high bias in its CO readings.
• **Comparisons:** Measurements were compared between commercial vendors and DU. Agreement was best when measuring NOx
• **Data Collection Dates and Locations:** 16 sites in Arizona in 2001. 5 sites were in Casa Grande, 7 in Phoenix, and 4 in Tucson. Measurements were made between August and December 2001.
• **Other --** Two instruments were at each site measuring vehicles simultaneously except for two days in Phoenix when ESP measured along. The DU instrument served as a referee instrument for the two commercial RSD manufacturers. MD-LaserTech's instrument measures speed before the exhaust is measured, DU and ESP measures speed after the exhaust is measured.

10. Using Remote Sensing Devices (RSD) to Evaluate the California Smog Check Program, Rob Klausmeier and Chris Weyn, prepared for California Bureau of Automotive Repair, October 2, 1997
• **Purpose:** The purpose of this study was to analyze data collected in California's OREMS project to determine the benefits of the California Smog Check program.
• **Conclusions Relative to 6 CA Pilot RSD Study Objectives:** **1. Identify high emitters for immediate testing:** Not addressed. **2. Exempt vehicles from I/M testing (i.e., "clean screening"):** Not addressed. **3. Identify candidate vehicles for subsidized scrappage programs:** Not addressed. **4. Improve the high emitter profile (HEI) used in California to select vehicles for testing in test-only stations:** Not addressed. **5. Evaluate the overall effectiveness of Smog Check program:** The study reported consistent trends in the effectiveness of Smog Check. Remote sensing CO and HC emissions after Smog Check were lower than CO and HC emissions before Smog Check. Emission levels for vehicles that passed the initial test were much lower then those that failed then passed indicating that repairs in many cases were inadequate. Remote sensing results much lower emission reductions then reported by the stations. **6. Characterize emissions in subcategories of the California fleet:** Not addressed.
• **Did study demonstrate a cost-effective and practical application for RSD?** No.
• **Were program options implemented?** No.
• **Peer Review Process:** None known
• **Data Collection Protocols:** OREMS
• **Equipment:** not mentioned in the report
• **Data Availability:** Contact BAR
• **Measurement:** not mentioned in the report (over 3.5 million records were gathered in OREMS, however, because of concerns over the accuracy of the data before June 1996, only data after that date were used. Also, data from questionable sites were removed. These sites were suspected of having many cold start vehicles since over 5% of vehicles less than two years old were seen with CO emissions greater than 2%.) Only HC and CO are mentioned in the report.
• **Comparisons:** Results were compared to results reported from testing stations and from the California 1100 car study.
• **Data Collection Dates and Locations:** started June 1996. No end date given in the report.
• **Post data processing:** Eliminated data prior to June 1996. Also, data from questionable sites were removed. These sites were suspected of having many cold start vehicles since over 5% of vehicles less than two years old were seen with CO emissions greater than 2%.

11. On-Road Emissions Changes Due to I/M 240 Inspection/Maintenance and Oxygenated Fuel Program as Measured by Mass Emission and Remote Sensing, J. Gallagher, K. Nelson, K. Livo, Colorado Department of Public Health and Environment Technical Paper, World Car Conference '97, Center for Environmental Research, University of California, January 19-22, 1997
• **Purpose:** The purpose of this study was to determine how Colorado's IM240 program and its oxygenated fuel program affect vehicle emissions. Remote sensing device (RSD) data were used to evaluate the impact of these programs on emissions.
• **Conclusions Relative to 6 CA Pilot RSD Study Objectives:** **1. Identify high emitters for immediate testing:** Not addressed. **2. Exempt vehicles from I/M testing (i.e., "clean screening"):** Not addressed. **3. Identify candidate vehicles for subsidized scrappage programs:** Not addressed. **4. Improve the high emitter profile (HEI) used in California to select vehicles for testing in test-only stations:** Not addressed. **5. Evaluate the overall effectiveness of Smog Check program:** The study found that the oxygenated fuels program had a more pronounced effect on emissions then the I/M program. Due in part to the oxygenated fuels program is phased in over a short period of time while the I/M program affect plays continuously. **6. Characterize emissions in subcategories of the California fleet:** Not addressed.
• **Did study demonstrate a cost-effective and practical application for RSD?** No.
• **Were program options implemented?** No.
• **Peer Review Process:** None known
• **Data Collection Protocols:** Not given in the report
• **Equipment:** not mentioned in the report
• **Data Availability:** Contact CDPHE
• **Measurement:** 92,000 measurements. Only measurements of CO and HC were reported in the report.
• **Comparisons:** Results were compared to IM240 Lane Data taken at the same time.
• **Data Collection Dates and Locations:** From first week of December 1995 to third week of September 1996 at an on-ramp onto east bound US 34 from 23rd avenue in Greeley CO.
• **Other --** Vehicle CO failure rates at the IM240 Lanes show a pronounced difference between summer and winter months, with the winter month failure rates at about 2/3 of the summer months.

12. Analysis of Data from the California I/M Pilot Program, T.C. Austin and P.L. Heirigs, report sr95-06-01, prepared by Sierra Research, Inc., prepared for: US EPA
• **Purpose:** The purpose of the California pilot program was to establish the relationship between vehicle emissions as measured by the IM240 cycle and emissions as measured by RSD. Another purpose was to determine the portion of the overall fleet that could be detected by a network of RSD during an extended period of time.
• **Conclusions Relative to 6 CA Pilot RSD Study Objectives:** **1. Identify high emitters for immediate testing:** Sierra concluded that it would be very difficult to obtain RSD observations on a significant portion of the fleet. Sierra also concluded that RSD results correlated poorly with IM240 results. Subsequent RSD analysis by Sierra contributed much of the lack of correlation due to the nature of RSD measurements, where only a snapshot of vehicle emissions were provided with RSD. In order for RSD to be effective, Sierra felt that speed and acceleration must be accurately recorded and perfectly aligned with the emission event. 2. Exempt vehicles from I/M testing (i.e., clean screening): Although this study did not address clean screen, Sierra in subsequent publications and correspondence stated that clean screen is not feasible for OBDII equipped vehicles, because it would be impossible to assure that the malfunction indicator light (MIL) is not illuminated in clean screen candidates. **3. Identify candidate vehicles for subsidized scrappage programs:** Not addressed. **4. Improve the high emitter profile (HEI) used in California to select vehicles for testing in test-only stations:** Not addressed. **5. Evaluate the overall effectiveness of Smog Check program:** Sierra strongly believes that remote sensing has severe limitations in the evaluation of I/M programs. **6. Characterize emissions in subcategories of the California fleet:** Not addressed.
• **Did study demonstrate a cost-effective and practical application for RSD?** No.
• **Were program options implemented?** No.
• **Peer Review Process:** Reviewed by EPA staff.
• **Data Collection Protocols:** Not reported
• **Equipment:** Not reported
• **Data Availability:** Contact BAR
• **Measurement:** Nearly 2 million raw records. RSD data: RSD readings with 0% CO2 were omitted and less than 15% CO [the authors probably meant CO+CO2]. HC readings were discarded if there was not a valid CO reading. Very few NO readings were in the database, so they were not analyzed. When multiple readings were made on the same vehicle, the average, the minimum and the maximum were considered. Comparisons were made to effectiveness of ASM and IM240 tests in the identification of excess emissions.
• **Data Collection Dates and Locations:** Data collected in a two month period during late summer and early fall of 1994.
• **Post data processing:** IM240 data: Vehicles with a GVWR above 8,500 pounds were removed. No distinction was made between cars and light trucks. Vehicles with HC, CO, NO scores all = 0 were omitted. Negative IM240 scores (which occurred for a few vehicles) were set to 0.

Appendix A
Added Value of Remote Sensing to High Emitter Profile
(Authored by Robert Slott)

In any high emitter identification program the motorist has the option of repairing the vehicle prior to an inspection unless a roadside pullover is immediately performed following an RSD measurement. In the case of a decentralized inspection program, especially one like California's Smog Check where there is a penalty for failing, the technician at the inspection station may recommend that the vehicle be repaired prior to having an official test. If the vehicle is repaired prior to the test, the correlation between the on-road identification and the failure at the inspection station is reduced.

The best way to test the efficacy of remote sensing as a potential high emitter identification tool is to use roadside pullover confirmatory testing as was done in California (BAR 2001).

Virginia Study Results

The State of Virginia is interested in the possibility of using remote sensing based high emitter identification instead of an emissions inspection program in the Richmond area although the legal basis for such a program has not yet been authorized. Richmond does not have an emissions inspection program. A high emitter identification program would require the minimum number of vehicles to be tested at an inspection station.

In the Virginia Remote Sensing Device Study, ESP has run a series of trials with varying cutpoints on a sample of 30,000 vehicles that received an ASM test following a remote sensing emissions measurement. Vehicles were identified as high emitters by either two remote sensing measurements or one remote sensing measurement and a high emitter index. The performance of the two alternatives was similar, but the requirement of a single remote sensing reading plus the high emitter index is more cost effective.

The high emitter index (HEIx) was based on characteristics of vehicles that failed the ASM test in Northern Virginia. "The HE Index cutpoint value is the percentage of ASM tested vehicles with that failure rate or lower - the lower the cutpoint the more vehicles fail the cutpoint (cutpoint of 0 will fail almost all vehicles). Twenty-five percent of ASM tested vehicles exceed a cutpoint of 75."

“Since the vehicles observed and matched on road are generally newer than all the vehicles tested as part of the I/M program (because newer vehicles are [seen more on the road], the percentage of vehicles failing the HE Index screen in the RSD sample is lower than indicated by the HE Index cutpoint value, e.g. an HE cutpoint of 50 acting alone fails 31% of the sample.” (Virginia 2003, Appendix C) With A HE Index of 75 the observed failure rate was 13%.

HEIx cut points and HEIx cut points together with remote sensing cut points were examined on 30,088 vehicles which had a remote sensing reading prior to being tested on the ASM. To examine the effect of adding remote sensing to the HEIx, a brief analysis was done on the data in Appendix C of the Virginia report.

A performance metric for high emitter identification is the percent of vehicles that failed the inspection test after they were identified. In Figure A1 when HEIx is equal to 75, 13% of the vehicles are identified and 25% of these failed the ASM. As HEIx is increased, fewer vehicles are identified, but the percentage of those identified that fail the ASM increases (see the blue line in Figure A1.) By adding remote sensing cut points to HEIx = 75, the percent of vehicles identified decreases but the percent failing the ASM increases more than was seen with the HEIx without remote sensing. .

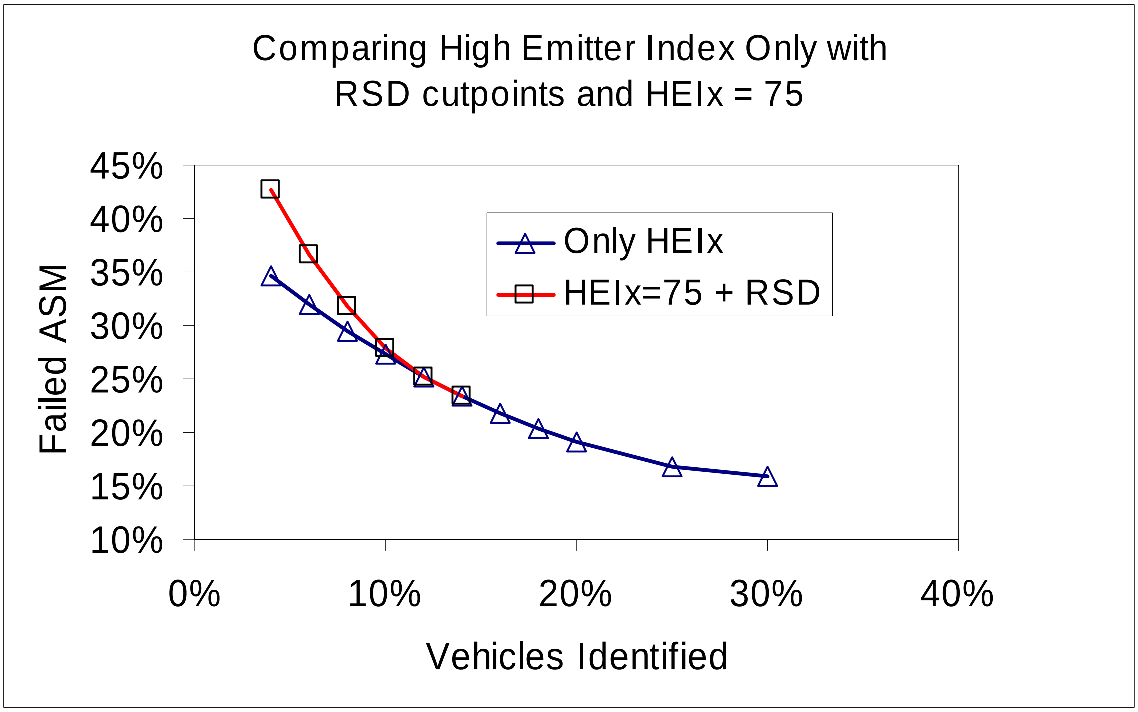

Figure A1: Comparison of Methods of Identifying High Emitters in Northern Virginia, percent of vehicles identified that failed the ASM inspection test.

Another performance metric from this data set is the average emissions reduced per vehicle. When HEIx is set at 75 adding remote sensing to the identification process increases this metric as is shown in Figure A2. Figures A1 and A2 show that remote sensing added value to the HE Index in the Virginia study.

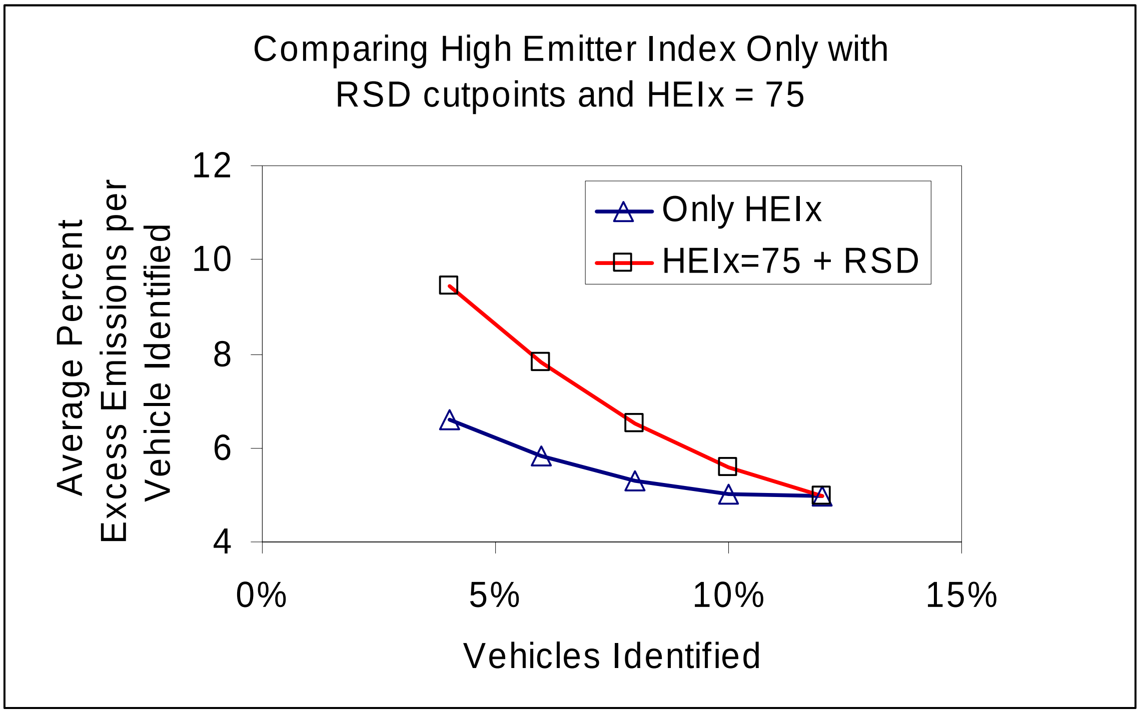

Figure A2: Comparison of Methods of Identifying High Emitters in Northern Virginia, average percent excess emissions reduced per vehicle identified.

According to ESP, "The costs of this [remote sensing high emitter identification] program in the Richmond area are expected to be $1.5M for RSD operations and program administration plus the costs of confirmatory ASM testing. Assuming the ASM testing is performed by licensed test and repair inspection stations, the cost of the ASM tests at $28 per test would be $5.2M (740,000 X 25% X $28) if 25% of vehicles are called in annually and half that amount if 25% of vehicles are called in biennially. The annual cost of this program is, therefore, $4.1M to $6.7M annually or $5.54 to $9.05 per vehicle – a considerable savings over a traditional ASM program." (Virginia 2003, page 71).

The Virginia Remote Sensing Device Study found a high percent of the excess emissions in the vehicles identified (see Table A1).

Table A1: Percent of NOx and HC Excess Emissions in Vehicles Identified as High Emitters		
	HEIx=75 + RSD, NOx	HEIx=75 + RSD, HC
Pre-1996 vehicles	80%	60%
1996+ vehicles	42%	50%

The report on the Virginia study estimated the amount of remote sensing equipment needed to get adequate coverage of the fleet in the Richmond area. "A dirty screen program must cover a majority of the vehicle fleet to be effective. Records indicate that 740,000 vehicles are registered in the 4-county Richmond area. Study data indicate that the State needs valid RSD observations totaling 2x this number (1.5 million observations) to cover 70% of the registered vehicles (a higher % of driven vehicles will be covered). This projection reflects the diminishing returns from additional RSD measurements at a given site. From the study, ESP determined that 30,000 valid observations can be made on vehicles registered in the Richmond area per van month[6]. From this ESP calculated that 50 van-months or about 4 vans per year will be needed to cover 70% of the Richmond Area fleet." In the study valid measurements were made on 23% of the Northern Virginia fleet.

The Virginia remote sensing used the latest instrument from ESP, the RSD4000. Also the data was post processed. The site to site variation was reduced by adjusting site bias using the median value of the 1996 and newer vehicles. VSP values below 3 kW/t and over 23 kW/t were removed in an attempt to keep the driving load in the FTP region.

Results of Other Studies

Earlier analyses of remote sensing as a high emitter identification aid were not as optimistic. However, these analyses were based on older remote sensing equipment, generally poorer quality assurance, and with no data post processing.

A program was operated in Arizona for five years which identified high emitting vehicles and sent them in for earlier testing. Identification was based solely on remote sensing readings. The remote sensing equipment was early 1990's Smog Dogs. The Arizona program ran for approximately five years and cost around $915,000 a year. Six remote sensing vans operated in the Phoenix Metro area collecting approximately 1.8 million valid records each year. The

[6] Each van averaged 47,000 valid observations per month. Adjusting this number for the % matched (97%), % with valid VSP (90%), and the % of observations in the 4 jurisdiction area that are on vehicles registered in the 4-Jurisdiction (72%) yielded 30,000 observations per van-month.

program was shut down, for poor performance. The program was only identifying about 3000 vehicles a year as high emitters. Criteria for being identified as a high emitter were two consecutive RSD measurements within 60 days where the vehicle emissions exceeded one of the RSD standards. Of those vehicles identified as high emitters, which were required to be emissions tested, approximately 60% failed the emissions test.[7]

In an analysis of the an earlier California I/M pilot program in which remote sensing test results were obtained in a large scale program in Sacramento, remote sensing was found to be ineffective at identifying high emitters even at high cut points of 4% CO and 1000 ppm HC. These cut points were higher than any of the cut point options used in the Virginia study. In the California I/M Pilot only 10% of the excessive HC and CO emissions in the fleet were identified and 58% of the vehicles identified passed a later IM240 test. (Sierra Research 1995).

As part of the annual on-road vehicle emissions study performed in the Illinois I/M area, RSD results in Illinois were matched with results of I/M tests that were performed within one year before the RSD observation. For the OBD test matches, the following groups were evaluated:

- Passed
- Advisory fail for MIL[8] being on or reject for not ready.

Results of this analysis are summarized below in Figure A3. Vehicles that failed the OBDII test had much higher HC, CO and NOx emissions than those that passed. The OBD inspection includes a check of MIL status and readiness. The readiness check determines if the OBD system has monitored a component. A vehicle that has monitors that are "not ready" could have had its codes cleared just prior to the OBD inspection to extinguish the MIL. During the period before the RSD measurements, if a vehicle failed, the motorist was given an IM240 test. Only vehicles failing the IM240 test had to be repaired. Most (97.4%) passed the IM240 test.

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[7] John Walls, Arizona DEQ, email 10/23/03

[8] Malfunction Indicator Lamp (MIL) is a term used for the light on the instrument panel, which notifies the vehicle operator of an emission related problem. The MIL is required to display the phrase "check engine" or "service engine soon". The ISO engine symbol also may be used as a substitute for the word "engine". In an OBDII inspection, the test system determines if the MIL is commanded-on by the vehicles computer. During the period before the RSD program, the MIL inspection was advisory.

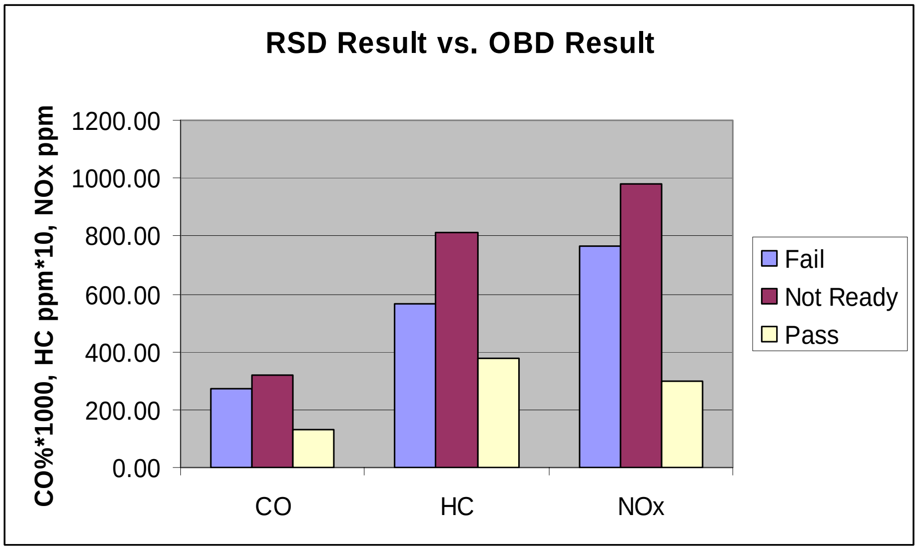


Figure A3 -- RSD Results vs. OBDII Results

ESP further investigated the ability of RSD to identify vehicles with illuminated MILs. ESP established possible cutpoints and grouped vehicles into passing and failing RSD categories. Then the following statistics were calculated:

- % exceeding RSD cutpoints
- % of OBDII Fails (MIL or Not Ready) identified
- % of RSD "Fails" that fail OBDII (MIL or Not Ready)

As shown on Figure A-4, RSD was able to identify 30 to 48% of the OBDII failures by failing 10 to 23% of the vehicles. Also, 25 to 30% of the vehicles failing RSD failed OBD compared to an overall OBD fail rate (including not ready rejects) of 11%. These data indicates that RSD can be used to identify some vehicles being operated that have circumvented OBD compliance requirements, including MIL status and readiness..

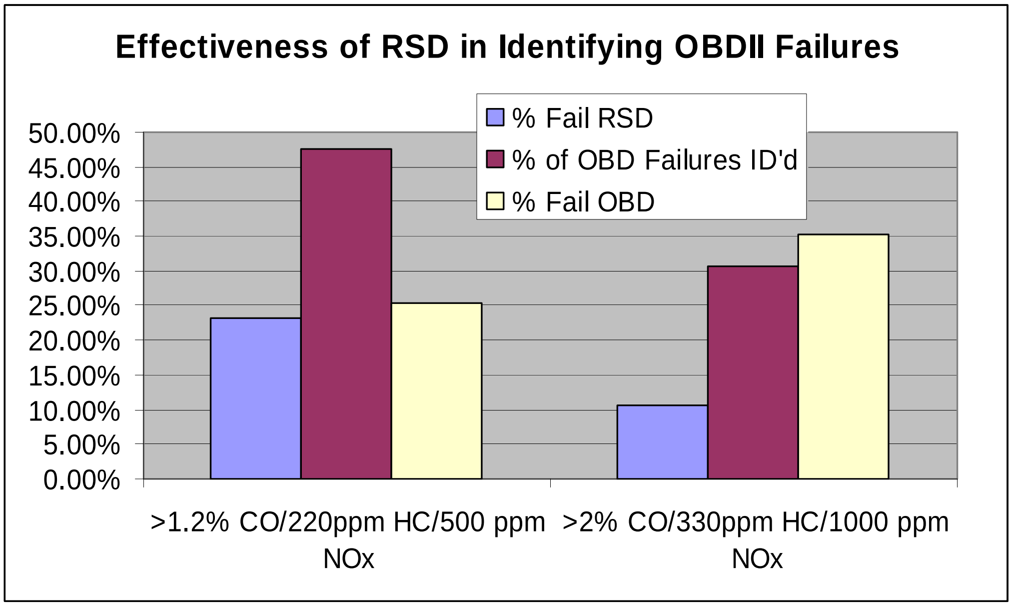


Figure A4 -- Effectiveness of RSD in Identifying Vehicles with Illuminated MILs

Clean Screening OBDII Vehicles

Data from the Illinois study raises concerns about using RSD to clean screen OBDII equipped vehicles. Setting HC, CO, and NOx screening criteria that would clean screen 5% of the 1996 and newer vehicles would result in 3% of the OBD failures in the Illinois dataset being exempted.

Appendix B
Variability of Emissions with Driving Behavior
(Authored by Robert Slott)

Thirteen vehicles were selected from the 346 vehicles tested in the NCHRP 25-11 program conducted by CE-CERT. These vehicles included high emitters and low emitters. A list of the vehicles and their FTP emissions are shown in the Table below.

13 Vehicles from NCHRP 25-11								FTP		
num	Vehicle	myr	Mass	Tier	Veh Type	State	Odom	HC g/m	CO g/m	NOx g/m
113	Nissan_Sentra_9	90	2,625	0	car	CA	141,134	0.43	10.69	0.22
117	Honda_Accord_92	92	3,250	0	car	CA	80,394	0.14	1.37	0.18
125	Dodge_Spirit_90	90	3,125	0	car	CA	183,392	0.51	13.14	0.51
136	Nissan_240SX_93	93	3,125	0	car	CA	43,009	0.26	6.58	0.32
205	Dodge_Caravan_8	85	2,750	0	truck	49	55,665	8.62	98.58	0.50
229	Honda_Civic_LX_	93	2,625	1	car	CA	61,032	0.11	1.01	0.31
242	Saturn_SL2_94	94	2,625	1	car	CA	64,967	0.16	1.34	0.23
250	Olds_98_94	94	3,875	1	car	CA	54,825	0.17	0.92	0.24
254	Hyundai_92	92	2,625	0	car	49	131,834	1.40	5.29	2.96
270	Mercury_Tracer_	91	2,750	0	car	CA	41,866	0.09	0.60	0.23
293	Plymouth_Voyage	94	5,200	1	truck	CA	80,722	0.25	2.05	0.71
298	Chevy_AstroVan_	90	3,000	0	truck	CA	145,799	0.84	1.78	7.41
334	Mercury_Cougar_	92	3,875	0	car	CA	55,397	0.17	1.72	0.11

The variation in emissions with driving mode (or driving behavior) can be seen in Chart B1 which shows Vehicle 334 in the last part of the FTP when the vehicle is warmed up. The driving speed and accelerations are within the range of a typical remote sensing site. In Chart B1 the emissions are expressed in concentration units, such as would be measured by a remote sensor. The speed and vehicle specific power (VSP) are also displayed. Changes in emissions are associated with changes in VSP.

Since these measurements were not made in real time, the procedure to bring the emissions measurements into time alignment with the speed measurements is important to consider. The following two paragraphs describe the time alignment procedure used in the NCHRP 25-11 project:

“For our time alignment procedure, CO2 was aligned with the speed trace, which is why CO2 doesn't lag behind VSP. The remaining emission traces had a constant shift with CO2 based on the physical setup of laboratory measurement system. These were NOT individually aligned with speed/acceleration because in many cases they were dynamic shifts based exhaust flow rate and emissions concentrations. If one wanted to time align each emissions event, that is possible but one has to be careful with the different emission events. For example, in looking at the HC spike in one of your examples, this is likely an unburned HC spike that often occurs with 1980s, 1990s cars following an accel-decel event. This is a real phenomenon that has an associated delay in removing unburned fuel from the cylinders.

On other species (such as CO), the emissions start to go up at certain events and then take a bit longer to peak due to instrumentation integration rates. These integrate delays might be interpreted as a misalignment."[9]

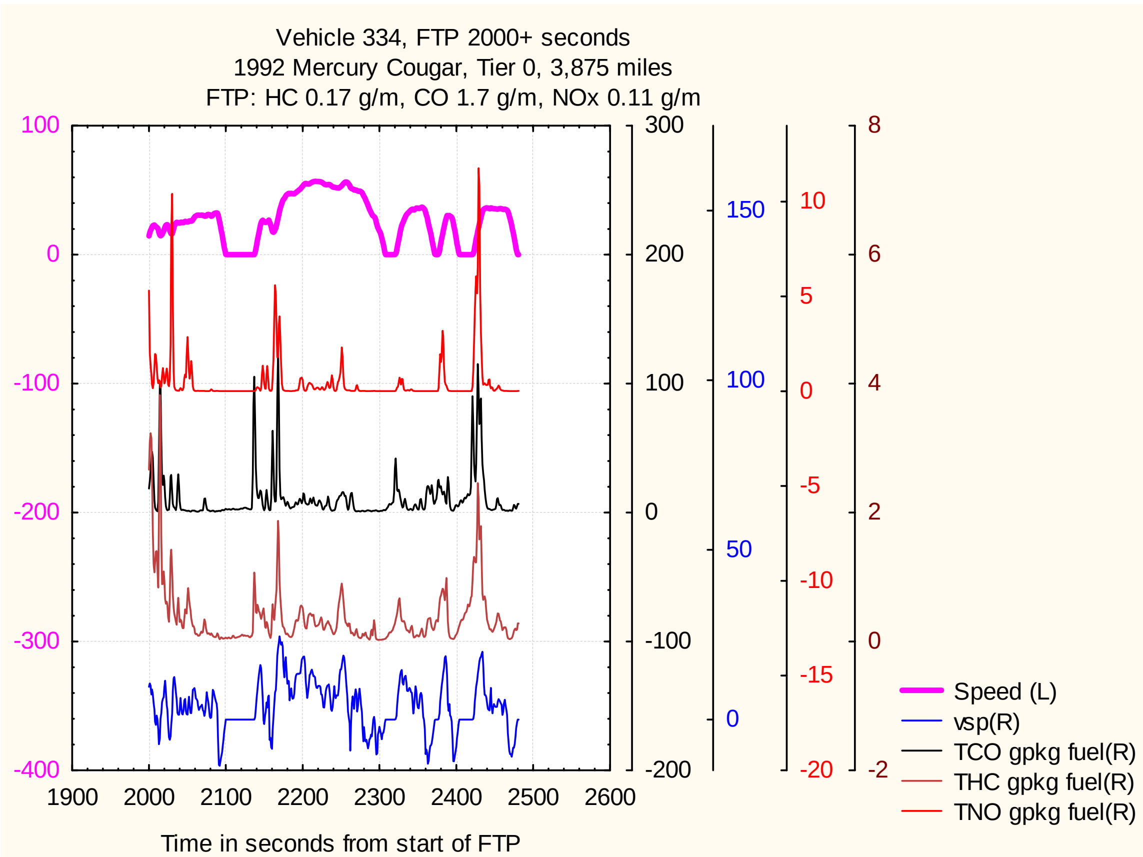


Chart B1. Vehicle 334, Emissions, Speed and VSP during hot 505 FTP.

Even though the emissions of Vehicle 334 vary with driving behavior, with cut points of 100 grams/kilogram (gpkg) fuel for CO, 10 gpkg fuel for HC, and 10 gpkg for NOx, this vehicle would almost always meet the low emission cut point under any of the driving conditions.

Not all the vehicles selected were this low emitting. Chart B2 shows CO emissions in gpkg fuel for all 13 vehicles at the end of the FTP and on a portion of the US06. The US06 is a

[9] Matt Barth, email 1/26/04

driving cycle with much more hard accelerations and decelerations than the FTP. It also has the vehicle operating at high speed.

One way to post process remote sensing data is through a VSP filter. VSP filters were used by McClintock in processing Missouri, Colorado, and Virginia remote sensing data. A typical filter limits VSP values to between 3 and 23 kW/t. The upper limit corresponds to the limit of the FTP. The 13 vehicles were certified to the FTP. If they were well maintained, they should all pass the low emission cut point similar to Vehicle 334. The lower VSP limit is set because many vehicles of this type show an increase of HC and/or CO at low VSP levels. However, since VSP is related to the fuel rate, mass tailpipe emissions are generally low at low VSP.

Chart B2 only shows CO emissions for VSP levels between 3 and 23 kW/t although the VSP levels in the US06 cycle are considerably outside that range during parts of the driving cycle. In Chart B2 the vehicle order has been arranged so that there is always a low emitting vehicle between two high emitting vehicles.

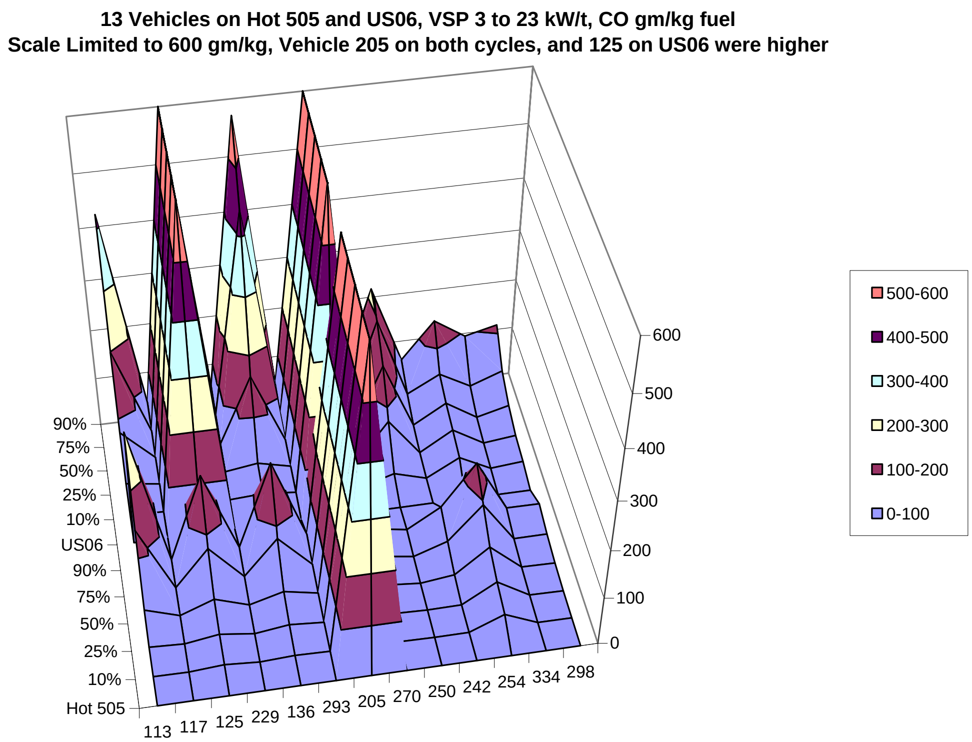


Chart B2: CO emissions for 13 Vehicles on FTP and US06, VSP 3 to 23 kW/t

Chart B2 is a surface plot to facilitate visualization of the amount of emissions which are plotted on the Z-axis. The color code in grams CO per kilogram of fuel is in the Legend on the right. The X-axis shows the vehicles by their number. The Y-axis, reading from bottom to top, shows CO emissions percentiles for the last bag of the FTP (the "Hot 505") increasing from 0% to 90%, and then the emissions for the US06 increasing from 0% to 90%. A point at 125 on the X-axis and 25% on the Y-axis in the Hot 505 section represents the 25th percentile of CO emissions for Vehicle 125 observed during the Hot 505 driving cycle.

By plotting the emissions in this way, Chart B2 illustrates a number of points about vehicle emissions.

- On the Hot 505 with a cut point of 100 gpkg fuel
  - Some vehicles are always below the cut point.
  - Vehicle 205 is always well above this cut point.
  - Some vehicles have emissions that will exceed the low emission cut point only during a portion of the Hot 505. Vehicles 113, 125, 136 (all identified as "Type 2" high emitters by Wenzel and Ross), and Vehicle 254 fit into this category. If these intermittent high emitters are to be classified as high emitter, and the conditions of the Hot 505 described the range of driving conditions at a remote sensing measurement site, remote sensing measurements would misclassify these vehicles most of the time without further post data processing.
- On the US06, with VSP limited to 3 to 23 kW/t
  - Some vehicles are still below the cut point, including Vehicle 334
  - Vehicle 250, which was below the cut point in the FTP, is now above the cut point during part of the driving cycle.
  - Vehicles 113, 136, and especially 125 exceed the cut point during much more of the driving cycle.
  - Vehicle 205 is still always well above the cut point.

The difference between FTP and US06 within the VSP range of 3 and 23 kW/t shows the importance of understanding the previous driving behavior in using instantaneous measurements to classify vehicles. If the driving behavior is not known, greater uncertainty must be attached to the classifications derived from remote sensing measurements.

Charts B3 and B4 are similar for HC and NOx.

Removing the VSP filter from the US06 cycle had less effect than the differences in driving cycles on the same vehicles with the filter in place.

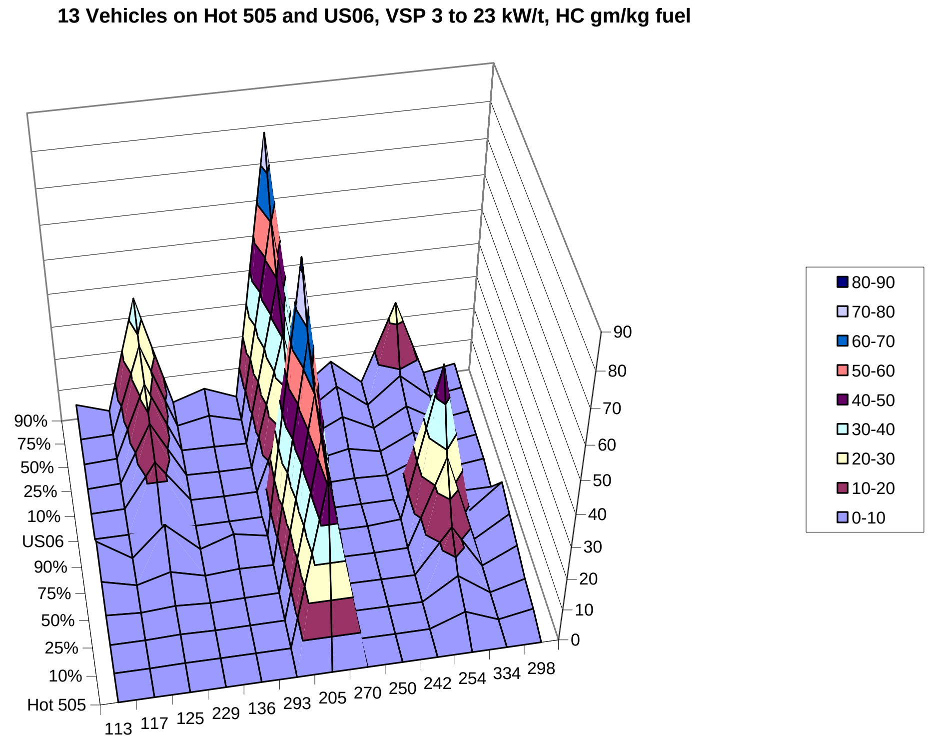


Chart B3: HC emissions for 13 Vehicles on FTP and US06, VSP 3 to 23 kW/t

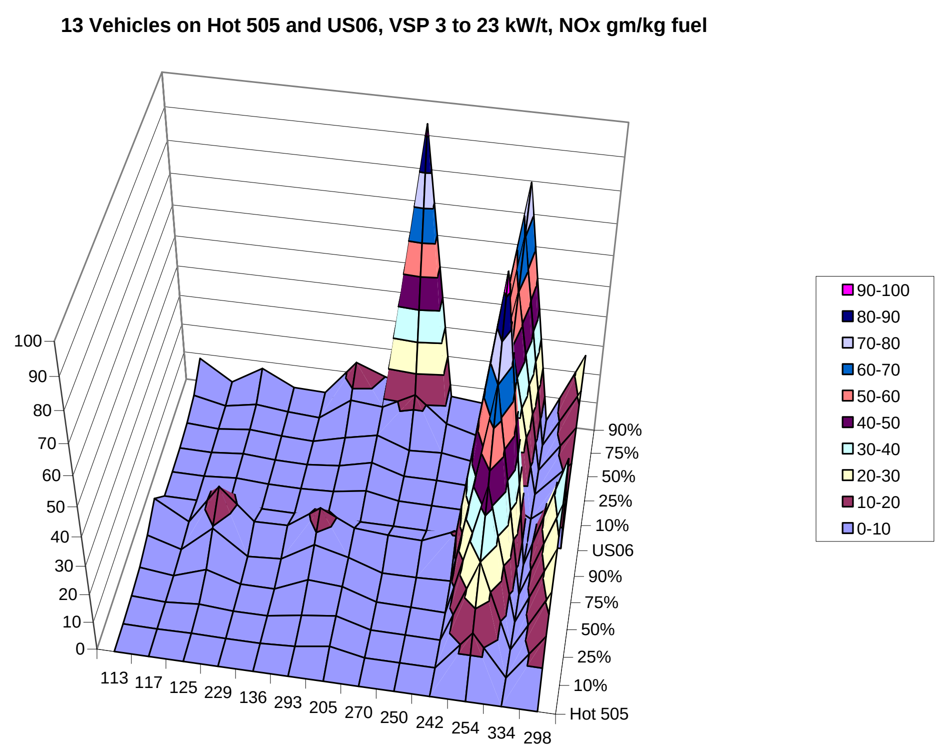


Chart B4: NOx emissions for 13 Vehicles on FTP and US06, VSP 3 to 23 kW/t

Appendix C
Measurements of Speed between Two RSD4000 Units in Virginia
(Authored by Robert Slott)

The "Virginia Remote Sensing Device Study" was carried out in 2002 using two RSD4000 remote sensing units. These were measuring the same vehicles on seven days of the campaign at different sites. The distance between the units was not recorded, but it is known that on the first four days, the units were far apart and on the last three days, they were closer together.

The distance between the remote sensing units can be estimated by dividing the difference in speed by the average acceleration. As is shown in Table C1, the distance apart is less in the last three days. Confirmation that the units were closer together on these three days is seen by comparing the acceleration measurements of unit S1 with those of unit S2. The sign of the distance apart depends on which unit is upstream of the other.

S1_Tdate	S1 Accel	S2 Accel	S2-S1 Accel	avg Accel	S2-S1 Spd	seconds	avg Speed	feet apart
3/5/2002	0.70	0.48	-0.22	0.59	-1.34	-2.25	28.62	-95
4/1/2002	1.19	0.63	-0.55	0.91	-0.67	-0.74	41.34	-45
4/29/2002	0.98	0.85	-0.14	0.91	-0.63	-0.69	52.53	-53
5/28/2002	0.52	0.43	-0.09	0.48	-0.70	-1.46	34.08	-73
6/24/2002	0.51	0.47	-0.04	0.49	-0.15	-0.31	32.41	-15
8/5/2002	0.91	0.89	-0.02	0.90	-0.10	-0.11	24.57	-4
9/30/2002	0.64	0.62	-0.01	0.63	0.09	0.14	29.92	6

Table C1: Estimating the distance between two remote sensing units in Virginia

The correlation in speed measurements between the two units is shown in Table C2. Table C2 describes the difference between the two speed values. If the units are close together, the speed values should be very similar. The last three days do have difference in speed values which are closer to zero. The distribution of speed values is also more flat as can be seen by the 10, 25, 50, 75 and 90 percentile values especially for 6/24 and 8/5/2002.

S2-S1Speed								
DATE	Means	N	Std.Dev.	Q10	Q25	Median	Q75	Q90
4/1/2002	-0.67	586	1.33	-1.37	-0.98	-0.71	-0.45	-0.19
4/29/2002	-0.63	348	0.87	-1.16	-0.87	-0.56	-0.29	-0.06
3/5/2002	-1.34	859	1.99	-3.51	-2.30	-1.33	-0.26	0.57
5/28/2002	-0.70	1991	1.26	-1.52	-1.00	-0.63	-0.30	0.00
6/24/2002	-0.15	1818	1.18	-0.26	-0.21	-0.15	-0.06	0.01
8/5/2002	-0.10	4289	0.56	-0.21	-0.15	-0.09	-0.04	0.01
9/30/2002	0.09	1918	1.70	0.00	0.04	0.08	0.11	0.14

Table C2: Speed differences at sites with two RSD ESP4000 units.

Chart C1 shows the correlation between the speeds of 4,289 vehicles measured at both units at the best site. The excellent correlation indicates speed measurements are being made accurately. The lack of correlation on the other days could be due to changes in acceleration when the units were not close enough together.

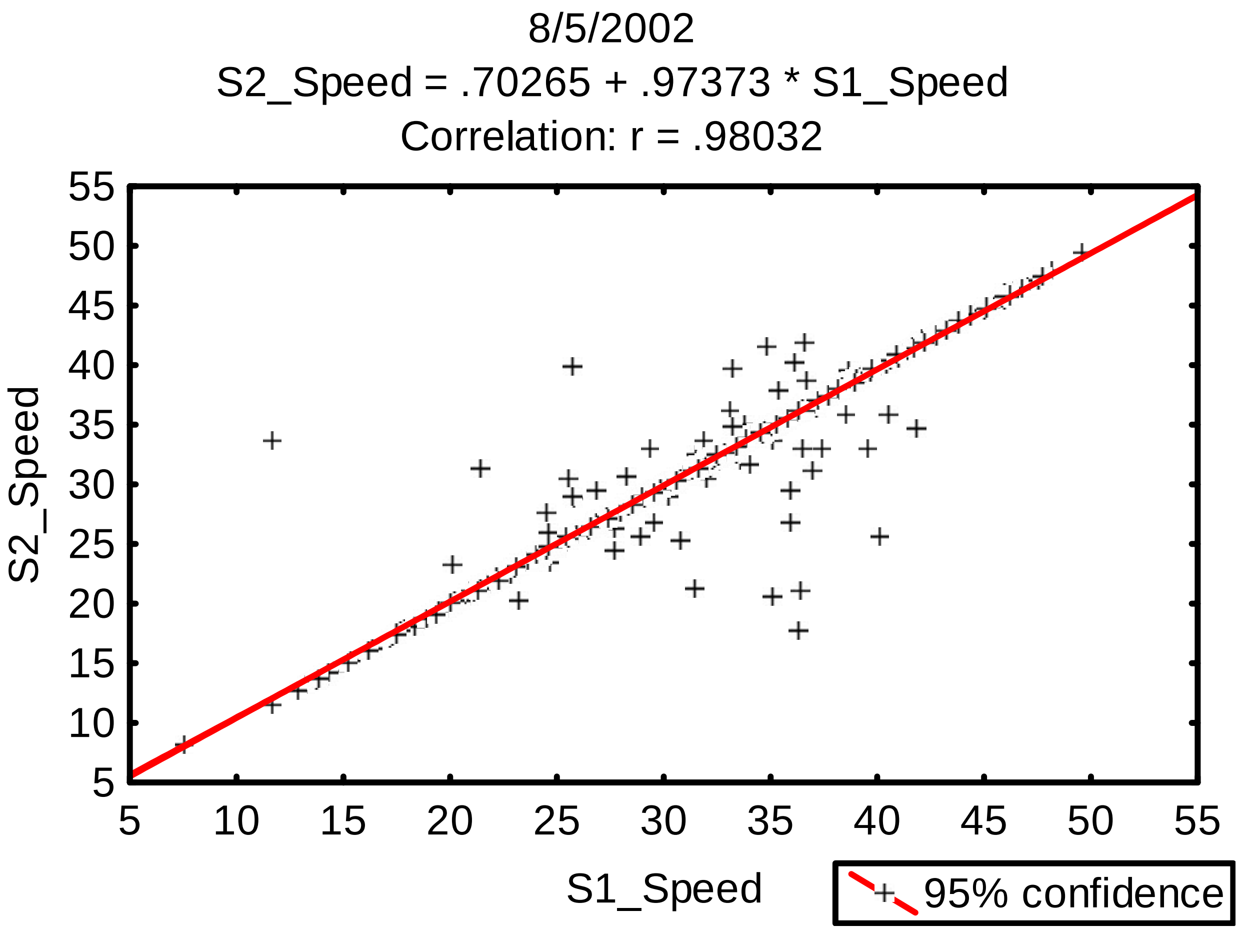


Chart C1 Measurements of Speed by Two RSD4000 units on 8/5/2002

Appendix D
Annotated Bibliography

P.M. McClintock "The Denver Remote Sensing Clean Screening Pilot," Prepared for: The Colorado Department of Public Health and Environment, December, 1999

Executive Summary

The purpose of the Denver Remote Sensing Cleaning Screening Pilot was to determine the feasibility and the technical parameters for using remote sensing in the Denver metro area to identify vehicles that are low in emissions and waive them from I/M inspection. This study was funded by the Colorado Department of Public Health and Environment at the direction of Senate Bill 98-182. Remote sensing (RSD) is a technology pioneered by the University of Denver that allows measurement of instantaneous exhaust emission concentrations while vehicles are driven on the road. Remote sensing has a significant advantage over other ways of measuring vehicle emissions because it provides a non-intrusive method for obtaining large numbers of measurements of in-use vehicle emissions.

In 1997, the Greeley Study1 determined that remote sensing clean screening could reduce the number of vehicles that must undergo Greeley's basic I/M test by about half with little loss in emission reduction benefits. In 1998, the Colorado Enhanced I/M Program 0.5% Sample2 determined a potential for clean screening in the Denver area. This pilot study builds on this earlier work and develops the technical parameters for implementing a clean screen program.

This study has also examined the use of vehicle profiling in combination with remote sensing to enhance the effectiveness of a clean screening program. Vehicle profiling is a statistical technique used to determine the probability of a vehicle being a high emitter based upon the past performance of similar vehicles and, if available, the results from prior emission inspections of the vehicle.

Information Used in the Study

Over 150,000 on-road remote sensing records were collected between December 1998 and October 1999. Of these, 103,000 had readable Colorado plates with valid emissions measurements and 94,000 were matched to current registrations. For comparative analysis, 13,600 initial IM240 inspections were identified that occurred some time after an on-road remote sensing measurement. Additional matched IM240 results will accumulate over time as vehicles measured by remote sensing continue to come in for their scheduled I/M inspections. In addition, 1900 vehicles were measured by remote sensing on inspection station entrance roads so the remote sensing measurement could be compared to an IM240 inspection following within a very short time. Vehicle profile data was developed from the results of 850,000 IM240 inspections conducted in 1998 using vehicle type, model year, make, model and number of cylinders. The use of a profile generated from the inspection results of the previous year mirrors how the profile is likely to be used in practice.

Clean Screening Findings

The use of remote sensing clean screening is feasible in the Denver area. The Denver fleet today is cleaner than the Greeley fleet in 1996. Therefore, more stringent clean screening standards are required in Denver to maintain a similar I/M benefit.

Combining vehicle profiling with remote sensing improves both clean screening and high emitter identification programs. It results in fewer false passes in remote sensing clean screening programs and allows a greater number of vehicles to be exempt from inspection. For example, 48% of 1982 and newer vehicles could be clean screened while retaining 95% of the enhanced I/M program benefits for HC, CO and NOx compared to 90% effectiveness without profiling.

High Emitter Identification

Remote sensing has the capability to identify on-road vehicles with high emissions. Because properly functioning vehicles can appear to be high emitters under certain modes of operation, steps must be taken to screen out RSD measurements made under these circumstances. As with remote sensing clean screening, it was found that the effectiveness of RSD high emitter identification can be improved by including vehicle profile information as part of the decision making process.

For 1982 and newer vehicles, a high emitter identification program that requires 1.5% of these to pass an unscheduled IM240 inspection is projected to identify excess emissions that are equivalent to 36% of the excess CO and 22% of the excess HC emissions identified by the IM240 program. This should more than offset the loss of I/M benefits contemplated under a clean screening program. However, it may require a change in the EPA modeling method for estimating high emitter identification benefits for EPA to agree. Public acceptance and program enforcement issues would also need to be considered.

I/M Program Compliance

The project scope of work included investigation of the ability of remote sensing to assess and improve I/M program compliance. Remote sensing is able to contribute valuable information about I/M compliance status of vehicles being driven within the enhanced I/M area.

Repair Effectiveness

Twenty-three vehicles were identified that had remote sensing measurements before and after an IM240 inspection and repair cycle. Reductions measured by RSD averaged about half those measured by IM240 testing:

Pollutant	Denver Pilot	IM240
	RSD Reduction	Reduction
CO	38%	81%
HC	46%	76%
NOx	0%	25% increase

The reasons for the disparity are believed to include: vehicle on-road variability, the difference in vehicle operating mode when measured on-road vs. the IM240 test, the difference between concentration measurements (RSD) and mass emission measurements (IM240), changes in vehicle condition prior to I/M inspection and deterioration of vehicles following ineffective repairs.

This measurement is consistent with what was seen in Arizona (Wenzel, T "Evaluation of Arizona's Enhanced I/M Program," Presented at the 9th CRC On-Road Vehicle Emissions Workshop. April 1999.)

K. L. Swayne, "Infrared Remote Sensing Of On-Road Motor Vehicle Emissions in Washington State," March, 1999, Air Quality Program, Washington State Department of Ecology, Northwest Regional Office, 3190 160th Ave. S.E., Bellevue, WA 98008-5452, 425-649-7101, kswa461@ecy.wa.gov, Publication #99-204

Executive Summary

The Department of Ecology conducted a pilot study to evaluate the usefulness of remote sensing, a technology intended to measure emissions from motor vehicles as they travel along the road, rather than by visiting a test station.

A contractor took more than 200,000 readings at freeway ramps in King, Pierce and Snohomish counties. These were compared with test station records on the same vehicles over the previous two years. One third of the readings came from vehicles that had been inspected within that period. Of these previously inspected vehicles, only seven percent, were "viewed" three or more times during the six week pilot program. Remote sensing programs typically require three readings on individual vehicles.

Data from the pilot study correlated with test station measurements at a rate less than chance, even when vehicles had more than three "hits." The range of data for each vehicle averaged 70% of the total range of readings.

To view the 800,000 vehicles now inspected annually at test stations in the Puget Sound region, more than 35 million readings would be required. During the study, the remote sensing unit collected an average of 7,753 readings per day per location. At this rate, 4,583 days of data collection would have to be conducted each year. This would require several mobile test units and a very large number of suitable on-road testing sites to view the fleet currently tested at the test stations.

The cost per vehicle to obtain a set of three or more hits was more than $11. Ecology currently pays approximately $8.50 to the test station contractor for each inspection.

The low rate of data correlation and high data range indicate that on-road vehicle operating factors significantly affect emissions at any time. Careful remote sensing site selection can offset only some of these factors. Test station inspections provide far superior control over engine load and speed, while ensuring that all vehicles are subject to an equitable number of inspections. This helps to ensure that inspections are conducted in a fair manner.

Remote sensing would provide no practical benefit to Washington's Emission Check program as a means to evaluate individual vehicle emissions. Ecology's past and planned efforts to reduce the frequency of test station inspections have promoted customer convenience without compromising the integrity of the inspections. A limited remote sensing program could track the at-large emissions trends of the subset of a geographic region's vehicle fleet that does not receive regular test station inspections as a group over a multi-year period.

Also, emissions increase with engine load. Under heavy load conditions, vehicle engines may enter enrichment modes in which an engine's process controls order a richer air/fuel ratio that can lead to high CO emissions. Heavy load conditions may also increase HC and NOx.

Craig S. Rendahl, E.I.T. (Remote Sensing Technologies, Inc.) and Peter McClintock, PhD. (Applied Analysis), Advances in Remote Sensing Technology.

(Delivered at 13th Annual Mobile Sources Clean Air Conference, Steamboat Springs CO, September 17, 1997.)

An RSD program has no control over the variety of factors that affect the load placed on the engine, such as a vehicle's cargo, number of passengers, tire pressure and accessory use. Payload weight: Test station dynamometers place identical weight loads on each vehicle size class. This is not possible in on-road testing. Increasing the load by only a few hundred pounds—two or three passengers—can skew emissions upward. (Reference – internal report to issue 1999) Tire pressure: Under-inflated tires have a higher surface area in contact with the road, which increases friction—and therefore load—and can significantly increase carbon monoxide emissions.(demonstration results pending) Accessories: Equipment such as headlights, air conditioners, blowers and defoggers place additional demand on the alternator, which requires more work from the engine to maintain an electrical current.(demonstration results pending) Headlights, air conditioners and defoggers place especially high loads on the engine. All accessories are turned off for test station inspections. Remote sensing cannot determine how much extra load a vehicle's accessories may be placing on its engine. RSD cannot recognize these load factors. Therefore, even if a site promotes uniformity in speed and acceleration, we cannot know what load each vehicle bears.

RSD has uses other than screening individual vehicles. A consistently operated RSD program that obtained a statistically valid number of readings could track the tailpipe performance of a large group of vehicles in a region from year to year. Washington may find RSD useful in assessing some informational gaps, e.g. Washington's exclusion of vehicle under five and over 25 years old from test station inspections, will leave this major group of vehicles -- 25 percent of the fleet -- unprofiled for emissions performance.

Ecology's RSD pilot study revealed significant numbers of vehicles operating in the Emission Check program area that were not registered in the area. RSD camera surveillance could help improve our understanding of where vehicle trips in area originate. Full RSD surveillance could profile emission trends of registered-out-of-area vehicles as a group. This information could help support decisions on adjusting Emission Check program area boundaries.

RSD may produce meaningful trend information on large groups of vehicles, even though it cannot do so for individual vehicles. While data from test station inspections supports the profiling of much of the fleet -- no additional cost -- special RSD projects could provide information on new vehicles under five years old and other uninspected vehicles that routinely operate in the program area. Given the shortcomings of remote sensing such projects would not yield definitive data, but could serve as screening studies to guide further evaluation of vehicle fleet segments. License plate surveillance could support efforts to track compliance with vehicle registration requirements. Vehicles based in the program area, but registered illegally outside of it, not only compromise the Emission Check program, they divert transportation funds away from the motorist's home county.

Vehicle Emission Testing using a Remote Sensing Device (RSD), Demonstrating the Value of Routine Vehicle Maintenance & Providing Initial Quantification of Vehicle Emissions in Pendleton, Bend and LaGrande, Oregon, September 2003, Vehicle Inspection Program Report, State of Oregon, Department of Environmental Quality.

Executive Summary

At the request of three cities in Eastern Oregon, the Oregon Department of Environmental Quality’s (DEQ’s) Vehicle Inspection Program (VIP) conducted remote sensing testing of vehicle emissions. The testing occurred in the Pendleton area during May 14-24, 2003, in the Bend area during June 4-14, 2003 and in the LaGrande area during August 6-17, 2003. The tests used DEQ’s MD LaserTech on-road remote sensing test equipment, which measures the pollutant levels of carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NOx) in vehicle exhaust as vehicles are driven past an optic sensor.

The goal of this testing is to demonstrate to cities of Pendleton, Bend and LaGrande what their potential vehicle emission levels are in comparison to the Portland area, and to educate the citizens there about the importance of vehicle maintenance in keeping their air clean and prolonging the life of their vehicles.

The scope of this project was limited to developing an initial “snapshot” of vehicle emissions in three Eastern Oregon cities. Typically, to perform a more sophisticated evaluation of an individual city, about 20,000 useable vehicle tests must be collected. In total, only 2805 useable vehicle tests were collected (896 from Bend, 1467 from LaGrande and 442 from Pendleton). This small data sample limits the detail that can accurately be presented in this report to composite pollution levels only. The small data set does not make it possible to accurately measure individual pollutants. The composite pollution levels when compared to Portland are presented below. The large variation of composite readings in the three Eastern Oregon cities may be due to the relatively small amount of vehicles tested.

DEQ tested 19,630 vehicles during this study to achieve the 2805 useable vehicle tests. This is an effectiveness rate of just over 14 percent. A good effectiveness rate is approximately

40 percent. The low effectiveness rate may be a result of testing at locations that did not provide for proper vehicle speed and acceleration.

VIP staff set up testing equipment in seven different locations in Pendleton, four locations in Bend and ten locations in LaGrande. Some of the testing was conducted in parking areas where VIP staff had the opportunity to answer questions for the public. The bulk of the testing was done on roadways where the stop light indicator showed people how their vehicle was doing.

DEQ reported results of the study to the EPA in November 2001, in a report titled Voluntary Vehicle Emission Testing by Remote Sensing with Repair Incentives, Does It Work? (November 2001). This report concludes that an RSD testing program with an on-road visual display of vehicle pollution levels coupled with voluntary repairs may be able to achieve a "4 percent reduction in overall fleet emissions" in the Bend area. This compares to an estimated 20 percent reduction that can be achieved with a mandatory "basic" test program (examines vehicles only at idle) and a 30 percent reduction for an "enhanced" test program (examines vehicles while under load on a treadmill). The report also concluded that a "voluntary RSD program is less cost-effective than a mandatory I/M program in reducing vehicle emissions."

Virginia Remote Sensing Device Study – Final Report, Prepared for: Virginia Department of Environmental Quality February 2003, Peter McClintock and Rob Klausmeier, for ESP, 2002 North Forbes Blvd., Tucson, AZ 84745

The Virginia Department of Environmental Quality (VDEQ) contracted Environmental Systems Products (ESP) to conduct a remote sensing device (RSD) study in the Northern Virginia Enhanced Inspection and Maintenance (I/M) Program area.

DEQ intends to use information gathered during this study to:

7. compare the emission test results from the existing I/M program area with the emissions as measured by remote sensing,
8. determine the overall feasibility and cost effectiveness of operating a future comprehensive remote sensing program in the Northern Virginia Enhanced I/M Program area,
9. determine the percent of "transient vehicles" not registered in the I/M program area and determine which of these are habitual commuters,
10. assess fleet emissions in the existing northern Virginia I/M area,
11. draw conclusions as to the effectiveness of the existing I/M program, and

12. assess the vehicle miles traveled (VMT) distribution of vehicles within the I/M area by vehicle age and body style.

CONCLUSIONS – This document describes the study and its results. Following are the key conclusions drawn from this analysis:

- The study met its data collection goals. Valid RSD measurements were made on 23% of the Northern Virginia I/M fleet.
- Vehicles registered in Virginia's I/M areas had significantly lower HC, CO, and NOx remote sensing levels than vehicles registered in Virginia's non-I/M
- Vehicle Specific Power (VSP) is a good measure to judge the conditions that a vehicle should be operating under to generate reliable RSD emission readings. In addition, site/hour combinations with high percentages of new vehicles with high emissions (after VSP screens are applied) are likely to be seeing more vehicles in cold start mode. ESP removed observations from these sites during those hours.
- Estimated emission reductions for Virginia's I/M program based on RSD observations in I/M and non-I/M areas are much greater than emission reductions estimated by EPA's MOBILE6 model.
- Combining RSD results with high emitter index values can identify most of the high emitters. Vehicles that are classified as high emitters by RSD and are in the dirtiest 25% of the high emitter index have much higher emission levels than the average vehicle.
- A dirty screen program using one hit plus high emitter indexing has similar performance to one using two-hits. Initially, it's much easier to get one hit on a vehicle than 2 hits, so this scenario would be more cost-effective.

Gateway Clean Air Program, Annual RapidScreen Report, January – December 2002; ESP Missouri, Inc., Prepared for: Missouri Department of Natural Resources, Prepared by: Peter M McClintock for ESP., July 2003.

The Missouri Department of Natural Resources operates a vehicle emissions inspection and maintenance program to improve air quality in the greater St. Louis metropolitan area. The Gateway Clean Air Program consists of an enhanced biennial I/M program in Jefferson County, St. Charles County, St. Louis County and St. Louis City and an annual basic I/M program in Franklin County. The centralized program is operated by a contractor, Environmental Systems Products Missouri.

The Gateway Clean Air Program is the first I/M program in the country to integrate clean screening from the outset as a means of improving motorist convenience and reducing the overall number of inspection lanes required. The program design includes a two model year new vehicle exemption accounting for approximately 15% of vehicles with a further 25% of vehicles to be selected using clean screening methods to meet a combined 40% clean screening goal. The contractor is required to report annually on the effectiveness of the clean screening program known as RapidScreen.

Preliminary remote sensing data collection started in October 1999. The first pilot RapidScreen notices were issued in the first quarter of 2000. Full RapidScreen processing and full testing at stations commenced in April 2000. The first RapidScreen audit report1 covered the preliminary six-month startup period from October 1999 through March 2000 and the first twelve months of full program operations from April 2000 through March 2001. In order to bring the reporting back onto a calendar year cycle, the 2001 report covered the full calendar year for 2001. This RapidScreen report covers the calendar year 2002.

RapidScreen notices were sent out in 2002 to 171,247 owners of vehicles with registrations due in 2002. For those 2002 registrants, 133,606 vehicle owners took advantage of the program by redeeming their notices. This represents an estimated 19% of St. Louis area vehicle registrations for the period. New model vehicle exemptions averaged 15% for the registration year 2002. Therefore, with 34% of the total vehicles exempted from a station-based emissions inspection, the program fell short of achieving the 40% clean screening goal. Nevertheless, more than one third of vehicle owners benefited from the clean screening program. An additional 5% of motorists who were mailed RapidScreen notices were eligible to benefit from the clean screening program but did not redeem the notice. Thus, the clean screening program could have exempted 39% of the total vehicles, nearly meeting the goal, if every mailed RapidScreen notice had been redeemed. Section III of this report contains specific information on the number of on-road measurements and the number of RapidScreen notices issued and redeemed.

Quality control and quality assurance continue to be important elements of the success of the RapidScreen program. The tag editing of license plate images is controlled using 200 quality assurance samples per dataset. All errors identified are corrected. The average QA error rate in the RapidScreen notice processing is 0.4% from tag edit errors and 1.7% from other sources. Additional statistics on quality control and quality assurance activities are provided in section III. C.

The emissions effectiveness of the RapidScreen program has been calculated using the results of a random 2% audit sample of vehicles identified as clean by the RapidScreen program. Instead of receiving a RapidScreen notice, these vehicles are tested at the inspection stations. The audit sample test results are then used to calculate the air quality impact of exempting the RapidScreen vehicles from a station-based test. The calculations are described in section IV and section VII. The RapidScreen program retained 97% of HC tailpipe reductions, 85% of gas cap related HC reductions, 98% of CO reductions and 92% of NOx reductions of the Gateway Clean Air Program. Therefore, the program continues to meet the goal of retaining 95% of the tailpipe HC emission reductions.

On-Road Remote Sensing of Automobile Emissions in the Chicago Area: Year 4; Sajal S. Pokharel, Gary A. Bishop and Donald H. Stedman; August 2001, Prepared for: Coordinating Research Council, Inc., Contract No. E-23-4

Executive Summary

The University of Denver has completed the first four years of a multi-year remote sensing study in the Chicago area. The remote sensor used in this study is capable of measuring the ratios of CO, HC, and NO to CO_2 in motor vehicle exhaust. From these ratios, we calculate the percent concentrations of CO, CO_2, HC and NO in the exhaust that would be observed by a tailpipe probe, corrected for water and any excess oxygen not involved in combustion. Mass emissions per mass or volume of fuel can also be determined. The system used in this study was configured to determine the speed and acceleration of the vehicle, and was accompanied by a video system to record the license plate of the vehicle.

The fourth year of this study involved four days of fieldwork conducted at the on-ramp from Algonquin Rd. to eastbound I-290 in northwest Chicago. A database was compiled containing 22,065 records for which the State of Illinois provided make and model year information. All of these records contained valid measurements for at least CO and CO_2, and 21,972 records contained measurements of HC and NO as well. The database, as well as others compiled by the University of Denver, can be found at www.feat.biochem.du.edu.

The mean CO, HC and NO emissions for the fleet measured in the fourth year of this study were 0.26%, 94 ppm (when offset is removed) and 316 ppm, respectively. These values are amongst the lowest we have observed for a statistically significant fleet, and are again considerably lower than those for fleets previously measured in the Chicago area.

Vehicle emissions as a function of vehicle specific power revealed that NO emissions show a positive dependence on specific power, while HC emissions show a negative dependence on specific power – the expected trends. Carbon monoxide emissions show a slight negative dependence on specific power in the range from –5 to 25 kW/tonne. This negative dependence of CO in less pronounced than previous years.

Using vehicle specific power, it was possible to adjust the emissions of the vehicle fleet measured in 2000, 1999 and 1998 to match the vehicle driving patterns of the fleet measured in 1997. After doing so, average emissions of all three pollutants of the current fleet were lower than the emissions of the 1997 fleet. A model year adjustment was applied to 1983 to 1997 model year vehicles to track deterioration. It was observed that the average emissions of the fleet had declined, apparently more than offsetting expected emissions deterioration. It is possible that the recently implemented reformulated gasoline program caused this effect. Finally, an analysis of high emitters shows that there is significant overlap of vehicles that are high emitting for CO and HC.

ERG, "Evaluation of Remote Sensing," Prepared for: Arizona Department of Environmental Quality, June 27, 2002.

In mid-2001, the Arizona Legislature mandated that a study be funded to investigate improvements to the overall efforts to reduce on-road vehicle pollution in Arizona. The Arizona Alternative Compliance and Testing Study (AZACTS) seeks to develop new methods and new ideas to improve automotive pollution control that are technically effective, as well as acceptable to the public. Wherever possible, the proposed improvements should satisfy EPA requirements set forth in current State Implementation Plans (SIPs).

One goal of the AZACTS is to evaluate vehicle Remote Sensing Devices (RSD) for their applicability to strategies for reducing vehicle pollution. Although RSD has been used to measure emissions of vehicle fleets since the late 1980's, in many respects it is still evolving as a technology. Most of the technological changes have been aimed at expanding the capabilities of RSD.

RSD has been used in Arizona before. Arizona DEQ ran a remote sensing high emitter identification program from 1996 until April 2000. Other uses of RSD in Arizona have been in the form of studies aimed at answering specific questions. For example, under an ongoing project funded by the Coordinating Research Council, vehicle emissions have been tracked once per year, over several years at a freeway ramp near the Airport in Phoenix.

RSD researchers have speculated that the technology is appropriate for application to many strategies for reducing on-road pollution. For example, the state of Virginia is conducting a pilot program aimed at determining several ways RSD can improve and/or quantify the effects of several strategies. For example, they want to determine how RSD can be used to quantify the emissions of vehicles driving in north Virginia, which are not subject to the inspection and maintenance requirements of that area.

ERG subcontracted two companies that manufacture and operate competing on-road remote sensing technologies: MD LaserTech and Environmental Systems Products (ESP). ERG also contracted the University of Denver to co-locate its remote sensing unit with each of the commercial vendors, for at least part of the time each of the vendors were collecting data. This established a common baseline to which the vendors could be compared. It also provided data for each area from a single system.

Recommendations were made to about protocol setting for RSD studies including establishing data protocols, setting standards for calibration frequency, collecting instrument noise analysis during measurement campaigns, defining a standard method to handle instrument offsets. Concern was expressed about the accuracy of the acceleration measurements, A further program to determine the accuracy of the acceleration measurements was recommended.

Rob Klausmeier and Chris Weyn, "Using Remote Sensing Devices (RSD) to Evaluate the California Smog Check Program," prepared for California Bureau of Automotive Repair, October 2, 1997

Data from the Statewide California remote sensing program (OREMS) after June 1996 was used to analyze the benefits of the California Smog Check program. Remote sensing based analysis found far less CO and HC tailpipe emissions benefits than claimed by the test analyzer system results from decentralized inspection stations. Remote sensing based analysis gave results similar to that found in the California 1100 vehicle study.

Over 3.5 million records were gathered in OREMS, however, because of concerns over the accuracy of the data before June 1996, only data after that date were used. Also, data from questionable sites were removed. These sites were suspected of having many cold start vehicles since over 5% of vehicles less than two years old were seen with CO emissions greater than 2%.

After screening the data, the measurements were linked to inspection times in the following way:

- Before smog check – from 90 to 30 days before the initial smog check
- After smog check – from 0 to 90 days after passing the smog check or, in the case of vehicles that did not pass, after the last recorded smog check.

The Before and After smog check categories were further subdivided.

- Vehicles that initially passed
- Vehicles that initially failed but eventually passed

- Vehicles that initially failed and never had a passing record (note: some of these vehicles may have gone to a referee station and have no recorded outcome.
- All vehicles before and after smog check.

In addition to these groupings, results were broken into model year groups.

- Pre 1975
- 1975-1980
- 1981-1986
- 1987-1990
- 1991 and later

Remote sensing CO and HC emissions averaged by model year groups followed the expected order. Similarly, remote sensing CO and HC emissions of After Smog Check vehicles were lower than CO and HC emissions of Before Smog Check vehicles, and vehicles which failed and then passed had higher emissions than vehicles that initially passed. These results were consistent with other studies of emissions. The percent reduction for all vehicles indicate that the fleet HC and CO tailpipe emissions are reduced by about 9% from the smog check program.

The remote sensing results were compared to test station claims and the 1100 vehicle study. The remote sensing and 1100 vehicle study found emissions reductions for failed vehicles to be between 17% and 20%, while the test station claimed reductions between 75% and 80%.

The authors concluded that remote sensing may provide a reasonable indication of repair effectiveness and they agree with previous evidence that smog check stations may be reporting fraudulent test results.

J. Gallagher, K. Nelson, K. Livo, "On-Road Emissions Changes Due to I/M 240 Inspection/Maintenance and Oxygenated Fuel Program as Measured by Mass Emission and Remote Sensing," Colorado Department of Public Health and Environment Technical Paper, World Car Conference '97, Center for Environmental Research, University of California, January 19-22, 1997

"In a remote sensing pilot program being conducted in Greeley CO, average weekly remote sensing measurements taken from one remote sensing monitoring site, have demonstrated reductions in carbon monoxide emissions during the oxygenated gasoline season. At one site which made over 92,000 measurements in December 1995 through the middle of September 1996, average %CO emissions were reduced from 1.25 %CO to 0.96 %CO during the winter oxygenated gasoline program months, a 23.2% reduction."

Unlike the IM240 lane data which cover the same period, the changes in average %CO emissions show a sharp step increase, which coincides with the seasonal end of the oxygenated gasoline program. Ambient temperatures and changes in air density, hypothesized as contributing/confounding factors in analysis of the lane data, are less likely factors as a result of the remote sensing data since average %CO emissions from the site are consistent from late winter into the fall. During this time period, there is large variation in ambient temperatures and air density.

T. C. Austin, F. J. DiGenova, T. R. Carlson, "Analysis of the Effectiveness and Cost-Effectiveness of Remote Sensing Devices," Sierra Research, Inc., prepared for the US EPA, May 18, 1994

Estimates were developed for the cost and effectiveness of using remote sensing devices (RSDs) to facilitate the identification and repair of vehicles with high emissions. These estimates were compared to cost and effectiveness projections for conventional vehicle inspection maintenance (I/M) programs requiring inspections at fixed locations on a scheduled basis. Estimates for decentralized program effectiveness and all cost estimates were based on data collected by the California IM Review Committee. As a supplement to a conventional I/M program, remote sensing with roadside pullovers and confirmatory roadside testing is projected to provide additional emission reductions at a favorable ratio of cost to effectiveness. However, widespread use of RSDs to screen vehicles for more comprehensive testing or to replace a conventional I/M program decreases the emissions reductions that would otherwise be achieved.

The report projects emission reductions from California's current decentralized I/M program in calendar year 2000 from vehicles subject to the program by 16.6% for HC, 25.3% for CO, and 10.4% for NO. Addition of a remote sensing program would increase these projected reductions by about 10%.

The additional RSD program uses six teams of RSD van operators, Highway Patrol officers, and inspectors who move from site to site on a daily basis, covering 1,000 sites each year. The annualized cost is estimated at 3.3 million dollars.

The same program is estimated to increased emissions reductions from a centralized enhanced I/M program by only half as much. Without the use of RSDs the enhanced centralized program is projected to reduce emissions by 35.8% for HC, 34.6% for CO, and 22.2% for NO.

The use of RSDs to screen vehicles for more comprehensive testing was also evaluated. This approach is projected to substantially lower the emissions reductions achievable by I/M.

Vehicles with moderately high exhaust emissions escape detection because of the limitations of RSD testing. Vehicles with defects in the evaporative emission control systems, crankcase control systems, or cold start control systems escape detection unless they also have high exhaust emissions. Most forms of emission control tampering would go undetected on vehicles that are otherwise well maintained.

In addition, the (then) currently available RSDs will not accurately measure NOx and HC emissions. The inherent lack of control over the operating conditions of the vehicles being tested by RSDs introduces substantial variability in the test results, making it more difficult to separate defective vehicles from properly maintained vehicles. In addition, the inability of the RSDs to measure mass emission rates makes the exhaust of all vehicles with the same emissions concentrations appear to be the same even when the mass of emissions may be substantially different.

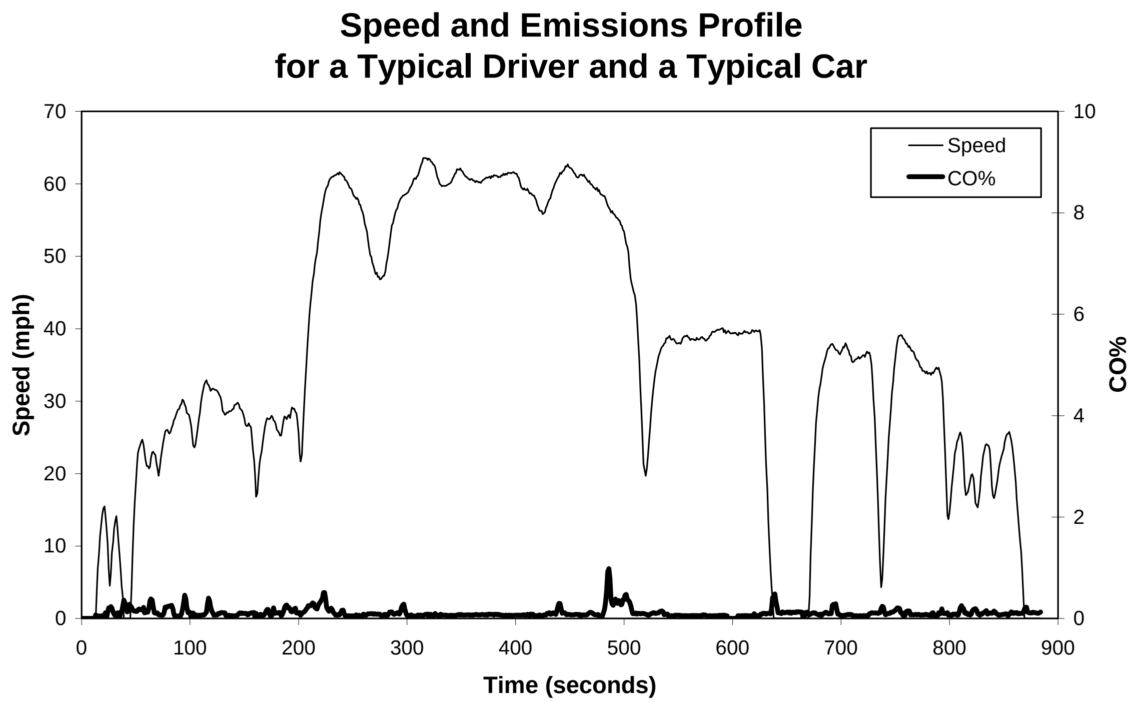
Failure to recognize the inherent variability of vehicle emissions when operating conditions are not tightly controlled has led to frequent misinterpretation of the results of experiments conducted using RSDs to measure emissions from vehicles in customer service. Foremost among the incorrect conclusions is that 10% of all vehicles are responsible for 50% of all vehicle emissions. This conclusion can only be drawn by assuming that

- instantaneous emissions measurements made by RSDs represent the average emissions from each vehicle measured
- emissions not measured by RSD (e.g., evaporative emissions) are perfectly correlated with carbon monoxide emissions [since, then, the only emissions which the authors felt could be accurately measured by RSDs].

Sierra concluded that neither assumption is correct.

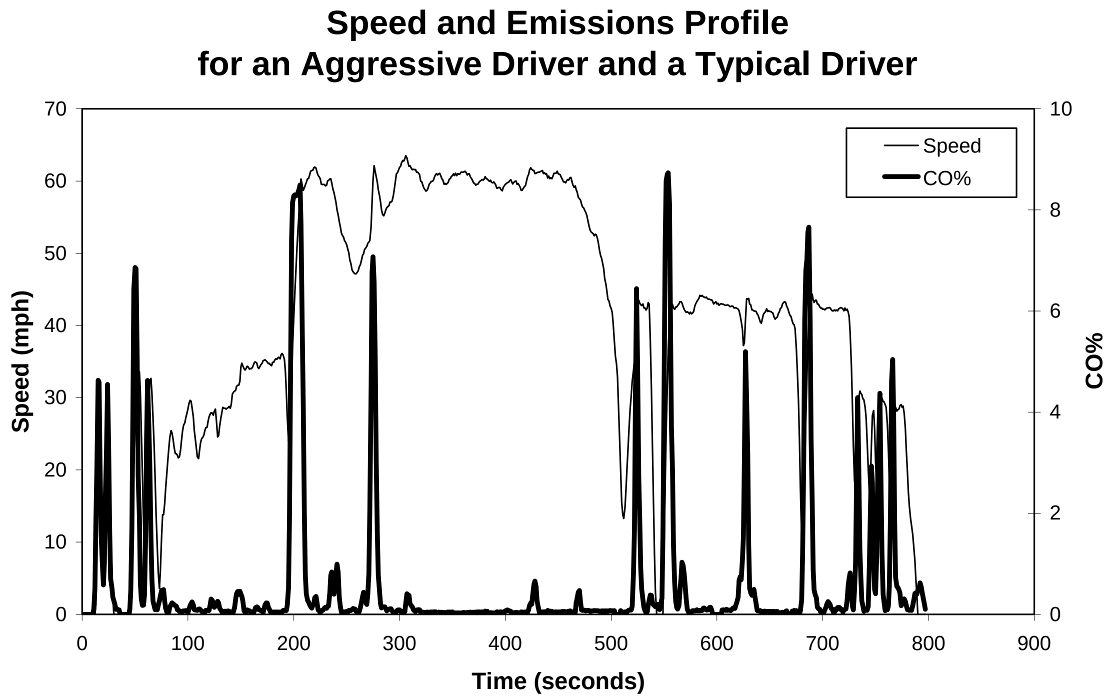
The report provides second-by-second emissions data from an instrumented vehicle driving over a particular road route in Sacramento, California, and shows that there are extreme variations in the instantaneous emissions from the vehicle depending on how it is being driven. The figures contained in the report are reproduced below. The variation in instantaneous emissions is evident whether or not the vehicle contains an emissions-related defect. Graphical presentations of the second-by-second emissions results indicate that instantaneous emissions from a vehicle without any emissions-related defects can be higher than the instantaneous emissions from a vehicle with a serious emissions-related defect.

Figure 1



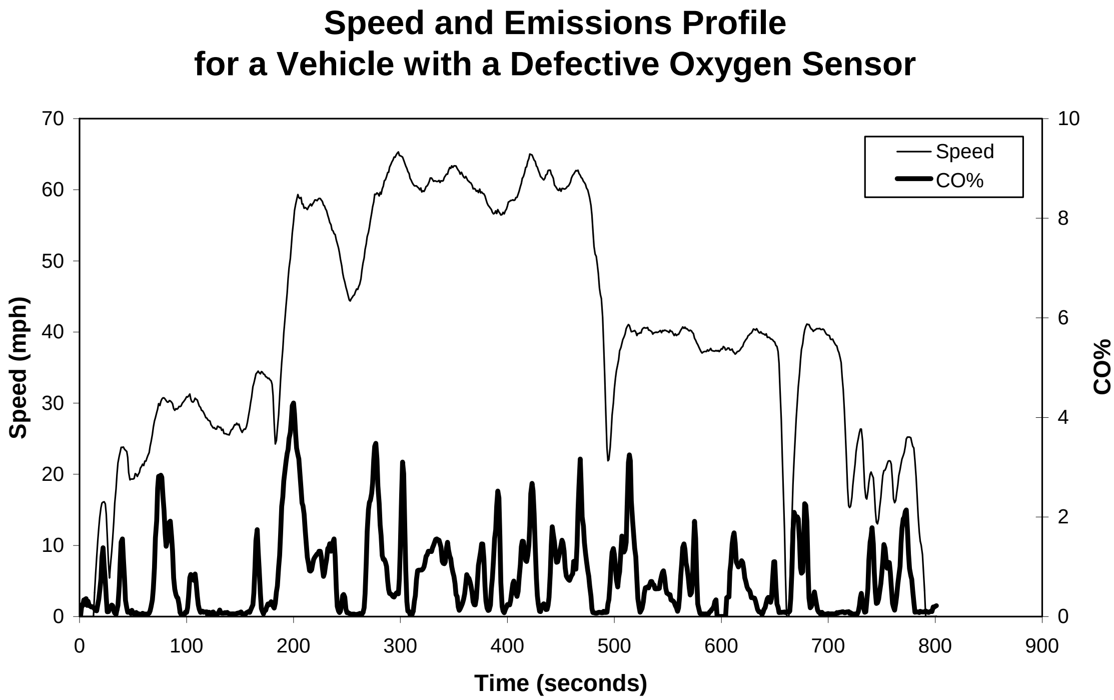
NOTE: Overall emissions 2.2 g/m.

Figure 2



NOTE: Overall CO emissions 39.0 g/m.

Figure 3



NOTE: Overall CO emissions 21.0 g/m.

Although it is now more widely recognized that there can be extreme variation in remote sensing measurements of the same vehicle, many recent studies are based on the assumption that the average of multiple measurements on the same vehicle can be used to accurately represent the average emissions from an individual vehicle. Although the 1994 Sierra report doesn't specifically address this issue, it is obvious from the data presented in the report that simply averaging two or three remote sensing measurements does not ensure that emissions from individual vehicles are accurately represented. For example, a motorist who routinely accelerates hard on freeway on-ramps might be repeatedly measured during an operating mode that generates relatively high emissions, regardless of whether emissions-related defects are present.

"Review of Air Quality and Motor Vehicle Technology Issues Pertaining to the Design of Air Care II," Sierra Research, Inc., prepared for Greater Vancouver Regional District, July 1998

Excepts about remote sensing:

In contrast to the increased emission control achievable from the implementation of an enhanced AirCare program, our analysis indicates that alternatives to conventional I/M programs are not yet capable of providing as much emissions control. Remote sensing devices (RSDs) are not yet developed to the point where they can reliably separate vehicles with emissions-related defects from vehicles that are defect-free.

The accuracy of the measurements of CO emissions is relatively good, and the HC and NOx measurement accuracy is improving, but several fundamental problems remain. First and foremost is the fact that vehicle emissions at any instant in time are strongly affected by recent changes in throttle position and the instantaneous load on the engine. I/M test procedures address this inherent variability by ensuring that operating conditions are carefully controlled. In contrast, measurements based on remote sensing allow radically different results to be obtained on the same vehicle depending on how smoothly and consistently it is being driven. The variability inherent in measurements made by remote sensing requires that extremely lenient emissions standards be used unless high rates of false failures are to be accepted. With lenient emissions standards, most of the emissions-related defects that exist in the fleet cannot be detected.

Another fundamental limitation of remote sensing is that it cannot detect evaporative emissions-related defects, the emissions from which primarily occur when the vehicle is parked.

In the longer term there is potential for improving the ability of remote sensing to separate vehicles with emissions-related defects from properly operating vehicles, however, in an atmosphere where significant disadvantages and limitations of the current systems are recognized and appreciated by relatively few people in decision-making roles, promoters of the remote sensing devices have shown little interest in improving the technology.

An additional source of confusion regarding the feasibility of remote sensing is the numerous reports published by proponents of remote sensing indicating that the majority of emissions from vehicles in customer service are caused by less than 10% of the vehicle population. This has led many people to conclude that an inspection program based on remote sensing would be extremely effective in identifying vehicles in need of repair without the need to subject all vehicles to periodic inspections. The feasibility of this approach was addressed during the California I/M Pilot Program.

The California study involved a large-scale remote sensing program combined with IM240 testing on over 2,500 vehicles recruited at random from vehicles registered in the Sacramento area. Participation in the program was mandatory and the capture rate was therefore very high.

Two of the purposes of the program were:

- to establish the relationship between average emissions in stop-and-go driving as measured by the IM240, vehicle characteristics (e.g., make, mode, age, previous I/M test results), and emissions measured by RSDs.
- Determine the portion of all registered vehicles that were detected by a network of RSDs during an extended period of time.

The remote sensing program involved two different contractors who moved several RSD vans from location to location during a two-month period. Most of the locations selected for deployment of the vans were heavily traveled surface streets.

The results of the RSD portion of the Pilot Project found that only 10% of the excess emissions from vehicles registered in the Sacramento area were identified by RSDs, even when the RSD cutpoints were set so low that more than half (58%) of the failing vehicles proved to be false failures. There were two problems contributing to the low number: (1) measurements were obtained on fewer than half of the vehicles registered in the Sacramento area, and older vehicles were underrepresented and (2) extremely poor correlation between data recorded by RSDs and average emissions in stop-and-go driving, as measured by the IM240 on the same vehicle.

A hypothetical example was given where if each vehicle on the road emitted 1 g/mi 90% of the time and 9 g/mi 10% of the time, it would appear that 10% of the vehicles were emitting 50% of the emissions, but all the vehicles would be contributing equally. This hypothetical example illustrates why the distribution of emissions of vehicles in customer service cannot be accurately constructed from an analysis of data collected by remote sensors.

Another factor commonly ignored in analyses of remote sensing test results is that vehicles are not designed or certified to meet concentration-based emission standards. The contribution of exhaust emissions to air pollution is caused by the product of emissions concentration and exhaust volume (g/sec or g/mi). RSDs can only determine emissions concentration. As a result vehicles with low fuel consumption will appear to have relatively high emissions compared to vehicles with relatively high fuel consumption. Because the range of fuel economy for vehicles in the existing fleet exceeds four to one, a fuel efficient compact car emitting 4% CO can have exactly the same gram/mile emission rate as a heavier car emitting 1% CO.

T.C. Austin and P.L. Heirigs, "Analysis of Data from the California I/M Pilot Program," report sr95-06-01, prepared by Sierra Research, Inc., prepared for: US EPA

The Sacramento-based program involved a large-scale remote sensing program combined with IM240 testing on over 2,500 vehicles recruited at random for vehicles registered in the area. The remote sensing portion of the program involved two different contractors who moved several different RSD vans from location to location during a two-month period. The locations selected for deployment of the vans included heavily traveled surface streets and freeway ramps. When there were more than two lanes flowing in one direction, a van was parked in a middle lane and traffic was diverted around both sides of the van. Large signs were placed in the roadway to warn motorists of the lane blockage. There was no indication to the motorists that the vans were measuring emissions. In total there were 501 van days of data collected before vehicles were recruited for IM240 testing.

One purpose of the Sacramento program was to establish the relationship between average emissions in stop-and-go driving (as measured by IM240), vehicle characteristics (e.g., make, model, age, previous I/M test results), and emissions measured by RSD. Another purpose of the program was to determine the portion of all registered vehicles that could be detected by a network of RSDs during an extended period of time.

Remote sensing test results obtained during a large-scale experimental program conducted in Sacramento were very poorly correlated with average emissions during stop-and-go driving (as measured by the IM240 test). Using mobile vans equipped with remote sensing devices (RSDs) measurement could not be obtained on about 75% of the pre-1980 model year vehicles during 500 van-days of testing. Using RSD cutpoints of 4% CO and 1000 ppm HC, only about 10% of the excessive HC and CO emissions in the fleet were identified (fleet-based excess emissions identification rates were discounted by the fraction of vehicles that were captured by RSD – also see footnote regarding the notice sent to motorists) and 58% of the vehicles exceeding the RSD cutpoints were false failures (i.e., they passed the IM240 test). While the presence of the remote sensing program is expected to have some deterrent effect on tampering, there is no evidence that RSDs can reliably detect some of the most common forms of tampering (e.g., disconnection of the EGR systems and removal of air injection systems), they are prone to false failures, and are unable to identify most of the excess emissions that exist in the fleet even using cutpoints that yield a relatively high false failure rate. (Remote sensing tests are IM240 tests were generally separated in time by 2 to 4 months. This time duration is longer than might occur if remote sensing were used as a method of identifying out-of-cycle I/M failures; however, some time lag would exist between remote sensing, motorist notification, and vehicle testing in any operating program. The effect of the time gap on the results of the study was not investigated.)

J.L. Jiménez-Palacios, "Understanding and Quantifying Motor Vehicle Emissions with Vehicle Specific Power and TILDAS Remote Sensing," Thesis, Massachusetts Institute of Technology, February 1999

To better relate emissions with operating conditions, a new parameter termed "specific power" (SP) is presented. SP is the instantaneous tractive power per unit vehicle mass. This parameter has three main advantages: it can be calculated from roadside measurements, it captures most of the dependence of light-duty vehicle emissions on driving conditions, and it is directly specified in emissions certification cycles. The dependence of CO, HC, and NOx emissions on SP is better than on several other commonly used parameters, such as speed, acceleration, power, or fuel rate. Using SP as the basic metric allows meaningful comparisons to be made between data from different remote sensing sites, dynamometer driving cycles, and emission models. Modern U.S. vehicles are likely to operate under commanded enrichment when SP exceeds the maximum value on the Federal Test Procedure (~22 kW/Metric Ton). This may allow transient high emissions to be screened out during future remote sensing campaigns.

Remote sensing can address the problem of inter-vehicle differences by quickly and cheaply measuring the emissions of large numbers of vehicles. Here, a tunable infrared laser differential absorption spectrometer (TILDAS) remote sensor was used to gather the first on-road measurements of N_2O and NO_2, and the first high precision measurements of NO. NO was detected with a sensitivity of 5 ppm, which allowed even Ultra Low Emission Vehicles to be measured. On-road accuracy was demonstrated by comparing the TILDAS results with the on-board measurements of a heavy-duty diesel truck (HDDT). The remote sensor could operate with an optical path length of 88 meters, more than five times that of competing instruments. The NO and N_2O emission distributions of passenger cars (PCs) and light-duty trucks (LDTs) were found to be highly skewed, while the NO emission distribution for HDDTs was not. N2O emissions from PCs and LDTs are estimated to contribute between 0.5% and 0.9% to U.S. greenhouse gas emissions.

J.L. Jiménez, Peter McClintock, G.J. McRae, David D. Nelson and Mark S. Zahniser, "Vehicle Specific Power: A Useful Parameter for Remote Sensing and Emission Studies," 9th CRC On-Road Vehicle Emissions Workshop, San Diego, April 21st 1999

Effect of Driving Conditions on Emissions:

- Driving conditions may strongly influence emissions
  - e.g. commanded enrichment at high power demand
- Problems:
  - False high emitters / False clean cars in remote sensing
- Texas Remote Sensing Study (CRC 98): 65% of cars at 5-6 mph/sec are high CO emitters
  - Difficult to compare between RS, dyno cycles, & models
  - Difficult to capture on emissions models
- MOBILE, EMFAC: EF * Speed Correction * Cycle Correction
- Modal, Neural Network: very detailed & complex

VSP Levels of Various Activities	
Activity	VSP (kW/ Metric Ton):
• Max. Rated Powers	44 - 112
• 0 to 60 mph in 15 seconds	33
• 60 mph up a 4% grade	23
• Maximum in FTP/IM240	23
• Remote Sensing site means	10 -15
• Average in IM240	8
• ASM 5015	6
• ASM 2525	5

Advantages of VSP

- Captures dependence of emissions on power
  - o Directly specified in certification cycles
- Can be calculated from roadside measurements
  - o Mass only appears in aerodynamic term
- One-dimensional
- Direct physical interpretation

Use of VSP Distributions:

- Characterize & Compare Driving Cycles, Remote Sensing Sites, or Models
- Detect onset of enrichment (Tier 0, Tier1 vehicles certified on FTP)
- Improve clean screen and high emitter detection (VSP 3 to 22 kW/t)
- Relate remote sensing to I/M test results.

- Quantify real emissions at high power levels.
- Compare results of remote sensing at different sites, with dynamometer tests, with emissions models.
- Better representation of vehicle power in emissions models.