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Analysis of a Remote Sensing Clean Screen Program in Arizona

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Abstract

This report analyzes the effectiveness of using remote sensing data to "clean screen" vehicles for exemption from their upcoming emissions inspection and maintenance (I/M) test. By exempting the cleanest vehicles from I/M testing, limited resources can be concentrated on identifying and repairing vehicles with the highest emissions. We apply the methodology used in the Colorado clean screen pilot program to 18 months of remote sensing and IM240 data from Arizona. We analyze a random sample of vehicles given the full IM240 test, as well as all vehicles tested during this period in Arizona. Our primary conclusions are that:

1) less than one-third of the vehicles in the Arizona I/M program were measured by remote sensing over an entire year of measurement;
2) the clean screen methodology used in Colorado is slightly less effective in identifying the cleanest vehicles in the Arizona fleet;
3) exempting the newest model years of cars is more effective than using a remote sensing clean screen; however, because much of the excess NOx emissions from light duty trucks comes from relatively new model years, states should carefully consider whether to exempt recent model year trucks from I/M testing.

This report describes these results, and examines other aspects of applying a clean screen program in Arizona.

Introduction

This report summarizes progress to date on analyzing the effectiveness of using remote sensing data to identify individual vehicles that are suspected of being cleaner than the average vehicle. If the effectiveness of "clean screening" can be demonstrated, states can use remote sensing to exempt vehicles from scheduled vehicle emissions inspection and maintenance (I/M) testing, in order to reduce the costs of their programs. There are three known evaluations of pilot clean screening programs in Colorado [1] and Arizona [2, 3]. This study uses remote sensing and IM240 data collected in Arizona to evaluate the effectiveness of the Colorado pilot clean screen methodology, as described in [1], in identifying clean vehicles in the Arizona I/M fleet. In this report we first describe how we matched remote sensing measurements with IM240 measurements of the same vehicle. Then we discuss the results of applying the cutpoints used in the Colorado clean screen pilot to the Arizona data. We also examine what fraction of the IM240 fleet had sufficient remote sensing measurements to qualify for clean-screening, and compare our clean screen results with results from exempting entire model years of vehicles from I/M testing.

Methodology

In this section we discuss the sources of data used, and how we matched remote sensing measurements with IM240 measurements of the same vehicle. We used two different samples of IM240 measurements, and different ways of using remote sensing measurements, to test the sensitivity of our methodology.

Three Samples of IM240 Measurements

For the analysis we obtained 18 months of IM240 measurements from the Arizona I/M program, from January 1996 to June 1997, from the contractor for the program, Gordon-Darby Inc. The entire database consists of over 1.2 million IM240 test results. We conduct our analysis of clean screening effectiveness on all initial IM240 tests conducted over 18 months (All Test sample), as well as a subset of the initial tests of vehicles randomly selected to receive a full IM240 (Random sample). Our reasoning for analyzing the two samples separately is described below.

One measure of the effectiveness of a clean screening program is the amount of excess emissions, defined as "IM240 emissions in excess of the IM240 cutpoints", attibutable to the vehicles identified by remote sensing. To accurately calculate IM240 excess emissions, one needs full IM240 test results. Arizona allows vehicles to fast-pass or fast-fail the IM240 before the full 240-second test is completed; about half of the vehicles tested fast-fail after only 31 seconds of testing. Roughly two percent of the vehicles tested in the Arizona program were randomly selected for a full IM240 test.

For his analysis of the Colorado clean screen [1], McClintock uses a random sample of full IM240 tests. The primary focus of our analysis, then, is the Arizona 2% random sample (referred to as the "Random" sample). However, because the total number of vehicles in the sample is small, we also analyze all initial tests conducted in the 18-month period, including vehicles that fast-passed or fast-failed the IM240; we call this sample the "All Test" sample. This sample is virtually the entire fleet of vehicles subject to the I/M program.

The drawback with the All Test sample is that emissions are measured over different portions of the IM240 driving cycle. To account for different test durations, we make rather simple adjustments to the emissions of vehicles that are not tested over the full IM240 cycle. These adjustments involve dividing measured grams per measured mile driven to obtain grams per mile. The grams per mile emissions are then divided by adjustment factors that vary by pollutant and by the test duration in seconds, but not by whether or not the vehicle passed or failed the IM240 or by vehicle attributes such as vehicle type or model year [4]. The result is adjusted gram per mile emissions that simulate the emissions of a given vehicle if it were run on the full IM240 cycle. The adjusted emissions are a rough approximation of the full test-equivalent emissions for an individual vehicle; the adjustments appear to be more accurate for vehicles tested over longer durations of the IM240 than vehicles passed after 31 seconds. Since Arizona does not fail high emitters until at least second 94 of the IM240, we believe the adjustment is better for the failing vehicles.

The use of adjusted emissions for vehicles not tested over the full cycle affects the calculations of excess emissions lost or retained by the clean screen, as well as the determination of whether or not a particular vehicle passes or fails the final IM240 cutpoints. Since the excess emissions only come from vehicles failing the IM240, and the adjustments are more accurate for failing vehicles, we believe using adjusted fast-pass/fast-fail test results does not introduce too much bias in the analysis. And as others have shown, inconsistent preconditioning results in many vehicles being falsely failed under Arizona's final cutpoints [5]. This bias exists in both the All Test sample and the Random sample of full test vehicles.

Remote Sensing Measurements

We also obtained over 4 million individual remote sensing readings over the same 18-month period from the remote sensing program contractor, Hughes. Two evaluations of the Hughes remote sensing equipment involving side-by-side comparison with similar instruments developed by others have found several problems with the data generated by the Hughes sensors. In particular, the studies found that:

- on average, the Hughes instrument measured both CO and HC emissions higher than measured by the other instruments;
- problems with the license plate recognition system resulted in the Hughes instrument matching vehicle license plates with remote sensing readings of a different vehicle; and
- the accuracy of the speed and acceleration measurements of the Hughes instrument is inconsistent [6].

Even with these limitations with the Arizona remote sensing data, we treat all reported measurements as accurate for this initial analysis. We hope to critically evaluate data from particular instrumented vans and sites to obtain a subset of the Arizona remote sensing data which minimizes these limitations, in a later analysis.

Because remote sensing measurements pick up the emissions variability of individual vehicles, analysts frequently require multiple measurements of individual vehicles, and often average multiple measurements. For his analysis of the Colorado clean screen [1], McClintock required that each of the last two remote sensing readings for an individual vehicle exceed both the HC and CO cutpoints; we apply similar criteria here. We discuss the sensitivity of our results to how we used the remote sensing data later in this report.

It is quite possible that vehicle owners make changes to their vehicles between the last remote sensing reading and the IM240 test, and that these changes affect vehicle emissions. If this practice is common, the ability of remote sensing readings to predict IM240 results will be reduced. McClintock restricted the remote sensing readings used to those taken within 365 days prior to the IM240 test; for this analysis we do the same. Shortening the time period between the two tests may improve the accuracy of the clean screen. However, it will also reduce the number of vehicles with useable remote sensing readings. We discuss this issue later in this report.

The McClintock analysis is based on remote sensing measurements taken at 6 sites; Hughes used over 100 remote sensing sites in the Phoenix area, in part to obtain remote sensing readings on as large a portion of the vehicle fleet as possible. Several of the Arizona sites have negative grades. In addition, starting in October 1996, Hughes measured vehicle speed and acceleration at every site; about half of the vehicles with speed and acceleration measurements were decelerating as they passed the remote sensor. CO, and to a lesser extend HC, emissions can increase dramatically under moderate to high loads, encountered when vehicles accelerate at moderate to high speeds; HC emissions can also increase dramatically during decelerations. It may be possible to improve the Arizona clean screen accuracy by using remote sensing measurements from only certain sites that are deemed efficient in collecting accurate readings, or by applying speed and/or acceleration criteria (to eliminate individual remote sensing readings of vehicles under deceleration, or moderate to high acceleration). However, we have not yet examined in detail the effect of placing these kinds of restrictions on the remote sensing readings used.

Analysis

In this section we discuss our analysis of applying the Colorado pilot clean screen program cutpoints and methodology to Arizona data. We first discuss the fraction of the Arizona I/M fleet for which useable remote sensing readings are available. Then we compare the effectiveness of the clean screen program applied to vehicles in Colorado and Arizona. Next we compare the effectiveness of the clean screen program to exempting entire model years of vehicles in Arizona. Finally, we discuss the sensitivity of our results to how we use the remote sensing data.

RSD Coverage

An important aspect of the effectiveness of a particular clean screen program is the fraction of vehicles measured by remote sensing. Even if the remote sensors are quite accurate in predicting the results of an IM240 test for individual vehicles, if only a small fraction of the vehicle fleet is measured by the sensors the effectiveness of clean screening will be reduced.[1] Previous evaluations of remote sensing have demonstrated a wide range in vehicle coverage, from 47% for Sacramento, a large, rather low-density urban area, to 72% for Greeley, Colorado, a relatively small community of 69,000 [7, 8].[2]

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1. One could argue that remote sensors focus on vehicles that contribute disproportionately to the emissions inventory, since the sensors are more likely to measure emissions from vehicles that are driven frequently. However, I/M programs currently treat individual vehicles equally, regardless of how many miles they are driven each year.
2. These coverages were achieved by requiring only one remote sensing measurement per vehicle; the Greeley coverage is reduced to 45% if two measurements are required for each vehicle.

Table 1 presents the fraction of initial IM240 tests in Arizona successfully matched with at least one remote sensing reading. The table calculates the coverage obtained for each of the two samples of the IM240 data described above. About 15% of the All Test sample are retests of vehicles which failed their initial test; we excluded these retests from the analysis (the database we used to extract the Random sample codes retests differently, and we could not easily calculate this number for the Random sample). Next, vehicle records without license plate information are excluded. About 15% of all tests have license plates coded as "NP", "PP", or "OS"; these codes stand for no plate, paper or temporary plate (typically a car dealer), and out of state plate, respectively. Finally, vehicles with inaccurate vehicle identification numbers (VINs) and subsequent tests coded as initial tests are excluded.[3] The result is that 70% to 80% of the entire IM240 sample are valid initial tests.

The next panel of Table 1 shows the fraction of remote sensing readings that are valid for use in the clean screen. The use of only remote sensing readings taken within the last year reduces the number of matched readings by about one-half. The ratio of matched remote sensing readings to matched initial IM240 tests is the same in each sample, 2.95. The final panel shows the overall match rate for each of the IM240 samples. Only 31% of the vehicles in the Random sample (4,649) could be matched with at least one remote sensing reading; this fraction drops to 19% (2,914) if two readings are required. The match rate for the All Test sample is comparable to that of the Random sample.

The match rates for each of these cases may be underestimated, however, if one considers that not a full year of remote sensing testing is available for all of the vehicles in the IM240 samples. For example, a vehicle tested on the IM240 in January 1996 (the first year of the IM240 data used in this study) would have at most only one month of remote sensing readings available for a possible match, since the first month of remote sensing data used in this study is also January 1996. To determine the effect of having a whole year of remote sensing testing available for all vehicles, we calculated a match rate for vehicles in the All Test sample receiving initial IM240 tests between January 1997 and June 1997. Each of these vehicles had at least one year of remote sensing testing available. If an entire year of remote sensing testing is available, the

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3. There are several reasons why a vehicle may have multiple initial tests within a two-year period: vehicles for sale by dealers that are not fleet-licensed must be tested every 90 days; subsequent tests of vehicles that were not passed within 5 months of the initial test are coded as initial tests; some repeat initial tests are for research purposes only; a small number of audit vehicles are covertly run through the system periodically; and a prospective buyer may voluntarily test a vehicle prior to purchase (personal communication with Frank Cox, Arizona Department of Environmental Quality).

match rate increases to 40% of the Full Test sample with at least one remote sensing reading, and 28% if two remote sensing readings are required.[4]

Table 1. Remote Sensing/IM240 Match Rates for Two Arizona Test Samples *(at least one RSD within 365 days)*

	Random 2%		All Tests	
	Number	%	Number	%
Useable IM240 Tests				
Total tests			1,265,867	
Less retests			*-192,230*	15%
Initial tests	18,175		1,073,637	
Less bad plates	*-3,052*	16%	*-173,494*	14%
Good plates	15,123		900,143	
Less bad VINs	*-36*	0%	*-3,383*	0%
Good VINs	15,087		896,760	
Less subsequent initial tests	*-25*	0%	*-41,726*	3%
First Initial Test	15,062	81%	855,034	68%
Useable RSD Readings				
Matches with RSD	30,988		1,760,111	
Less Readings not within 365 days	*-17,279*	56%	*-981,567*	56%
Matched Readings	13,709	44%	778,544	44%
Matched Vehicles	4,649		264,204	
Avg Numb of Rdgs per Vehicle	2.95		2.95	
Match Rate				
Valid IM240 Tests	15,062		855,034	
Matched w/at least 1 valid RSD	4,649		264,204	
Match Rate	31%		31%	
Matched w/at least 2 valid RSD	2,914		168,074	
Match Rate	19%		20%	

There is another reason why these match rates may understate the coverage rate of a clean screen program. The Arizona remote sensing program was established to identify high emitting vehicles for mandatory additional I/M testing. It is possible that drivers intentionally avoided locations where remote sensing vans were making measurements, in order to avoid the possibility of being called in for an additional I/M test. A clean screen program, which provides an incentive for drivers to intentionally drive by the remote sensors in the hope of being excused from I/M testing, would likely have higher fleet coverage.

Clean Screen Results

There are two ways to evaluate the effectiveness of a clean screen program: the false pass rate and the fraction of excess emissions retained by the program. The false pass rate is the fraction

4. Part of the increase in the rate is due to relaxing the requirement of both a valid CO and a valid HC remote sensing reading. Because the Hughes instruments used in Arizona frequently gave a valid reading for CO only, we removed this requirement to determine the maximum coverage possible in the Phoenix area.

of all vehicles that pass the remote sensing screen but fail subsequent IM240 testing. In an earlier, preliminary analysis, EPA used an alternative measure of the false pass rate: the fraction of vehicles that fail the IM240 but falsely pass the remote sensing screen [2]. Since the denominator of this value (the number of IM240 failures) is smaller than the denominator of the overall false pass rate (all tested vehicles), the alternative false pass rate typically is dramatically higher.

It is useful to examine false pass rates because they are not affected by short tests in programs that utilize fast-pass/fast-fail algorithms (such as Arizona's).[5] Because different vehicles are tested over different portions of the IM240 in Arizona, emissions values are not necessarily comparable between vehicles. And the Arizona contractor has demonstrated that inconsistent preconditioning of vehicles prior to IM240 testing can cause vehicles to be improperly failed [5]; inadequate preconditioning tends to increase emissions measurements. The drawback of analyzing false pass rates in isolation is that they treat all failing vehicles equally, without accounting for the relative emission levels of high emitting vehicles. And false pass rates become problematic when determining whether a particular vehicle would fail under the stricter final IM240 cutpoints; since this determination can only be made with the emissions measurements already made, there is the potential for certain vehicles to improperly "pass" or "fail" a hypothetical tighter cutpoint.

Fraction of excess emissions retained is the other way to measure clean screen effectiveness, as discussed above. This measure calculates the emissions in excess of the IM240 cutpoints for vehicles that fail the IM240. Excess emissions from vehicles passing the clean screen (false passes) are said to be lost, while excess emissions from vehicles failing the screen (true fails) are retained by the program. Using excess emissions to evaluate a clean screen program becomes a problem when we analyze the All Test sample of vehicles, in which vehicles are tested over different portions of the IM240. In addition, the excess emissions calculation is based on composite emissions, the cumulative grams of pollutant measured. Arizona allows vehicles to pass if their HC and CO emissions over Phase 2 of the IM240 are below a second set of cutpoints; some vehicles that pass on the basis of Phase 2 cutpoints may have composite emissions higher than the composite IM240 cutpoints. These vehicles would have excess emissions, even though they officially passed the IM240 test. We determine the size of these two sources of error by calculating the fraction of all excess emissions that come from vehicles that officially pass the IM240.

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5. Although the algorithms used may falsely fast-pass individual vehicles that would have failed a full IM240 (and vice versa).

Results from the Random Sample

Table 2 presents a comparison of the results from the McClintock study of the Colorado clean screen pilot with our analysis of a similar program in Arizona. The table shows the number and distribution of tested vehicles by model year groups; the remote sensing pass rate based on two readings of less than 0.5% CO and 200ppm HC for each vehicle; the fraction of all vehicles that the screen falsely passes; and the excess emissions the screen retains, based on both start-up and final IM240 cutpoints.[6] Colorado requires IM240 testing on 1982 and newer vehicles, while Arizona requires the test for 1981 and newer vehicles; the first model year we include in this analysis is 1982.

Our analysis indicates that the vehicle distributions and remote sensing pass rates from the two states are very similar . However, the Arizona clean screen would not be as effective in identifying low emitters as the Colorado screen. The overall false pass rates are quite a bit higher in Arizona; 3% and 6%, depending on IM240 cutpoint, as opposed to 0.1% and 4% in Colorado. And the Arizona clean screen retains a smaller portion of the excess emissions (89% and 86% of the start-up HC and CO, respectively, as opposed to 100% and 97% in Colorado). In general, we see that although the false pass rate tends to decrease with more recent model years, the fraction of excess emissions retained also tends to decrease. Note that only 18% of the excess CO emissions are retained for the model year 1990 and newer vehicles in Arizona; this is due to two vehicles with very high excess CO emissions (124 and 243 gpm excess) falsely passing the clean screen.

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6. In each state the cutpoints are lower, i.e. more strict, for newer model year vehicles; however, each state uses different cutpoints, and the model years for which the cutpoints are applicable vary. For example, in 1997 Colorado failed all model year 1986 to 1995 passenger vehicles with HC in excess of 4.0 grams per mile; Arizona failed all model year 1991 to 1995 vehicles with HC in excess of 1.2 grams per mile. The Arizona cutpoints are nearly identical to the start-up cutpoints recommended by EPA, and were not changed over the 18-month study period.

Table 2. Comparison of results from Colorado and Arizona Clean Screens (1)
(at least 2 RSD within 365 days, CO < 0.5% and HC < 200ppm)

										Excess Emissions Retained			
IM240	Model	Number of Vehicles		Distribution of Vehicles		RSD Pass Rate		False Pass Rate		HC		CO	
Cutpoints	Years	COL	AZ	COL	AZ	COL	AZ	COL	AZ	COL	AZ	COL	AZ
Start-up	1982-85	76	302	9%	11%	22%	22%	0.0%	6.6%	100%	93%	100%	92%
Start-up	1986-89	233	747	27%	26%	30%	34%	0.0%	3.3%	100%	91%	100%	97%
Start-up	1990+	559	1,825	64%	64%	59%	51%	0.2%	1.4%	100%	55%	86%	18%
	Total	868	2,914	100%	100%	48%	43%	0.1%	2.5%	100%	89%	97%	86%
Final	1982-85	76	302	9%	11%	22%	22%	9%	13%	94%	89%	97%	91%
Final	1986-89	233	747	27%	26%	30%	34%	6%	11%	91%	87%	95%	93%
Final	1990+	559	1,825	64%	64%	59%	51%	3%	3%	69%	66%	80%	36%
	Total	868	2,914	100%	100%	48%	43%	4%	6%	91%	87%	94%	87%

(1) All of the Colorado data come from an analysis of vehicles with valid CO and HC remote sensing measurements. The McClintock report provides similar data for a smaller sample of vehicles (594) with valid HC, CO and NOx remote sensing measurements. The clean screen retained 98% and 93% of the excess HC and CO emissions based on start-up IM240 cutpoints, and 91% and 93% of the excess emissions based on final IM240 cutpoints.

Results from the All Test Sample

Tables 3 and 4 present the results from the two samples of Arizona IM240 tests that we analyzed. The tables are similar to Table 2; however, we have added some additional data that help in comparing the different samples from the Arizona data (which were not published in the McClintock report on the Colorado clean screen). First, we show more detail in terms of model year groups. Second, we include the false pass rate as a percentage of all vehicles tested (as in the previous tables) and as a percentage of all vehicles that failed the IM240. This second false pass rate tells us what fraction of vehicles that failed the IM240 were falsely passed by the clean screen. Third, in addition to excess HC and CO, we calculate the excess NOx emissions retained by the clean screen, even though the Arizona clean screen does not use remote sensing NOx measurements. Finally, we show the distribution of excess emissions by model year group.

Table 3. Results from the Arizona Random Sample
(at least 2 RSD within 365 days, CO < 0.5% and HC < 200ppm)

IM240 Cut-points	Model Years	Number of Vehicles	Disn of Vehicles	Pass Rates		False Pass Rate		Excess Emissions Retained			Distribution of Excess Emissions		
				IM240	RSD	All Vehicles	Failing Vehicles	HC	CO	NOx	HC	CO	NOx
Start-up	1981	40	1%	35%	12%	5%	8%	98%	100%	77%	11%	2%	9%
Start-up	1982-85	302	10%	57%	22%	7%	16%	93%	92%	77%	49%	56%	29%
Start-up	1986-89	747	26%	85%	34%	3%	23%	91%	97%	76%	28%	32%	37%
Start-up	1990-92	677	23%	93%	42%	2%	33%	91%	82%	64%	6%	2%	17%
Start-up	1993+	1,148	39%	98%	55%	1%	36%	19%	7%	73%	6%	9%	8%
	Total	2,914	100%	88%	43%	2%	21%	89%	86%	74%	100%	100%	100%
Final	1981	40	1%	17%	12%	10%	12%	97%	100%	85%	10%	3%	8%
Final	1982-85	302	10%	28%	22%	13%	18%	89%	91%	80%	45%	55%	29%
Final	1986-89	747	26%	59%	34%	11%	26%	87%	93%	72%	35%	33%	39%
Final	1990-92	677	23%	81%	42%	6%	31%	82%	80%	65%	7%	3%	16%
Final	1993+	1,148	39%	95%	55%	2%	36%	39%	10%	71%	4%	6%	7%
	Total	2,914	100%	75%	43%	6%	25%	87%	87%	74%	100%	100%	100%

We make several important observations from Table 3. First, nearly 40% of the vehicles tested are model year 1993 or newer; these vehicles account for between 6% (HC) and 9% (CO) of excess emissions using the start-up cutpoints. Second, although both IM240 and remote sensing pass rates are higher for newer vehicles, the overall IM240 pass rate (88%) is much higher than that for remote sensing (43%), indicating that the remote sensing cutpoints are more stringent than those of the IM240. Relatively strict remote sensing cutpoints are desirable, since one wants to use clean screen criteria that select only the cleanest vehicles in the fleet. Third, although the false pass rates based on all vehicles are lower for newer model years, the false pass rates based on IM240-failing vehicles only are higher. This means that the clean screen passes more of the newer vehicles, but is less accurate in predicting their IM240 results. This is confirmed by examining the fraction of excess emissions retained; the clean screen retains less than 20% of the HC and CO excess emissions for the newest vehicles. The final columns indicate that these vehicles account for about 10% of total excess emissions. Finally, the Arizona clean screen retains about 70% of the excess NOx emissions, even though remote sensing measurements of NOx are not used in the screen.

As discussed above, the number of vehicles in the Random sample is relatively small, raising concerns about the representativeness of the sample. The small fraction of excess CO and HC emissions retained from model year 1993 and newer vehicles are the result of two extremely high emitters that falsely passed the screen.[7]

7. The excess HC/CO/NOx emissions of these two vehicles are 8.7/243/0 and 4.0/124/0 gpm.

Table 4 presents similar data from the analysis of all IM240 tests. As one can see, this sample is much larger than the Random sample. In general, the data in Tables 3 and 4 are quite similar, suggesting that the vehicles in the Full Test sample are representative of the Arizona I/M fleet, and that the emissions adjustments used to predict full test emissions for the vehicles fast-passed or fast-failed in the All Test sample are reasonable. Note that much more of the excess emissions from 1993 and newer vehicles are retained in the All Test sample (69% and 65% for HC and CO, respectively) than in the Random sample (19% and 7%).

Table 4. Results from the Arizona All Test Sample
(at least 2 RSD within 365 days, CO < 0.5% and HC < 200ppm)

IM240 Cut-points	Model Years	Number of Vehicles	Disn. of Vehicles	Pass Rates		False Pass Rate		Excess Emissions Retained			Distribution of Excess Emissions		
				IM240	RSD	All Vehicles	Failing Vehicles	HC	CO	NOx	HC	CO	NOx
Start-up	1981	1,795	1%	63%	17%	4%	10%	97%	98%	82%	7%	5%	4%
Start-up	1982-85	18,204	11%	67%	24%	5%	15%	92%	94%	75%	47%	53%	36%
Start-up	1986-89	42,647	25%	87%	34%	3%	19%	88%	89%	76%	35%	33%	37%
Start-up	1990-92	39,024	23%	93%	44%	2%	28%	81%	80%	73%	9%	7%	17%
Start-up	1993+	66,403	40%	99%	55%	0%	33%	69%	65%	67%	2%	2%	6%
	Total	168,073	100%	91%	43%	2%	20%	90%	91%	75%	100%	100%	100%
Final	1981	1,795	1%	38%	17%	8%	13%	95%	96%	82%	6%	5%	3%
Final	1982-85	18,204	11%	40%	24%	12%	19%	89%	92%	76%	43%	49%	31%
Final	1986-89	42,647	25%	59%	34%	12%	28%	83%	86%	73%	40%	36%	41%
Final	1990-92	39,024	23%	74%	44%	10%	39%	74%	75%	68%	10%	8%	18%
Final	1993+	66,403	40%	91%	55%	5%	49%	62%	59%	59%	2%	3%	7%
	Total	168,073	100%	73%	43%	8%	31%	85%	88%	72%	100%	100%	100%

As discussed above, the All Test sample is valuable since it includes many more vehicles than the Random sample, and likely is most representative of the on-road fleet. Because vehicles are tested over different portions of the IM240 cycle, however, the emissions results of individual vehicles are not directly comparable. How accurate are our simple adjustments to predict full IM240-equivalent emissions for the vehicles that are fast passed or fast failed? Table 5 shows what portion of excess adjusted emissions are attributable to vehicles that officially pass the IM240, from the All Test sample. Here we see that our adjustments to the fast pass/fast fail IM240 test results incorrectly assign as much as 3% of the overall excess emissions to vehicles that actually passed the IM240. That is, our adjustments overestimate full IM240 emissions for a relatively small portion of passing vehicles; the overestimation is greater for CO than for HC or NOx. However, our adjustments appear less accurate for the newest vehicles; 25% of the excess

CO emissions from 1993 and newer vehicles are overestimated full IM240 emissions from fast-passed vehicles. [8]

Table 5. Fraction of "Excess Emissions" from Vehicles Passing the IM240

IM240 Cutpoints	Model Year	"Excess Emissions" from Passing Vehicles HC	CO	NOx
Start-up	1981	0%	0%	0%
Start-up	1982-85	1%	1%	0%
Start-up	1986-89	2%	3%	0%
Start-up	1990-92	3%	8%	1%
Start-up	1993+	5%	25%	1%
	Total	1%	3%	0%

The large number of vehicles in the All Test sample allows us to examine the relative accuracy of the clean screen in identifying low-emitting cars versus light duty trucks. Table 6 shows the statistics for cars and light duty trucks of all model years (heavier trucks, with gross vehicle weights greater than 6,000 pounds and subject to looser emissions cutpoints than lighter trucks, are included in our truck category). A larger fraction of trucks pass the IM240 than cars (93% versus 89%); this suggests that the IM240 cutpoints for trucks are less stringent than those for cars. Interestingly, the same remote sensing cutpoints applied to all vehicle types result in identical pass rates for cars and trucks (43%). The false pass rates and percent excess emissions retained are nearly identical for cars and trucks, with the exception of the amount of excess emissions retained based on final cutpoints.

Table 6. Results from the Arizona All Test Sample
(at least 2 RSD within 365 days, CO < 0.5% and HC < 200ppm)

IM240 Cutpoints	Type	Number of Vehicles	Pass Rates IM240	RSD	False Pass Rate All Vehicles	Failing Vehicles	Excess Emissions Retained HC	CO	NOx
Start-up	Cars	102,764	89%	43%	2%	20%	89%	90%	75%
Start-up	LDTs	65,309	93%	43%	1%	19%	90%	94%	75%
Final	Cars	102,764	69%	43%	10%	31%	83%	76%	82%
Final	LDTs	65,309	78%	43%	7%	30%	87%	91%	71%

Table 7 presents the summary results for all model year 1982 and newer vehicles, from the Colorado study and the two Arizona samples (the data from the Colorado study and the Arizona

8. There are no excess emissions from passing vehicles using the final cutpoints, because the cutpoints themselves are used to determine whether an individual vehicle passes or fails the IM240. Similarly, there are no excess emissions from passing vehicles from the Random sample, because no adjustments are needed to predict full IM240 emissions (although it is possible to have excess emissions from vehicles that fail composite cutpoints but pass Phase 2 cutpoints, since the excess emissions are calculated based on the composite IM240 emissions).

Random sample are taken from Table 2; the Arizona All Test data are taken from Table 4, excluding model year 1981 vehicles). The table indicates that the Colorado pilot clean screen appears to be more effective in identifying clean vehicles than a similar program applied to the Random and All Test samples of vehicles in Arizona. Differences in the effectiveness of identifying clean vehicles in the two states may be due to a variety of factors:

- the small sample size of the Colorado study, relative to the two Arizona data samples;
- differences in remote sensing measurement and/or IM240 measurement technology and techniques; and
- regional differences (how different weather, fuels, maintenance practices, and driving habits affect in-use emissions).

Table 7. Summary Results for MY82+ Vehicles
(at least 2 RSD within 365 days, CO < 0.5% and HC < 200ppm)

			RSD Pass	False Pass	Excess Emissions Retained	
Sample	IM240 Cutpoints	Vehicles	Rate	Rate	HC	CO
Colorado	Start-up	868	48%	0.1%	100%	97%
Arizona Random	Start-up	1,726	43%	2.5%	89%	86%
Arizona All Test	Start-up	99,875	36%	2.8%	89%	91%
Colorado	Final	868	48%	4%	91%	94%
Arizona Random	Final	1,726	43%	6%	87%	87%
Arizona All Test	Final	99,875	36%	11%	85%	88%

Results of Model Year Exemptions

In the previous analysis we have seen that clean screening is less effective in identifying the cleanest vehicles among newer vehicles. Rather than applying a clean screen, some states may choose to exempt from IM240 testing all vehicles of the newest model years.[9] Because Arizona currently does not exempt the newest vehicles from testing, we examined how effective model year exemptions are in terms of retaining excess IM240 emissions.[10]

Table 8 presents the model year exemption analysis for the Arizona Random and All Test samples, based on the start-up IM240 cutpoints. For each sample, we calculate the cumulative fraction of vehicles and excess emissions by model year. Reading down the columns, one can determine the fraction of vehicles exempted for any group of model years, and the excess emissions associated with those vehicles. For example, 17% of all vehicles in the Random

9. For example, in late 1994 Colorado began exempting vehicles from the four newest model years from I/M testing.
10. Arizona does allow owners of new vehicles to opt out of the first I/M testing cycle. However, the state does not have an estimate for the portion of eligible vehicles that do so. Arizona began exempting the newest five model years from their first I/M test in late 1998.

sample are model years 1995 and newer; Arizona could exempt all these vehicles from I/M testing and still not lose any of the excess emissions identified by the IM240 program.

The last row of Table 8 shows the results of applying the clean screen to all 1981 and newer vehicles in both samples, taken from Tables 3 and 4 (Table 8 shows excess emissions lost, which is the inverse of excess emissions retained in the earlier tables). In all cases, the same portion of the fleet could be exempted based on vehicle model year, and fewer excess emissions would be lost. For example, clean screening the All Test sample would relieve 43% of the vehicles in the Arizona fleet from testing, while losing 9% to 25% of the excess IM240 emissions, depending on the pollutant. On the other hand, exempting model year 1992 and newer vehicles would relieve 47% of vehicles from testing, with losses in excess emissions of only 4% to 11% (using the All Test sample). Model year exemptions are even more effective when one considers that all registered vehicles of the exempted model years would automatically be relieved of testing. On the other hand, only those vehicles that drive by a remote sensor and pass the emissions cutpoints would be exempt from testing under a clean screen (recall that less than one-half of the vehicles in the Arizona fleet were matched with valid remote sensing readings, as discussed above).

Table 8. Cumulative Vehicle Distibutions and Excess Emissions, by Model Year and Arizona IM240 Sample

	Random Sample				All Test Sample			
	Vehicle	Cumulative Excess Emissions			Vehicle	Cumulative Excess Emissions		
Model Year	Disn.	HC	CO	NOx	Disn.	HC	CO	NOx
1997	0%	0%	0%	0%	0%	0%	0%	0%
1996	4%	0%	0%	0%	4%	0%	0%	0%
1995	17%	0%	0%	0%	17%	0%	0%	1%
1994	29%	2%	3%	1%	29%	1%	1%	2%
1993	39%	6%	9%	8%	40%	2%	2%	6%
1992	*47%*	*9%*	*9%*	*12%*	*48%*	*5%*	*4%*	*11%*
1991	55%	11%	10%	19%	56%	8%	7%	18%
1990	63%	12%	11%	25%	63%	11%	9%	23%
1989	70%	16%	15%	34%	70%	15%	13%	31%
1988	76%	21%	20%	41%	77%	23%	20%	43%
1987	82%	28%	30%	48%	82%	33%	31%	51%
1986	88%	40%	42%	62%	88%	46%	43%	61%
1985	92%	54%	57%	74%	92%	63%	61%	73%
1984	96%	71%	79%	82%	96%	78%	78%	84%
1983	97%	81%	94%	90%	98%	87%	90%	91%
1982	99%	89%	98%	91%	99%	93%	95%	96%
1981	100%	100%	100%	100%	100%	100%	100%	100%
Clean Screen (1981+)	*43%*	*11%*	*14%*	*26%*	*43%*	*10%*	*9%*	*25%*

Table 9 presents the effect of model year exemptions for passenger cars and light duty trucks, based on the Arizona All Test sample. Again, exempting model year 1992 and newer cars from

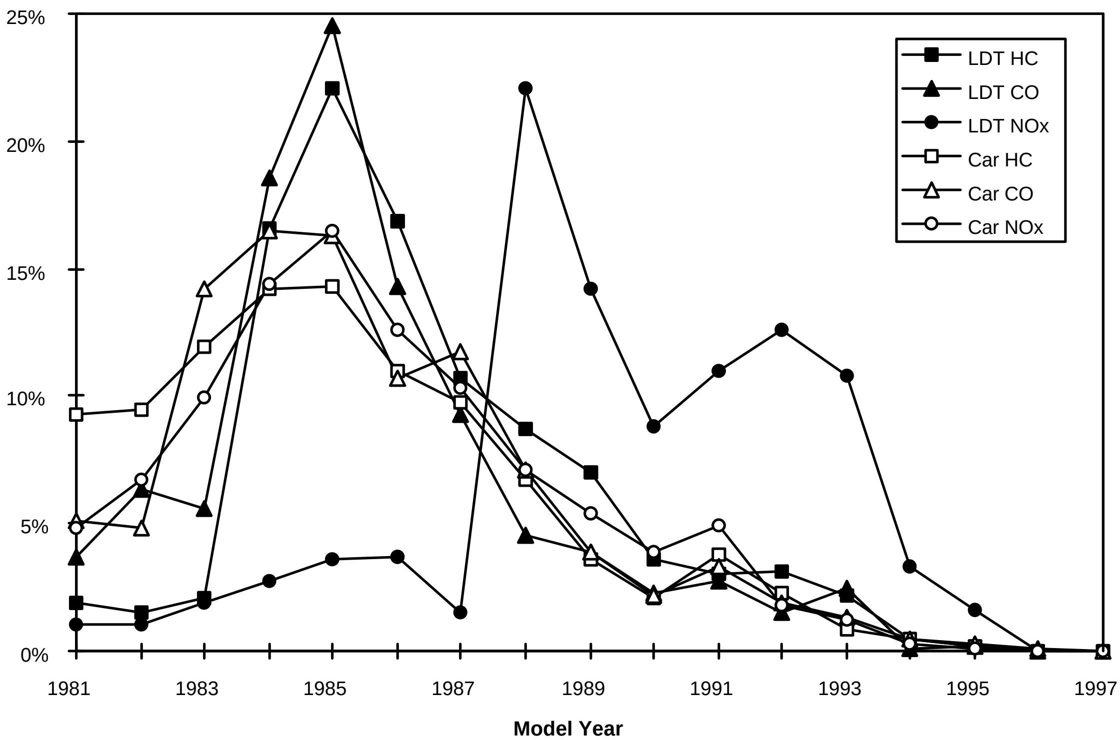
I/M testing results in a smaller loss of excess emissions (3% or 4%) than using a remote sensing clean screen (10% to 25%). However, exempting 1992 and newer trucks from I/M testing results in a slightly larger loss of excess NOx emissions (28%) than the clean screen (25%), even though the Arizona clean screen is based on HC and CO measurements only.

Figure 1 shows the distribution of excess emissions (based on start-up IM240 cutpoints) by model year and vehicle type, using the All Test sample (the emissions distributions from the Random sample are similar). The distribution of excess emissions for the three pollutants is quite similar for cars and trucks, with the exception of truck NOx emissions. A large fraction of excess NOx emissions from trucks comes from model year 1988 and newer trucks. The difference in the car and truck excess NOx distributions may be due to the relative stringency of the standards for each: 1988 and newer trucks are subject to much tighter NOx cutpoints than earlier trucks (3.5 gpm NOx for 1988 and newer trucks under 6,000 pounds gross vehicle weight, as opposed to 7.0 gpm NOx for 1987 and older trucks).

Table 9. Cumulative Vehicle Distibutions and Excess Emissions, by Model Year and Vehicle Type

	Cars				Light Duty Trucks			
	Vehicle	Cumulative Excess Emissions			Vehicle	Cumulative Excess Emissions		
Model Year	Disn.	HC	CO	NOx	Disn.	HC	CO	NOx
1997	0%	0%	0%	0%	0%	0%	0%	0%
1996	4%	0%	0%	0%	4%	0%	0%	0%
1995	15%	0%	0%	0%	19%	0%	0%	2%
1994	26%	1%	1%	0%	34%	1%	0%	5%
1993	36%	2%	2%	2%	45%	3%	3%	16%
1992	*44%*	*4%*	*4%*	*3%*	*54%*	*6%*	*4%*	*28%*
1991	52%	8%	7%	8%	61%	9%	7%	39%
1990	60%	10%	10%	12%	67%	13%	9%	48%
1989	68%	13%	13%	18%	74%	20%	13%	62%
1988	75%	20%	21%	25%	80%	28%	18%	84%
1987	81%	30%	32%	35%	85%	39%	27%	86%
1986	87%	41%	43%	48%	90%	56%	41%	90%
1985	91%	55%	59%	64%	94%	78%	66%	93%
1984	95%	69%	76%	79%	97%	95%	84%	96%
1983	97%	81%	90%	89%	98%	97%	90%	98%
1982	99%	91%	95%	95%	99%	98%	96%	99%
1981	100%	100%	100%	100%	100%	100%	100%	100%
Clean Screen (1981+)	*43%*	*11%*	*10%*	*25%*	*43%*	*10%*	*6%*	*25%*

Figure 1. Distribution of Excess Start-Up Emissions by Model Year and Vehicle Type, All Test Sample, 1996-97 Arizona IM240



With the exception of truck NOx emissions, exempting the newest model years of vehicles from I/M testing appears to be more effective than applying a clean screen based on remote sensing measurements. However, there are reasons why a state may not want to exempt the newest model years from I/M testing. One reason is the sense of equity; motorists may feel that all vehicles should be given the same opportunity to fail an I/M test. Another reason is that a state may wish to test a large representative sample of vehicles do demonstrate to EPA the effectiveness of their I/M program. Finally, a state may want to ensure that vehicles get at least one I/M inspection before the vehicle's warranties on emissions-related components expire. States should consider the number of vehicles excused from I/M testing, as well as the expected loss in emission reductions, when deciding between using a remote sensing based clean screen or model year exemptions.

Other Criteria for Remote Sensing Data

As discussed above, for this study we applied the Colorado clean screen cutpoints to the last two remote sensing measurements of individual vehicles in Arizona. In order to test the sensitivity of our results to how we used the remote sensing data for individual vehicles, we used the remote sensing data in three other ways:

1) the last single reading prior to the IM240 test ("Last RSD");
2) the average of all multiple readings prior to the IM240 test ("Avg of All"); and
3) the average of the last two readings prior to the IM240 test ("Avg of Last 2").

Table 10 shows the absolute difference in the results from those obtained for all vehicles, as shown in Tables 3 and 4. For example, the clean screen based on the last remote sensing measurement ("Last RSD") using the random IM240 sample ("Random") resulted in a higher percentage of vehicles passing the screen and a higher false pass rate, and less excess emissions retained (5, 14 and 11 percentage points less HC, CO, and NOx, respectively). Table 10 indicates that the three other ways of using remote sensing data are less effective than using both of the last two remote sensing measurements: more vehicles pass the remote sensing screen under the other scenarios, yet false pass rates are higher and a smaller percentage of the excess emissions are retained. On the other hand, using the last measurement ("Last RSD") and the average of all measurements ("Avg of All") requires only one remote sensing reading per vehicle, while the other two scenarios require at least two measurements. As demonstrated above, requiring at least two readings substantially reduces the remote sensing coverage of the fleet.

Table 10. Absolute Difference from Comparable Last 2 RSD Scenario

IM240 Sample	RSD Scenario	IM240 Cutpoints	RSD Pass Rate	False Pass Rate	Excess Emissions Retained		
					HC	CO	NOx
Random	Last RSD	Start-up	+19%	+10%	-5%	-4%	-11%
Random	Avg of All	Start-up	+18%	+14%	-11%	-11%	-14%
Random	Avg of Last 2	Start-up	+17%	+10%	-6%	-5%	-12%
All	Last RSD	Start-up	+18%	+11%	-8%	-7%	-14%
All	Avg of All	Start-up	+18%	+15%	-11%	-11%	-18%
All	Avg of Last 2	Start-up	+18%	+11%	-7%	-6%	-14%
Random	Last RSD	Final	+19%	+5%	-8%	-6%	-13%
Random	Avg of All	Final	+18%	+19%	-13%	-13%	-16%
Random	Avg of Last 2	Final	+17%	+14%	-8%	-8%	-13%
All	Last RSD	Final	+18%	+15%	-10%	-9%	-15%
All	Avg of All	Final	+18%	+18%	-14%	-12%	-18%
All	Avg of Last 2	Final	+18%	+15%	-9%	-7%	-14%

As discussed above, we used remote sensing measurements made up to one year prior to the vehicle's initial I/M test. Since vehicle owners may make changes to their vehicles prior to bringing them in for I/M testing, allowing such a long period between remote sensing and I/M measurement may account for some of the inaccuracy in the clean screen. We did not test the sensitivity of the clean screen to shortening the time allowed between remote sensing measurement and I/M test. However, Table 11 shows how the clean screen coverage would be affected by reducing the time between the two measurements. As the table indicates, only half of the vehicles with valid remote sensing and IM240 measurements in the Random sample were measured by the remote sensor within 90 days prior to I/M testing (the fraction is slightly smaller if two remote sensing readings are required). The results from Table 11 can be combined with the calculated fleet coverage based on up to one year between remote sensing and I/M testing (from Table 1) to determine the impact on overall fleet coverage. If only remote sensing measurements within 90 days of I/M testing are used, the overall clean screen coverage would be reduced by one-half, to only 15% of the I/M fleet (or 8%, if at least two remote sensing readings are required). The dramatic reduction in coverage from limiting the time between remote sensing and I/M measurement will dampen any improvement in the accuracy of the clean screen.

Table 11. Fraction of Vehicles Measured by Remote Sensing, by Time between Measurement and I/M Test, Arizona Random Sample

	At Least 1 RSD Reading		At Least 2 RSD Readings	
Number of Days between RSD and I/M Measurement	Cumulative Number of Vehicles	Cumulative Percent of Vehicles	Cumulative Number of Vehicles	Cumulative Percent of Vehicles
30	1,064	23%	505	17%
60	1,764	38%	901	31%
90	2,311	50%	1,246	43%
120	2,762	59%	1,560	53%
180	3,476	75%	2,042	70%
365	4,651	100%	2,916	100%

Conclusions

In this report we have applied the methodology and cutpoints of a pilot clean screen program in Colorado to the Arizona I/M area, using 18 months of remote sensing and IM240 data. Our primary conclusions are:

- Clean screening can be an effective method to exempt a fraction of the vehicle fleet from I/M testing, while retaining nearly all of the excess emissions. A clean screen program can make an I/M program more cost-effective by concentrating resources on vehicles that are more likely to be high emitters. By exempting the cleanest vehicles from regular I/M testing, a clean screen program can also reduce the inconvenience to the public of bringing likely clean vehicles in for I/M testing.

- A small fraction of the I/M fleet was measured by remote sensing in Arizona; about one-third of the vehicles were matched with at least one remote sensing measurement, and only 20% had at least two measurements. Such low coverage reduces the effectiveness of using remote sensing to exempt vehicles from I/M testing. On the other hand, there was an incentive for Arizona drivers to avoid driving by the remote sensors. A true clean screen program, where there is no potential penalty for being measured by a remote sensor, could encourage more drivers to drive by the sensors, resulting in greater fleet coverage.
- The clean screen program applied to Arizona vehicles is not as effective as the same program applied to Colorado vehicles; for example, using start-up IM240 cutpoints, the Colorado clean screen retains 97% of excess HC, and 100% of excess CO emissions, while the clean screen applied to the Arizona Random sample retains only 93% and 94% of excess emissions (Table 8). This result holds even after we exclude the newest vehicles that are exempted from IM240 testing in Colorado, and examine a larger sample of vehicles from Arizona that is more representative of the I/M fleet than the Random sample of full IM240 tests. It is likely that the noted problems with the Arizona remote sensing measurements affect the accuracy of the Arizona clean screen. Additional differences in how the two states measure emissions (using both remote sensing and IM240), the small samples of vehicles studied in the Colorado study and the Arizona Random sample, and regional differences that may affect in-use emissions (such as weather, fuels, maintenance practices, and driving habits) also likely account for the differences in the effectiveness of clean screen programs in the two states.
- Clean screening using remote sensing is not as accurate for newer vehicles as it is for older vehicles. This may be due to several reasons, including the relatively few high emitters among the most recent model years, and the use of a single remote sensing cutpoint for all ages of vehicles. The accuracy of the screen in identifying clean vehicles from later model years may improve as this cohort of vehicles ages. Tighter remote sensing cutpoints applied to newer vehicles may also improve the clean screen accuracy for newer vehicles.
- Remote sensing clean screening is just as accurate for light duty trucks as it is for passenger cars, even if the same remote sensing cutpoints are used for different vehicle types.
- Exempting entire model years of <u>cars</u> from initial I/M testing is more effective than using a remote sensing clean screen for the newest vehicles. Model year exemptions also apply to all vehicles of the model years exempted, and not just the clean vehicles that drive by a remote sensor. However, it is likely that a clean screen that uses remote sensing NOx measurements would be more effective than a model year exemption of <u>light duty trucks</u>, since nearly 30% of excess NOx emissions from trucks comes from relatively recent model years (1992 and

newer). In addition, there are other reasons why states may choose not to exempt new vehicles from I/M testing.

- Applying cutpoints to the last two remote sensing readings of an individual vehicle appears to be the best use of remote sensing data to predict that vehicle's IM240 result. However, this approach requires at least two remote sensing readings per vehicle, which reduces the remote sensing coverage of the vehicle fleet.
- Restricting the time between remote sensing measurement and the next scheduled I/M test to 90 days results in a reduction in fleet coverage of 50%.

In this report we have not examined the sensitivity of various aspects of the Colorado pilot on clean screen accuracy. These include: using alternative remote sensing cutpoints; shortening the time allowed between remote sensing measurement and IM240 test; or restricting the analysis to measurements made during stabilized vehicle behavior, based on average site characteristics or speed and acceleration measurements of individual vehicles. This report also does not analyze the effectiveness of using remote sensing to identify suspected high emitters. We plan to do these types of analysis in the future.

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