The Enhanced I/M Program in Arizona: Costs, Effectiveness, and a Comparison with Pre-regulatory Estimates

Winston Harrington
Virginia McConnell
Amy Ando

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RESOURCES FOR THE FUTURE
1616 P Street, NW
Washington, DC 20036
Telephone 202-328-5000
Fax 202-939-3460
Internet: `http://www.rff.org`

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Abstract

Using data from 1995 and 1996, we estimate the cost of the Arizona Enhanced I/M Program and the emission reductions achieved. We begin by enumerating briefly the components of I/M costs and discuss their size and incidence. Then we describe the empirical information from Arizona and how we use it to construct cost estimates for both vehicle inspection and repair of failing vehicles. Inspection costs include the costs of operating the test stations and the costs motorists incur in time and money to get to the station and go through the testing process. We find that the inspection costs account for over two-thirds of the full costs of I/M, while costs associated with actual vehicle repair account for only one third. We conclude by comparing the empirical estimates of costs and program effectiveness in the Arizona program with the *ex ante* estimated Enhanced I/M program costs made by the EPA in the 1992 Regulatory Impact Analysis (RIA). The *ex ante* EPA analysis appears to have underestimated the costs of achieving the ambitious reductions in emissions hoped for under I/M.

Key Words: I/M cost-effectiveness, vehicle emissions, mobile sources

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THE ENHANCED I/M PROGRAM IN ARIZONA: COSTS, EFFECTIVENESS, AND A COMPARISON WITH PRE-REGULATORY ESTIMATES

Winston Harrington, Virginia McConnell, and Amy Ando[*]

INTRODUCTION

In 1992 the EPA promulgated new regulations for "Enhanced I/M" programs, required in "Serious" and "Severe" Nonattainment Areas by the Clean Air Act Amendments of 1990. The EPA program, or a close facsimile, has now been implemented in five states, beginning with Arizona in 1995.[1] In this paper we report on the cost of the Enhanced I/M program in Arizona. Because costs only have meaning in the context of the results achieved, we also discuss the evidence about emission reductions achieved by the program.

We begin by enumerating briefly the components of I/M cost and discuss their size and incidence. Then we describe the empirical information from Arizona and how we use it to construct cost estimates. The data are discussed in two sections, the first concerned with the costs of vehicle inspection and the second with the costs of repair of vehicles identified as having excess emissions. We conclude by comparing our empirical estimates costs and program effectiveness with the estimated program costs made by the EPA in the 1992 Regulatory Impact Analysis (RIA).

COMPONENTS OF I/M COST

EPA's Enhanced I/M program requires all subject vehicles[2] to report to a centralized inspection station periodically (usually every two years) for an emission test capable of generating vehicle emission rates for HC, CO and NOx in terms of grams per mile. The Agency has developed a sophisticated emission test for this purpose, called the IM240 because of the 240 second length of the full dynamometer test. Vehicles that fail the test must retake the test at a later time, presumably after repair. Because the Enhanced I/M program requires test-only stations, owners of failing vehicles must either make home repairs or take the vehicle to a repair shop and then return to the testing station for a retest. The only legitimate ways to exit the I/M process are to pass the test, get rid of the vehicle, or obtain an emissions waiver. Waivers are granted at the discretion of the I/M authorities, but in any case only to vehicles that are unable to pass the test even after repair expenditures of at least $450.

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[*] Harrington and McConnell, Senior Fellows, and Ando, Fellow, Quality of the Environment Division, Resources for the Future.

[1] The other four states are Colorado, Maryland, Ohio and Wisconsin.

[2] Usually defined as the vehicles in the 1981 and later model years. Older vehicles are either exempt from I/M programs or are subject to a simpler (and less informative) emission test.

Table 1 shows the aspects of the I/M process that generate costs, how the costs are manifest and who bears them. Three points are of note. First, the only costs that can be estimated by expenditures data are the cost of the test and the cost of repair. When repair expenditures are reported, we take them to be estimates of repair cost. The problem is that frequently these costs are not reported. In the section on repair cost below we describe an imputation procedure for the Arizona program whereby we estimate the cost of repairs where repairs are described but no costs reported.

Table 1. I/M Cost Categories

Cost category	Nature of cost	Who bears the burden?
Travel to and from inspection station	Travel time Vehicle operating cost	Motorist
Queuing at station	Waiting time	Motorist
Emission tests	Resource cost of test	Either motorist or taxpayers
Vehicle repair	Resource cost of repair (if done at repair shop) Expenditures on parts and value of time (for self-repair)	No warranty – Motorist Warranty – Manufacturer

We use the reported prices of emission tests as an indicator of the cost of the administration of the test itself, even though expenditures and costs may diverge for several reasons. The states that have adopted Enhanced I/M have contracted out the emission testing services. The agreed upon price of testing is an outcome of bargaining between the state and the contractor, and because the contractor has the status of a regulated monopoly, There is some reason to doubt whether the price approximates marginal cost of the service. On the other hand, if one does not use the price of the test, one must make assumptions about the cost of inputs and the nature of demand, including the cost and productivity of testing equipment, the price of land, and the ratio of peak to average demand. As it happens, even when one makes such assumptions--as in the RIA (USEPA 1992) or in McConnell and Harrington (1992)--the costs are about $20 per test, in the ballpark of the price-based estimate ($16.75).[3] Given the likely magnitude of the errors in estimating testing cost, using the actual price does not appear likely to significantly distort the overall cost estimate.

Other I/M cost components--time for travel, queuing and home-based repair--are not observed in market activity. For example, to estimate the costs of queuing, we must use some estimate for the average value of time spent waiting in line, which is usually taken to be some multiple of the wage rate.

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[3] Other states have different testing prices, even for the same centralized IM240 test program. For example, Maryland tests vehicles for $9 each.

Table 1 also indicates that most of the costs of I/M programs are borne by motorists. The only exceptions are repair costs, which are the responsibility of manufacturers while vehicles are under warranty, and some aspects of the cost of the emission test itself. The distribution of emission test costs depends to a considerable extent on the details of the I/M policy. Each motorist will bear the cost of testing his own vehicle if motorists are required to pay by the test, but other distributions are possible; for example, if tests are financed out of general revenues then tax payers in general will pay, while if tests are financed by registration fees, then motorists as a group will pay, but not necessarily in proportion to their emissions or the amount of testing required by individual vehicles. In Arizona, motorists pay to have their own vehicles tested, except that the fee is waived on every other retest.

A third observation from Table 1 is that activities in only one cost category--vehicle repair--actively achieve emission reductions. The other categories, those concerned with vehicle inspection, are a component of the transaction costs of achieving the emission reductions under the design of the current I/M program. The incidence of these transaction costs, as well as the level of such costs, is a policy variable. Even though all I/M programs have assigned the burden primarily to the motorist, that assignment is not inevitable nor obviously superior to other ways of assigning the burden. Further discussion of the transaction costs of I/M programs and how they are affected by different policy approaches can be found in Harrington and McConnell (1999).

We use the data from Arizona to develop estimates of these costs. First, the inspection costs, including the cost of administering the test and motorists out-of-pocket and time costs, and then the repair costs. As discussed above, we use the inspection fee itself as the measure of the cost of administering the I/M program, in Arizona it is $16.75. The non-monetary costs to motorists are not as easily observed, and we draw on data from the Arizona program to develop estimates of those.

1. Empirical Results from Arizona: Non-monetary Costs of Inspection

In late 1994 Maricopa county, Arizona (the county in which Phoenix is located) became the first air quality control region in the nation to implement a version of the Enhanced I/M program. We have obtained 17 months--January 1995 to May 1996--of inspection and repair data from the Arizona program, which we use as the primary source of data for calculating the components of program cost. In this section we first use the Arizona data to calculate the three components of nonmonetary cost associated with inspection: the cost of travel to and from the site (including the value of time), the value of the time spent in the queue at the inspection site, and the value of time for the duration of the emission test itself (which we call the "vehicle service time").

Travel time and cost

In Maricopa County there are ten Enhanced I/M testing stations to service an area of over 9,000 square miles. Of course, the population is not spread evenly over this area; nearly half is in Phoenix, with an area of 420 square miles. City residents typically live reasonably close to a test station, probably no more than a few miles from the nearest station. County residents may have a bit farther to go, but their travel speeds are probably higher. We assume a round trip to the test station of 9 miles, at an average speed of 20 mph. Travel time is therefore assumed to be 27 minutes.[4] Valuing motorists' time at the average after-tax manufacturing wage in Arizona in 1995-96 (which is $8.62 per hour) results in the value of travel of $3.88. Vehicle operating cost is computed assuming a rate of 25 cents per mile, or $2.25 per trip. We also assume these trips are single-purpose trips, so that the I/M test absorbs all the costs.

Time at the station

The total time at the station is made up of service time and queuing time. There are three different time intervals that first must be defined, in order to develop measures of each of these. First, we define the following points in time:

T_0	the vehicle arrives at the emission test station
T_e	the emission test begins
T_1	the vehicle leaves the station.

The three intervals defined by these events are the total elapsed time at the station $L = T_1 - T_0$, the queuing time $Q = T_e - T_0$, and the service time $S = T_1 - T_e$, with $L = Q + S$. We find that the average time at the station is about 27 minutes, of which 8.7 is the vehicle service time and the remaining 18.3 minutes is waiting time. The next sections summarize the estimations of these times.

Vehicle service time

The service time begins when the vehicle at the head of the queue enters the testing lane to be processed and ends when it leaves the facility after the test is over. It is the sum of three components: (i) test preparation time, during which the vehicle is moved on to the dynamometer, various housekeeping functions are performed and the vehicle is "preconditioned," to assure that it is not in a cold start condition, (ii) the time it takes to run the IM240 transient test and (iii) the time it takes to take a vehicle off the dynamometer and inform the motorist of the results. The Arizona dataset does not report on the time the vehicle arrives, nor the time it departs. The only time variables reported are the clock time to the nearest minute the IM240 test begins, and the length of the emission test in seconds. The latter varies between 31 and 240 seconds due to Arizona's use of fast-pass and fast-fail algorithms in its IM240 test procedure.

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[4] In an earlier study, McConnell (1990) found that average commuting times to centralized I/M stations were longer, closer to 45 minutes round trip.

One way to get an estimate of test duration is to compare the time the current test begins with the time the next test in the same lane begins. However, to conclude that the difference in time represents test duration requires the assumption that the lane is constantly engaged in testing, with no down-time. This assumption could be violated if, for example, a lane is taken offline for an hour and vehicles are shifted to another lane, in which case the test duration reported by this method would exceed the actual time by an hour. (Stations have several lanes and rarely use them all at once.) Elapsed time could also give a misleading result if the lane were open but underutilized, in which case the lane might be idle for a few minutes waiting for the next vehicle to arrive. There is no conclusive way to avoid this problem, since we don't have independent information on when the various lanes are open.

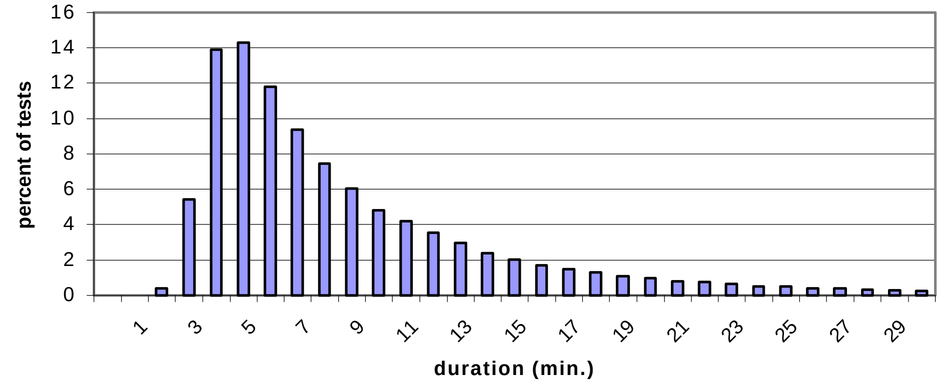
We also tried a statistical approach. If the test lane does not sit idle for a significant period between tests, then we may be able to find a relationship between the elapsed time and the characteristics of the test and the vehicle being tested. We found such a relationship, but it is very weak. When we regress interval between test starts against a set of variables that might affect test length, such as vehicle age or emissions , we obtain a very poor fit ($R^2 = 0.01$), as shown in Table 2. However, one variable does show up as highly significant: the length of the transient emission test. Considering that the interval between tests is measured in minutes and the test duration in seconds, the coefficient of 0.0149 suggests about what one would expect if the transient test duration were affecting the test interval on a second-for-second basis. (It is slightly less than 1/60.) If there were slack in the system, then the coefficient on this variable would very likely be much smaller. Thus, these results lead us to conclude that the reported time between vehicle tests is a reasonable measure of the service time on the vehicle.

Table 2. Regression results: Explaining the interval between successive test starts by lane
July 1995

Model year	-.0317* (0.011)
Transient test duration	.0149* (0.00078)
HC emissions	-.0836 (0.187)
CO emissions	-.745* (0.233)
nox0	-.550* (0.184)
_cons	12.92* (0.99)
* Significant at the 1% level	

For the purposes of estimating the service time we will take the elapsed time between tests and truncate it at 30 minutes. Figure 1 shows the distribution of the remaining observations. As shown, the modal service is only 5 minutes per test, but the distribution is heavily skewed, so that the mean is 8.7 minutes.[5]

Figure 1. Distribution of service interval



Waiting time

We now turn to developing a method to estimate the average waiting time, *Q*, in the Arizona program. Because vehicle arrival and departure times are not collected at the inspection facilities, average waiting times must be estimated by using other information. First, we have the time of day the actual emission tests begin, as discussed in the preceding section. In addition, Arizona keeps a running one-month history of waiting information, consisting of average queue lengths measured by numbers of vehicles, by day and hour at each IM240 station in Maricopa County. The queuing data for the months in 1995 and 1996 for which we have emission test data have long since been erased, but we were able to get from Arizona the average queue length, by I/M station, for each hour of station operation during July 1998. These queue lengths are expressed as the average number of vehicles waiting to enter the test lanes. To get an estimate of motorist waiting time, then, we have to combine 1995 testing data from which length of the test can be inferred, and the queuing data from 1998 on the number of cars. Thus, from the 1998 data we take the distribution of arrival times at all ten

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[5] The 30 minute truncation point is arbitrary but not likely to result in large errors because a relatively small mass is in the tail of the distribution. The mean with no truncation is 9.8 minutes, about a minute longer, and if the truncation point is at 20 minutes the mean is 7.7 minutes.

test stations during the day, and from the 1995 queue data we take the average queue by hour of day, and combine them to obtain a distribution of the queue length during the day.

Obviously, this procedure requires the assumption that operating conditions and practices are the same in the two years, or at least that their differences do not affect waiting times.[6] It also requires the assumption that the waiting time distribution does not change very much from one day to the next. We checked the data to determine whether there are large differences one day of the week to the next and whether there is a large pileup of tests at the end of the month. Fortunately, the arrivals appear to be fairly evenly spread by day of week, and the end-of-month effect appears to be limited to the last two days of the month. These results are discussed further in the Appendix.

We combine the information about the service time, *S* with *N*, the queue length at each station in number of vehicles to arrive at the total elapsed time that a vehicle must spend at the test station. If an arbitrary vehicle enters the queue when there are *n* vehicles already in it, then it must wait for each of those vehicles to be serviced. Their service times $s_1, s_2, \ldots, s_n$ are random variables each with the distribution of *S*. Thus, the expected queueing time for a vehicle that enters when *n* vehicles are already in the queue is $E(Q \mid n) = nE(S)$. The unconditional expectation of *Q* is therefore

$$E(Q) = \sum_{n \geq 0} nE(S)P(N = n) = E(S)E(N)$$

Combining the 1998 data on the number of cars waiting with the 1995 data on the service time for each vehicle as described above, we can estimate frequency distributions for the length of time in the queue. We find from the 1998 queuing information that expected queue length is just over 2 vehicles, or E(*N*)=2.1, and from above, the expected service time is 8.7 minutes. Hence the expected queuing time is 18.3 minutes.

This calculation assumes that the service time distribution is independent of the queue length, an assumption that seems reasonable, for this process at least. It also assumes a single server. But I/M stations typically have multiple lanes, and we cannot be sure how easily motorists can switch queues. However, we have carried out a simulation in which there is a single queue and multiple servers, and the results are nearly identical to the above.

Finally, the total elapsed time for each vehicle at the station is the sum of the expected service time and the expected length of time in the queue, $E(L) = E(Q) + E(S)$. The total elapsed time is therefore 27 minutes. The distribution of *L* is shown in Figure 2. There is a fair amount of variation in the average elapsed time; the interquartile range is 20 to 34

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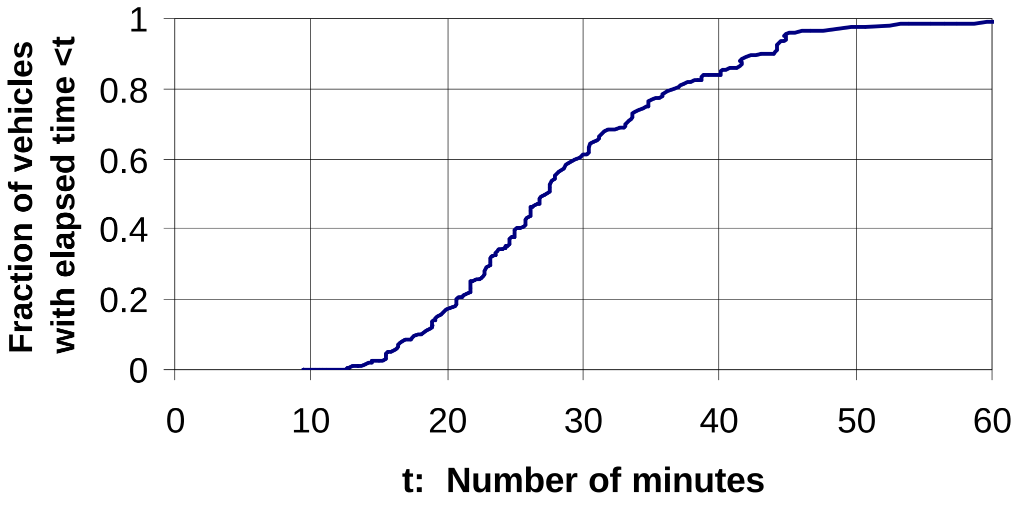
[6] If anything, waiting times were reported to be slightly shorter in 1998 than in 1995 and 96. This is because I/M rules changed slightly around 1997 when the newest model year vehicles were exempt from inspection. This has reduced the total number of vehicles being tested, and has thus shortened wait times. Hence, the estimates made here about waiting times made for the 1995-96 period will slightly underestimate actual waiting times.

minutes. Queues tend to be considerably longer in the morning, a fact that implies some combination of the following: (i) motorists are not well informed on queue lengths, or (ii) the average value of waiting time varies over the course of the day, and is lower in the morning than the afternoon. The persistence and consistency of the observed daily pattern favors the second of these conclusions, although both could be valid.

We convert these estimates of time costs into money costs using the average wage rate in Arizona of $8.62 an hour.

Figure 2.
Distribution of total elapsed time



2. Empirical Results from Arizona: Repair

The I/M test in Arizona is biennial and consists of three components: the IM240 test, a transient test of tailpipe emissions, tests to examine the integrity of the evaporative system, and a visual inspection intended to detect tampered vehicles. Unfortunately, there is no feasible way to measure evaporative emissions, so our comparisons of repair effectiveness are limited to tailpipe pollutants. A vehicle which fails the biennial I/M test in Arizona must be repaired to meet designated standards before it can have its registration renewed.[7] Each time

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[7] Despite this rule, using the Arizona dataset of failing vehicles, we find that about 22 percent of vehicles that fail their initial tests have passing emission rates as of their last tests. There is no clear evidence about why this occurs, but it appears that it is not all due to waivers (only about 4 percent of failing vehicles in Arizona receive them) or the presence of vehicles that are simply mired in the normal process of getting repairs.

a vehicle comes back for a retest, the owner must submit a repair summary which shows, for that round of repair, the changes that were made to the vehicle and the costs of the repairs.[8] In some cases, a vehicle requiring repair expenditures over $450 may get a waiver from the state exempting it from further repairs regardless of test outcome. However, any problems caused by tampering must be fixed.

To analyze repair costs and effectiveness in the Arizona program, we use a dataset that consists of all vehicle tests and repairs for the same 17-month period used above from January 1995 through May 1996. We work with a very large sample of 82,786 vehicles[9] that failed the tests over this period. Some vehicles were retested and presumably repaired more than once, resulting in 110,584 rounds of repair.

There are several modifications we have made to the data to allow for the calculation of costs and emission reductions below.[10] First, because vehicles can fast-pass or fast-fail in the Arizona program, the raw emissions data are not consistent across tested vehicles. Vehicles can fast-pass the test starting at second 31, and they can fast-fail any time after second 93. To make the results consistent across vehicles, we have forecast full 240-second readings from the fast-pass or fast-fail results for each vehicle.[11]

Second, we have added to the information on costs of repair by using the reported data on costs by repair type to infer missing cost information. The data on vehicle repairs, including cost and parts repaired, are self-reported by motorists and not verified by test inspectors. Many of the rounds of repair have reported costs equal to zero. While zero or trivial costs can occur, there are other explanations, including warranty repair or home repairs by do-it-yourself mechanics. Reported zeroes could also indicate missing data. However, to determine the full economic costs of repair, we want to know the costs of all the repairs that were done, regardless of who performed and paid for them. We have developed a method for imputing the costs of repairs when reported costs are zero but reported repairs are not (Ando, Harrington, and McConnell 1999). The costs reported here, unless otherwise indicated, include both raw and imputed costs of repair.

Motor-vehicle repair may yield benefits through improved fuel economy**.** In its regulatory impact analysis (RIA) for the Enhanced I/M rule, for example, EPA estimated that fuel economy for failed vehicles would improve on average by 12.6 percent (USEPA 1992).

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[8] The repair reporting however is incomplete, and there is concern that at least some vehicles getting retested, especially on the same day as the initial test, may not be getting repaired. See Coninx (1998) for a summary of this problem.

[9] There were initially 135,734 failing vehicles out of a total of 995,904 tested vehicles during the entire 17 month period. We cleaned the data extensively, dropping vehicles that were plagued by any of a number of random data problems. For example, some had bogus license numbers, or multiple "initial tests." We also dropped failing vehicles which had no retests at all because we had no repair information for them.

[10] These modifications are described in more detail in Ando, Harrington and McConnell (1999).

[11] Using the 2 percent random sample of vehicles in Arizona that have full 240 second tests, we estimated a separate equation for each pollutant for each second of the test, which we then used to forecast the full 240 second reading. For a detailed discussion of the methods used and the resulting equations, see Ando, Harrington and McConnell (1998).

We calculate the fuel economy changes among failed vehicles in Arizona.[12] As shown below, fuel economy does improve on average, but the improvements are much smaller than EPA's estimates--about 3.5 percent better than pre-repair levels. (See the discussion in Section 3 below.)

Table 3 provides a summary of the failure rates, costs, fuel economy savings and emissions reductions from the Arizona I/M program by model year. The shaded rows show the averages across all model years for cars, and small and large trucks. Average repair costs for both types of trucks are lower than they are for cars, and the fuel economy effects are also slightly lower, especially for large trucks. However, the emissions reductions associated with repair are somewhat larger for trucks for all three pollutants. Trucks appear to provide more cost-effective repair than cars under the Arizona program, perhaps in part because the standards to which vehicles in the Arizona program are subject are quite a bit less stringent for trucks. The cutpoints are shown in Table 4.

Overall, there is not a great deal of variation in costs or emission changes associated with repair across model years for either costs or trucks. There is, however, a great deal of variation in the failure rates by model year, as Table 3 shows. Older vehicles will bear most of the costs of I/M and yield most of the emissions reductions, primarily because failure rates are high for older model years. The other noteworthy result from Table 3 is that NOx emission reductions from trucks are much greater among model years 1989 and newer. As Table 4 shows, the NOx cutpoints for trucks in the Arizona program were much stricter for those newer model years than for models. For example, the NOx cutpoint falls from 7 g/m to 3.5 g/m for small trucks for 1989 and newer model years. In contrast, the HC and CO cutpoints for trucks are not changed for the 1989 model year; and, the emission reductions for those pollutants are quite small. This is some indication that meeting the tighter NOx standards for trucks in the 1989 model year may have resulted in repairs that could not achieve as much in the way of HC and CO emission reductions.

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[12] We use a carbon mass-balance equation supplied by EPA to estimate mpg. Our forecasted 240-second readings of HC, CO, and CO_2 emission rates are the inputs used. The equation is: mpg = 2421/((.866*HCgram/mile) + (.429*COgram/mile) + (.273* CO_2gram/mile)). We get a small number of unreasonable outliers when we use this method to estimate fuel economy. EPA staff explained to us that these very high estimates of fuel economy may be the product of measurement errors for CO2. CO2 levels are only read in I/M programs to determine whether there are leaks in the exhaust pipes or if the exhaust funnel has been attached incorrectly, so these readings may be less accurate than those of the emission rates of the other pollutants. Thus, we discard vehicles with fuel economy estimates above the 99th percentile for their vehicle type (car, small light trucks, medium light trucks). The mean initial fuel economy for the remaining vehicles is 20.5 mpg.

Table 3. Mean Repair Costs and Emissions Reduction by Vehicle Type and Model Year

	Number of Vehicles	Mean Repair Costs[c]	Failure Rate (%)	Change in MPG	Change in HC (g/mi)	Change in CO (g/mi)	Change in NOx (g/mi)
Cars	57,559	$129	15%	.78	.71	11.7	.87
81-82	10,320	$123	50%	.57	.77	11.8	.87
83-85	24,067	$135	38%	.71	.72	.12.4	.92
86-88	14,696	$128	17%	1.01	.71	11.9	.86
89-90	4,121	$120	7%	.99	.68	10.5	.87
91-92	3,254	$128	5%	.68	.58	8.6	.71
93-95	1,101	$72	1%	.98	.41	6.3	.51
Trucks 1[a]	18,691	$110	11%	.74	1.01	13.2	1.00
81-82	2,458	$67	26%	.72	1.00	15.0	.66
83-85	4,855	$113	26%	.77	1.37	20.0	.73
86-88	3,442	$100	15%	.86	1.24	17.1	.52
89-90	4,691	$129	10%	.72	.74	7.3	1.5
91-92	2,061	$124	8%	.59	.64	5.9	1.5
93-95	1,184	$114	2%	.60	.61	6.6	1.4
Trucks 2[b]	6,536	$109	14%	.61	1.23	15.6	1.10
81-82	1,252	$77	40%	.65	1.04	17.3	.69
83-85	1,863	$121	33%	.60	1.63	21.1	.93
86-88	1,422	$120	21%	.65	1.40	18.8	.90
89-90	1,106	$113	9%	.55	.93	7.3	1.63
91-92	568	$122	10%	.67	.92	9.5	1.88
93-95	325	$76	3%	.52	.48	3.2	1.33

[a] Trucks less than 6,000 pounds

[b] Trucks greater than 6,000 pounds

[c] Repair costs include reported costs plus imputed costs when repair are made but zero costs reported (Ando, Harrington and McConnell, 1999). Fuel economy savings and costs of retesting are not included.

Table 4. Inspection and Maintenance Program Cutpoints
(grams per mile)

	Arizona		
	HC	CO	NOx
LDV, 1981-82	2.0	60.0	3.0
LDV, 1983-90	2.0	30.0	3.0
LDV, 1991+	1.2	20.0	2.5
LDT1 and LDT2, 1979-83	7.5	100.0	7.0
LDT1 and LDT2, 1984-87	3.2	80.0	7.0
LDT1 and LDT2, 1988-90	3.2	80.0	3.5
LDT1 and LDT2, 1991+	2.4	60.0	3.0
	EPA[1]		
1981+ model year, all vehicles	0.8	15.0	2.0

[1] EPA repair assumptions are based on repair at EPA labs at which vehicles were repaired with no particular cutpoint. However, the cutpoints specified in official documents (EPA, 1992) are those shown here.

As noted above, the test and repair data have some quirky features. In Table 5 we attempt to provide some sense of the range of cost and emissions estimates across types of repair and by the extent of information provided. Many vehicles that fail the I/M test do not have emission rates above the I/M cutpoints for any of the pollutants (about 20 percent of all of the failing vehicles in our data set). We assume these vehicles fail because they have been subject to some type of tampering. Many tampering repairs appear to be quite minor, such as replacement of a gas cap, and the costs of repairing them would be expected to be quite low.

Table 5 separates the repair evidence by whether vehicles have failed the tailpipe test for one or more pollutant (row 1), or whether they have failed for some other reason (we assume it is tampering--row 3). There are indeed low costs and small emission reductions associated with what we call tampering repairs. The prevalence of gas cap repairs, which reduce evaporative emissions, suggests that total HC emissions from tampering repair are underestimated in Table 5, since the reported emission reductions exclude evaporative emissions. (There is no attempt to measure evaporative emissions, an impossible task without a test that lasts a minimum of several hours.)

The repair information is self-reported by motorists or mechanics, and there are many observations that have no reported repairs or repair costs of zero. As we discussed above, zero costs are consistent with home repairs or with repair of vehicles still under warranty, which would include vehicles up to five years old for most emission control equipment, or no costs can simply indicate missing data. We have developed a method for imputing costs of repair when the repairs themselves are reported but the costs are not (Ando, Harrington, and McConnell 1999). Table 5 reports both types of costs: imputed costs, which is likely to be the best measure to the full social costs of repair, and the raw reported costs which may be a better indication of motorist costs, but which may include some zeros that represent missing data. The second row of Table 5 shows the results for only those vehicles that report repairs in all rounds of repair. Both the imputed costs and the reported costs are higher for these vehicles, but their emission reductions do not differ much from the average vehicle failing the tailpipe test. Not surprisingly, vehicles that fail the tampering or evaporative portions of the test, but pass the tailpipe test, show very little improvement in tailpipe emissions.

Table 5. Cost and Emission Reduction from Repair in Arizona by Type of Failure

	Number of vehicles	Mean Repair Costs		HC reduction (g/mi)	CO reduction (g/mi)	NOx Reduction (g/mi)
		With Imputed Costs[c]	Reported Costs Only[d]			
Vehicles failing tailpipe test for at least one pollutant [a]						
All vehicles	66,002	$145	$90	1.02	15.5	1.13
Only vehicles which report repairs[b]	45,492	$180	$115	1.00	15.4	1.19
Vehicles that fail test, but do not fail for any pollutant (tampering or evaporative emission failures)	15,917	$29	$13	.01 (tailpipe emissions only)	-.67	.06

[a] Includes only vehicles that failed at least one pollutant in all rounds of failure and repair.
[b] Includes only vehicles that reported repairs or costs for all rounds of failure and repair.
[c] Includes imputed costs for those vehicles which report repairs but either zero or missing values for costs (see Ando et al. 1998). Not including fuel economy savings.
[d] Raw reported repair costs (no imputed costs included). Not including fuel economy savings.

3. Summary: Cost estimates in Arizona

Tables 6-8 combine the information in the previous sections to produce a monetary estimate of the cost of the Arizona I/M program and compares the cost (Table 6) and emission reductions (Table 7) of the Arizona program to the *ex ante* estimates of the "High Option" Enhanced I/M program. The EPA estimates were produced by EPA's Office of Mobile Sources and were taken from its 1992 Regulatory Impact Analysis of the Enhanced I/M Rule (USEPA 1992). That study presented costs on a per vehicle tested basis so we have converted the Arizona results in order to compare the two estimates. Finally, Table 8 shows the emission reductions in tons per vehicle and calculates the cost-effectiveness of the program.

Overall, EPA's total cost estimates are about 15 percent below the estimate of costs described here for the Arizona program. The main discrepancy is in the estimates of fuel economy improvements; EPA's estimates are much larger than the fuel efficiency improvements we find in the Arizona data. EPA's *ex ante* estimates of the costs of other aspects of the program, however, are much closer to our *ex post* estimates of the cost outcomes. The repair costs, which appear comparable in this table, actually conceal some important differences in the two programs.

Table 6. Enhanced IM Cost comparison
$ per vehicle per year

	Arizona Enhanced I/M, 1995-96[a,b]	EPA estimate, 1992[g]
Inspection Costs	$12.45	$16.05
Test costs	7.41[c]	8.55[k]
Motorist waiting time and travel costs	5.04[n]	7.50[h]
Total repair costs net of fuel economy	$ 6.53[n]	$ 0.89[n]
Repair – tailpipe emissions	8.01[e]	8.73[k]
Repair – evaporative emissions	-	3.95[k]
Repair – tampering repair	.88	-
Fuel economy – tailpipe repair	-2.36[e,f]	-8.82[k]
Fuel economy – evaporative repair		-2.97[k]
Total Costs	$18.98	$16.94

Source: Harrington and McConnell 1998.

Notes: Although the repair costs are similar for the Arizona and EPA estimates, the underlying components are different. From Table 6 above, per vehicle repair costs are higher in the Arizona program compared to the EPA estimate but the number of vehicles repaired (or the failure rate) is lower.

[a] Costs are in 1992 dollars.

[b] Uses October 1996 actual value of 1.13 tests per passing vehicle per testing period.

[e] Uses actual price charged for each test: $16.75, adjusted for inflation.

[d] From text above, mean service time is 8.7 minutes and average waiting time is 18.3 minutes operating costs are $2.25 per trip and the time spent getting to and from station is 27 minutes. Assumes value of motorist time equals the after-tax wage ($8.62 per hour in Arizona).

[e] Repair costs taken from Table 3 above. Fuel economy benefits of $35 per failing vehicle per two-year testing cycle. For purposes of this table these costs are distributed over all vehicles.

[f] Includes both tailpipe and tampering repair.

[g] "High Option," Biennial Enhanced I/M (EPA, 1992).

[h] EPA (1992) assumes 45 minutes elapsed time, at a leisure time value of $20.00/ hr.

[k] Taken from EPA (1992) Tables 6-9 and 6-7. We have made their fuel economy estimates consistent with ours by converting gas prices from $1.25 to $1.00 per gallon.

Table 7. Comparison of emission reductions EPA estimates vs. Arizona experience (Light-duty vehicles only)[b]

	Emissions Before Enhanced I/M	Emissions After Enhanced IM	% Reduction in Emissions Reductions
	g/mi		
EPA estimate [a]			
All HC	1.96	1.27	35%
Exhaust HC	0.88	0.59	33%
CO	10.9	6.67	39%
NOx	0.89	0.83	7%
Arizona Enhanced I/M, 1995-96			
HC	0.81	0.70	13%
CO	12.2	10.6	13%
NOx	1.5	1.38	8%

Source: Harrington and McConnell 1998

Notes: Cutpoints looser for EPA analysis, See Table 4 above.

[a] "High Option," Biennial Enhanced I/M, year 2000 (EPA, 1992, Appendix I).

[b] EPA emissions are weighted averages computed from tables in EPA 1992 Appendix I p. 7.

Table 8. Cost-effectiveness of Enhanced I/M in Arizona

Cost per vehicle tested	$18.98
Emission reductions(tons per 1000 vehicles)	
HC	0.965
CO	14.3
NOx	1.12
Cost effectiveness – A weights[a]	$3,661/ton
Cost effectiveness – B weights[b]	$5,408/ton

[a] HC=1, CO=0.1, NOx=2.5

[b] HC=1, CO=0.1, NOx=1

The repair cost per tested vehicle can be calculated as the product of the average cost of an emission repair and the fraction of vehicles failing the test (the failure rate). The average costs of repair are somewhat higher in the Arizona program,[13] and the failure rates are lower in Arizona than assumed in the EPA forecast.[14] Another difference is that the Arizona program does not require evaporative emission tests and the EPA analysis assumed evaporative tests would be done; however, many of the so-called "tampering" failures in Arizona were due to missing or faulty gas caps, which tend to increase evaporative emissions. Our empirical estimates of motorist waiting and travel cost in Arizona actually turn out to be somewhat lower than the EPA assumptions, but this is because the EPA analysis assumed a value of time of $20 per hour and our analysis uses the average wage in Arizona of $8.62.

For both studies, the costs of inspecting vehicles are a large fraction of the total costs of the program. For the EPA analysis, the inspection costs are almost all of the cost; in Arizona, they are over two thirds of the total costs.

The costs have to considered together with estimates of the emission reductions achieved. The emission reductions reported by the EPA are greater by a wide margin than those found in Arizona for both tailpipe HC and CO, as shown in Table 7. While EPA had HC and CO emission rates falling by 35 percent and 39 percent, respectively, the Arizona analysis finds emission-rate improvements for those pollutants in Arizona of only about 12-13 percent.[15] Both estimates put NOx rate reductions at about 7 percent.

In making these comparisons we should keep in mind the differences between the program analyzed by the EPA and the actual program implemented in Arizona. Compared to the latter, the EPA program had more stringent cutpoints for all three pollutants (see Table 4). It is not surprising, then, to find the forecasts of tailpipe HC and CO reductions greater in the EPA program, since all but a small fraction of failing vehicles (one or two percent) are assumed to be repaired to these strict cutpoints. Although the cutpoints are also tighter for NOx emissions in the EPA program, NOx reductions for the two programs are comparable. It is possible that in attempting to obtain greater reductions in HC and CO in the EPA program, NOx reductions must be sacrificed because of the pollutant interactions.

The actual costs of the Arizona Enhanced I/M program are slightly greater than the EPA estimate, but the estimated emission reductions achieved are much lower. To achieve the emission reductions envisioned by the EPA in 1992, the Arizona program would be even more costly. Although we know very little about the increased costs and emissions reductions that can be achieved as stringency is tightened in I/M programs, there is some evidence that at tighter cutpoints, costs rise more than in proportion to emissions reductions (Ando,

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[13] EPA assumed the average costs (1992 $) of "transient failures" to be $120 in 1992. NOx repairs were assumed to be $100, and pressure and purge tests were $38 and $70, respectively (EPA 1992 p. 84). We found repair costs to be about $180 for vehicles that have emission test results that exceed cutpoints, and about $50 for vehicles that that have acceptable emission test results but fail the test anyway. We infer that these vehicles fail the tampering portion of the test.

[14] The failure rate is not explicit in the EPA forecast, but the cutpoints are tighter than the Arizona program.

[15] It is important to note, once again, that the HC comparison is limited to tailpipe HC only, since no estimates of evaporative emission reductions are possible.

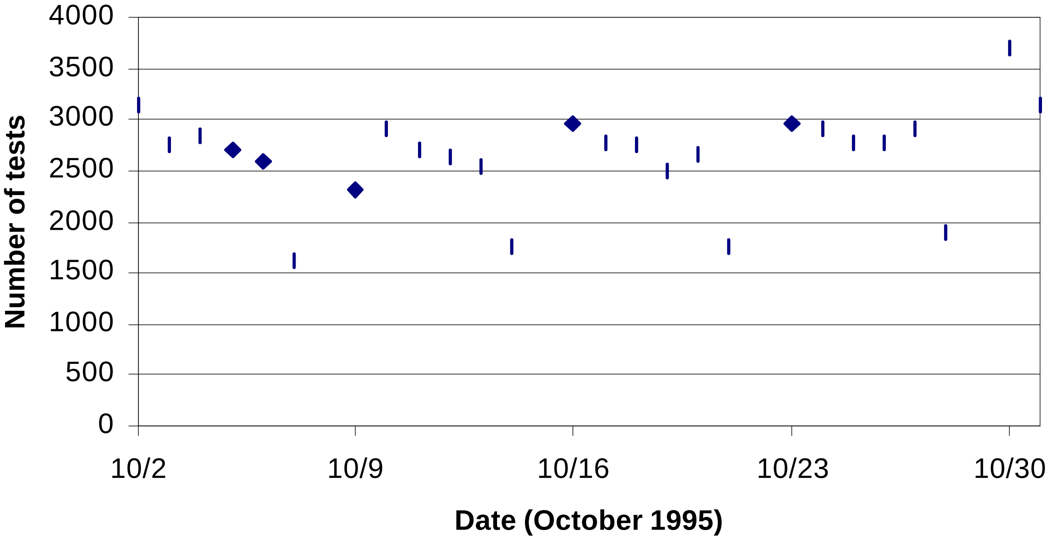
Harrington and McConnell 1999). Therefore, it appears that the pre-regulatory estimates of the costs of achieving the forecasted emission reductions from I/M were underestimated.

APPENDIX: TIME DISTRIBUTION OF EMISSION TESTS

To gain an understanding of the distribution of emission tests over time, we conducted an analysis of motorist arrival times at all test stations in Maricopa County for a single month, October 1995. The main results of this investigation were that hourly and daily arrival frequencies emission tests in Arizona appear to be fairly evenly distributed over time.

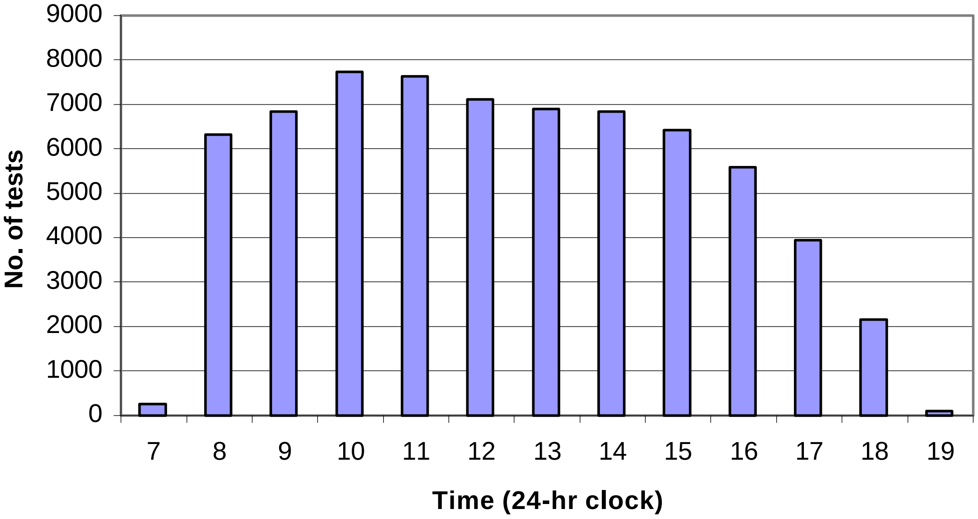
As shown in Figure A-1, the number of daily tests have a noticeable weekly pattern, with the largest number of tests conducted on Monday, gradually tailing off until a big drop for Saturday. Columbus Day was celebrated on Monday the 9th, which explains why that day resembles a Saturday more than it does another Monday. There was also a modest monthly pattern, with the number of tests on the last two days of the Month about 10 to 20 percent greater than the corresponding number of tests on corresponding days earlier in the month. We were somewhat surprised that motorist procrastination did not make the monthly pattern more pronounced.

Figure A-1. Daily IM Tests in Maricopa County



The daily distribution of emission tests was also surprisingly flat. The test stations were open from 7 a.m. until 8 p.m. (though a few of the smaller stations did close before 8:00 p.m.), and Figure A-2 shows the frequency of emission tests by hour for October 1995. As shown, the daily pattern consists of a broad, flat peak in the middle of the day, with off-peak periods occurring in the morning and the evening. Not only was it flat, but the pattern was a little surprising. If motorists stopped in for the test on the way to or from work, the frequency distribution would have resembled that of the daily commute: high during early morning and late afternoon and lower during the rest of the day.

Figure A-2. Test Frequency by Time of Day



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