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REMOTE SENSING DEVICE HIGH EMITTER IDENTIFICATION WITH CONFIRMATORY ROADSIDE INSPECTION

State of California Department of Consumer Affairs

Bureau of Automotive Repair
Engineering and Research Branch

BAR ENGINEERING Engineering Clean Air

INTRODUCTION

Several uses of remote sensing devices (RSDs) have been proposed, such as on-road identification of high emitting vehicles and monitoring on-road vehicle emissions for program evaluation purposes. The Bureau of Automotive Repair (BAR) conducted a study to evaluate the ability of RSDs to consistently identify vehicles with excessive emissions and correctly classify the vehicles as failing the Acceleration Simulation Mode (ASM) inspection test. The ASM test was performed using the BAR-97 Emission Inspection System (EIS) which includes an emissions analyzer and steady-state dynamometer. As a special study, BAR deployed two remote sensors upstream of the roadside inspection lane at multiple sites. These units were used to measure and pre-select high-emitting vehicles (HEVs) for an immediate ASM inspection by the roadside team. For comparison purposes, the RSDs also measured passing vehicle emissions.

BACKGROUND

The 1994 State Implementation Plan (SIP) anticipated an in-use emissions audit program, such as RSD, to detect HEVs. Early RSD studies focused on remote sensing to measure carbon monoxide (CO) and hydrocarbons (HC) in lieu of other testing procedures to measure tailpipe emissions. For example, the South Coast Air Quality Management District's study, *Program for the Use of Remote Sensing Devices to Detect High-Emitting Vehicles*, dated April 1996, examined CO and HC RSD identification with IM240 confirmatory testing. The study included approximately 150 pull-over vehicles, 10% of which exceeded a combined cutpoint of 4% CO and/or 1000 ppm HC, resulting in a 95% confirmatory test failure rate.

Recently, the National Academy of Sciences recommended improving the effectiveness of I/M programs in their report, *Evaluating Vehicle Emissions Inspection and Maintenance Programs,* dated 2001. One recommendation made was that remote sensing should have an increased role in assessing vehicle emissions. More specifically, the evaluation states "I/M programs should focus primarily on identification, diagnosis and repair of the highest emitting vehicles along with verification of those repairs… remote sensing provides a useful screening tool to identify vehicles likely to fail conventional I/M program tests".

California's Smog Check Program requires most vehicles in California to have a biennial emissions test. The potential benefits of more frequent inspections, also known as "off-cycle testing" have been well documented. For example, in a recent evaluation of California's enhanced vehicle inspection and maintenance program, *Smog Check Station Performance Analysis, Based on Roadside Test Results,* dated June 27, 2000, BAR estimated that over 20% of the vehicles certified in the Enhanced Smog Check Program exceeded their allowable emissions in subsequent roadside tests.

DATA COLLECTION

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. Figure 1 shows the RSD portion of a typical inspection lane.

FIGURE 1
RSD Surface Street Setup

Note: Arrow indicates RSD.

Each RSD unit measures HC, CO and nitric oxide (NO) in percent. The criteria ("pull-over cutpoints") used for a high emitting vehicle was any ASM testable vehicle exceeding 1% CO or 500 ppm HC or 500 ppm NO on either RSD unit. During the study, one of the RSD units was not functioning due to a problematic NO detector. As a consequence, multiple RSD readings were not available for each ASM tested vehicle. In addition, AQRs occasionally tested non-targeted vehicles, when a high emitting vehicle was unavailable.

Figure 2 (page 4) shows the roadside pull-over test equipment including the BAR-97 EIS. Most inspections included a visual, functional, and dynamometer ASM test. To prevent inconveniencing the consumer by not exceeding ten minutes for a typical inspection, AQRs occasionally skipped visual and/or functional tests on vehicles with inaccessible emissions components.

FIGURE 2
BAR-97 ASM Test Equipment at Roadside Pull-over Site

RESULTS

Characteristics of the Pull-over Vehicles

BAR Engineering and Research analyzed the paired ASM and RSD data for the targeted vehicles. The analysis was based on data collected from May 23, 2000 through June 22, 2000. In total, 326 vehicles had at least one RSD test record in addition to an ASM test record.

Table 1 shows how each FEAT unit classified the pull-over vehicles. For example, 104 vehicles were classified as HEVs by both FEAT units using the pull-over cutpoints, whereas, only 8 vehicles were not classified as high emitting vehicles by either unit. In addition, twenty vehicles shown in bold type in Table 1 were removed from the HEV analysis because they were non-high emitting vehicles that were pulled over when a high emitting vehicle was unavailable and therefore not part of the targeted vehicles.

TABLE 1
Classification of Pull-over Vehicles by FEAT Unit

Unit 3006	Unit 3005			
	HEV	**Not HEV**	**No RSD reading**	**Total:**
HEV	104	4	26	134
Not HEV	7	**8**	**2**	17
No RSD reading	165	**10**	0	175
Total:	276	22	28	326

Table 2 shows the distribution of the pull-over HEVs by cutpoint exceeded and RSD. During this particular study, vehicles most often exceeded both the CO and the HC pull-over cutpoints in combination.

TABLE 2
Pull-over Distribution by Pollutant Combination and FEAT Unit

Cutpoint Exceeded	3005		3006	
	Number	Percent	Number	Percent
HC only	6	2.2	6	4.5
CO only	55	19.9	20	14.9
NO only	65	23.6	18	13.4
HC and CO	95	34.4	66	49.3
HC and NO	17	6.2	11	8.2
CO and NO	15	5.4	6	4.5
HC and CO and NO	23	8.3	7	5.2
Total:	276	100.0	134	100.0

Comparison of Pull-over HEVs to On-road HEVs

Table 3 shows the distribution of the "on-road" (vehicles passing by) HEVs by cutpoint exceeded. Approximately 26%, or 10,021 of the 37,657 "on-road" RSD readings recorded by unit 3005 exceeded the pull-over cutpoints. Whereas, approximately 29%, or 8,455 of the 29,408 "on-road" RSD readings recorded by unit 3006 exceeded the pull-over cutpoints. The differences observed between the two RSDs in part are due to occasional single unit operation and different "on-road" vehicle samples (license plates were unavailable to facilitate matching between the two RSDs).

TABLE 3
On-road Distribution by Pollutant Combination and FEAT Unit

Cutpoint Exceeded	3005		3006	
	Number	Percent	Number	Percent
HC Only	1,497	14.9	3,384	40.0
CO only	1,330	13.3	666	7.9
NO Only	4,429	44.2	2,003	23.7
HC and CO	1,282	12.8	1,130	13.4
HC and NO	651	6.5	823	9.7
CO and NO	411	4.1	144	1.7
HC and CO and NO	421	4.2	305	3.6
Total:	10,021	100.0	8,455	100.0

Table 4 shows the average emissions for RSD identified HEVs for pull-over vehicles compared to on-road vehicles. The pull-over vehicles are a subset of the on-road vehicles and their emissions are included in the on-road emission averages shown. In general, average emissions for pull-over vehicles were larger than average emissions for on-road vehicles. In part, this may be due to sample size, since the pull-over vehicles represent less than 3% of the on-road fleet. We would expect the average emissions for pull-over HEVs to become less variable and more consistent with the on-road HEV average emissions as more HEVs are targeted. Median emissions were also calculated and are given in Appendix B.

TABLE 4
Average Emissions for RSD Identified HEVs

RSD Pull-over Cutpoint Exceeded	Unit 3005						Unit 3006					
	HC (ppm)		CO (%)		NO (ppm)		HC (ppm)		CO (%)		NO (ppm)	
	Pull-over	On-road	Pull-over	On-road	Pull-over	On-road	Pull-over	On-road	Pull-over	On-road	Pull-over	On-road
HC only	1,313	979	0.48	0.23	171	75	967	963	0.21	0.26	61	53
CO only	270	251	3.68	2.62	105	109	205	212	3.49	2.60	207	108
NO only	229	151	0.29	0.20	2,264	1,261	257	151	0.23	0.19	2,153	1,079
HC and CO	1,787	1,815	6.02	4.74	5	51	2,378	2,025	5.16	3.91	56	44
HC and NO	1,040	970	0.48	0.36	2,020	1,473	1,220	1,011	0.40	0.39	1,511	1,059
CO and NO	275	286	2.28	1.99	1,178	1,196	378	230	2.09	1.95	1,134	1,086
HC and CO and NO	1,540	1,618	2.92	3.11	1,304	1,621	1,571	1,454	3.06	2.52	815	1,054
Total:	900	621	3.06	1.31	804	802	1,336	863	3.04	1.04	504	451

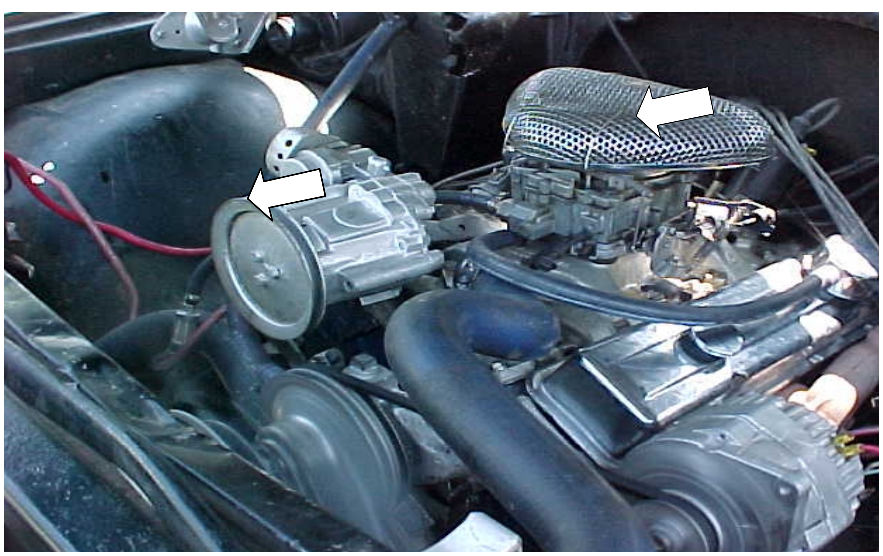
RSD Cutpoint Analysis

Various RSD target cutpoints, in addition to the pull-over cutpoints were evaluated, taking into consideration correct identification by the RSD and the number of vehicles affected. Correct identification occurred when a vehicle identified as a HEV for any pollutant by the RSD also failed the ASM inspection test. An ASM inspection test failure occurred when: 1) the vehicle failed the emissions portion of the test for any pollutant and/or 2) the vehicle failed the visual/functional inspection. Only vehicles with valid ASM emissions readings were used in the subsequent analyses. Valid ASM test records were determined using the routine roadside filter criteria given in Appendix A.

Although BAR Phase 2.3 ASM cutpoints were in effect during this study, BAR's Phase 3.2 ASM cutpoints (Appendix C), designed to tighten the HC cutpoints for some Emissions Standards Categories (ESC) by 30%, were used to calculate emissions failure rates in this analysis. Phase 3.2 ASM cutpoints were implemented August 8, 2001.

Due to the limited visual/functional portion of the ASM inspection for some vehicles, the failure rates presented are approximate and may underestimate the expected ASM test failure rate. Approximately 50% of the pull-over vehicles received a complete visual/functional inspection, due to time constraints associated with testing inaccessible emission components. Figure 3 shows a tampered vehicle that would fail the visual portion of the ASM inspection due to a missing Thermostatic Air Cleaner (TAC) and a disconnected air injection system (AIS).

FIGURE 3
Tampered Vehicle

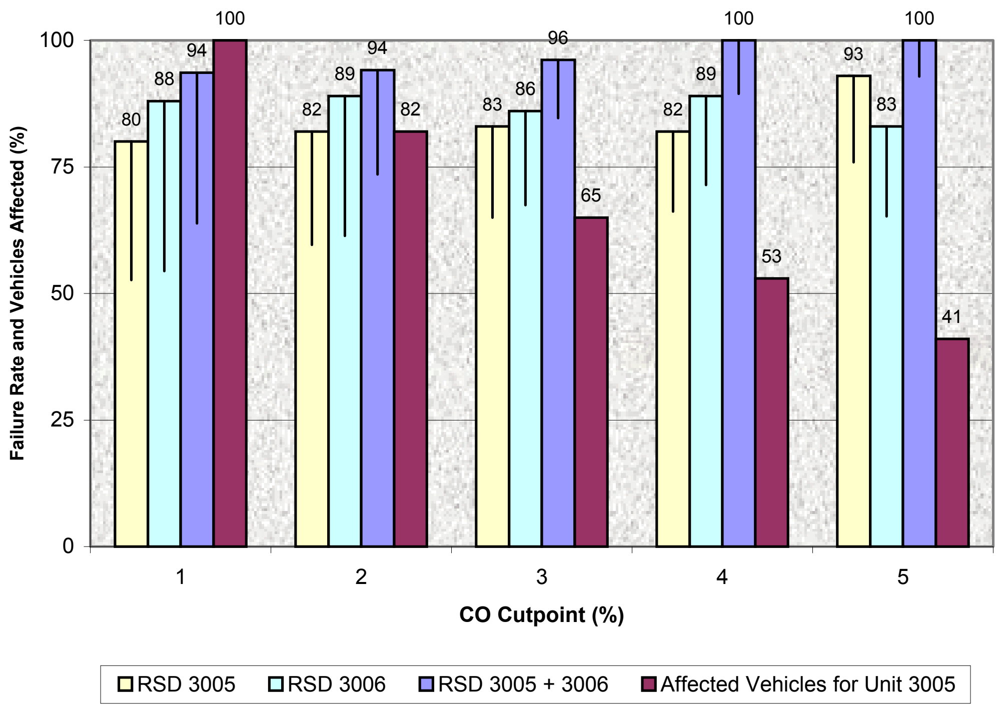


Note: Arrows indicate: 1) missing TAC and 2) disconnected AIR.Injection System (i.e., no belt).

Additional information on the specific emissions components evaluated during routine roadside inspections can be found in the BAR report, *Visual/Functional Analysis California Roadside Data,* dated December 4, 2000.

Historically, RSD CO readings have been a reliable identifier of high emitting vehicles. Figure 4 shows an increasing success rate (ASM inspection failure rate) as the RSD CO cutpoint increases; however, the percentage of affected vehicles decreases with an increasing RSD cutpoint.

FIGURE 4
ASM Inspection Failure Rate for RSD Identified CO HEVs



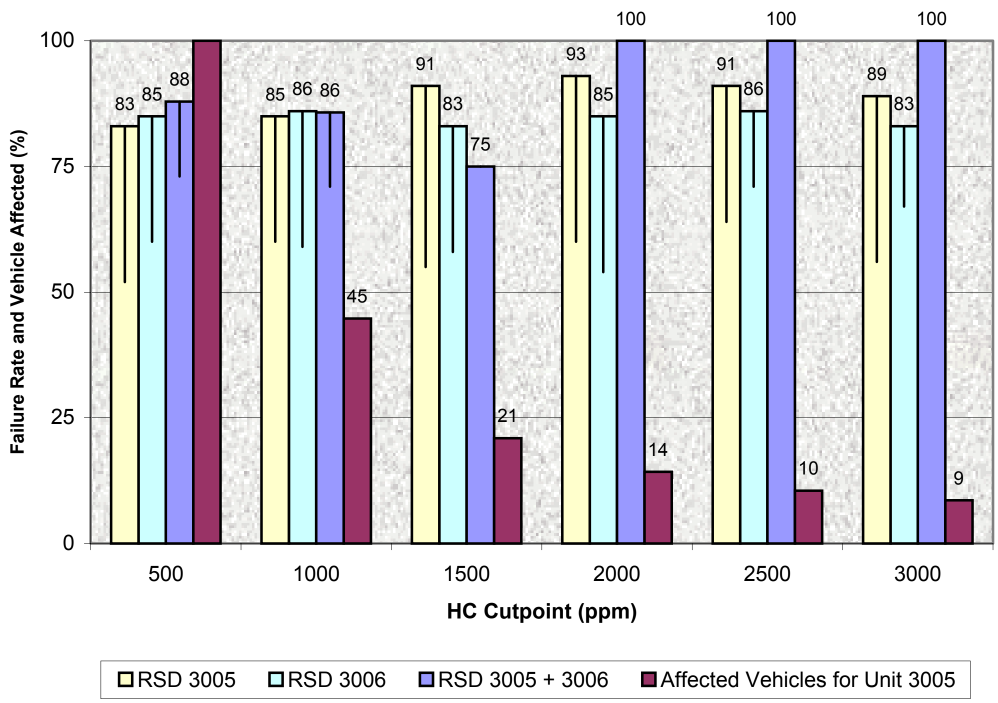
Note: Lines within bars indicate the portion of the ASM inspection failure rate due to other than CO failure.

Given enough test equipment, approximately 8% of the on-road fleet could be targeted using a cutpoint of 1% CO to pull-over vehicles. At CO pull-over cutpoints of 2%, 3%, 4% and 5%, we could affect approximately 8%, 5%, 4%, 3% and 2%, respectively, of the passing fleet.

Figure 4 also shows that CO identification by two RSDs instead of one RSD assists in the successful identification of high emitting CO vehicles. In most cases, for each cutpoint shown, the failure rate with multiple RSD readings is larger compared to the failure rate when the vehicle is identified by a single unit. So, when two RSD units are operating a lower CO cutpoint could be used.

Next, hydrocarbon HC RSD cutpoints were plotted against the ASM inspection failure rate in Figure 5. In general, RSD 3005 displays the same trend of increasing failure rate with increasing RSD cutpoint, however, the percentage of vehicles rapidly decreases.

FIGURE 5
ASM Inspection Failure Rate for RSD Identified HC HEVs



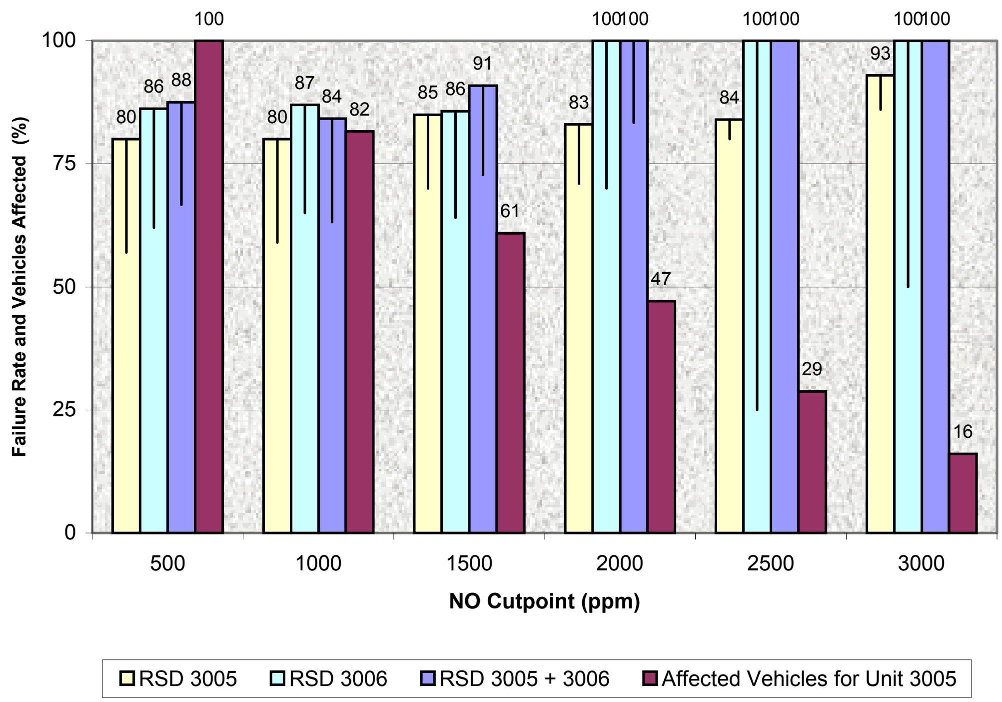
Note: Lines within bars indicate the portion of the ASM inspection failure rate due to other than HC failure.

Given enough test equipment, approximately 10% of the on-road fleet could be targeted using a cutpoint of 500 ppm HC to pull over vehicles. At 1000, ppm, 1500 ppm, 2000 ppm, 2500 ppm and 3000 ppm, we would affect 4%, 3%, 2%, 1% and 0.8%, respectively, of the passing fleet vehicles.

Figure 6 shows NO RSD cutpoints and the ASM inspection failure rate. Again, the increasing failure rate with increasing RSD cutpoint trend exists, with the percentage of affected vehicles decreasing. In general, we can also see that NO identification by two RSDs instead of one RSD provides a higher rate of successful identification as measured by a confirmatory ASM inspection test.

Given enough test equipment, approximately 12% of the on-road fleet could be targeted using a cutpoint of 500 ppm NO to pull over vehicles. At 1000, ppm, 1500 ppm, 2000 ppm, 2500 ppm and 3000 ppm, NO pull-over cutpoints, we would affect 6%, 3%, 2%, 1.5% and 1%, respectively, of the passing fleet vehicles.

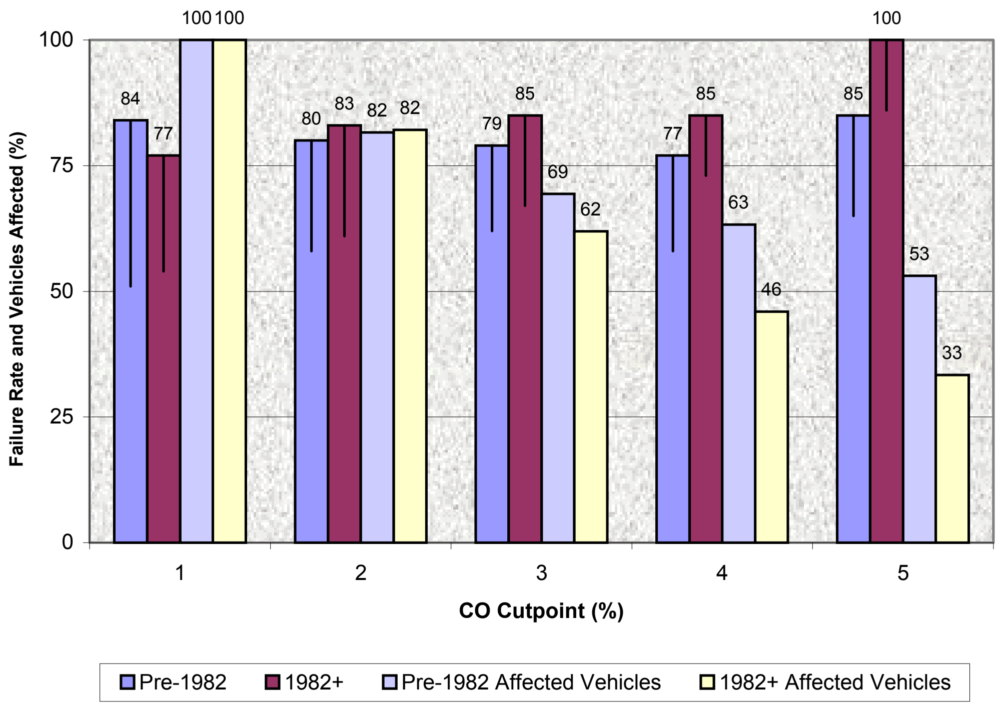
FIGURE 6
ASM Inspection Failure Rate for RSD Identified NO HEVs



Note: Lines within bars indicate the portion of the ASM inspection failure rate due to other than NO failure.

Finally, using unit 3005, the vehicles were partitioned into two model year groups with pre-1982 in one group, and 1982 and newer in a second group. For the pre-1982 group, the ASM inspection failure rate for RSD identified CO HEVs decreased with increasing cutpoint as shown in Figure 7 (page 11). However, the ASM inspection failure rate increased with increasing cutpoint for the later model vehicles identified as CO HEVs. This trend would suggest a lower RSD CO cutpoint for pre-1982 vehicles than for 1982 and newer vehicles. This pattern was not observed in the RSD HC or NO identified HEVs as shown in Figures 8 and 9 on page 12.

FIGURE 7
ASM Inspection Failure Rate for RSD Identified CO HEVs
By Model Year Group for Unit 3005

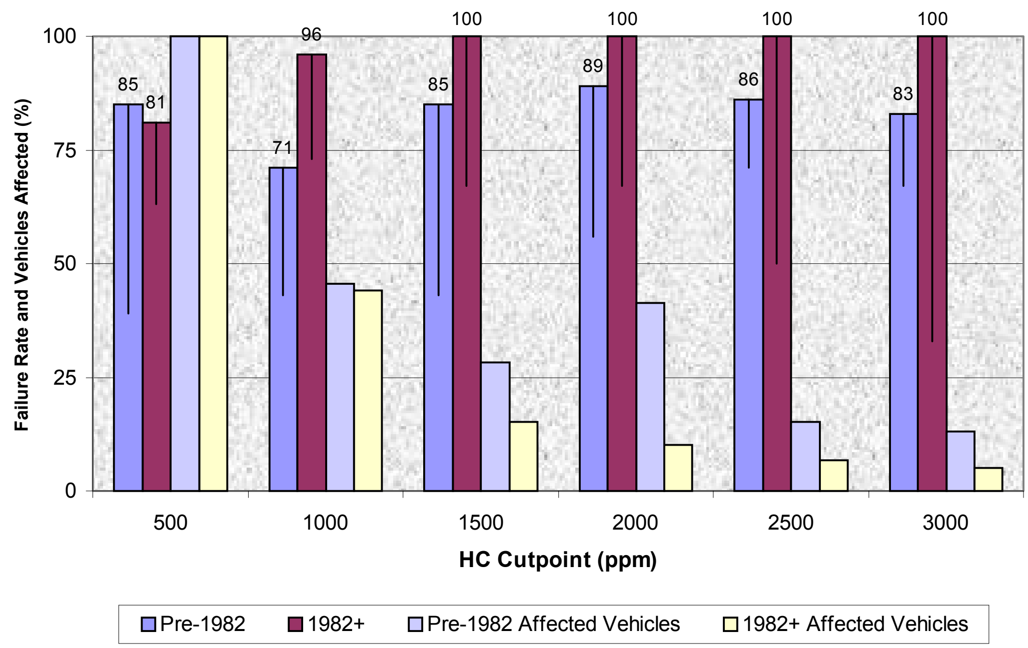


Note: Lines within bars indicate the portion of the ASM inspection failure rate due to other than CO failure.

Application of Cutpoints

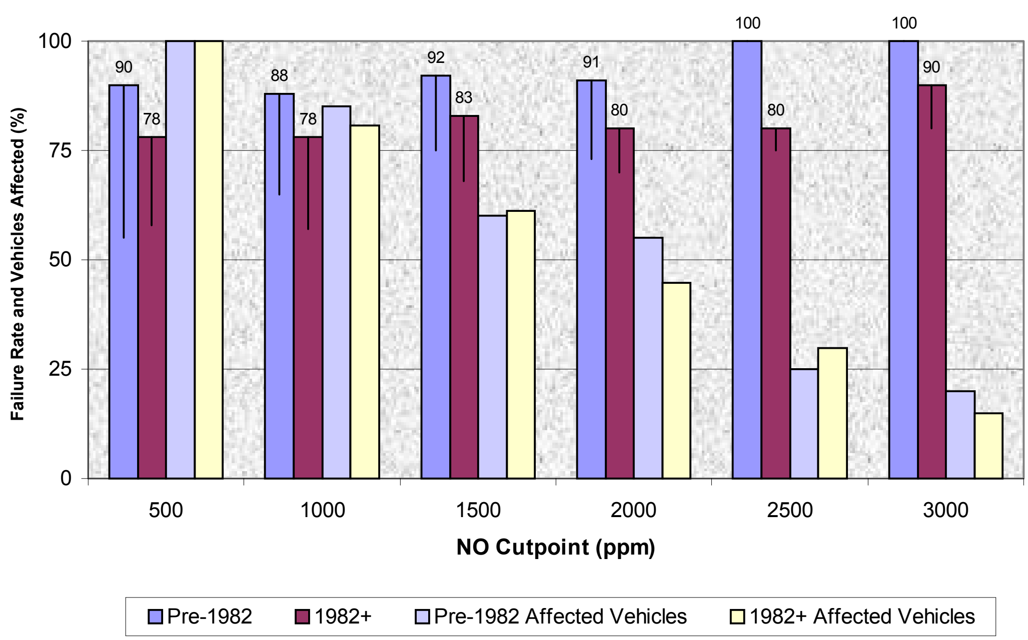
Table 5 (page 13) shows an example of how many on-road vehicles would be available for testing by the roadside team on a daily basis, if BAR used the cutpoint combination of 2% CO 1,000 ppm HC and 1,500 ppm NO to pull-over all vehicle model years. These RSD readings are from a typical day, June 21, 2000, when both units were operating from 8:30am to 3:30pm. Using a single unit, approximately 330 HEVs could be identified for immediate ASM inspection. For this particular site, a roadside team could easily identify and inspect 20 to 30 vehicles, the number of roadside inspections that are typically completed per day.

FIGURE 8
ASM Inspection Failure Rate for RSD Identified HC HEVs
By Model Year Group for Unit 3005



Note: Lines within bars indicate the portion of the ASM inspection failure rate due to other than HC failure.

FIGURE 9
ASM Inspection Failure Rate for RSD Identified NO HEVs
By Model Year Group for Unit 3005



Note: Lines within bars indicate the portion of the ASM inspection failure rate due to other than NO failure.

TABLE 5
On-road Distribution by Pollutant Combination and FEAT Unit
on June 21, 2000 from 8:30 am to 3:30 pm

RSD Result	3005		3006	
	Number	Percent	Number	Percent
Cutpoints Exceeded:	329	13.8	326	15.7
HC only	35	1.5	122	5.9
CO only	110	4.6	72	3.5
NO only	136	5.7	80	3.8
HC and CO	38	1.6	48	2.3
HC and NO	8	0.3	0	0.0
CO and NO	1	0.0	4	0.2
HC and CO and NO	1	0.0	0	0.0
Number of readings that did not exceed	2,063	86.2	1,753	84.3
Total Number of Readings	2,392	100.0	2,079	100.0

Note: Cutpoints applied were HC = 1,000 ppm, CO = 2% and NO = 1,500 ppm.

CONCLUSIONS

In conclusion, RSD has proven to be an effective tool for high emitting vehicle identification. By targeting vehicles with RSD emission readings exceeding 2% CO or 1,000 ppm HC or 1,500 ppm NO, we can expect at least an 83% to 88% ASM inspection failure rate. By adding multiple RSD readings exceeding the predetermined cutpoint, we can increase the successful identification of high emitting vehicles to at least 92%. The data suggests using a lower cutpoint for RSD CO identified HEVs for the specific model year group pre-1982. Given additional data, optimal cutpoints could be determined for more specific model year groups.

Appendix A

ASM Filter Criteria for Roadside Inspected HEVs

Discussion

The BAR-97 equipment used to perform roadside inspections differs from that used at Smog Check Stations. The dynamometer and sample system have special features (less constraints on variables) for roadside usage. The roadside equipment still meets accuracy requirements for BAR-97 test equipment, however some post-processing is required. Raw test records from the roadside inspections were edited by deleting aborted, duplicate, non-ASM test records. Vehicles with a recorded license of "TEST" were also removed, as were vehicles with a GVWR greater than 8,500 pounds. Further filtering based on humidity, temperature, barometric pressure, CO_2 and ASM test speeds was also performed. More specifically: test records with relative humidity less than 4 or greater than 96 percent were removed; test records with temperature less than 30^0 F or greater than 130^0 F were removed; test records with barometric pressure less than 26 or greater than 32 mm Hg were removed; test records with CO_2 greater than 17% were also removed. The sum of CO (dcf backed out) and CO_2 was required to be less than 6%. Records with a test weight of 2000 pounds in addition to a weight source entry of 'M', a roadside software-related problem, were removed. In addition, test records with negative emissions were removed, as were records with a recorded humidity correction factor (hcf) less than 0.7. Finally, NO readings were post-processed to reflect the updated EPA humidity correction formula.

Appendix B

Median Emissions for RSD Identified HEVs

TABLE B-1
Median Emissions for RSD Identified HEVs

RSD Pull-over Cutpoint Exceeded	Unit 3005						Unit 3006					
	HC (ppm)		CO (%)		NO (ppm)		HC (ppm)		CO (%)		NO (ppm)	
	Pull-over	On-road	Pull-over	On-road	Pull-over	On-road	Pull-over	On-road	Pull-over	On-road	Pull-over	On-road
HC only	1,260	690	0.47	0.17	173	86	650	760	0.21	0.22	74	68
CO only	290	270	3.16	1.98	88	89	280	270	3.19	1.94	208	95
NO only	210	160	0.16	0.13	2,153	999	275	190	0.12	0.13	1,961	878
HC and CO	1,030	930	5.84	4.26	22	62	1,340	1,060	4.99	2.98	56	59
HC and NO	920	690	0.46	0.31	1,998	1,089	880	800	0.44	0.37	1,461	833
CO and NO	300	330	2.27	1.62	1,003	1,007	385	325	2.13	1.64	999	825
HC and CO and NO	770	860	2.41	2.47	973	1,084	1,240	1,000	2.43	1.81	734	901
Total:	480	360	2.23	0.36	256	611	620	630	2.21	0.33	221	275

Appendix C

BAR Phase 3.2 ASM Cutpoints