Review of the AirCare On-Road (ACOR) Program

Final Report

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May 2002

Metric measures are generally used throughout this report. However, in a number of cases figures indicate imperial measures as they are copied from original materials.

As there is a chance of currency confusion between Canadian and US dollars, all costs have been shown in Canadian dollar equivalents unless explicitly stated.

Trade or manufacturers' names appear in this report only because they are essential to its objectives.

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Executive Summary

In 1999, British Columbia's government passed legislation to establish a mandatory program to regulate emission levels in diesel fuelled buses and trucks with licensed gross vehicle weights in excess of 5,000 kilograms. This heavy vehicle smoke prevention program is called AirCare ON-ROAD (ACOR). The aim of the AirCare ON-ROAD testing program, run by the Insurance Corporation of British Columbia (ICBC), is to reduce PM emissions from heavy-duty diesel trucks and buses in Greater Vancouver and the Lower Fraser Valley (LFV). The establishment of the ACOR program followed a pilot program, initiated in 1996, of on-road smoke inspection testing of heavy-duty vehicles operating in the LFV. This report is intended to provide a review of the effectiveness of the program, following three years of the operation of the mandatory phase, and make recommendations for future heavy duty vehicle control strategies in the GVRD/LFV airshed.

Findings

This study was tasked to address the following series of issues. The main findings are summarized under each issue.

1. ***Estimate the emissions reductions that resulted from the ACOR program's activities and estimate the cost-effectiveness of the program.***

The changes in heavy-duty diesel emissions over the program period were assessed in two ways. First, a comparison of the distributions of a variety of roadside visible smoke surveys was performed. Secondly, the estimation of the changes in the mass emissions generated through the use of an emission "malperformance" model was linked to the 1999 emission inventory estimates for the LFV.

According to series of roadside visible opacity surveys performed between 1995 and 2002, the percentage of heavy-duty diesel vehicles with exhaust opacity of less than 20 percent has steadily risen from 62 percent in 1995 to over 98 percent in 2002. The large change in the opacity distributions between 1995 and 2000 is the result of both an improvement in the engine control technology and the deterrent and enforcement effect of the ACOR program.

Table 1 Comparison of Roadside Visual Assessment Surveys

Roadside Visual Assessment Survey	1995 GVRD	1998 GVRD	2000 GVRD	2001 GVRD	Kelowna 2001	2002 ICBC	2002 GVRD
Percent 20% Opacity or Less	62%	81%	95%	92%	91%	98%	100%

Using the emission model developed for this assessment, an estimate of the emission reduction impact of the program in 2000 was made and is presented in Table 1. These estimates are derived from a comparison of the baseline estimates (no inspection program) with those for a snap-acceleration test with cutpoints set at 55 percent opacity for pre-1991 vehicles and 40 percent opacity for post-1990 vehicles. A total reduction of 85 tonnes of PM_{10}, 113 tonnes of NOx and 99 tonnes of HC (24, 2 and 12 percent, respectively, of the baseline emissions) was estimated for 2000.

The analysis of program activity found that it operated in a consistent and effective manner throughout the three years of mandatory repair. Of the vehicles ticketed, 59 percent of the vehicles were repaired within 60 days with 88 percent of the vehicles being repaired before their next registration renewal. The remaining 12 percent of the vehicles were removed from operation within a year of ticketing.

The program costs were estimated from the total government testing and vehicle repair costs. The government costs in 2000 were $432,000 and repair costs were estimated based on average costs at $298,000, for a total of $730,000. To develop an estimate of program cost-effectiveness, the individual pollutant reductions were combined into a "weighted" emission value in which the pollutants were weighted for their relative health damage impacts. Based on this methodology, the 2000 cost-effectiveness ratio was estimated at $312 per tonne (weighted). This value of cost-effectiveness places ACOR in the category of very cost-effective measures in the context of the GVRD Air Quality Management Plan (and related) measures.

Table 1 Estimated Emission Benefits of the ACOR Program in 2000

Pollutant	Baseline (t/y)	Emissions Change (t/y)	Percent Change
HC	832	-99	-12%
CO	57100	0	0%
NOx	5630	-113	-2%
PM_{10}	348	-85	-24%
$PM_{2.5}$	306	-75	-24%
Total (Impact Weighted)*		-2338	
Program Cost		$ 730,000	
Cost per Weighted Emission/ tonne ($/t)		$312	

Damage weighting = 25PM+HC+NOx+CO/7+3SO_2. Reference cited in text.

2. *Forecast the heavy-duty vehicle fleet characteristics and estimate how future stock changes will affect the current program cost-effectiveness.*

ICBC registration data for 1998 and 2000 were used to build a demographic profile of the HDV fleet in the LFV. Based on the 2000 registration data, there were a total of 37,611 vehicles over 5,000 kg in operation, of which 72 percent were diesel (HDD), 20 percent gasoline (HDG) and 7 percent alternate fuelled vehicles (AFV). The analysis of age distributions indicated a stable population age distribution and therefore the current distribution was used for the forecasts of future populations. A growth rate of 3.3 percent for the vehicle population through the forecast period was used and was based on the findings contained in the most recent comprehensive review of BC commercial vehicles.

Figure 2 shows a forecast of the total HDV market by fuel and level of control. For the forecast, the diesel fleet is segmented by age groups which represent mechanically controlled engines (pre-1991), electronically controlled (post-1991) and advanced control systems (post 2007). The alternate fuel vehicle (AFV) fleet has been reduced overtime in line with the reduction in new vehicle sales. There is a possibility that the AFV fleet will increase in the latter part of the forecast period (post 2015) if fuel cell technology is proven to be economically attractive, or if other currently non-commercial technologies become viable – such as high pressure direct injection natural gas-fuelled diesel. Similarly, it is forecast in this business-as-usual scenario that gasoline HDVs will gradually be replaced by diesel powered vehicles over the next 10 years.

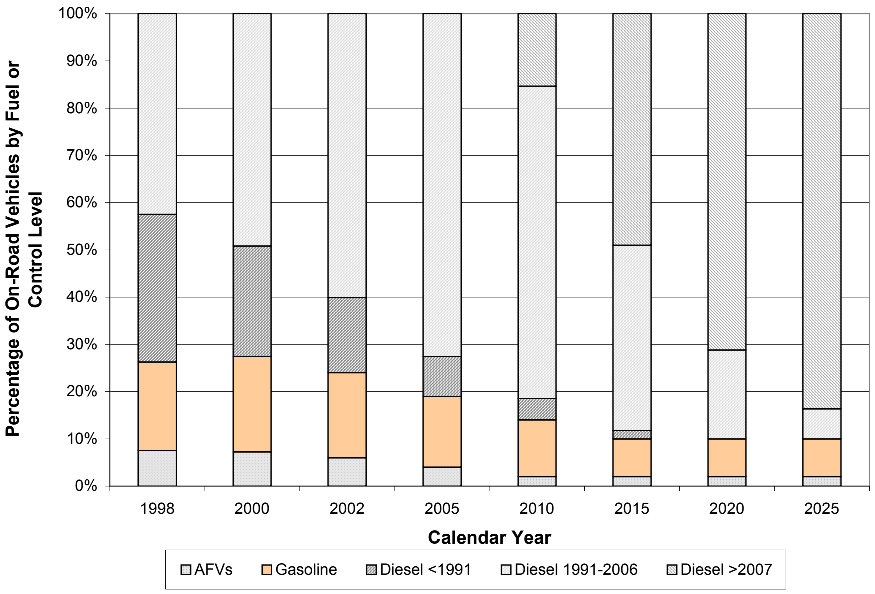

Figure 2 Forecast of HDV Engine Technology

One of the unique capabilities of the ICBC vehicle information database is its ability to link the vehicle with the type of insured use and a fleet identifier. This is important as it allows insight into the concentration of vehicle types and, thus, an understanding of the possibility for targeted control programs. In Table 2, it can be seen that the largest percentage of the vehicles (40 and 18 percent respectively) are used for delivery and trade/artisan applications. Government controlled or operated vehicles (government, bus and garbage) are the second largest group with 21 percent of the vehicles.

Table 2 HDV Population by GVW and User Type (1998)

User Type	GVW Weight Class						Total	
	Class 3-4		Class 5-7		Class 8			
Bus	628	11%	656	7%	1492	9%	2776	9%
Cement	1	0%	3	0%	479	3%	483	2%
Delivery	1231	21%	3767	39%	7721	47%	12719	40%
Dump	69	1%	305	3%	2355	14%	2729	8%
Farm/Fish	321	5%	851	9%	511	3%	1683	5%
Garbage	26	0%	101	1%	496	3%	623	2%
Government	740	12%	978	10%	1084	7%	2802	9%
Log	0	0%	40	0%	1165	7%	1205	4%
Rental	106	2%	454	5%	135	1%	695	2%
Trade/Artisan	2531	43%	2270	24%	1095	7%	5896	18%
Wreckers	280	5%	186	2%	51	0%	517	2%
Grand Total	5933	100%	9611	100%	16584	1	32128	100%

The market share of gasoline and alternate fuelled vehicles is forecast to shrink, with virtually all the new gasoline fuel vehicle sales being replaced by diesel by 2010. AFV new sales have already been reduced to very low penetration rates. Note that government is the largest operator of AFVs at 36% of the total fleet, with approximately 10% of these being electric buses. As noted, the trendline forecast does not attempt to account for any breakthrough new technologies that may achieve commercial status in the forecast period.

3. *Provide a commentary of future HDV emissions control standards and probable emissions control system technologies*

The new vehicle emission control standards are regulated by Environment Canada. However, there is a stated policy of maintaining the Canadian standards in harmony with those of the US, thus the US regulations and standards are what really define the upcoming technology. The next reduction in diesel emission limits will occur starting in 2002, when the US “consent decree” standards of 2.4 g/bhp-h (HC+NOx) become effective (through a Memorandum of Understanding between Environment Canada and the engine manufacturers, these limits will apply to Canada as well). Starting in 2007 and phasing in fully by 2010, the standards will decrease to 0.01 g/bhp-h for PM, 0.14 g/bhp-h for non-methane HC and 0.2 g/bhp-h for NOx, resulting in a further 90 percent decrease in emissions.

Because of these new emission control standards, dramatic changes in the vehicle emissions controls and rates can be expected, as can be seen in the forecast of average fleet emission rates in Figure 3. Starting in the fall of 2002, the consent decree standards will almost certainly require the use of exhaust gas recirculation. The requirement for low (15ppm) sulphur fuel in 2006 will cause a significant drop in particulate emissions for any vehicle using the fuel. With the further drop in allowable emissions in 2007, the use of aftertreatment devices will come into standard use. These devices will control particulate emissions with the use of particulate traps, and NO_x through in-cylinder combustion control and aftertreatment filters and catalysts.

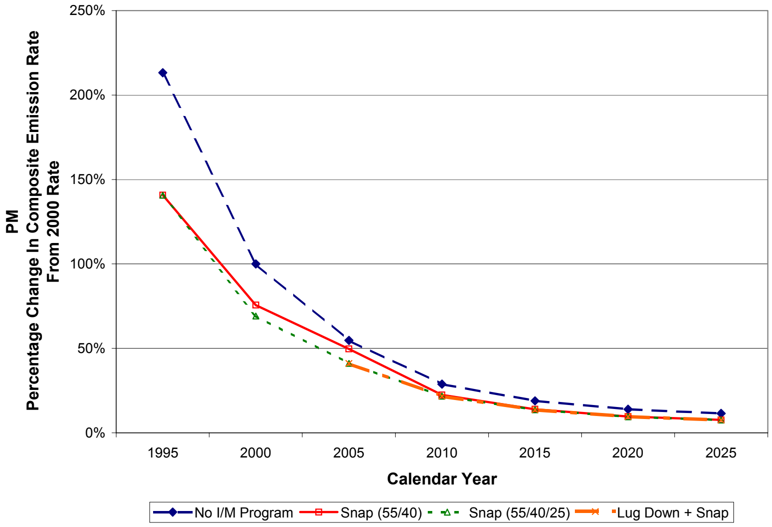

Figure 3 Forecast of Change in Average PM Emission Rates

The use of aftertreatment systems that require special (low sulphur) fuels to operate correctly is similar to the introduction of catalytic converters and unleaded fuel in the light duty gasoline fleet in the 1970’s. Many of the same problems encountered then should be anticipated to occur with the HDV fleet beyond 2007. These problems include tampering and removal of the aftertreatment systems, use of incorrect fuels and disablement or improper maintenance of control systems. Thus, the need for an in-use inspection system will increase in the latter part of this decade, as these systems become more complex and vulnerable to tampering. On the positive side, there will be requirements within the standards to require the increased use and accuracy of on-board diagnostic systems, which should be able to provide warning to the operator or the inspection agency of system malfunction or tampering.

4. Compare a series of possible optional in-use control programs for their effectiveness and costs.

A number of specific options were assessed as enhancements to the existing program. They were all compared against a “no program” baseline and the current program forecasts. The options included:

- Adding a third level of stringency of 25 percent smoke opacity to the current roadside snap-acceleration program for vehicles newer than 1994;
- Requiring an annual test using a loaded dynamometer to lug down the engine while measuring smoke, HC, CO and NOx;
- Requiring the annual testing of all non-diesel vehicles over 5,000 kg using a two-speed idle test for HC, CO and NOx.

For the diesel options, a malperformance model was used to estimate the incidence and effect of specific engine problems. For the non-diesel (gasoline) vehicles, estimates were obtained from MOBILE 6. Estimates for each pollutant (HC, CO, NOx, PM) were made, and the results were then weighted for their estimated health damage effects into a “weighted” emission value (as shown above for the 2000 base year). For each testing option, annual program costs estimates were made based on the testing rates, failure rates and repair costs. The cost estimates were then divided by the weighted emission reductions to create a cost-effectiveness ratio in $/tonne. The forecast effects of each of the testing options are provided in the Table 3.

Table 3: Estimates of Emissions Reductions and Costs by Test Option

Program Option	Measure	Calendar Year					
		2000	2005	2010	2015	2020	2025
Snap (55/40)	Weighted tonnes	2,338	641	850	781	781	845
	Cost	$730,000	$395,000	$336,000	$377,000	$495,000	$539,000
	Cost/tonne	$312	$616	$395	$483	$634	$638
Snap (55/40/25)	Weighted tonnes	2,928	1,549	967	856	833	895
	Cost	$730,000	$395,000	$336,000	$377,000	$495,000	$539,000
	Cost/tonne	$249	$255	$347	$441	$594	$602
Lug Down + Snap	Weighted tonnes		1,703	1,069	928	893	958
	Cost		$1,567,000	$1,888,000	$2,196,000	$2,196,000	$2,646,000
	Cost/tonne		$920	$1,765	$2,365	$2,459	$2,762

The cost-effectiveness analysis indicates that the more stringent snap-acceleration option would be approximately four times more cost effective for PM reduction than the lugdown option throughout the forecast period. It would also be more cost effective, and provide a greater emissions reduction than the current two-tier cutpoint option. The lugdown option was found to be capable of reducing NOx more than the snap-acceleration options. However, as the focus of the HDV control program has been on PM and smoke reduction then there would be no improvement in the cost effectiveness of the program (which is currently focused on PM control) with an expansion of the program to the lugdown test option. The snap-acceleration options remain very cost-effective relative to other emission reduction measures. The lugdown option becomes relatively high cost (i.e., $2,000-3,000/t) beyond 2010, as the cleaner engines are produced in response to more stringent standards.

The analysis indicated that further reducing the cutpoints for the pre-1990 and 1991-1994 vehicles could create significant error of commission (false positives) problem as some of the original engines were certified with smoke opacity levels close to the current standards. Thus, failing (and repairing) these vehicles may not lead to reduced emissions. It is thus recommended that the cutpoints for these vehicles not be altered.

5. Comment on other program operational and effectiveness issues

The study assessed the impact of a number of other program issues, including:

1. Refusal of Testing: Legally, it is possible that the vehicle operator can refuse to have their vehicle inspected. This refusal results in a fine. However, the current level of the fine at $86 is less than the cost of re-inspection ($100) without any repair costs. This loophole, while present, does not appear to have been used very often during the program with less than five fines issued. In order to assure that testing avoidance is maintained at a minimal level, it is recommended that the level of the fine be increased to $150 which would place it at approximately the same level as the most common repair and the retest cost.

2. Failure to Comply: Analysis of the program failure and repair data indicated that the overall level of compliance has been good, with 59 percent of all failed vehicles repaired within 60 days, 88 percent within their renew date, and the remaining 12 percent removed from operation before their next registration date. Only 8 vehicles out of 421 vehicles were possibly still operating in violation of the citation after the re-registration date.

3. Staffing Levels: The historical staffing levels have been five persons (two Commercial Transport Inspectors (CTI) and two emission technicians) and two vehicles. A reduction of this staffing level to two persons and two vehicles is possible if in the emission technician were made special constables with peace officer authority. This staff reduction should not significantly reduce testing volumes. Additional managerial and program support will be required which could be provided through PVTT or GVRD.

4. Program Delivery: The past program was managed and delivered by ICBC due mainly to the need for a CTI to be part of the inspection team. If special constable status can be obtained for the emission technicians, the CTI can be eliminated and there is no organisational need for ICBC to be directly involved in program delivery. In this case, the program could be delivered and managed under one of the regional agencies involved in air quality (e.g., PVTT or GVRD).

5. Gliders: It is not possible to assess the impact of “gliders” (the installation of older engines in newer chassis) as it is unknown how often this practice occurs. However, it is believed that it is relatively infrequent practice. There are technical loopholes in both the Federal and Provincial regulations that allows for an existing engine, transmission or axle to be installed on a newer or new chassis. This practice can result in higher emitting engines staying in service longer than their original chassis. It is possible that the incidence of the use of gliders could increase in frequency with the increased stringency of the upcoming new vehicle standards. The minimization of the impact of the loophole could be achieved through the modification of the BC Motor Vehicle Act to require that vehicles pass in-use standards applicable to the newer of the chassis or engine date of manufacture.

6. “Out of Province” Vehicles: These vehicles account for less than 10 percent of all trips in the LFV and from both an analysis of their age distributions and the results of roadside smoke surveys are cleaner on average than the average LFV vehicle. Therefore, no special enforcement actions are recommended. Effort should be made to maintain information flow and contact with other jurisdictions involved in HDV I/M and in the future to develop methods of sharing emission violation information between jurisdictions.

6. Provide a discussion of the health impacts of HDV emissions and the impact of ACOR

Diesel emission particulates (DEP) are associated with a variety of health outcomes – both morbidity (illness) and mortality (premature death). Most of the conclusions about the effects of DEP in ambient air are based on its relative contribution to total fine particle (PM_{10} or $PM_{2.5}$) levels. There are few studies that identify the effects of DEP in ambient air independently. Morbidity and mortality effects on laboratory animals have been demonstrated, including evidence of carcinogenic (cancer-causing) effects. Human studies of exposed occupational groups, such as mine workers and railway workers, and a few clinical studies of human response to exposure to DEP, have indicated both acute morbidity effects, increased mortality and carcinogenic effects. Reductions in DEP emissions, as targeted by ACOR, improve air quality and decrease exposure to DEP, thus reducing the associated health effects.

The estimated emission reduction of PM_{10} or $PM_{2.5}$ for 2000 attributable to ACOR (see above) is estimated to have reduced the regional annual average concentration of fine particles by 0.1-0.2 $\mu g/m^3$. The new light-duty vehicle emission standards (Tier 2) that will come into effect for model year 2004 are estimated to have the effect of reducing the average fine particle loading in the airshed by about 0.2 $\mu g/m^3$ by 2020. The ACOR reduction, thus, is significant, since its effect now is essentially equivalent to the ultimate effect on PM_{10} of the Tier 2 standards in 2020.

The estimated emission reductions that are attributable to the existing ACOR program and possible options indicated that the emission reductions for an ACOR-style program or its possible successor through the period from 2005 –2025 are in the following ranges:

- for PM (either PM_{10} or $PM_{2.5}$) from about 20 to 60 tonnes per year,
- for NOx from about 40 to 230 tonnes/year, and
- for HC from about 25 to 80 tonnes/year.

The NOx and HC emission reductions are not expected to have a material effect on ozone concentrations in the region. The PM reductions, however, would have a comparable impact on region-average PM concentrations to the estimates for the ultimate impact of the Tier 2 LDV/MDV emission standards - about 0.1 $\mu g/m^3$. This would be a significant additional benefit given the current values of PM_{10} in the region and the difficulty in the future of gaining emission reductions from other source sectors. Such a reduction is especially significant, since effectively all of the DEP is known to be in the smaller $PM_{2.5}$ size fraction that is of particular concern for both health and visibility impacts. Further, the impact of diesel emissions is exacerbated by the fact that the emissions occur in proximity to residential neighbourhoods and other roadside development. The elevated concentrations of particulate matter that are produced at street level fall off slowly with distance away from a street and cause significantly elevated concentrations at street-side residences or commercial buildings for the first few hundred meters from the centre of the street.

An estimate of the economic value of the emission reductions attributable to ACOR or its successors may be made by pro-rating the benefit estimated in a recent study for the implementation of the Tier 2 light-duty vehicle emission standards in the LFV. The effect of an ACOR-style program is estimated to produce 20-60% of the long-term emission reduction in ambient PM_{10} compared with the Tier 2 standards. Tier 2 was estimated to produce an annual average benefit (in terms of avoided health and welfare damage) of about $11 million (2000 CAD) over the period 2005-2020. On a pro-rated basis, therefore, an ACOR-style program would have a deemed economic benefit value of about $2 to 7 million/year, which significantly outweighs program costs. Based on other studies, the actual health care cost saving portion of the total health and welfare benefit is expected to be 15-25%, or $0.4 to 1.4 million per year – making the program cost beneficial even in this more restricted context.

Conclusions

1. The program performance data compiled indicates that the ACOR program had a consistent testing level of activity and pre-screening efficiency throughout the program period.
2. Through the use of a malperformance emission model, the current ACOR program is estimated to have reduced total PM air emissions from heavy-duty diesel vehicles by 85 tonnes per year, or 24 percent, from where the emissions would have been in the absence of any inspection program.
3. A cost-effectiveness ratio of $ 312/tonne (weight) is estimated from a health impact-weighted composite of emission reductions, which leads to the conclusion that the current version of the ACOR program has been very cost-effective in reducing particulate emissions from the on-road diesel fleet in the region.
4. The program staffing level can be reduced to a field force of two persons, two vehicles and additional managerial support if the inspection technicians are designated as peace officers. Without the need for CTIs on the inspection team, managerial and operational control of the program could be transferred from ICBC to another regional agency, such as PVTT or GVRD.
5. Enhanced versions of the ACOR using a lug-down test and including HDGV's would further decrease total emissions but increase the cost per tonne ratio by a factor of more than four. The quantity of incremental emission reduced by the enhancement options decreases, particularly for NOx, as the new diesel emission requirements take effect after 2010.
6. Since the ACOR program focuses directly on reducing fine particle emissions, its contribution to reducing regional PM_{10} or $PM_{2.5}$ levels appears to be comparable to that of the forthcoming major change in light-duty vehicle emission standards (Tier 2 standards). The health and welfare benefit of these reductions is substantial compared with program costs.

Recommendations

Based on the analysis and forecasts contained in this study, we recommend that the following programs and actions be considered:

1. The current ACOR program should be continued in its present function, but the staffing levels should be reduced. This can only be achieved if special constable status can be obtained for the inspectors.
2. The failure rate using the current ACOR pass/fail limits has been falling and is anticipated to continue to decline. To increase the severity of the test and increase the number of vehicles that will be repaired, it is recommended that a third tier opacity limit standard of 25 percent be added for post-1994 vehicles.
3. No change to the pre-1990 or 1991-1994 vehicle smoke opacity limits is recommended.
4. To minimize testing avoidance, the current refusal-to-test fine should be doubled to $150.
5. Provincial motor vehicle regulations should be modified to assure that any glider vehicles are required to pass standards appropriate for the date of manufacture of the chassis or engine, whichever is younger.
6. A fine (suggested at $300) in-lieu of repair could be applied to out-of-province vehicles that fail emission testing as a mechanism to increase the economic cost of non-compliance. This fine should be able to be waived on proof of repair.
7. There currently is a legislative gap concerning the testing of light duty vehicles for smoke and thus legislative and regulatory changes should be made to allow for the testing and

enforcement of a smoke standard on light duty vehicles, similar to regulations in place in other jurisdictions.

8. Increased public information should be developed and disseminated on the ACOR program.

9. Heavy-duty gasoline, propane and natural gas fuelled vehicles should be annually inspected using a two-speed idle test for HC and CO. The testing should be integrated into the current AirCare operations and would require one, or possibly two testing stations. The study makes no recommendations on cut points for this test, as it is necessary to undertake a field survey of the current vehicles to assess their current state of compliance.

10. The initiation of a retrofit or replacement program aimed at older gasoline and diesel vehicles could be an effective way of reducing emissions, but would impose significantly higher government costs, if a subsidy program is used, than the current I/M program. It may be possible to require the mandatory upgrading of vehicles (and thus avoid direct government costs) but this requires more legal analysis. If this retrofit/replacement program is considered, then the standards, verification methods and program design should draw heavily on the existing programs developed in the US.

11. While the effects of low sulphur fuels will be seen region-wide in 2006, it may be an effective measure to accelerate the use of low sulphur fuels in high use in government-controlled fleets, since the use of low sulphur fuels results in immediate reductions in particulate formation.

12. Because of the uncertainties of the physical reliability and tampering potential of aftertreatment emission control technology and low sulphur fuels in 2007, a further assessment of the need for and design of an in-use inspection program should be undertaken in the 2005-6 time period.

13. Continual liaison and information transfer with other jurisdictions involved in heavy-duty vehicle inspection should be maintained to allow PVTT and GVRD staff to keep apprised of technology and regulatory changes.

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ACOR	AirCare On-Road
AFV	Alternate Fuel Vehicle
ARB	(California) Air Resources Board
BC	British Columbia
EGR	Exhaust gas recirculation (emission control method)
ICBC	Insurance Corporation of British Columbia
LDV	Light-duty Vehicle
LFV	Lower Fraser Valley
GVRD	Great Vancouver Regional District
GVW	Gross Vehicle Weight (Registered)
HDV	Heavy-duty Vehicle
SAE	Society of Automotive Engineers

1. Introduction

In 1999, British Columbia's government passed legislation to establish a mandatory program to regulate emission levels in diesel fuelled buses and trucks with licensed gross vehicle weights (GVW) in excess of 5,000 kilograms. This heavy vehicle smoke prevention program is called AirCare On-Road (ACOR). The aim of the AirCare On-Road testing program, run by the Insurance Corporation of British Columbia (ICBC), is to reduce particulate matter (PM) emissions from heavy-duty diesel trucks and buses in Greater Vancouver Regional District (GVRD) and the Lower Fraser Valley (LFV). The establishment of the ACOR program followed a pilot program, initiated in 1996, of on-road smoke inspection testing of heavy-duty vehicles (HDV) operating in the LFV.

The contribution of heavy-duty vehicles to total emissions was estimated in the emission inventory developed by GVRD in 1999. As shown in Figure 1-1, heavy-duty vehicles were a small component of total emissions on a total mass basis. A different perspective of these emissions can be seen in Figure 1-2 which weights the individual pollutants for their health effects (as discussed in Section 5 of this report). In this chart, the heavy-duty emissions relative to light-duty vehicles are larger, primarily due to the particulate matter emissions which have a very high health effect rating. Also, it is important to note that these estimates deal with total airshed emissions and do not fully account for the localized nature of vehicle emissions which tend to be closer to motorists and pedestrians.

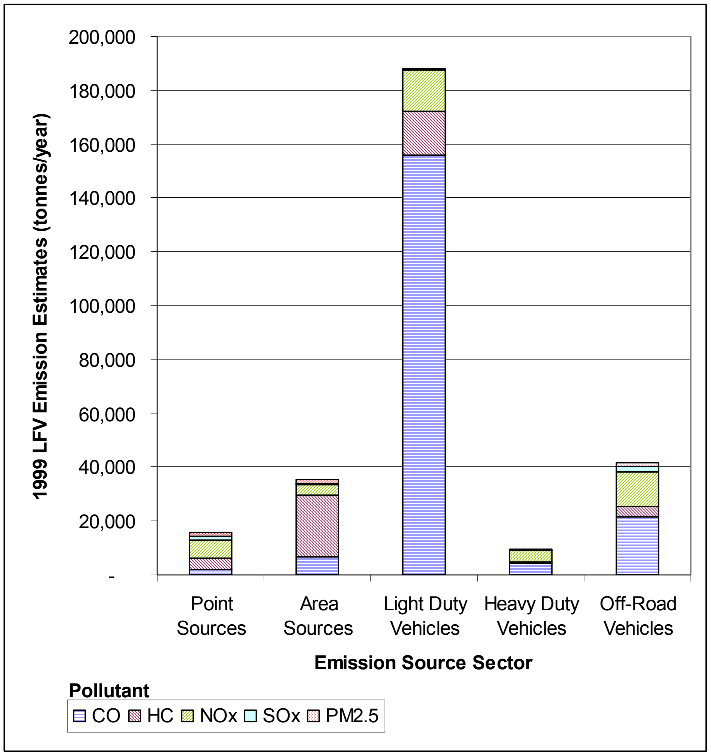


Figure 1-1 1999 LFV Emission Inventory by Source

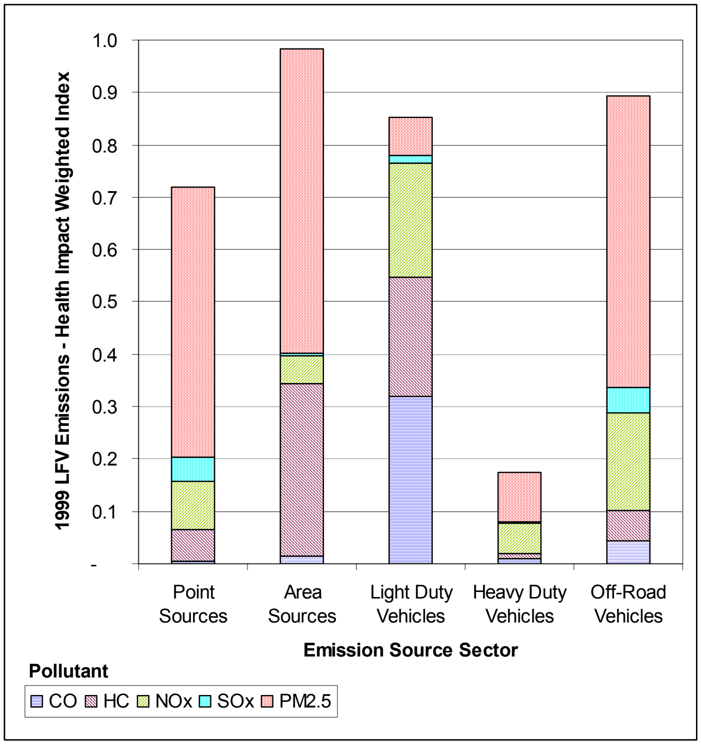


Figure 1-2 LFV 1999 Health Damage Weighted Emissions

This report is intended to provide a review of the effectiveness of the ACOR program, following three years of the operation of the mandatory phase, and make recommendations for future heavy duty vehicle control strategies in the GVRD/LFV airshed.

1.1 Scope of Work

This study was tasked to address the following questions:

1. Estimate the emissions reductions that resulted from the ACOR program's activities;
2. estimate the cost-effectiveness of the program;
3. forecast the heavy duty vehicle fleet characteristics and how future stock changes will affect the current program cost-effectiveness;
4. provide analysis and commentary on the importance and methods of controlling emissions from "out of region" vehicles;
5. assess the impact and possible control options for non-diesel HDV's;
6. provide a commentary of future HDV emissions control standards and probable emissions control system technologies;
7. provide a discussion of the health impacts of HDV emissions; and
8. compare a series of possible optional in-use control programs for their effectiveness and costs.

1.2 Report Organization

The report is segmented into six main sections:

Section 1: Introduction

Section 2: Program Performance Analysis provides a compilation and analysis of program efficiency and effectiveness measures.

Section 3: Vehicle Demographic Analysis undertakes a detailed analysis of the current vehicle stock and projections of the stock and technology mix out to 2025.

Section 4: Future Program Options reviews and discusses the various inspection options that are potentially applicable to the LFV fleet. The Chapter starts with a review of new vehicle standards followed by estimates of the mission and cost impacts of a variety of program options.

Section 5: Health Impacts discusses and assesses the impacts of changes in the air quality resulting for any in-use control program.

Section 6: Recommendations presents a series of suggested actions and future changes to the ACOR program.

2. Program Performance Analysis

2.1 ACOR Program history

In September 1992, the AirCare light duty vehicle emissions inspection and maintenance (I/M) program was introduced in the Lower Fraser Valley area of British Columbia, as an important component of the GVRD Air Quality Management Plan [*1*]. This program requires annual testing of all light duty vehicles up to 5,000 kg (11,000 lb.) GVWR to reduce the amount of smog-forming emissions released into the airshed. Heavy-duty vehicles were excluded from the I/M program at that time.

Subsequently, a series of studies [*2*,*3*] and industry consultations were undertaken to design an HDV I/M program. The program final design recommended in-use testing based on random roadside smoke inspections of HDV's operating in the LFV. This model was widely accepted by the local trucking industry as it focused only on vehicles with visually obvious problems and provided for equal treatment of locally registered trucks and trucks from outside the region.

To implement the program, a two-phase approach was undertaken:

- A pilot phase, consisting of voluntary testing, and driver & repair industry education and training, followed by
- A mandatory phase, requiring vehicle repair and compliance.

The pilot phase began in February 1996, with one inspection team operating out of the main AirCare facility, using the SAE J1667 snap acceleration opacity test procedure. The pilot program was operated for a 3-year period. The majority of pilot program testing was done at fleet yards, where drivers and fleet managers were given written reports of test results, and told whether they passed or failed, based on opacity criteria that had been used in California at the time (55 percent for 1990 and older engines and 40 percent for 1991 and newer engines). It is reported that throughout the pilot program, generally good co-operation from local truckers was experienced, with many actually requesting that the testing team come to their yard to test all of their trucks. Operators were informed that they should repair failing vehicles in advance of the mandatory program, and thus avoid any penalties that could be applied at that time, and many fleets undertook repairs.

An evaluation report of the pilot program was produced [*4*] based on the more than 4,000 tests done in the pilot phase of the program. The evaluation concluded that:

- Engines with electronic controls exhibited much lower opacity than engines with mechanical systems. Readings for snap acceleration tests were typically less than 10 percent opacity for normal-operating electronic engines.
- Older engines with mechanical fuel systems tended to have higher normal opacity results with averages readings between 20 percent and 30 percent.
- Failing vehicles tended to have very high peak opacity levels, usually over 70 percent and sometimes as high as 99 percent. Even newer technology engines, when malfunctioning, were found to be capable of opacity readings greater than 70 percent.

- The failure rate averaged about 20 percent but varied with both vehicle age and mileage. The vast majority of the failing vehicles were in the 1990 and older age group.

- No relationship was evident between engine horsepower rating, engine manufacturer, or gross vehicle weight rating and opacity.

- Drivers and owners were generally co-operative and allowed their vehicles to be tested despite the fact that the program was voluntary.

- A survey of fleet owners that had repaired vehicles as a result of the pilot program indicated that significant reductions in opacity levels could be achieved at a reasonable cost. Often, an adjustment of the injector pump was all that was required to bring the vehicle into compliance.

The pilot phase of the program confirmed that there was an adequate population of excess-emitting trucks in the region to support a mandatory program. It was also clear from the pilot phase that some owners of smoking trucks would not make the necessary repairs to their vehicles until there were legal standards in place. These findings supported moving forward with the mandatory phase of the program. In addition, there was public pressure for “equity” between LDVs, which had an annual inspection requirement, and HDVs which had no emissions inspection requirement. There were also continued public complaints of smoking trucks.

In May 1999, the program became mandatory, and was called the AirCare On-Road Program (ACOR). The program corresponds roughly to the “Pre-screened Random Roadside Inspection of HDDVs” described in the Phase II design report [*3*], and uses the SAE J1667 snap acceleration test procedure. This is similar to the roadside testing design recommendations contained in the recently published draft of the Canadian “Environmental Code of Practice for On-Road Heavy-Duty Vehicle Emission Inspection and Maintenance Programs” [*5*]. As in the pilot program, it was decided to concentrate on reducing “excess” emissions from heavy-duty diesel vehicles.

2.1.1 Operational Program Model

As the name “AirCare On-Road” implies, the program is a roadside testing type and does not include a requirement for periodic testing of vehicles registered in the area. All heavy-duty diesel vehicles travelling in the Vancouver region are subject to being stopped and tested if they appear to be smoking excessively. There are two, 2-man teams currently patrolling the region in mobile units capable of performing the SAE J1667 Snap Acceleration Test. Each team consists of a Commercial Vehicle Inspector who is also considered a Peace Officer under provincial law, as well as a smoke-testing technician.

Legislation was enacted under the Motor Vehicle Act of British Columbia to allow a Peace Officer to stop a truck that he/she believes is potentially out of compliance with the smoke standards (55 percent opacity for 1990 and older engines and 40 percent opacity for 1991 and newer engines). The driver of the vehicle must then allow the team to perform an SAE J1667 Snap Acceleration Test. Refusal to submit to the test results in a violation ticket being issued to the driver. Vehicles that fail are:

1. Given an Emissions Notice and Order (EN&O) – essentially a fix-it ticket. The EN&O advises the vehicle operator that the vehicle must be re-inspected within 30 days and demonstrate compliance with the standard.

2. A follow-up letter is also sent to the registered vehicle owner to advise that the vehicle has been determined to be out of compliance with the smoke standards and to explain what is required to do to clear the EN&O.

3. A vehicle whose owner has not submitted a passed re-inspection report within 30 days is flagged in the motor vehicle registration database, preventing it from being re-licensed at time of renewal. A second letter is sent to the registered owner prior to this point, reminding that action is required to prevent a sanction being placed on the vehicle.

4. If there is still no action after 30 days, a third letter is sent advising that a ”Refuse to Issue” sanction has been imposed on his vehicle. The Refuse to Issue means that it will not be possible to purchase licensing or insurance for that vehicle to operate it on the road once the current license/insurance expires.

The program currently imposes no other penalties.

2.1.2 Re-Inspection Procedures

Vehicles issued an Emissions Notice and Order must be re-inspected at any of nine Qualified Inspection Facilities (QIF). These facilities are private businesses that have voluntarily purchased an opacity meter and have received training in the performance of the J1667 test procedure by the ACOR co-ordinator. The ACOR co-ordinator provides the QIF with a Procedures Manual, a certificate designating it as an approved re-inspection facility, and a diskette containing a computer program that can be used to correct the results of the J1667 test for environmental conditions. The owner of the QIF or suitable representative must sign a declaration that he will abide by the procedures specified for carrying out re-inspections and will submit to any audits initiated by the program co-ordinator.

Vehicle operators are provided with a list of the re-inspection centres at the time the Notice and Order is issued. Vehicle owners are free to choose where the vehicle is repaired and, once the repairs have been made, to have the vehicle re-inspected at a QIF that is most conveniently located for them. Most of the QIFs are capable of performing repairs on HDDVs, and often do the repairs as well as the re-inspection. The technician at the QIF that performs the re-inspection sends a copy of the Re-Inspection Report (RER) by fax to the program co-ordinator at the Program Administration Office (PAO). Upon receipt of the RER indicating compliance with the standards, the co-ordinator updates the status of the vehicle and lifts any sanction that has been applied.

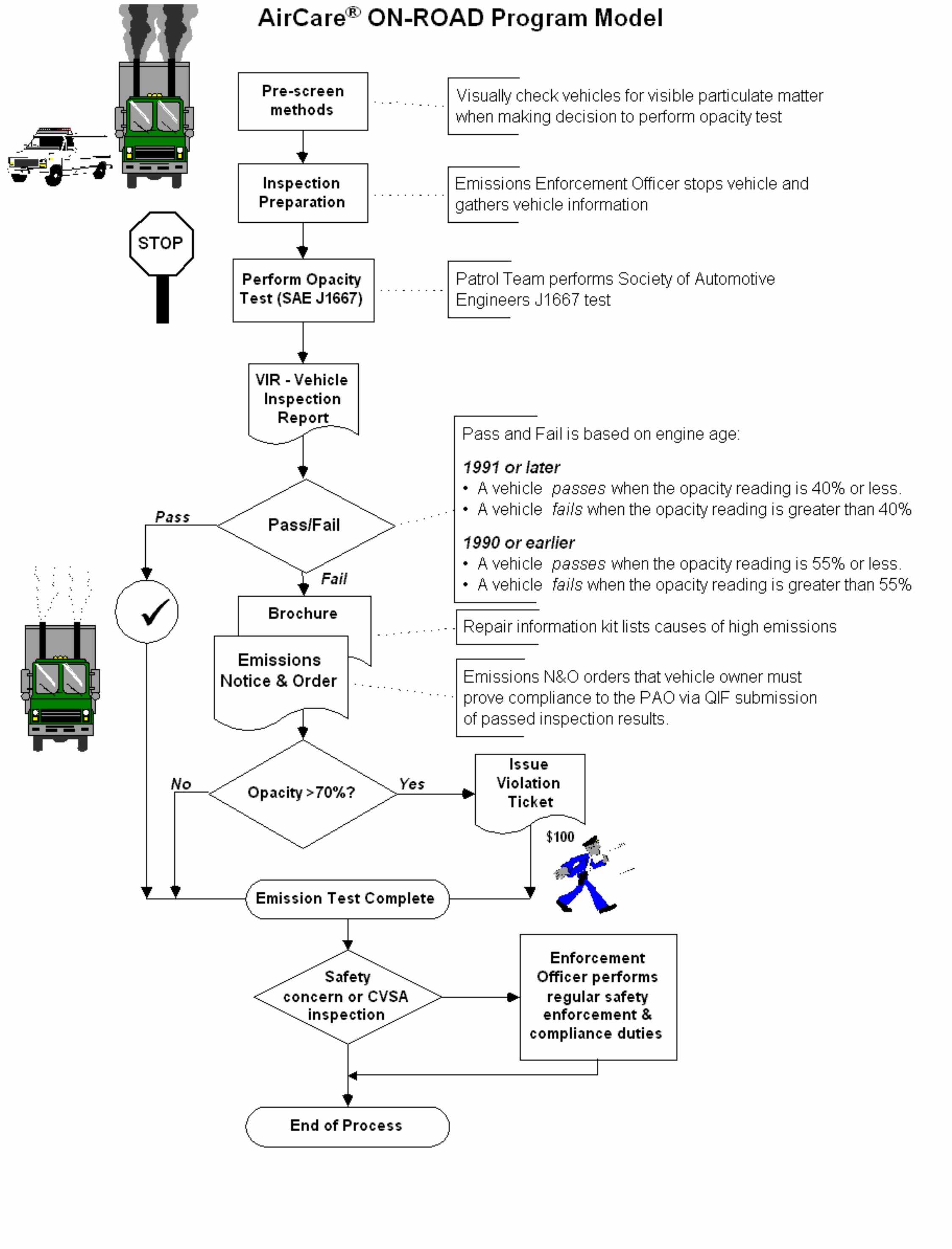
A flow chart (Figure 2-1) outlines the steps involved from the initial identification of a smoking truck through the clearing of the Emissions Notice and Order.

2.2 Current Program Performance Analysis

2.2.1 Performance Measures

The analysis of the performance of the ACOR program is based on the assessment of the following measures:

- Total activity and observation of truck population
- Vehicle selection and testing efficiency;
- Change in emissions distribution in population;



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March 25, 1998

Figure 2-1 ACOR Program Flow Chart

- Estimated changes induced by ACOR program;
- Cost of the program.

2.2.2 Data Sources

Program performance and activity data were supplied by ACOR, ICBC, GVRD, and AirCare staff from internal historical databases. The data sets reviewed included:

1. Pilot program testing data and on-road surveys;
2. a count of the number of on-road visual assessments undertaken (count only no opacity vehicle data). Note that prior to May 2000 only the high emitter visual count was contained in the records;
3. a count of the number of road-side assessments (visual estimate of the snap-acceleration);
4. snap-acceleration test results including test date, test data, detailed vehicle information and test standard.
5. re-certification test data; and
6. roadside visual assessment surveys data from 2000, 2001 and 2002 in the GVRD, and 2001 in Kelowna.

2.2.3 Program Activity

The data from the daily activity logs have been assembled into monthly totals and presented in Table 2-1, which contains the count of total vehicles observed, number of roadside visual snap tests, number of legal snap tests, the number of failures, and a series of calculated percentage ratios. Figure 2-2 and Figure 2-3 provide plots of the monthly test activity and vehicle failure rates, respectively. Note that during the first six months of the program data (November 1999 to April 2000), information on the total number of vehicles observed was not taken – only the number of vehicles with significant smoke. Therefore, those months are excluded from the subsequent discussion.

The data indicates that the total monthly volume of trucks observed on the road was relatively steady throughout the program at 3200/month in 2000 and 3800/month in 2001. There were minimal seasonal variations in the averages, with the notable exception of an increased observation rate (5100 and 5900) in the June and July of 2000. In the last year of the program (2001) the effective staffing levels decreased due to a early retirement program within the BC government which caused a number of the inspectors to use up outstanding sick and holiday time during that year. No precise actual person-hour estimates were available for the analysis.

Of the total 63,509 vehicles observed from May 2000 to November 2001, an average of 7 percent of the vehicles were stopped and a roadside quick visual assessment undertaken. Of these, an average of 18 percent were selected for a full SAE 1667 test (1.5 percent of the total vehicles observed). The data indicates a significant decrease in the SAE1667/assessment ratio through the program period starting out in November 1999 at 65 percent, dropping to between 41 percent and 23 percent in December 1999 through May 2000, and continuing the drop through the balance of the program timeframe. The lowest ratio occurred in September 2000 at 4 percent.

Table 2-1 ACOR Testing Data (1999-2001)

Month	**On-Road Visuals**	**Roadside Visual Snap Tests**	**J1667 Tests**	**J1667 Failures**	**Roadside/ On-road %**	**J1667/ Roadside %**	**J1667/ On-road %**	**Fail/ On-road %**	**Fail/ Roadside %**	**Fail/ J1667 %**
Nov 99	423	74	48	30	17%	65%	11%	7%	41%	63%
Dec 99	643	97	32	17	15%	33%	5%	3%	18%	53%
Jan 00	572	111	30	18	19%	27%	5%	3%	16%	60%
Feb 00	1011	247	96	63	24%	39%	9%	6%	26%	66%
Mar 00	1109	362	103	59	33%	28%	9%	5%	16%	57%
Apr 00	792	265	60	27	33%	23%	8%	3.4%	10%	45%
May 00	3557	209	57	40	6%	27%	2%	1.1%	19%	70%
Jun 00	5118	313	129	63	6%	41%	3%	1.2%	20%	49%
Jul 00	5965	460	74	46	8%	16%	1%	0.8%	10%	62%
Aug 00	3546	186	50	17	5%	27%	1%	0.5%	9%	34%
Sep 00	3838	189	37	22	5%	20%	1%	0.6%	12%	59%
Oct 00	3138	150	42	24	5%	28%	1%	0.8%	16%	57%
Nov 00	2521	159	30	19	6%	19%	1%	0.8%	12%	63%
Dec 00	2407	115	8	5	5%	7%	0%	0.2%	4%	63%
Jan 01	3244	339	26	14	10%	8%	1%	0.4%	4%	54%
Feb 01	3175	185	22	7	6%	12%	1%	0.2%	4%	32%
Mar 01	3568	233	19	8	7%	8%	1%	0.2%	3%	42%
Apr 01	2752	280	16	7	10%	6%	1%	0.3%	3%	44%
May 01	3316	194	48	8	6%	25%	1%	0.2%	4%	17%
Jun 01	3621	487	30	18	13%	6%	1%	0.5%	4%	60%
Jul 01	2732	266	24	16	10%	9%	1%	0.6%	6%	67%
Aug 01	2949	281	17	8	10%	6%	1%	0.3%	3%	47%
Sep 01	2663	255	10	7	10%	4%	0%	0.3%	3%	70%
Oct 01	3099	99	8	5	3%	8%	0%	0.2%	5%	63%
Nov 01	2300	55	9	6	2%	16%	0%	0.3%	11%	67%
Total	68059	5611	1025	554	8%	18%	2%	1%	10%	44%

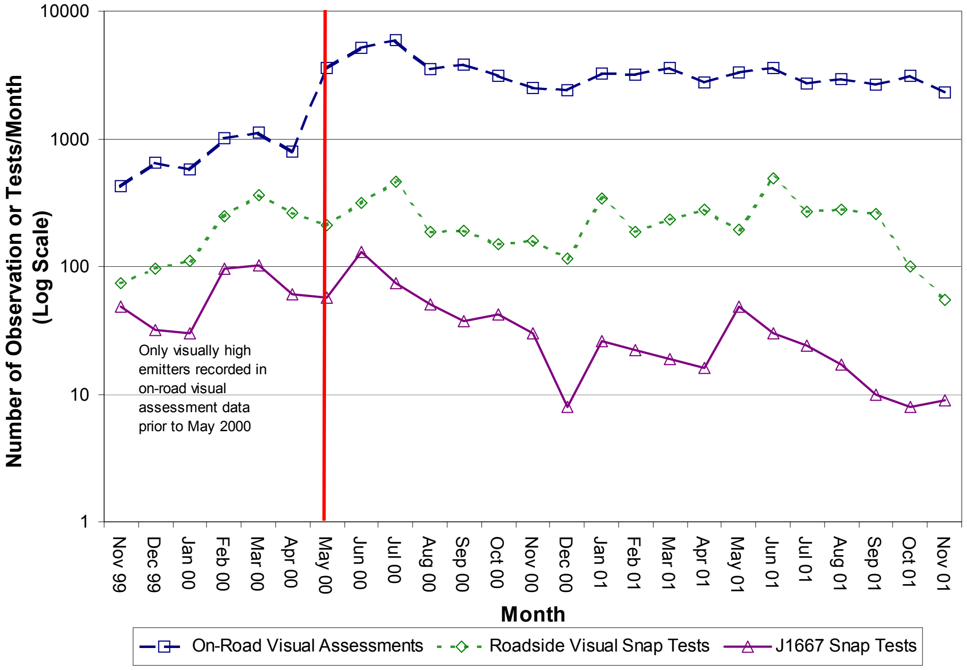

Figure 2-2 ACOR Testing Monthly Volumes

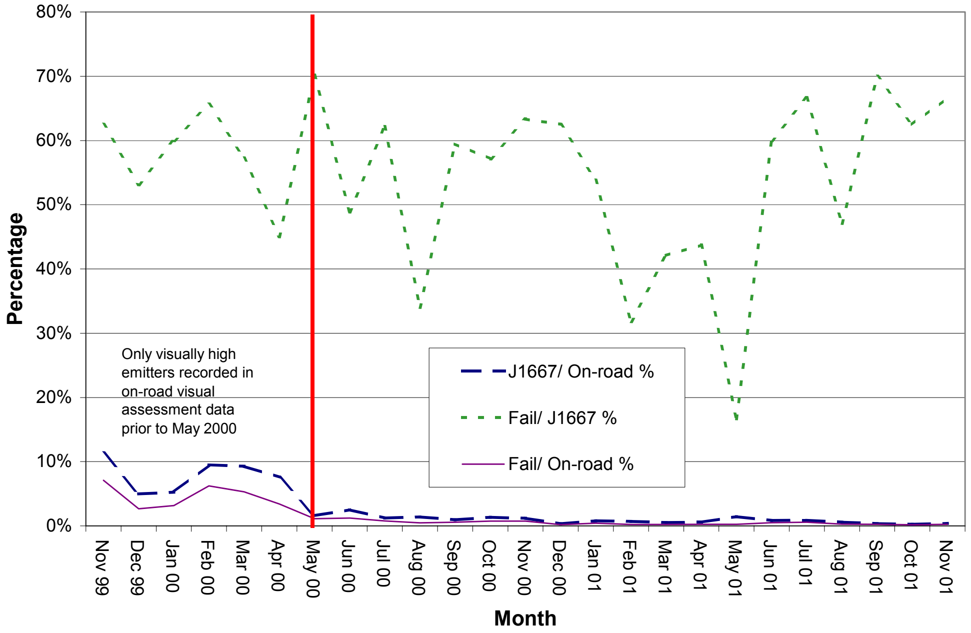

Figure 2-3 ACOR Monthly Testing and Failure Rates

2.2.4 Testing Efficiency

A measure of the efficiency of the ACOR program can be estimated by tracking the failure rates as measured against a variety denominators over the life of the program. The first measure is the failure rate as a function of the number of SAE 1667 tests undertaken. Remembering the vehicles are pre-selected twice (an on-road visual, then a roadside visual snap) before a full SAE 1667 test is undertaken, this ratio assesses the efficiency of this pre-selection process. As seen in Figure 2-4, this efficiency measure stays relatively constant at approximately 60 percent - that is 6 out 10 pre-screened vehicles failed the SAE 1667 test. For the post-1990 mechanically controlled vehicles, the efficiency rate initially was 40 percent but fell in the last year of the program to 20 percent.

The electronically controlled vehicles (both pre and post 1990) have a low total count and thus the statistical error of the means is higher. In 2000, the test failure rate for these vehicles was approximately 30 percent. The ratio fell to 5 percent and 0 percent in 2001 for the pre- and post-1990 vehicles respectively. Note that these percentages are based on a low total number of tests of 37 and 3 respectively for the pre- and post-1990 vehicles.

The other ratio of interest is the percentage of failures with respect to all the vehicles observed on the road. The road count was unfortunately not subdivided by vehicle age group and thus no segmentation of the total ratio is possible. Further, in 1999 the total observed number of vehicles was not recorded. The total failure rate indicates a decline from 0.8 percent in 2000 to 0.3 percent in 2001.

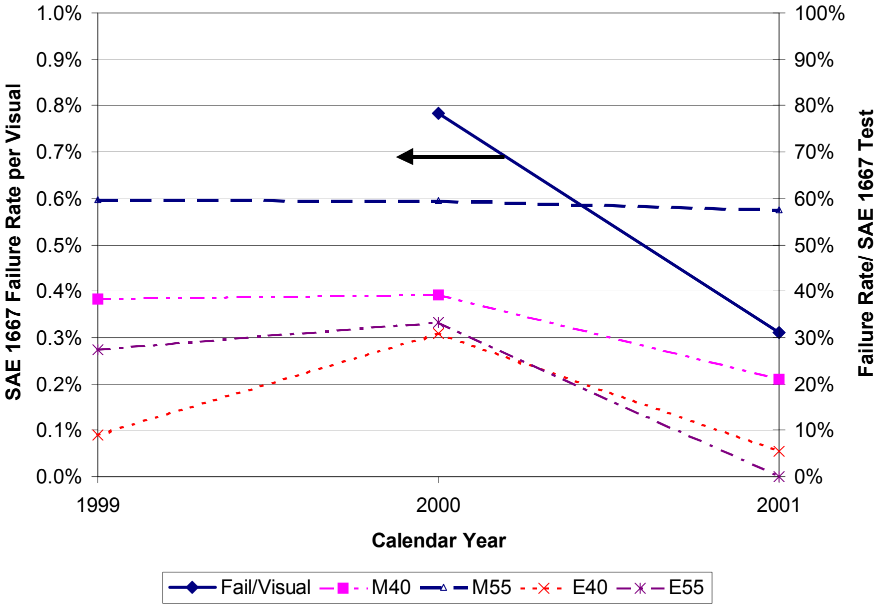

Figure 2-4 Annual Vehicle Failure Rates by Engine Technology

2.2.5 Opacity Survey Data

There is a lack of historic data of the emissions of trucks in the GVRD[i]. The data that has been made available by AirCare and ICBC staff consists of several random visual smoke opacity surveys and non-random SAE 1667 snap-acceleration based surveys. There has been no random survey of the total population for opacity levels using an accurately measured test such as the SAE 1667. Further, no mass emission measurements on loaded driving cycles have been collected for HDVs in the GVRD area.

A number of surveys of roadside estimates of visible smoke using EPA Method 9 have been completed during the pilot and full ACOR programs. The visual opacity data sets are potentially useful in assessing if there has been a change in the percentage of potentially non-complying vehicles and if these changes are a result of the program or simply the effects of changes in the demographic make-up of the fleet. However, the data sets have a number of problems:

1. Sampling method consistency, as some surveys were random while others were non-random; and
2. except for the most recent survey undertaken as part of this study, make and model year information was not estimated, thus, the segmentation of the vehicle fleet by fuel control system (mechanical/electronic) is not possible.

The data sets analyzed included:

1. 1995 and 1998 compiled by AirCare staff totalling 660 and 901 vehicles respectively;
2. surveys undertaken in 2000 and 2001 in the GVRD area totalling 1025 and 852 vehicles respectively;
3. a non-random 1360 vehicle sample taken in Kelowna, BC in 2001;
4. a survey undertaken by ACOR staff in late February 2002 in the GVRD area which observed 718 vehicles; and
5. a survey undertaken by AirCare Staff in early March 2002 in the GVRD area which observed 411 vehicles.

These data sets can be compared to assess what changes in the distribution of smoke emissions have occurred among the surveys. The opacity estimates are grouped in bins of 10, 20, 50, and 80 percent opacity. Figure 2-5 plots the cumulative distributions from each of the surveys. It can be noted from this chart that the distributions have moved to the left – that is they have become cleaner – over the six years covered by the surveys.

Using the cumulative percentage of vehicles which had 20 percent or less opacity as the measure of distribution change, it can be seen (Figure 2-6) that this percentage has increased significantly from 61 percent in 1995 to between 98 to 100 percent in 2002 surveys. Note that the 2001 Kelowna survey was not use full random sampling but rather was part of an “outreach” program aimed at fleet operators; thus, the validity of comparing the surveys is questionable. However, the distributions are remarkably similar with 91 percent of the vehicles having 20 percent or less opacity.

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[i] This is not criticism, since there is generally a very limited amount of in-use mass emission test data for HDVs anywhere.

The 2002 roadside visual opacity survey estimated the model year group of the observed vehicles, this allowed for the segmentation of the data by both test standard and engine control method, as the majority of engines after 1991 were electronically controlled. The data are summarized in Figure 2-7 and clearly indicate the opacity superiority of the post-1990 vehicles, with 98 percent having 10 percent opacity and all the vehicles less than 20 percent. 96 percent of all the pre-1991 vehicles had opacity estimates less than 20 percent, with 48 percent in the 10 percent opacity range and 48 percent in the 20 percent range. Only 4 percent of the pre-1991 vehicles were estimated at 50 percent opacity and no vehicles were observed with the 80 percent opacity level.

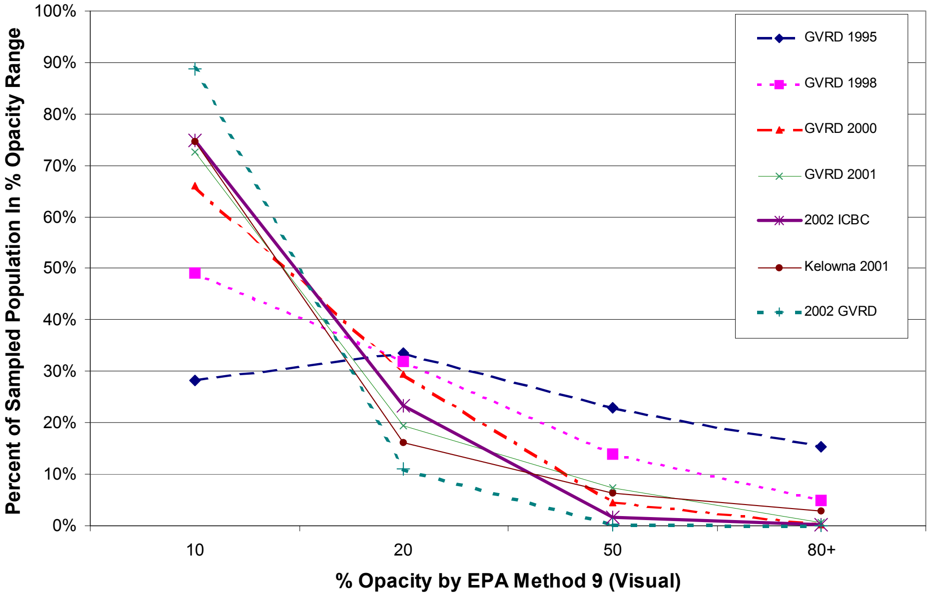

Figure 2-5 Comparisons of Cumulative Distributions of Visual Opacity Surveys (1995 - 2002)

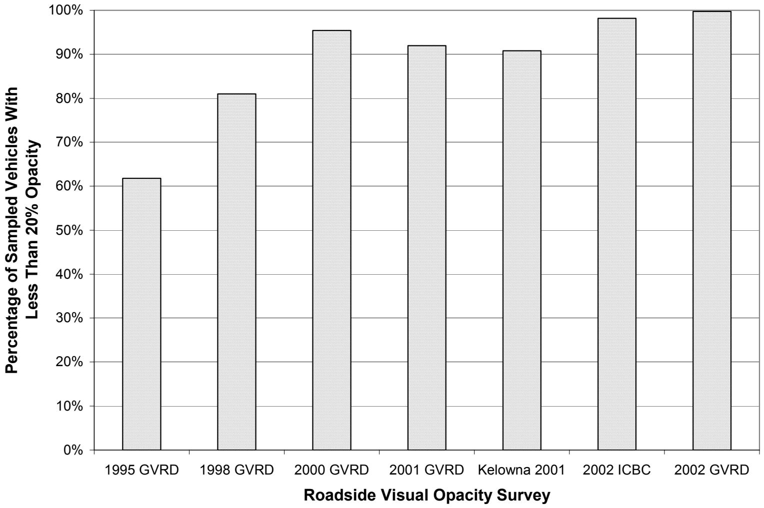

Figure 2-6 Less Than 20 percent Opacity Survey Comparisons

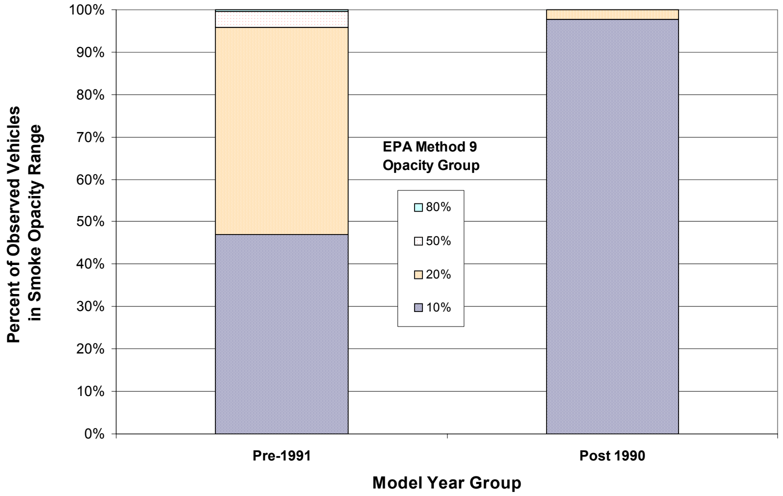

Figure 2-7 2002 Opacity Distribution by Vehicle Age

2.2.6 Public Complaints

Another measure of program effectiveness is the number of public complaints that are received about smoking trucks. The AirCare program maintains a SMOG-line telephone service on which members of the public can report sighting of smoking cars and trucks. The calls from Sept 1998 through to Oct 2001 were summed monthly and segmented by car and truck related complaints. As seen in Figure 2-8, there is some seasonality in the data, but the number of calls in the peak summer months has stayed relatively the same at 30-40 calls per month for all types of vehicles. What is also evident is that the number of truck related calls has been steady dropping through the years going from 25-30/month in 1999 to under 10/ month in 2001. This is another clear sign that the HDDVs are getting measurably cleaner through the course of the ACOR program.

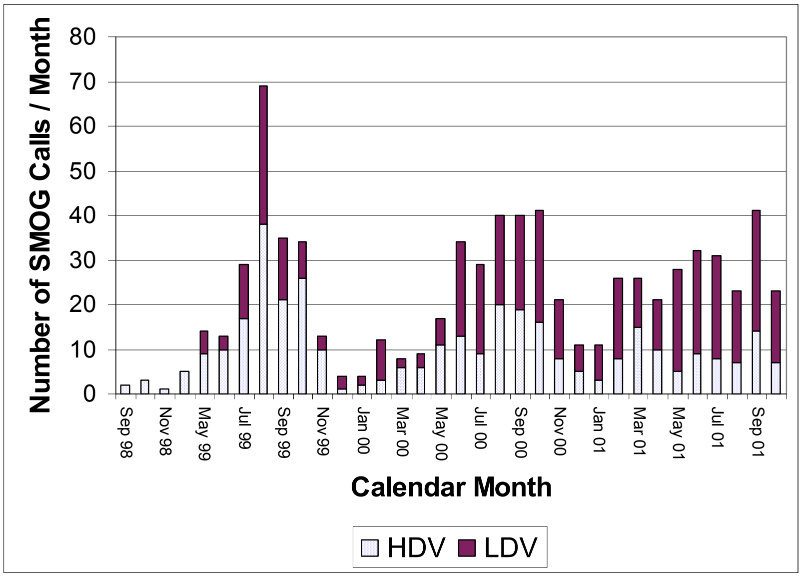

Figure 2-8 Monthly Smog Calls by Vehicle Type

2.2.7 Repairs

Information on the repairs undertaken on failed vehicles provides an important source of both program performance and cost data. The re-inspections of vehicles are performed at qualified inspection facilities (QIF), of which there are 10, and all the test data are submitted to the ACOR program. All of the QIF operators are also licensed heavy-duty repair facilities but it is not necessary that the QIF do the repair work on the tested vehicle. However, in many cases, both the repairs and the re-inspection are performed by the QIF, and in these cases data are available from which to determine repair costs.

Location of Re-certification Testing

The re-inspection test database was analyzed to determine the distribution of retests by QIF and the opacity value following repair. Table 2-2 provides data on where re-inspections were performed over the period from May 1999 to November 2001. The data indicate that the retest market was highly concentrated, with two firms performing 55 percent of the retests.

Effect of Repair

The re-inspection opacity test data provides a measure of the effectiveness of repair. All the QIF test data were compiled into Table 2-3 that provides the average test opacity cross- tabulated against program year and model year group. The data are disaggregated also by “pass on first test” and those vehicles that required a second test (and repair) which are identified as “retest”.

For visual comparison, the data also are shown graphically in Figure 2-9 and indicates that the mechanical technology average retest opacity levels all lie within the 20-30 percent range and are insensitive to vehicle vintage (within the group). Electronically controlled vehicles (post-1990) have average opacities approximately half that of the mechanically controlled group (the scatter is due to the small sample size of the electronically controlled vehicles). The data line for the “pass on second test” group has a small sample size and thus all program years are pooled. The average of all the second test vehicles is 30 percent - the same as the “pass on first test” group – the scatter by model year group is again a result of the small sample sizes.

Table 2-2 Locations of Emission Re-inspections

Qualified Inspection Facility	Total Number of Retests	% Total
ACOR Program Admin. Office	14	2%
AKAL Diesel Automotive Ltd.	80	11%
Bansal & Sons Diesel Automotive	40	5%
Dawson Truck Repair Ltd.	40	5%
Detroit Diesel Allison BC Ltd.	42	6%
K.N.W. Diesel	263	35%
Mainland Truck Repair Inc.	17	2%
Reliance Diesel Ltd	12	2%
Seawest Holdings Ltd.	38	5%
Valley Fuel Injection Ltd.	63	8%
Vancouver Mack Sales & Service	149	20%
Grand Total	758	

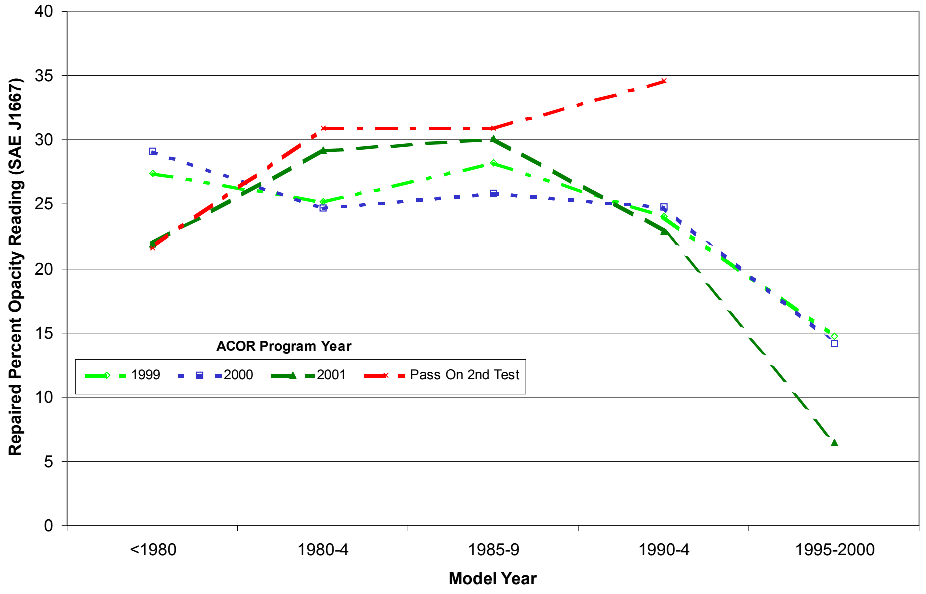

Figure 2-9 Opacity Levels After Repairs

Table 2-3 Opacity Levels After Repairs

Program Year		Percent Opacity For Pass on First Test						Percent Opacity For Pass On Second Test					
		<1980	1980 - 1984	1985 - 1989	1990 - 1994	1995 - 2000	Total	<1980	1980 - 1984	1985 - 1989	1990 - 1994	1995 - 2000	Total
	n	40	81	147	35	4	307	2		6	3		11
1999	avg	27	25	28	24	15	27	24		21	37		26
	sd	14	14	14	15	17	14	11		9	16		13
	n	64	64	160	43	11	342	4	3	18	2		27
2000	avg	29	25	26	25	14	26	20	31	33	39		32
	sd	16	14	14	15	18	15	17	15	16	1		16
	n	24	17	50	16	2	109	1		4	2		7
2001	avg	22	29	30	23	6	27	23		34	27		30
	sd	10	14	14	15	0	14			10	19		12
	n	128	162	357	94	17	758	7	3	28	7		45
Total	avg	27	25	27	24	13	26	22	31	31	35		30
	sd	14	14	14	15	16	14	13	15	15	14		14

Repair Costs

In a previous program analysis undertaken in 2000 by GVRD and AirCare staff [*1*], a sample of work orders were drawn from the repair records of the highest volume QIF. In total, over 148 re-inspection records were reviewed of which 58 cases had associated repair information. Furthermore, a second sampling of 51 work orders from the same QIF was taken as part of the current study. In both cases, the repair data was coded into similar repair categories.

The cost data for the previous analysis only included direct labour and parts costs - taxes and other charges were not included in the data, nor was there any identification of the engine manufacturer. In the current sample, the total repair costs – including tax (7 percent) and the cost of the retest ($100) was included – and the engine manufacturer identified. The summary data from the two sample sets are provided in Table 2-4.

The data indicate that:

- Adjustment of the air fuel control (AFC) on the injector pump is the most common type of repair, appearing in 60 percent and 53 percent of all the repair bills for the two surveys.

- While the average cost of repairs in the 1999 data was $821, almost half of the repairs, 27 cases in all, were performed for less than $100. In the 2002 sample, the average cost (ex tax and retest) was $713 with 52 percent of the repairs costing less than $600 (or $461 ex tax and retest) as seen in the cumulative cost data presented in Figure 2-10.

- In a few cases, crankcase flushes were performed as well as the AFC adjustment which increased the cost to more than $300.

- In cases where the injector pump, injectors or the engine itself were overhauled, the cost was much higher. Injector pump work was performed in 25 percent of the repairs in the 2002 survey and the cost of these repairs was normally over $1,000.

- The average 2002 costs was $870 however, this contained one repair that required an engine overhaul for a total costs of $6,965 which it could be argued would have been needed for other than emissions reasons. If this vehicle is eliminated from the data the average cost drops by $32 to $838. It is the study team's opinion that this repair should be included, as it was initiated by the ACOR program and probably the costs were allocated, at least in the owner's mind, to the program.

The fact that many of the repairs were performed by adjusting the AFC is encouraging because it suggests that lower opacity readings can be obtained fairly simply and inexpensively. It also suggests that the air/fuel adjustment had been deliberately maladjusted on these vehicles at some time in the past. There is also a possibility that the air/fuel ratio adjustment is being used as a convenient means of achieving complying opacity readings without actually addressing the root cause of the problem. Because of the possibility of adjustment, consideration should be given to requiring all QIFs to seal any adjustable item on the AFC or fuel pump pressure regulator after the vehicle has passed the re-certification test. This seal should be considered part of the emission control system and thus, if removed, could be considered tampering under the Motor Vehicle Act.

Table 2-4 Emissions Related Repair Incidence and Costs

Type of Repair	1999 Data			2002 Data				
	Repair Incidence	% Incidence	Cost Range	Cummins	DDC	MACK	CAT	Total
Adjust AFC	35	60%	$31-$61	59%	0%	0%	94%	53%
Adjust Injector Pump	6	10%	$265-$500	0%	75%	0%	0%	18%
Injector Pump Parts	6	10%	$1,000	35%	50%	0%	6%	25%
Adjust Fuel Delay	8	14%	$150	0%	0%	100%	0%	8%
Fuel Delay Parts	7	12%	$650	0%	17%	75%	0%	10%
Repair Injectors	3	5%	$62-$100	6%	33%	0%	6%	12%
Injector Parts	2	3%	$75-$300	0%	8%	0%	0%	2%
Adjust Valves	3	5%	$62-$124	18%	33%	0%	0%	14%
Adjust Rack	1	2%	$124	6%	25%	0%	0%	8%
Turbo/Blower	1	2%	$1,000	0%	0%	0%	0%	0%
Cooling System	1	2%	$50	6%	0%	0%	6%	4%
Crankcase Flush	9	16%	$250	0%	0%	0%	33%	12%
Cylinder Head Overhaul	1	2%	$4,500	6%	0%	0%	0%	2%
Engine Overhaul	2	3%	$11,000	0%	17%	0%	0%	4%
Air Filter	1	2%	$97	12%	8%	0%	0%	6%
Other	3	5%	$50	0%	0%	0%	0%	0%
Number of Work Orders	**58**			**17**	**12**	**4**	**18**	**51**
Average Total Cost				**$1,098**	**$1,298**	**$542**	**$443**	**$870**
Average Cost Ex Tax and Retest Charge			**$821**	**$926**	**$1,113**	**$407**	**$314**	**$713**

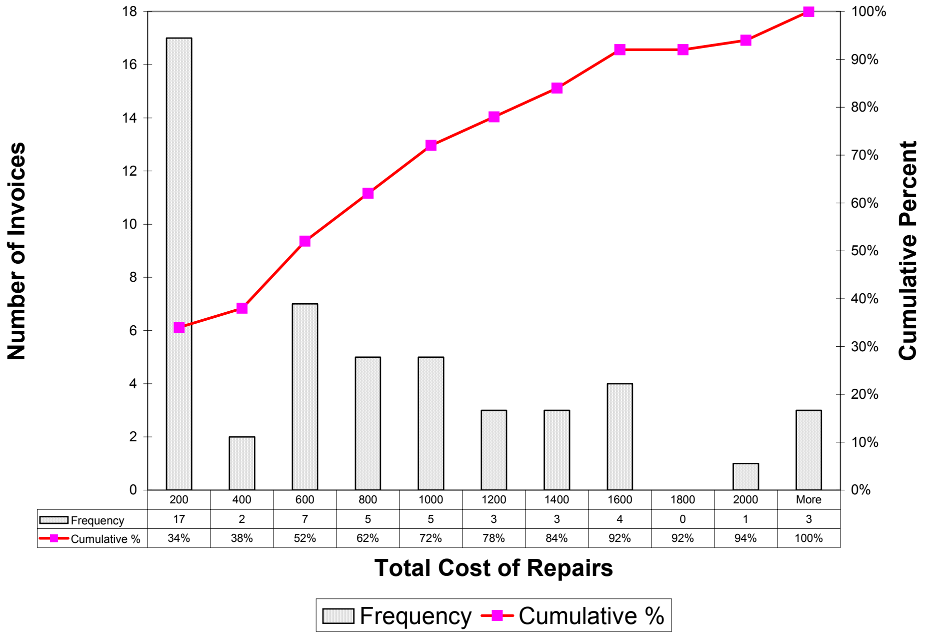

Figure 2-10 2002 Repair Survey Cost Histogram

2.3 Program Costs

Total program costs were estimated based on governmental costs and the costs of compliance for the truck owners. Program expenditures were provided by ICBC, and industry repair costs were estimated based on the average repair costs developed by the survey of repair work orders reviewed in Section 2.2.7. The actual number of repairs was estimated from the total QIF retest database, excluding any second retest data. The data indicated that there were 307, 342 and 109 repairs undertaken in the program years 1999, 2000, and 2001 respectively.

The ICBC program costs increase throughout the period as staff and equipment levels were increased – going from one van in 1999 to two in 2000. The total calculated program costs are shown in Table 2-5 and indicate that the first two years of the program had total costs of $586,000 and $730,000. There was a major drop in program costs in 2001. This decrease was due in part to

- the incomplete year (program ended in November);
- the lack of new capital equipment and
- the decrease in failing vehicles.

Table 2-5 Summary of Annual Program Costs

Cost Item		Annual ACOR Program Costs (000)		
		1999	2000	2001
	Salaries	$183	$272	$286
ICBC Costs	Operating	$136	$160	$41
	Total	$319	$432	$327
Failed (retest)Vehicles/Year		307	342	109
Industry Costs	$870/Repair	$267	$298	$95
Total Costs		**$586**	**$730**	**$422**

2.4 Emission Impact Estimates

While no direct measurements of HDDV emissions other than smoke opacity have been made on trucks operating in the LFV, estimates of the impact of the ACOR program have been estimated utilizing the malperformance model discussed in later Section 4.4. An estimate of the impact of the program in 2000 was made by inflating the 1999 LFV air inventory estimates by 3.3 percent to provide a baseline estimate. The relative emission rate changes for the snap-acceleration test option, at the 55/40 percent cut points, that were estimated by the malperformance model were then applied to calculate the total mass of pollutant reduced by the program.

The estimates are presented in Table 2-6. Note that CO is insensitive to an I/M program on diesel engines. The cost effectiveness of the ACOR program in 2000 is calculated by dividing the health impact-weighted reductions in emissions (discussed in Section 4.8.3) by the total program costs. The overall cost per tonne (weighted) is calculated at $312.

There is a relatively large estimate of “excess” emissions for PM implied by the malperformance model, and the resulting large estimate of PM benefits from the inspection program. All available data from actual testing of in-use heavy-duty diesel vehicles (HDDV) confirm the fact that PM emissions are much higher than applicable standards. For example, EEA recently conducted tests on about 40 HDDVs in New York City in which the vast majority exceeded PM certification standards by 40 to 400 percent. Although the percentages are large, it should be noted that absolute standards are quite low at 0.25 g/bhp-hr for 1991 to 1993 and 0.10 g/bhp-hr for 1994 and newer trucks. Indeed, only 3 vehicles (all less than three years old) met the standard with all of them at 0.09 to 0.10 g/bhp-hr. Average percentage excess emissions were in the range of 50 to 150 percent of the standard, although the averages were dominated by high emitters. More recent testing in Denver, Colorado confirm these trends although the small tested sample of 16 trucks of varying vintages make it difficult to arrive at statistically significant results. However, it is possible to say that original estimate of total “excess” emissions of 20 percent [3] is very clearly an underestimate of actual excess emissions, which we estimate as ranging from fifty to 100 percent for post-1990 HDDVs, consistent with the test data.

The NOx emissions reductions estimated by the malperformance model are due to the assumed improvement in maintenance practice. Results from California showed that the presence of six inspection teams state-wide resulted in a very large drop in the percentage of smoky trucks from the first year to the second, with the drop being much larger than if the reduction was simply due to ticketed trucks being repaired. The deterrence effect of IM programs is well known, and the analysis of the California random smoke test data suggested a decline of one-third in malperfomance rates. This effect of owners maintaining their vehicles in better condition is the primary reason for the projected decline in NOx emissions, and is an indirect benefit of the smoke program.

Table 2-6 Estimated Emission Benefits of the ACOR Program in 2000

Pollutant	Baseline (T/y)	Emissions Change (T/y)	Percent Change
HC	832	-99	-12%
CO	57100	0	0%
NOx	5630	-113	-2%
PM_{10}	348	-85	-24%
$PM_{2.5}$	306	-75	-24%
Impact-weighted emissions		-2338	
Program Cost		$ 730,000	
Cost per Weighted Emission/ tonne ($/t)		$312	

Impact-weighted = 25*PM+HC+NOx+CO/7. See Sections 4.8.3 and Chapter 5 for details.

2.5 Other Operational and Legislative Issues

2.5.1 Refusing Testing

It is possible that the vehicle operator can refuse to have the vehicle inspected. This refusal would result in a fine. However, the current level of the fine at $86 is less than the cost of re-inspection ($100) without any repair costs. This loophole, while present, does not appear to have been used very often during the program with less than 5 fines issued. To assure that testing avoidance is maintained at a minimal level, it is recommended that the level of the fine be doubled, which would place it at approximately the same level as the most common repair and retest cost.

2.5.2 Vehicles Failing to Comply

In the current ACOR program, a failing vehicle is issued an Emission Notice and Order to Comply. Compliance is achieved by repairing the vehicle and showing proof of passing a retest undertaken by a QIF. If the vehicle has an outstanding EN&O at time of re-registration, it will be refused registration. The program's database tracks the issuance and clearance of the EN&Os and the data was used to compile the summary of the 'cleared'/'not cleared' vehicle counts in Table 2-7. The data indicates that, excluding the vehicles with plates from other jurisdictions, over 90% of the BC vehicles were brought into compliance within the one year re-registration window.

Table 2-7 Incidence of Failure to Comply

Calendar Year	BC Vehicles				Other Plates	% Other	Total Failed
	Not Cleared	Cleared	BC Total	% Cleared			
1999	30	367	397	92%	24	6%	421
2000	37	349	386	90%	18	4%	404
2001	37	51	88	58%	11	11%	99

By grouping the EN&O compliance data by month, a more detailed trend in overall compliance rate can be seen. Figure 2-11 provides a plot of the data from which it can be seen that non-compliance rate increases in the last year of the program as a function of the time since failure. When a histogram of the date differences between initial EN&O and ultimate repair and re-certification is plotted (Figure 2-12), it shows that 59% of all the repairs are completed with 60 days and by the end of 360 days 86% of the repairs are made.

Analysis undertaken by ICBC staff [i] of 61 vehicles that were non-complying over one year from date of ticketing indicated that 53 of the vehicles were unlicenced, terminated, or unrenewed. This leaves 8 out of 61 possibly operating illegally.

These data indicate that while the program does not achieve rapid repairs (less than 30 days), the majority of the vehicles were repaired within 60 days. Also, approximately 12% of the vehicles are removed from operation instead of having them repaired. An acceleration of the time to repair may be possible with the application of fines for repair delay over 30 days.

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[i] Data provided by Stephen Parkinson, ICBC

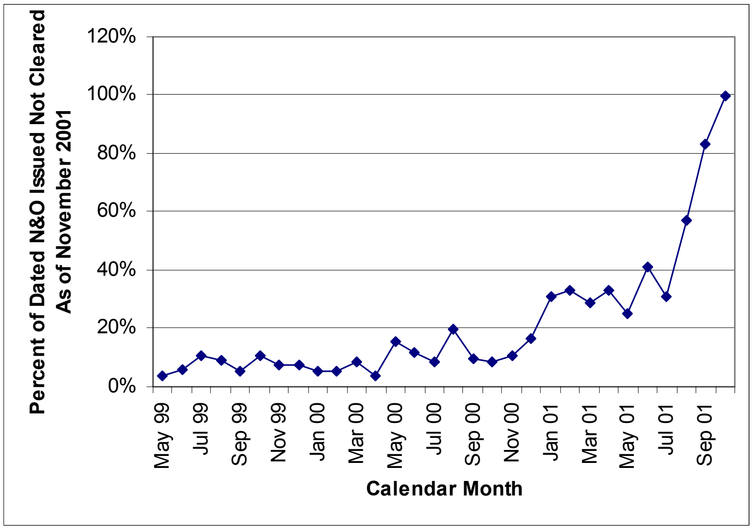

Figure 2-11 Monthly Trend in Compliance Rate

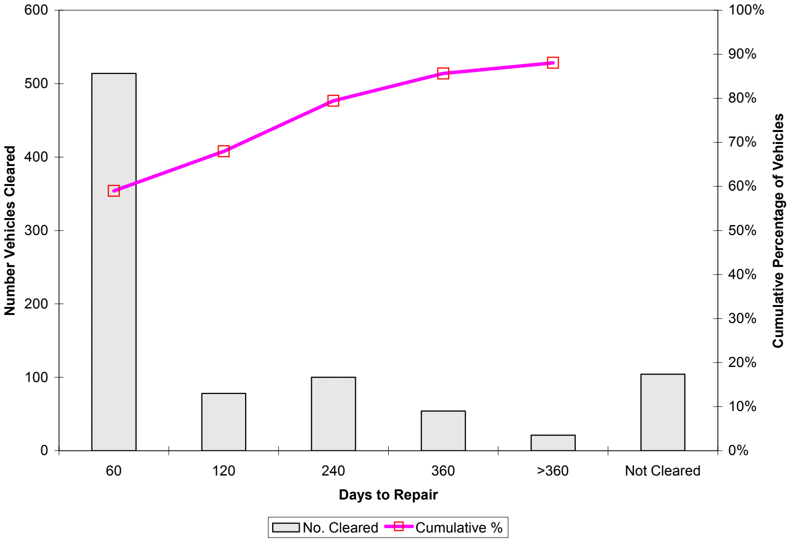

Figure 2-12 Histogram of Time to Repair

2.5.3 Program Delivery and Staffing Levels

The ACOR program was initiated as a pilot program in 1995 with one full time staff person. When the program was made mandatory in 1998, this staffing level was increased to 5 personnel and two vehicles by the 2000 calendar year. This staffing consisted of one manager, two Commercial Transport Inspectors (CTI), who were also peace officers, and two emission technologists[i]. All staff were ICBC employees and the program management and delivery was the total

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[i] Although not documented in the costs received from ICBC, there was additional senior management time from ICBC, GVRD, PVTT and MELP for program management and review.

responsibility of ICBC. In November 2001, the program operational support by ICBC was terminated.

The actual program staff requirements are likely to be less than that of the past 3 year operation. The two person teams were needed, in part, because the presence of a peace officer was required to enable the legal stopping of a motor vehicle. While having a CTI presence allowed both the peace officer function and for the option of undertaking full safety inspections on the vehicles (estimated by ICBC as approximately half the time for inspections), the CTI was a high cost labour component of the program. Evidence of the capability to maintain inspection rates with a reduced workforce is found in the 2001 operations. Because of the governmental down-sizing and ACOR program support cessation in 2001, actual in-field staff hours in 2001 were substantially less than the budgeted as retiring staff took accumulated sick and holiday leaves. Even visual inspection rates were maintained at previous year levels.

Also, the historic vehicle observation rates can be used to estimate the personnel efficiency. During the period May 1999 to April 2000, the number of vehicles visually assessed was 42,829. This inspection rate was achieved with a nominal staff complement of five persons. Assuming a nominal working hours of 1,755 hours per person per year, with an estimated 30% non-inspection time for administrative time, travel time, etc., the observation rate is calculated as 7 vehicles/ person-hour. This is observation rate is less than half the observation rates obtained in the 2002 random surveys in which 3 people observed a total of 1,129 vehicles in 3 days, or a ratio of approximately 17 vehicles per person-hour. If the organizational model of two single person inspection teams (with 30 percent down time) and some part person-year for management is used in a future program and the same 42,829 vehicles per year are observed, then the efficiency ratio would be the very similar to achieved in the spot surveys. Thus, it appears that much improved inspection productivity could be achieved by moving to a two single person operation.

In discussions with both the present ACOR enforcement manager and the program officer for the pilot program, both contended that an effective program could be delivered with a two-person, two-vehicle level of effort, especially if the safety inspection time was removed. If there is no need for a fully certified and trained CTI, the labour cost will be lower (starting at $35,000 for a test technologist and $60,000 for a CTI). However, if the CTI/peace officer were not part of the team then the emissions inspector would need to have special constable powers assigned to them by the BC Solicitor-General's office (similar to the powers that Translink police officers have). This staffing model also assumes that two people are not required for the roadside inspection. This is likely the case as full roadside safety inspections are currently undertaken by a CTI. In the reduced staffing model, an additional part person-year position will be needed to handle administration, planning, inter-jurisdictional liaison and public communication.

Historically, the program has been delivered through ICBC. This is large measure was due to the need to have a CTI in the van to act as the peace officer and do safety inspections as required. One of the problems noted with the current organizational structure is that the program is a very small portion of the total ICBC enforcement branch's responsibility and is viewed as an orphan program with limited ICBC management backing or interest. If the presence of a CTI were not a requirement, then the program could be both significantly less expensive and be delivered through another provincial or regional agency such as PVTT or GVRD.

2.5.4 "Glider" Vehicles

"Gliders" are defined as vehicles in which an engine older than the chassis manufacturing date has been installed. This can result is higher emissions if, for example, a pre-1990 mechanically controlled engine in placed in a new or newer chassis. This practice occurs with an unknown, but probably low frequency. The issue has two aspects to it, one the possibility of a higher emission rate and two what standard to use when testing vehicle.

This problem arises from the following causes:

1. when a "glider" chassis[i] is purchased directly from a truck manufacturer and the dealer or owner installs an existing older engine before the vehicle is initially registered;

2. when the vehicle is re-engined after initial registration with an engine older than the original vintage.

In both cases, the emissions from the vehicle maybe higher than the current or original engine certification depending on the emissions standards in place at the time of manufacture for the engines.

In the first case, the vehicle may be in contravention of the Canadian Motor Vehicle Safety Act (administered by Transport Canada) which requires the final assembler to certify that the vehicle meets all applicable standards at the time of its completion and apply a National Safety Mark on the vehicle. Further, the Provinces are supposed to require proof of compliance prior to first registration on the New Vehicle Information Sheet. Thus, any vehicle that does not comply (as a glider would not) would be contravention and should not be licensed.

However, there is a loophole under the Federal legislation which allows the owner (not for resale) to install used powertrain components in a new chassis [ii]. This rule is apparently in place to cover replacement of the chassis due to accident, fire, etc., but could be used by an operator to avoid moving up to electronically controlled engines or the more advanced emission control systems that will come into the market in the next few years.

The second case, when the vehicle's engine is replaced by an older unit, should be illegal under the current BC Motor Vehicle Act (section 47 – see the text box below) which prohibits the removal or change in emission control systems on vehicles.

Extract from BC Motor Vehicle Act

47 (1) A person must not sell, offer for sale, expose or display for sale or deliver to a purchaser a motor vehicle or a motor vehicle engine of a class or type required by the regulations to have installed on or incorporated in it a system or device to prevent or lessen the emission into the outdoor atmosphere of an air contaminant, unless the motor vehicle complies with the regulations.

(2) A person must not operate a motor vehicle of a class or type that, by regulations made under this Act or under the *Waste Management Act,* is required to have installed on or incorporated in it a system or device to prevent or lessen the emission into the outdoor atmosphere of an air contaminant, unless the motor vehicle has the system or device installed on or incorporated in it and makes effective use of the system or device.

(3) A person who contravenes this section commits an offence and is liable on conviction to a fine of not less than $50 and not more than $500.

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[i] an incomplete truck chassis which has no engine installed.

[ii] The following is Transport Canada's position regarding the assembly of a truck that involves a "glider kit": Combining new and used components; When a new cab (incl. glider kit) is used in the assembly of a truck, the truck will be considered newly manufactured . . . unless the engine, transmission, and drive axle(s) (as a minimum) of the assembled vehicle are not new, and at least two of these components were taken from the same vehicle. Stated another way, if either the engine, transmission, and/or drive axle(s) are new or no two of them are from the same vehicle, then the vehicle is new. If the vehicle is considered new, it must be certified to meet all applicable Federal safety standards (including ABS) in effect on the date of its manufacture. If the vehicle was built using at least two of the used parts described above, then the truck is not considered new and therefore is not subject to the Federal laws that regulate the manufacture of new vehicles. Source: Transport Canada, Road and Motor Vehicle Safety Branch

Thus, the avoidance of more stringent emission design requirements by the creation of gliders with older engines in them (but new or newer bodies) is legally possible at present although not a widespread practice. One way to overcome the negative emissions aspects of this loophole would be to consider changing the BC Motor Vehicle Act to require a vehicle to meet the in-use standards applicable to the younger of the chassis or engine manufacture date.

2.5.5 Out of Area Vehicles

One of the sub-issues to be addressed by this study is the emissions of vehicles from outside of the airshed that operate in the LFV area. It can be expected that the vast majority of these vehicles will be long-haul semi-trailers, which are mostly delivering or picking up goods from the ports and manufacturing operations in the LFV. A 1999 study of trucking in the region [*6*] confirms this as shown in Table 2-8. The study defined an external trip as one the originated or terminated outside of the Lower Mainland and a through trip as one that enters one gateway (port, border crossing, or highway cordon) and leaves from another on the same trip without making a freight stop. Unfortunately, no estimate was made in the study of the total kilometres of truck travel, and only trip counts were collected. Of all truck trips, 5 percent were for external trips. Of these trips, only 6.8 percent of all truck traffic are through trips with the 92 percent of these trips using a heavy truck.

Table 2-8 1999 Truck External and Through Trips

Truck Type	Total Trips	External Trips	Percent External Trips	Through Trips	Percent of External Trips	Percent of All Trips
Light	127,000	2,200	2%	75	3.4%	0.1%
Heavy	60,300	7,700	13%	596	7.7%	1.0%
Total	187,300	9,900	5%	671	6.8%	0.3%

Of course, a percentage of the vehicles registered in the LFV are travelling outside of the region. An estimate of this percentage can be obtained from the 1998 registration data, as it had an insurance “operating range” and “region of use” code. The data has been cross-tabulated by vehicle age groups, and presented in Table 2-9. It is not known how accurate or complete this coding is, as some 58 percent of the records have no coding. However, of those coded, some 12 percent were explicitly coded for intra- or ex-BC operations. Note that the ex-BC vehicles have a significantly younger age distribution than the uncoded vehicles with operating ranges greater than 500 km/day. No information about the percentage of total use was available, but it is perhaps reasonable to expect that, especially for the Class 8 vehicles, a large percentage of these vehicles’ travel will be external to the LFV.

Table 2-9 Age Distribution of LFV Registered Vehicles Over 5000 kg GVW by Operating Range

Operating Range	Region of Use	Number of Vehicles	Percent Total	Pre-1991	1991-1995	1996-1999
Non Specified		27616	58.0%	55%	27%	19%
<160 km		13856	29.1%	59%	26%	15%
>500 km		354	0.7%	49%	16%	35%
160-500 km		82	0.2%	56%	32%	12%
>500 km	BC	555	1.2%	34%	34%	33%
160-500 km	BC	1500	3.2%	39%	32%	30%
>500 km	Can	1032	2.2%	30%	29%	41%
160-500 km	Can	106	0.2%	33%	25%	42%
>500 km	US	2179	4.6%	19%	34%	48%
160-500 km	US	321	0.7%	40%	34%	26%

The roadside opacity observational surveys undertaken in 2000, 2001 and February 2002 provide some estimate of the percentage of traffic at the sample locations that were from outside of the LFV. The observation sites covered the entire LFV region and were on truck routes. In Table 2-10, it is seen that the percentage of non-LFV vehicles was 13 percent in 2000, and dropped to 2-3 percent in the 2001 and 2002 surveys. Also in the table is the percentage of vehicles with opacity estimates that were 50 percent or more, and this shows that the non-LFV vehicles are actually cleaner than the BC registered vehicles.

Table 2-10 Opacity Levels by Plate Jurisdiction

Survey Year	Plate Jurisdiction	Number of Vehicles Observed	Percent Vehicles With Opacity 50% or More
Feb 2002	BC	696 (98%)	2%
	Other	14 (2%)	0%
2001	BC	994 (97%)	8%
	Other	30 (3%)	3%
2000	BC	744 (87%)	5%
	Other	108 (13%)	3%

In the opacity surveys undertaken in February and March of 2002, the observers were instructed to estimate the vintage of the vehicles and classify them in two groups, pre-1990 and 1991 and newer. The data in Table 2-11 indicate that the non-BC vehicles tend to be newer, although the sample size is quite restricted and thus the statistical uncertainty in high. However, this trend would fit with the fact that virtually all the non-BC trucks will be long haul freight and these vehicles are known to be younger. This is illustrated in Figure 2-13 where close to 50 percent of the long haul trucks are less than 5 years old [7]. Note also that the age splits for the BC vehicles were very close to the uncoded (probably mostly locally operating) vehicles in Table 2-9, giving some confidence in the quality of the sampled data.

Table 2-11 2002 Opacity Survey Populations by Age Group and Plate

Plate Jurisdiction	Model Year Group	
	1990 and newer	Pre-1990
February Survey BC	377 (54%)	319 (46%)
Other	10 (72%)	4 (28%)
March Survey	371 (90%)	40 (10%)

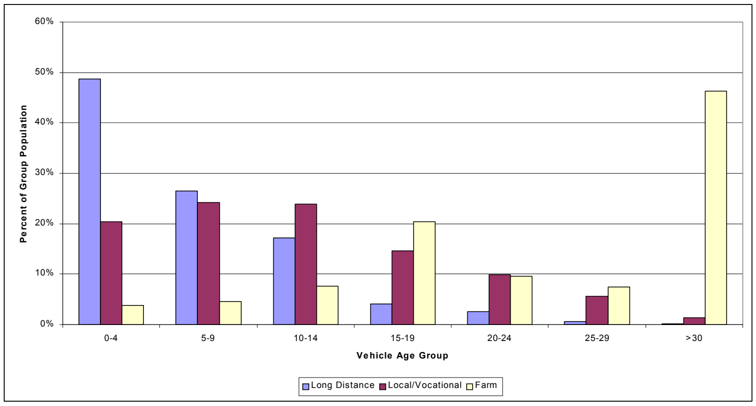

Figure 2-13 All Canada HDV Age Distribution by Usage Group (1998)

Finally, the ACOR test database provides further evidence that the non-BC vehicles tend to be both newer and cleaner. As shown in Table 2-12, of the 1716 inspections undertaken during the program, 98 (6 percent) of these have been of non-BC plated vehicles. Segmenting by enforcement standard, it can be seen that the non-BC vehicles are underrepresented in the pre-1990 group (5 percent) and over-represented in the post 1990 group (11 percent). The failure rate for the newer technology group in the non-BC vehicles is less than half that of the BC vehicles and represents only 1% of the group's total failures. In the older group, the failure rate is 4 percent, compared to the 5 percent of the total fleet that they represented.

Table 2-12 Non-BC Vehicle Enforcement Analysis

Plate Location	Standard for Opacity										Total
	40 Percent					55 Percent					
	Aborted	Fail	Pass	Total	% Fail	Aborted	Fail	Pass	Total	% Fail	
Non BC		3	22	25	12%		52	21	73	71%	98
BC	2	55	149	206	27%	4	840	568	1412	59%	1618
Total	2	58	171	231		4	892	589	1485		1716
Non-BC Percent of Group Total		1%	10%	11%			4%	1%	5%		

In summary, it would appear that the ex-BC vehicles constitute less than 10 percent of the total operating fleet and constitute about 6% of the inspection failures. Their contribution to the VKT and emission in the LFV may well be offset by the external travel of the LFV-registered long haul vehicles. In both sets of vehicles (non-BC and ex-BC), the age distributions are younger than the rest of the LFV fleets and there is evidence that they are cleaner than the average LFV vehicle.

At present, these vehicles, pay no penalty for an infraction nor are they obliged to have a repair undertaken. There is, however, the cost of the delay imposed by the testing and this by itself probably has some deterrent value. However, if it is desired to increase the economic cost of infractions, then a fine in lieu of repair could be levied on these vehicles. The amount of the fine should be significant enough to be “meaningful”, perhaps in the $300 range (equivalent to retest plus a minor repair cost). Allowance of a “buy down” of the fine based on proof of repair and retest should be allowed, as recommended in the Draft Canadian Heavy-duty Vehicle Inspection Code (section 1.0.2).

2.6 Smoking Light Duty Vehicles

While the number of publicly observed heavy-duty vehicles reported on the SMOG line has been decreasing, the incidence of smoking LDV reports has been increasing with an average of 18 calls per month in 2001. Analysis undertaken by ACOR program staff [*8*,*9*,*10*] indicates that

- a significant percentage of the both diesel (18 percent) and non-diesel (48 percent) vehicles reported failed the AirCare inspections;
- approximately 11 percent of reported vehicles are removed from operation (not insured or licenced) within 18 months;
- the problem of smoking LDVs (and non-diesel HDVs) is partly due to the lack of legislation under the BC Motor Vehicle Act which makes it an offence to operate (or permit) a motor vehicle which emits visible smoke or particulates and/or allows ICBC inspectors to inspect and reject vehicles based on the emission of visible particulates.

This oversight in BC Provincial regulations has been identified in prior reviews of the AirCare LDV program [*11*, *12*]. In Stewart’s analysis, he points out that

> *“The Motor Vehicle Act Regulations do not actually prohibit the production of smoke by a vehicle. It only mandates that the engine and exhaust system shall be equipped and adjusted to prevent the escape of excessive fumes or smoke. The test for what is excessive in comparison to other motor vehicles of the same or similar types and sizes. Some types of vehicle do commonly smoke. Diesel vehicles, for example, often smoke in particular circumstances, and the AirCare inspection recognises this by actually measuring the amount of smoke and applying a maximum allowable limit. Vehicles in BC do not usually use two-stroke engines, but basic technology two-strokes do normally smoke. It is common for old high-mileage vehicles to smoke. There are certain fairly common models which almost always smoke once they have accumulated enough mileage. However, the criterion for rejection as currently practised at AirCare inspection centres is that any smoke at all is too much.*
>
> *AirCare does not have any authority to enforce the Motor Vehicle Act Regulations Division 7, Schedule 1, Section 16. This is why a smoking vehicle cannot be given an inspection failure. Non-compliance with Section 16 does not actually make a vehicle untestable. Thus, it cannot justifiably be quoted as a reason for rejecting a vehicle from being inspected.”*

In other jurisdictions, Provincial or State regulations have been put in place which give the capability of prohibiting the operation of vehicles which emit any visible smoke or particulates (see Ontario regulations [i]). Also, Ontario's DriveClean program has a test standard for both LDV and HDV which includes a 5 second limit on any visible exhaust. The lack of regulatory power in BC to fail JDV for smoke alone is an obvious regulatory loophole and one that can be easily fixed through changes to the BC legislation.

The other aspect of the smoking LDV issue is that of the perceived equity of enforcement rigor with trucks. "If trucks can not smoke, why can cars". By starting to enforce smoke limits on LDVs it is likely that both the number of public complaints will decrease and a positive reaction will be received from the trucking industry.

2.7 Public Communications

While no formal public opinion data was collected or analyzed as part of this study, numerous negative comments received from both professionals interviewed as part of the study and from members of the general public, clearly indicated that more information on the existence and performance of the ACOR program would help in instilling a greater amount of public support for the program. There appears to be little consumer information at the AirCare inspection stations about the ACOR program. The addition of informational material (brochures, posters, etc) would be a key addition to help educate the light-duty vehicle owner what part HDV play in the LFV emissions problem and how the ACOR program is an effective and low cost approach to controlling HDV emissions. Similarly, information directed at the trucking community about the effectiveness of the ACOR program should be developed to insure that they both know the facts and the costs of the program.

2.8 Conclusions

1. The program performance data compiled indicate that the ACOR program had a consistent testing level of activity and pre-screening efficiency throughout the program period.
2. The opacity survey data indicated a significant shift over the program period to a lower average opacity level – this shift started during the pilot program and continued through the mandatory program.
3. A large portion of the shift is due the change in vehicle age distributions, however, there appears to be some evidence that indicates that the older pre-1990 vehicles were on average cleaner in 2001 than reported in the pilot program data review [4].
4. Through the use of a malperformance emission model, the current ACOR program is estimated to have reduced total PM air emissions from heavy-duty diesel vehicles by 85 tonnes or 24 percent from where the emissions would have been in the absence of any inspection program.
5. The total 2000 program costs were estimated at $730,000, which includes both the government testing and industry repair costs.

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[i] **Ontario Regulation 361.98 under the Environmental Protection Act -** Visible Emissions

6. (1) No person shall operate or cause or permit the operation of a motor vehicle with a GVWR of 4,500 kg or less from which there is a visible emission for more than 15 seconds in any five minute period. (O. Reg. 86/99 s. 5(1))

6. A cost-effectiveness ratio of $ 312/tonne is estimated based on a damage impact-weighted composite of emission reductions.
7. The program staffing level can be reduced to two inspection personnel, a part-time program co-ordinator and two vehicles. This is only possible if the inspection officers can have special constable status (peace officer) which would avoid the need to have a Commercial Transport Inspector as part of the inspection team. If a CTI was not required, the managerial control the program could then be placed with GVRD or PVTT.
8. It was assessed that the out-of region vehicles tended to be younger and have a lower average smoke opacity than the local operating fleet.
9. There currently is a legislative gap concerning the testing of LDV for smoke. Legislative and regulatory changes should be made to allow for the testing and enforcement of a smoke standard on light duty vehicles.
10. Increased public information should be developed and disseminated on the ACOR program.

3. Vehicle Demographic Analysis

A key component to predicting future emissions is the understanding of the demographics of the vehicle fleet. The forecast builds on the historic information of the total populations, the age and ownership profiles, as well as information on the amount and nature of the vehicle usage. This study was fortunate in being able to access registration data from the Insurance Corporation of British Columbia (ICBC). These databases are especially powerful as they link the vehicles' physical attributes (manufacturer, weight, age, etc.) with the ownership and insured use (body style, owner type, usage code, operating range, etc.). There are few jurisdictions in Canada – and none in the US – where this ownership data is so well cross-linked.

Furthermore, two sets of ICBC registration data were available:

1. A 1998 database of the BC commercial vehicle population that was compiled by ICBC for a Transport Canada study [*13*]. This database contains only vehicles used for commercial purposes and thus excludes personal used light heavy vehicles such as recreational vehicles. The data set contains postal codes, vehicle insurance (use) codes, vehicle age, make, model, fuel type and a special "conditional" code which explicitly identifies vehicles used in government fleets.

2. The 2000 ICBC Lower Fraser Valley (LFV) vehicle in-use data set which was obtained by GVRD. This data set contains similar data variables to the 1998 data with the exclusion of the condition code.

There are a number of selection issues that cause these two data sets to not be exact replicas of each other. Firstly, the 1998 data does not contain personal vehicles. Secondly, the 1998 database was extracted from the full BC file based on a two digit postal code (V2 to V6) which covers a slightly smaller physical area than the LFV region. Even with these discrepancies, the two data sets provided two good cross-sectional pictures of the populations and could validate the penetration of the vehicle types and control technologies by vintage. Additional data was obtained from the GVRD mobile source emission model, which had age distributions for 1995 and from R.L.Polk Ltd. new vehicle registration data for 1990, 2000 and 2001.

Based on the 2000 registration data, there were a total of 37,611 vehicles over 5,000 kg in operation of which 72% were diesel (HDD), 20% gasoline (HDG) and 7% alternate fuelled vehicles (AFV).

3.1 Age Distribution Analysis

The age distribution of the LFV fleet by fuel type was compared among the three cross-sectional data sets (2000, 1998, and 1995) in Figure 3-1. This graph presents the cumulative distributions of the vehicle population by age (i.e., the percentage of the total population that is younger than the given age). It can be seen in the chart that there are two distinct clusters of lines – the upper three lines belong to diesel fuelled vehicles and the lower ones for gasoline fuelled vehicles. For the 1998 and 2000 diesel populations, the age distributions are essentially identical. When compared with the 1985 distribution, the data indicate that the diesel population has been getting younger in the last half of the decade as shown by the shift of the median (50 percentile) from approximately 8.5 years in the 1995 data to 6.5 years in the 2000 data.

The gasoline vehicles are significantly older than the diesel populations and have a large (25 to 35 percent) residual population of over 19 years old. The gasoline vehicles have been, on average, getting older with a shift of the median age from 13 to 13.5 between the 1995 and 2000 data.

By way of comparison, the total Canadian truck population over 4,500 kg is similar to the LFV fleet (over 5,000 kg). The LFV fleet has a slightly older age distribution up to age 12 as is shown in Figure 3-2.

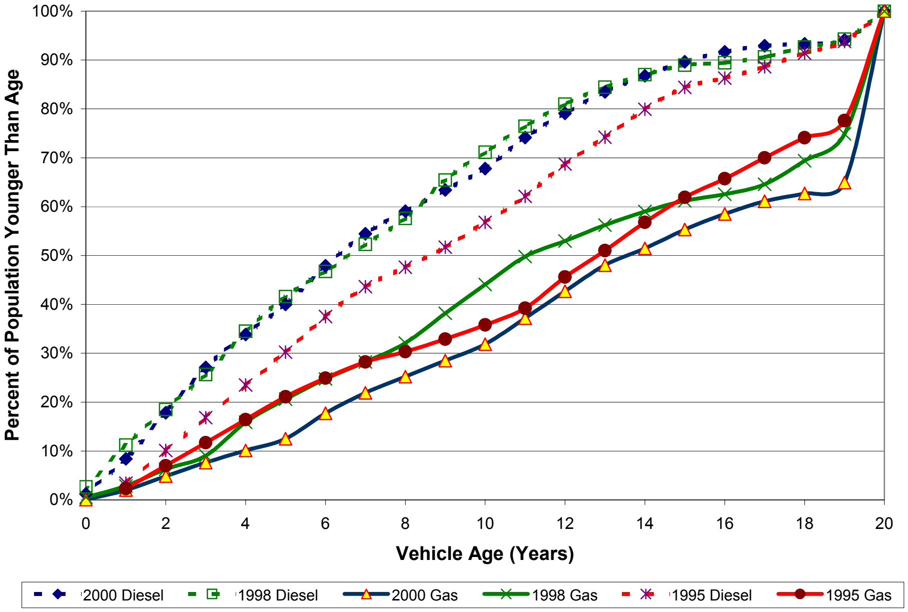

Figure 3-1 Comparative Age Distributions 1995/1998/2000 by Fuel Type

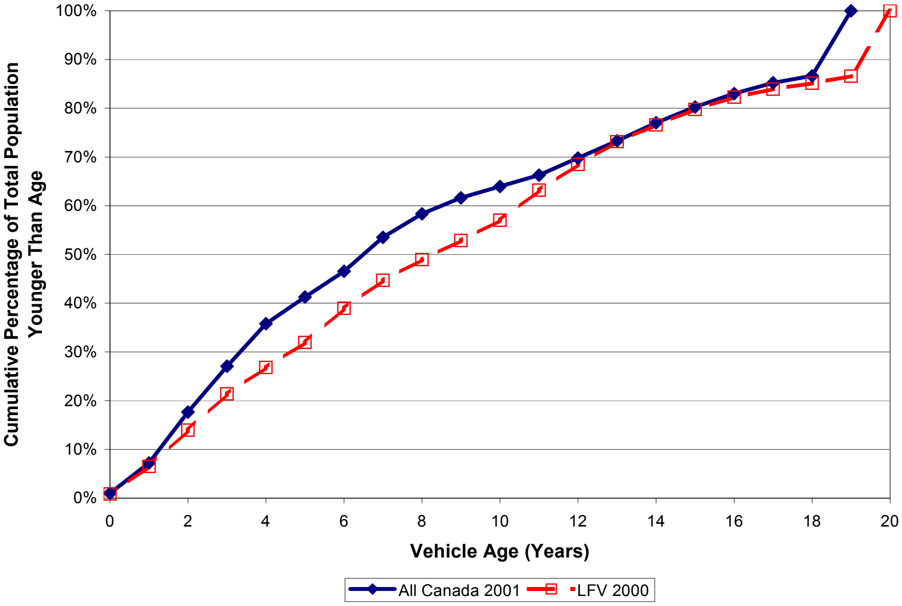

Figure 3-2 Comparison of LFV and All Canada Truck Age Distributions

3.1.1 Age Distributions By Vehicle Gross Weight Categories

The 1998 and 2000 data were also segmented for vehicle Gross Vehicle Weight[i] group. The segmentation was based on the standard weight classification system, shown in Table 3-1.

Table 3-1 Weight Classifications

GVW Class	Weight Limits		Percentage of LFV Population*
	Kg	Lbs.	
3	4537 – 6350	10001 – 14000	14% **
4	6251 – 7257	14001 – 16000	4%
5	7258 – 8845	16001 – 19500	6%
6	8846 – 11793	19501 – 26000	7%
7	11794 – 14969	26001 – 33000	12%
8A	14970 – 23678	33000 – 52200	13%
8B	>23678	>52200	44%

* Note that ICBC registration data records the licenced GVW which may be different from the original manufacturer's rated GVWR
** Vehicle lower weight limit 5,000 kg

Age distribution plots of the three main vehicle weight groups (5-10,000, 10-26,000 and over 26,000 lb. GVW) are presented in Figure 3-3, Figure 3-4, and Figure 3-5 below. They indicate that for diesel fuelled vehicles in classes 5-7 and 8, the age distributions were stable between the two census years (1998 and 2000). The Class 3-4 vehicles grew older between the two census years, with the median age moving from 4.5 to 6 years.

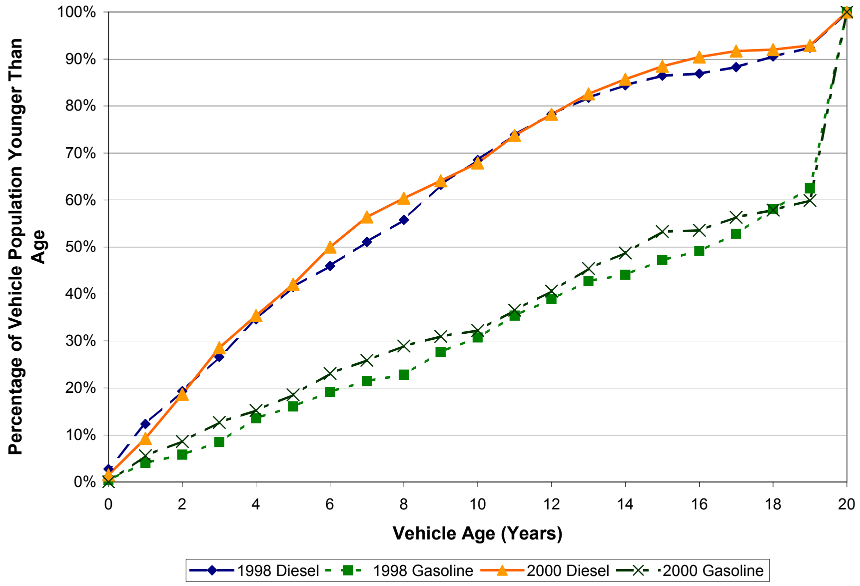

Figure 3-3 Class 8 Vehicle Age Distributions

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[i] Note that the ICBC registration data are based on the registered weight which is different (usually lighter) than the Gross Vehicle Weight maximum designated by the manufacturer.

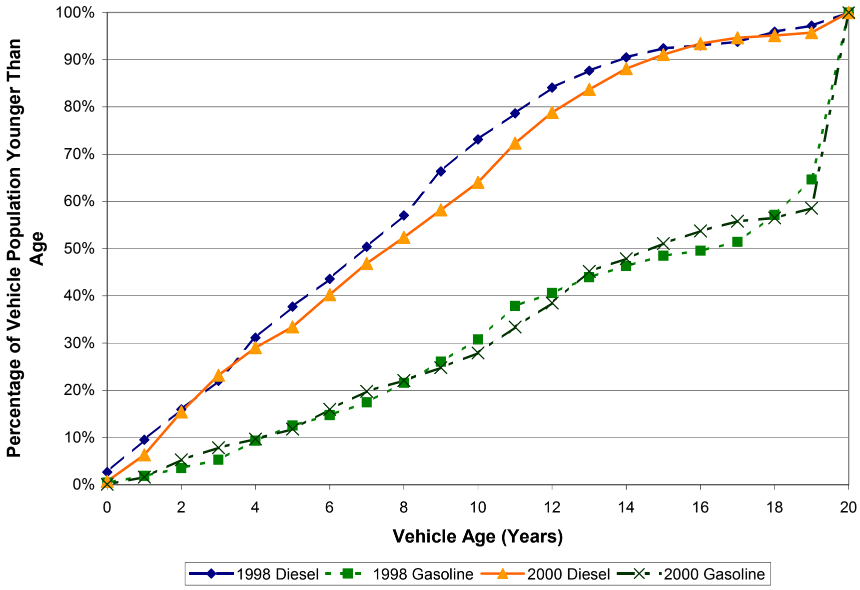

Figure 3-4 Class 5-7 Vehicle Age Distributions

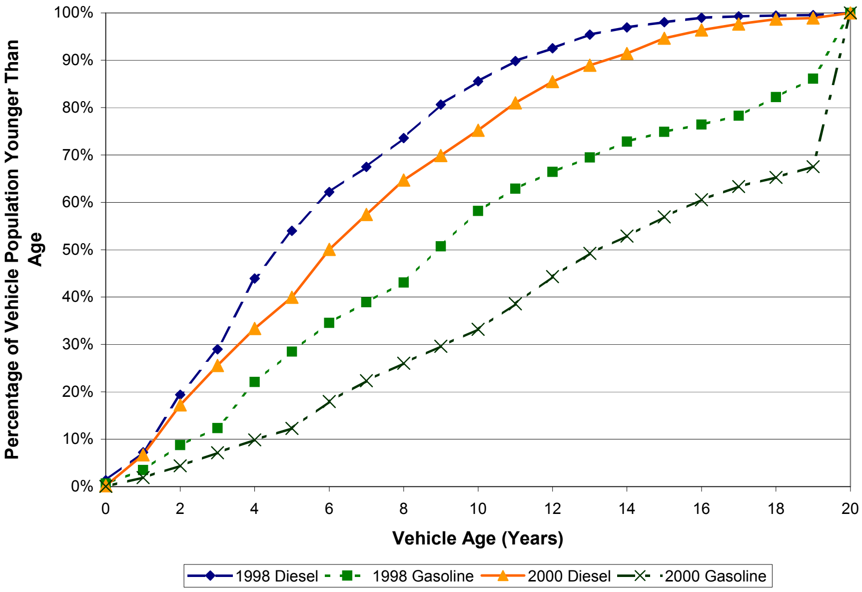

Figure 3-5 Class 3-4 Vehicle Age Distributions

For gasoline fuelled vehicles, there was also little change between the 1998 and 2000 census data for the Class 8 and Class 5-7 vehicles. Note that the gasoline vehicles were substantially older than the diesel group (50th percentiles of 6 and 14 years, respectively, in the 2000 data). The lighter Class 3-4 vehicles showed significant changes with the age distribution going from a median age of 9 in 1998 to 13 years in 2000. The gasoline fuelled age distributions in all size groups were heavily skewed to very old vehicles, with 20 percent of Class 3-4 vehicles and approximately 40 percent of Class 5-7 and 8 vehicles being more than 20 years old in the 2000 census. The old age distributions pose significant problems in achieving rapid changes in the technologies of these vehicles.

3.1.2 Vehicle Ownership and Usage

The 1998 ICBC registration data was also segmented by user type (insured use code and ‘conditional’) and GVW. The results of this segmentation are provided in Table 3-2 by fuel type. For all vehicles, 58% were in delivery or trades/artisan service. 20% were in government, garbage and bus user groups.

Table 3-2 1998 LFV Vehicle Population by User and GVW

(All)	**GVW Weight Class**							
User Type	**Class 3-4**		**Class 5-7**		**Class 8**		**Grand Total**	
Bus	628	11%	656	7%	1492	9%	2776	9%
Cement	1	0%	3	0%	479	3%	483	2%
Delivery	1231	21%	3767	39%	7721	47%	12719	40%
Dump	69	1%	305	3%	2355	14%	2729	8%
Farm/Fish	321	5%	851	9%	511	3%	1683	5%
Garbage	26	0%	101	1%	496	3%	623	2%
Gov't	740	12%	978	10%	1084	7%	2802	9%
Log	0	0%	40	0%	1165	7%	1205	4%
Rental	106	2%	454	5%	135	1%	695	2%
Trade/Artisan	2531	43%	2270	24%	1095	7%	5896	18%
Wreckers	280	5%	186	2%	51	0%	517	2%
Grand Total	5933	100%	9611	100%	16584	1	32128	100%

AFV	**GVW Weight Class**							
User Type	**Class 3-4**		**Class 5-7**		**Class 8**		**Grand Total**	
Bus	177	16%	192	18%	304	53%	673	25%
Cement	0	0%	0	0%	14	2%	14	1%
Delivery	214	20%	364	34%	89	16%	667	24%
Dump	13	1%	41	4%	41	7%	95	3%
Farm/Fish	21	2%	79	7%	21	4%	121	4%
Garbage	6	1%	9	1%	4	1%	19	1%
Gov't	124	11%	120	11%	46	8%	290	11%
Log	0	0%	1	0%	9	2%	10	0%
Rental	0	0%	5	0%	2	0%	7	0%
Trade/Artisan	382	35%	223	21%	43	8%	648	24%
Wreckers	152	14%	31	3%	0	0%	183	7%
Grand Total	1089	100%	1065	100%	573	100%	2727	100%

Gasoline	**GVW Weight Class**							
User Type	**Class 3-4**		**Class 5-7**		**Class 8**		**Grand Total**	
Bus	270	9%	103	4%	17	3%	390	7%
Cement	0	0%	2	0%	16	3%	18	0%
Delivery	486	17%	567	22%	125	24%	1178	20%
Dump	27	1%	98	4%	58	11%	183	3%
Farm/Fish	191	7%	430	17%	78	15%	699	12%
Garbage	7	0%	16	1%	12	2%	35	1%
Gov't	394	14%	369	14%	82	16%	845	14%
Log	0	0%	5	0%	6	1%	11	0%
Rental	49	2%	87	3%	1	0%	137	2%
Trade/Artisan	1433	49%	886	34%	119	23%	2438	41%
Wreckers	49	2%	8	0%	3	1%	60	1%
Grand Total	2906		2571		517		5994	

Diesel	**GVW Weight Class**							
User Type	**Class 3-4**		**Class 5-7**		**Class 8**		**Grand Total**	
Bus	181	9%	361	6%	1171	8%	1713	7%
Cement	1	0%	1	0%	449	3%	451	2%
Delivery	531	27%	2836	47%	7507	48%	10874	46%
Dump	29	1%	166	3%	2256	15%	2451	10%
Farm/Fish	109	6%	342	6%	412	3%	863	4%
Garbage	13	1%	76	1%	480	3%	569	2%
Gov't	222	11%	489	8%	956	6%	1667	7%
Log	0	0%	34	1%	1150	7%	1184	5%
Rental	57	3%	362	6%	132	1%	551	2%
Trade/Artisan	716	37%	1161	19%	933	6%	2810	12%
Wreckers	79	4%	147	2%	48	0%	274	1%
Grand Total	1938	100%	5975	100%	15494	100%	23407	100%

For the diesel fuelled fleet the largest user segment was for delivery (46 percent) followed by trades/artisans at 12 percent. For gasoline vehicles, the largest group was trade/artisan at 41 percent followed by delivery at 20 percent. Note that the total populations were 23,407 and 5,994 for diesel and gasoline respectively.

If bus and garbage fleets are included with the government vehicles, then the total percentage of vehicles under government ownership or control was 16 percent for diesels, 22 percent for gasoline fuelled vehicles, and 20 percent for all vehicle types. This makes the government fleet the second largest sector in both fuel groups. This relatively high percentage of the vehicles in government ownership or control may lead to important control and inspection options for any revised program.

3.2 Fuel Market Penetration Trends

3.2.1 Diesel/Gasoline

The new vehicle sales data from R.L.Polk Ltd. stratifies the vehicle sales by GVW and fuel type as shown in Table 3-3. This data does not explicitly identify vehicles used for commercial purposes, as in the ICBC data. Therefore the 5-10,000 kg weight class populations are expected to contain a large percentage of personal use vehicles, which have proven resistant to accepting diesel technology. The penetration of diesel by GVW class is calculated and shows that its share of the 5-10000 and 10-26,000 kg groups has been increasing – doubling in the light class (7 to 14 percent) and gaining about 4 percent per year in the mid-weight group.

Table 3-3 New HDV Sales in LFV Region by Fuel Type and GVW (kg)

Calendar Year	Gasoline				Diesel				percent Diesel		
	5-10000	10-26000	>26000	Total	5-10000	10-26000	>26000	Total	5-10000	10-26000	>26000
1999	2527	166	0	2693	187	129	214	530	7%	44%	100%
2000	2950	122	0	3072	248	119	250	617	8%	49%	100%
2001	2441	128	0	2569	385	142	143	670	14%	53%	100%

This increase in diesel at the expense of the gasoline population confirms the relative change in the total population from ICBC 1998 to 2000 data in which gasoline vehicles decreased from 20 percent to 15 percent over the two year period. This drop is projected to continue as the old vehicles are removed and the new vehicles continue to have a high proportion of diesels. Using the ICBC data, a historical penetration rate for diesels by age group can be calculated, and the results are provided in Figure 3-6, which shows the steady gain of market share by diesel in all weight categories over the 20 vehicle model years. The complete conversion to diesel is essentially complete in the Class 8 and 5-7, and the trend line would predict that all new Class 3-5 vehicles would be diesel by about 2010.

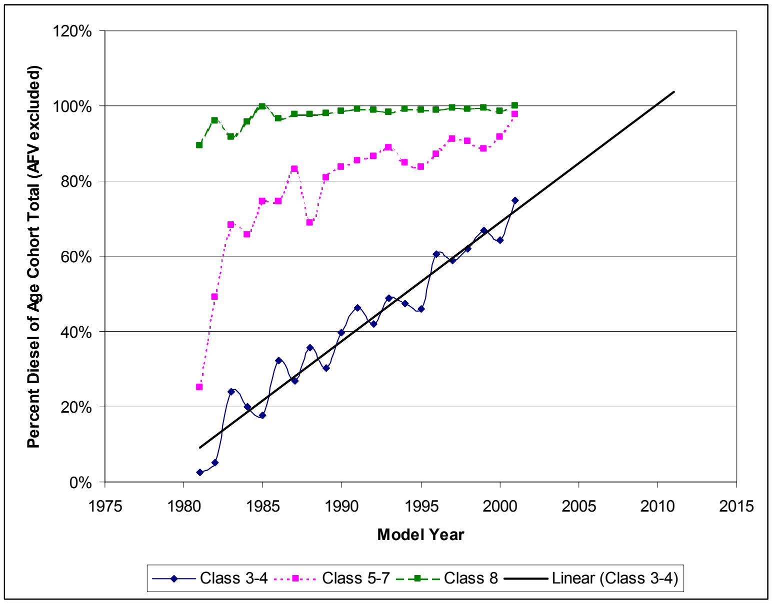

Figure 3-6 Diesel Penetraion Rates by Model Year

3.2.2 Alternate Fuelled Vehicles

From the ICBC registration database, a profile of alternate fuelled vehicles (AFVs)[i] has been constructed. In 1998 and 2000, they constituted 7 percent of the total commercial fleet over 5,000 kg. Table 3-4 provides a summary of the 1998 registration data. Within, the AFV group, the predominant fuel, in all age groups, is propane. Note that all the electric vehicles are a pool of 247 electric transit buses (1983 vintage) operated by Translink. The data also indicates that the age distribution of these vehicles is relatively old, with 78 percent the total 2727 vehicles of 1990 and earlier vintages.

The market share for AFVs by model year is plotted in Figure 3-7 which provides a clear indication of the rapid decline in AFV replacement in the newer model years, with essentially no newer vintage vehicles in any weight class (over 5,000 kg) being an AFV. The high market share in the older age cohorts is indicative of a longer service life for the AFVs – as opposed to a high initial penetration. The 72 percent anomaly in the Class 8 vehicles is the 247 electric buses.

Based on these trends, the forecast is for a continued attrition of the fleet through retirement of the old vehicles with virtually no new vehicle replacement. Thus, AFVs will not be factor in the HDV market in the LFV region. This trend assumes, of course, that new technologies, such as high pressure direct injection natural gas diesel engines, do not reach the commercial stage over the forecast period. The forecast is essentially a business-as-usual trend.

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[i] Theses include propane, natural gas, multi-fuel and electric powered vehicles.

Table 3-4 Alternative Fuel Vehicle Ownership by Usage Group

User	Multi-fuel	Propane	Natural Gas	Electric	(blank)	Total
Bus	1	363	55	247	7	673
Cement		2			12	14
Dump		62	3	1	29	95
Farm/Fish	2	82	2		35	121
Garbage		15	1		3	19
Government	1	201	44	1	43	290
Log		1			9	10
Trade/Artisan	2	542	38		66	648
Wreckers		179	1		3	183
Delivery	2	508	71	1	85	667
Rental					7	7
Total	8	1955	215	250	299	2727

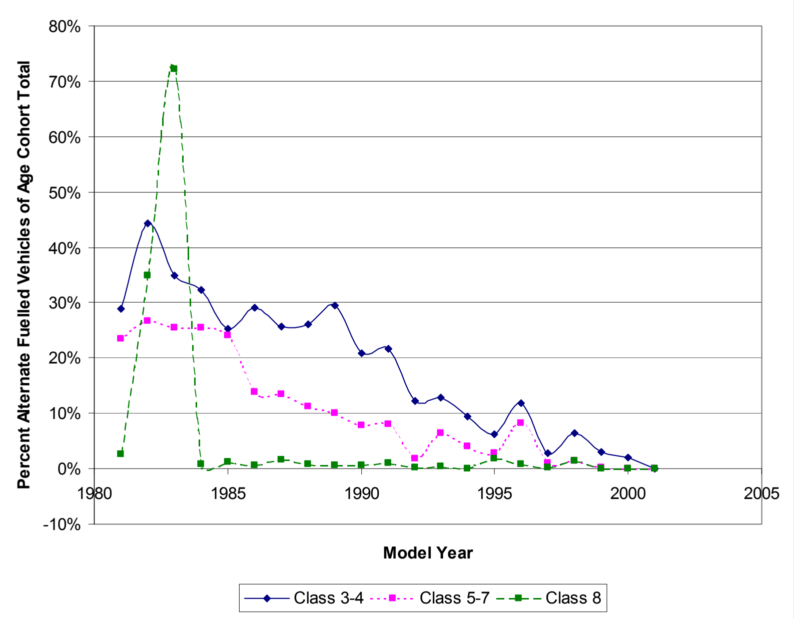

Figure 3-7 AFV Market Share by Model year

3.3 Fleet Size Distributions

The understanding of the concentration of vehicles in fleets is an important program planning variable, as vehicles under centralized management and maintenance control may be more cost-effective targets for emission control tests or outreach programs than those owned by individual owner-operators. The 1998 ICBC registration database contained a fleet identification number that allowed for the aggregation of the vehicles into their respective fleets. This fleet size grouping was done to produce a cumulative histogram of the number of fleets and the number of vehicles as shown in Table 3-5 and Figure 3-8. Note that 45 percent of the vehicles had no fleet number coding, which means that they are owned by individuals.

In Figure 3-8, it is seen that the average fleet size for older pre-1990 vehicles is slightly smaller than the post-1990 vehicles (90 percent of the fleets are under 10 vehicles as compared with 85 percent). When the distribution of the number of vehicles in the fleets is compared, again the older vehicles are concentrated in smaller fleets with 72 percent compared to 55 percent of the vehicles in fleets of 10 vehicles or less. Note that 53 percent and 37 percent of the pre-1991 and post 1990 vehicles respectively were operated by individuals. The preponderance of the older vehicles in small fleets would argue against any “fleet" based compliance program and would lend support to an annual testing requirement at centralized facilities.

Table 3-5 1998 Fleet Size Distribution Data

Fleet Size	# Fleets	% of Fleets	Cumulative % of Fleets	# Vehicles	% of Vehicles	Cumulative % of Vehicles
No Fleet #				14356	45%	45%
1	360	22%	22%	360	1%	46%
2-5	672	41%	63%	2167	7%	53%
6-10	281	17%	80%	2159	7%	59%
11-50	272	17%	96%	5693	18%	77%
51-100	40	2%	99%	2791	9%	86%
101-500	19	1%	100%	3491	11%	97%
101-1000	0	0%	100%	0	0%	97%
>1000	1	0%	100%	1111	3%	100%
Total	1645			32128		
Model Year Less Than 1991						
No Fleet #				8509	53%	53%
1	414	33%	33%	414	3%	55%
2-5	563	45%	78%	1718	11%	66%
6-10	151	12%	90%	1105	7%	73%
11-50	105	8%	99%	2163	13%	86%
51-100	9	1%	99%	548	3%	90%
101-500	7	1%	100%	1030	6%	96%
101-1000	1	0%	100%	639	4%	100%
>1000		0%	100%		0%	100%
Total	1250			16126		
Model Year Greater Than 1990						
No Fleet #				5847	37%	37%
1	366	30%	30%	366	2%	39%
2-5	503	41%	71%	1564	10%	49%
6-10	149	12%	83%	1157	7%	56%
11-50	170	14%	97%	3694	23%	79%
51-100	23	2%	99%	1499	9%	88%
101-500	10	1%	100%	1875	12%	100%
101-1000	0	0%	100%		0%	100%
>1000	0	0%	100%		0%	100%
Total	1221			16002		

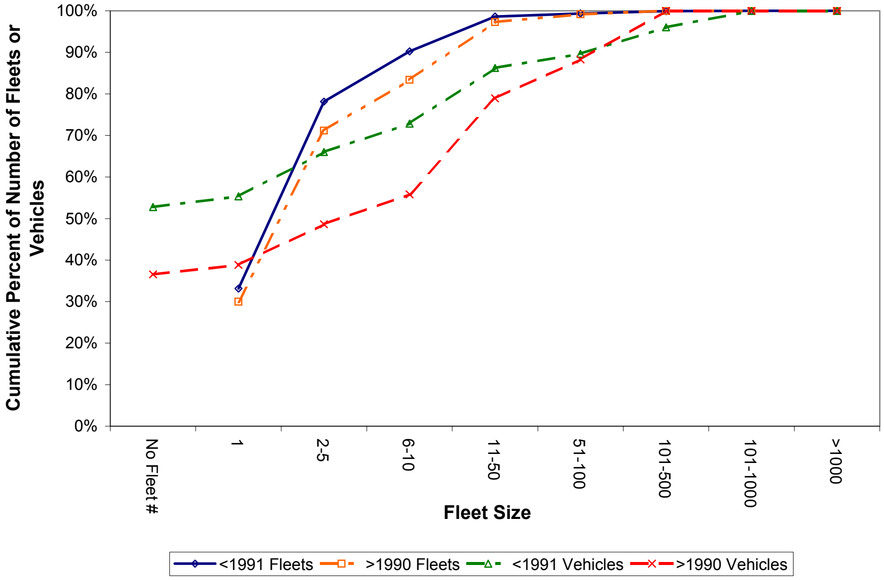

Figure 3-8 Distributions of Fleet Size by Vehicle Age Groups

3.4 Vehicle Population Forecasts

We have selected to use the 2000 ICBC registration data as the current estimate of the total commercial vehicle population (33,092). This is the same data that will be used for the current LFV inventory revision and therefore should provide continuity between the two analyses.

The forecasts of vehicle population and activity for this study are based on the findings contained in the most recent comprehensive review of BC commercial vehicle traffic [*14*]. This extensive study reviewed the economic and demographic factors that will affect commercial vehicle traffic growth in the Province (with segmentation for the LFV region) and recommended the following set of growth factors (Table 3-6).

For the long-term (10 year) commercial vehicle population growth, the commercial traffic study selected an average value of 3.3 percent per year (this is higher than the 2.3 percent per year that it recommended for passenger vehicles). The short-term (5 year) growth rate was estimated at 5.2 percent. Note that with the recent economic slowdown, this value may over-estimate the current short-term growth. The 3.3 percent growth rate for the total commercial vehicle population is used in this study.

Table 3-6 Long Term Growth Trends

Population	
Vancouver CMA	1.69%
British Columbia	1.56%
Average	1.62%
Employment	
British Columbia	1.96%
GDP	
British Columbia	2.28%
Canada	1.83%
U.S.	2.04%
Average	2.05%
Trade - Import growth rate,'(Export growth rate)	
Canada to US	1.70% (1.87%)
Canada to All Countries	3.25% (3.16%)
B.C. to All Countries	N/A (2.67%)
Average	2.53%
Container Traffic	
Container Traffic	7.2%
Border Crossing Traffic	
Commercial Vehicles	4.4%
Highway Network Traffic	
Total Vehicles-Lower Mainland	Approximately 2.511/o-4% (3.25%)
Long Term Commercial Vehicle Growth Rate	3.3%
Long Term Passenger Vehicle Growth Rate	2.3%

3.4.1 Forecast of Vehicle Technology Mix to 2025

The vehicle age distributions are the basis for Table 3-7, which divides the total HDV market by fuel and level of control. The forecast is premised on the relative age distributions remaining stable and similar to the 1998/2000 distributions. It is believed that this is a reasonable assumption for the model although perturbations in the distribution should be expected around the time of major emission standard changes (2002 and 2007). In these years, it is probable that sales of new vehicles may be relatively higher than the year prior to the changes and proportionately lower thereafter. Similarly new sales will fluctuate with current economic conditions. However, over time these are expected to cause only minor changes to the overall age distributions.

For the forecast, the diesel fleet is segmented by age groups which represent mechanically controlled engines (pre-1991), electronically controlled (post-1991) and advanced control systems (post 2007). The Alternate Fuel Vehicle (AFV) fleet has been reduced over time in line with the reduction in new vehicle sales discussed in the non-diesel vehicle section. There is a possibility that the AFV fleet will increase in the latter part of the forecast period (post 2015) if fuel cell technology is proven to be economically attractive, or if other AFV technologies achieve commercial viability during the period. Similarly, it is forecast that gasoline HDVs will gradually be replaced by diesel powered vehicles over the next 10 years.

Table 3-7 Forecast of Engine Technology Groups to 2025

Calendar Year	AFVs	Gasoline	Diesel MY<1991	Diesel MY 1991-2006	Diesel MY>2007
1998	7%	20%	32%	33%	0%
2000	7%	15%	25%	59%	0%
2002	6%	10%	17%	67%	0%
2005	4%	7%	9%	80%	0%
2010	2%	5%	5%	62%	26%
2015	2%	1%	2%	37%	58%
2020	2%	1%	0%	15%	82%
2025	2%	1%	0%	6%	91%

MY - model year

The total population and the percent diesel penetration are plotted in Figure 3-9 and indicate that diesel fuelled vehicles will approach 90 percent by 2015. Further, the total population is forecast to double by the end of the forecast period (2025).

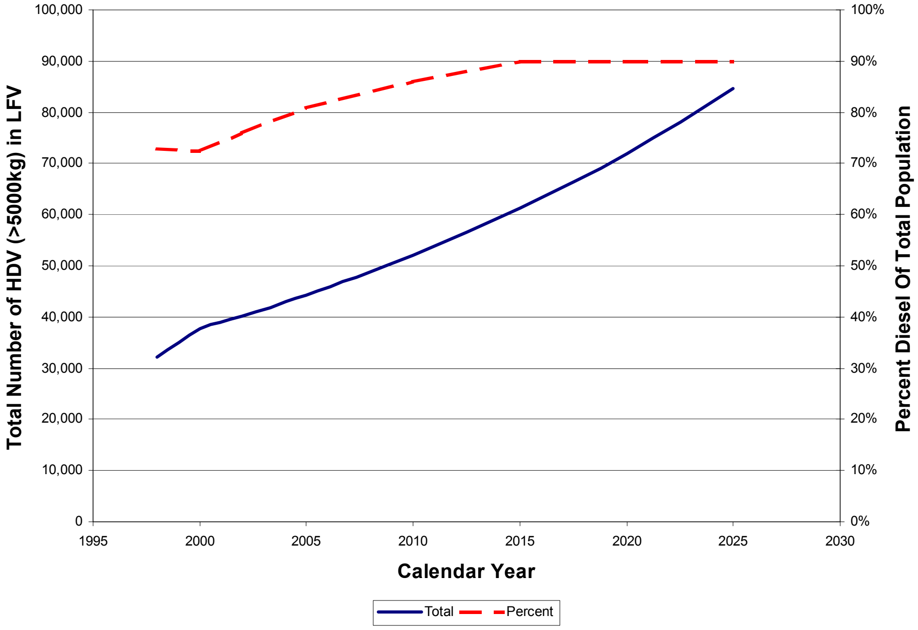

Figure 3-9 Forecast of Heavy Duty (>5,000 kg GVW) Vehicles in the LFV

3.5 Conclusions

The demographic analysis indicates that:

1. Diesel is the predominant fuel for vehicles over 5,000 kg with a 72.5 percent market share. It is forecast to continue its increasing market share reaching 90 percent by the 2015 timeframe.

2. The median age of diesel vehicles in the region is 6.2 years compared to 13.7 for gasoline vehicles. Six percent of the diesel fleet and 25 percent of the gasoline fleet is older than 19 years.

3. The age distributions have been relatively stable since 1998 with the greatest changes occurring in the ageing of the gasoline fleet.

4. The ownership data indicated that 58 percent of the vehicles were in delivery or trades/artisan use with 20 percent owned or controlled by governments (bus, garbage and government).

5. Governments are operating a higher percentage of gasoline and alternate fuel vehicles at 22 percent and 38 percent, respectively.

6. The market is continuing a fairly rapid change to diesel and the market shares of AFVs and gasoline are forecast to diminish to very lower percentages within the next ten years.

7. 45 percent of the vehicles are owned by individuals with a higher percentage (53 percent) of the older than 1991 vehicles individually owned compared to 37 percent of the post-1990 vehicles.

8. 80 percent of the fleets have 10 or less vehicles and contain 59 percent of all the vehicles.

9. The overall HDV population is forecast to grow at an average rate of 3.3 percent, which will result in the population doubling to 80,000 vehicles by 2025.

4. Analysis of Program Options

4.1 Federal HDV Emission Control Programs

In 1959, the California government was the first jurisdiction to control vehicle emissions. In the early 1970's, Canada adopted its first set of vehicle emission standards following the lead of the US Environmental Protection Agency. Since that time, Canada has maintained a close parallel to the US standards. Over the history of control, there have been some differences either due to the regulatory process delays or decisions to wait for control technology to be developed and validated before imposing it on Canadian new vehicle purchasers. However, Canadian standards have generally been the same as the US standards.

Before the vehicle or engine can be sold it must be "certified" by the manufacturer as meeting the emissions standards in force at the time of its manufacture. The standards are defined in terms of the maximum mass of emissions per distance travelled in the case of light-duty vehicles (less than 3,855 kg) or per brake horsepower hour (bhp-hr) in the case of heavy-duty vehicles. The Federal Government regulates the new vehicle emissions while the Provinces have the jurisdiction over in-service vehicles. In Canada, the regulation of new vehicle emissions was originally set out under regulations in the Motor Vehicle Safety Act, which is administered by Transport Canada, with the vehicle emissions components of the Act administered by Environment Canada. Recently, the full responsibility for emission regulations has been transferred to Environment Canada under the Canadian Environmental Protection Act of 1999.

4.1.1 New Vehicle Standards To 2001

The current definition of a compression-ignition (diesel) engine is based on the engine cycle, rather than the ignition mechanism, with the presence of a throttle as an indicator to distinguish between diesel-cycle (compression ignition) and Otto-cycle (spark ignited) operation. Regulating power by controlling the fuel supply in lieu of a throttle corresponds with fuel lean combustion and the diesel-cycle operation (this allows the possibility that a natural gas-fuelled engine equipped with a sparkplug is considered to be a compression-ignition engine).

Heavy-duty vehicles are defined as vehicles of GVW (gross vehicle weight) of above 3,855 kg in the US and Canadian standards. In the US, under the light-duty Tier 2 regulation (phased-in beginning 2004), some vehicles of GVW up to 4,545 kg have been re-classified as "medium-duty passenger vehicles" and are subject to the light-duty vehicle legislation. This will be adopted by Canada.

The emission standards are designed to try to assure compliance with emission standards throughout the "useful life" of the engine. Thus, manufacturers must test engines for durability which was been defined as follows:

- Light Heavy-Duty Diesel Engines - 8 years/176,000 km (whichever occurs first)
- Medium Heavy-Duty Diesel Engines - 8 years/296,000 km
- Heavy Heavy-Duty Diesel Engines - 8 years/464,000 km

Model year 1974-2003 Canadian/US Federal emission standards for heavy-duty diesel truck and bus engines are summarized in Table 4-1. Applicable to the 1994 and following year standards, sulphur content in the certification fuel has been reduced to 500 ppm by weight.

Table 4-1 US/Canada Emission Standards for Heavy-Duty Diesel Engines, g/bhp·hr

Year	HC	CO	NOx	HC+NOx	PM
1974-1978	-	40	-	16	-
1979-1984	-	25	-	10	-
1985-1986	1.3	15.5	10.7	-	-
1987-1989	1.3	15.5	10.7	-	0.60
1990	1.3	15.5	6.0	-	0.60
1991-1993	1.3	15.5	5.0	-	0.25
1994-1997	1.3	15.5	5.0	-	0.10
1998-2003	1.3	15.5	4.0	-	0.10

4.1.2 Upcoming New Vehicle Emission Regulations

In October 1997, EPA adopted new emission standards for model year 2004 and later heavy-duty diesel truck and bus engines. These standards reflect the provisions of the Statement of Principles signed in 1995 by the EPA, California ARB, and the manufacturers of heavy-duty diesel engines. The goal was to reduce NOx emissions from highway heavy-duty engines to levels approximately 2.0 g/bhp·hr beginning in 2004. Manufacturers have the flexibility to certify their engines to one of the two options shown in Table 4-2.

Table 4-2 US Emission Standards for MY 2004 and Later HD Diesel Engines, g/bhp·hr

Option	NMHC + NOx	NMHC
1	2.4	N/A
2	2.5	0.5

All emission standards other than non-methane hydrocarbons (NMHC) and NOx applying to 1998 and later model year heavy-duty engines will continue at their 1998 levels. However, EPA has extended the definition of “useful life” for the heavy-duty diesel engine service class to 696,000 km, 22,000 hours, or 10 years, whichever occurs first, for all pollutants beginning in model year 2004. This should significantly extend the durability of the emissions performance of these vehicles. Note that any maintenance items that are required during this “useful life” to achieve certification will be covered under warrantee and thus should have no charge to the operator.

Canadian standards are in the process of being harmonised with the US federal standards and the intent of the Canadian government is to maintain harmonised standards into the future. In advance of this full harmonization, the Canadian government has negotiated a Memorandum of Understanding (MOU) with the vehicle manufacturers to sell the same engines as in the US regardless of the legal standards. This will mean that vehicles sold in Canada in the 2002 – 2004 Consent Decree period (see next section) will be the same as the U.S. vehicles[i].

4.1.3 Consent Decree

In October 1998, a court settlement was reached between the EPA, Department of Justice, California ARB and engine manufacturers (Caterpillar, Cummins, Detroit Diesel, Volvo, Mack Trucks/Renault and Navistar) over the issue of high NOx emissions from heavy-duty diesel engines during certain driving modes. Since the early 1990s, the manufacturers used engine control software that caused engines to switch to a more fuel-efficient (but higher NOx) driving

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[i] More information on the agreements can be found at http://www.ec.gc.ca/air/engines_e.htm

mode during steady highway cruising. The EPA considered this engine control strategy an illegal “emission defeat device”.

Provisions of the Consent Decree included the following:

- Civil penalties for engine manufacturers and requirements to allocate funds for pollution research
- Upgrading existing engines to lower NOx emissions
- Certification of engines on both the transient FTP and the Supplemental Steady-State Test
- Meeting the 2004 emission standards by October 2002, 15 months ahead of time.

Additional emission testing requirements, introduced in 1998 for parties to the Consent Decree and that are part of the 2004 and later standards, include the following:

1. The Supplemental Steady-State Test was introduced to help ensure that heavy-duty engine emissions are controlled during steady-state type driving, such as a line-haul truck operating on a freeway. The test is identical to the EU 13-mode ESC schedule (in the US commonly referred to as the “Euro III” cycle). The supplemental steady-state test has the same numerical emission limits as the FTP standards.
2. The NTE (“not to exceed”) limits have been introduced as an additional instrument to make sure that heavy-duty engine emissions are controlled over the full range of speed and load combinations commonly experienced in use. The NTE approach establishes an area (the “NTE zone”) under the torque curve of an engine where emissions must not exceed a specified value for any of the regulated pollutants.

The NTE test procedure does not involve a specific driving cycle of any specific length (mileage or time). Rather it involves driving of any type that could occur within the bounds of the NTE control area, including operation under steady-state or transient conditions and under varying ambient conditions. Emissions are averaged over a minimum time of thirty seconds and then compared to the applicable NTE emission limits. Under the EPA proposal, the specified value under which emissions must remain is 1.25 times the FTP standards. Note that this provision is currently in litigation between the companies and EPA.

4.1.4 Model Year 2007 and Later

On December 21, 2000 the EPA issued their final rulemaking on emission standards for model year 2007 and later heavy-duty highway engines. The proposed standards were signed into effect in December 2000.

The new rules include two components:

- diesel fuel regulation and
- emission standards.

The fuel regulation limits the sulphur content in on-highway diesel fuel to 15 ppm by weight, down from the previous 500 ppm. The fuel provisions would go into effect in June 2006. This ultra-low sulphur diesel fuel is seen as a “technology enabler” to pave the way for advanced, sulphurintolerant exhaust emission control technologies, such as diesel particulate filters and deNOx catalysts, which will be necessary to meet the 2007 emission standards.

The second part of the new standards introduces new, very stringent emission standards. The new particulate matter (PM) emission standard of 0.01 g/bhp-hr is to take full effect in the 2007 heavy-duty engine model year. As well, the new rules have reduced standards for NOx and non-methane hydrocarbons (NMHC) to 0.20 g/bhp-hr and 0.14 g/bhp-hr, respectively. These NOx and NMHC standards would be phased in for diesel engines between 2007 and 2010. The phase-in would be on a percent-of-sales basis:

- 25 percent in 2007,
- 50 percent in 2008,
- 75 percent in 2009, and
- 100 percent in 2010.

The EPA has also imposed a formaldehyde emission standard of 0.016 g/bhp-hr to assure that this gas is not emitted when the expected shift to catalyst exhaust after-treatment occurs in the next decade.

The combine effect of these future standards should be a dramatic reduction in the emissions of HDVs and an increase in the durability and reliability of the control systems in-use. The levels of emissions will be, in some cases, on the margin of measurability and certainly well below any simple inspection technique such as smoke opacity.

4.1.5 Fuel Sulphur Standards

National level fuel standards are set by Environment Canada. A Notice of Intent (NOI) was published by the federal Minister of Environment (Feb 2001) that sets out the federal agenda on cleaner vehicles, engines and fuels for next decade. Overall, the policy is to align with U.S. requirements.

> *"Environment Canada plans to continue its approach of generally aligning Canadian environmental fuel requirements with those of the U.S., while taking into consideration environmental standards developed by the European Union. There may be instances, however, where Canada takes additional action to protect the health of Canadians and the environment."*

Specifically, with respect to sulphur in on-road diesel the NOI states the intention to "align with the final U.S. level and timing". A 15 ppm limit starting June 1, 2006 was proposed in the Canada Gazette I (Dec/01) and Environment Canada is targeting Gazette II for summer / fall 2002 with no substantive changes from the proposal expected.

The introduction of low sulphur will result in immediate reductions in PM and SOx from all HDV vehicles in the LFV. Current estimates are that the average emission rate for PM will decrease by approximately 6-7 percent directly due to the fuel change. This factor has been integrated into the emission forecast model.

4.2 Future Emission Control Technologies

Over the course of the last decade, engines have dramatically improved in their emissions levels and durability. This has been the result of internal changes to the engine, with the use of higher precision parts, reduction in oil loss, and higher fuel injection pressures. Enabling much of the progress in emission control is the large increase in the use of electronic sensors and controls.

Through the next ten years even more dramatic changes can be expected. Starting in the fall of 2002, the Consent Decree standards will almost certainly require the use of exhaust gas recirculation. The requirement for low (15ppm) sulphur fuel in 2006 will make a cause a significant drop in particulate emissions for any vehicle using the fuel. With the further drop in allowable emissions in 2007, the use of aftertreatment devices will come into standard use. These devices will control both particulate emissions with the use of particulates traps and NOx through in-cylinder combustion control, 3-way catalysts, and the use of selective reaction catalysts that use a urea injection system to create a reductive atmosphere in the muffler.

The use of aftertreatment systems that require special fuels to operate correctly is highly reminiscent of the introduction of catalytic converters and unleaded fuel in the light duty gasoline fleet in the 1970's. Many of the same problems encountered then should be anticipated to occur with the HDV fleet beyond 2007. These problems include:

- Tampering and removal of the aftertreatment systems;
- Use of incorrect fuels (non-road fuel oil);
- Disablement or mal-maintenance of urea injector systems.

Thus, the need for an in-use inspection system will increase in the latter part of this decade as these systems become more complex and vulnerable to tampering. On the positive side there are strong initiatives within the standards which will require the increased use and accuracy of on-board diagnostic systems, which can provide warning to the operator or the inspection agency of system malfunction or tampering.

4.3 In-Use Emission Performance Measurement Options

Emissions inspection procedures for heavy-duty trucks can be broadly divided into two categories. The first includes any type of emissions test that can directly identify high smoke or gaseous pollutant emitters. The second includes component inspection that verifies that all critical diesel engine components are present and not malperforming. This second type of test can introduce a degree of subjectivity in determining if a specific component passes or fails inspection, whereas the emissions test procedures can be based on objective criteria. Both types of tests are examined in this section.

In-use emissions tests for diesel engines have historically concentrated on smoke emissions for two reasons:

1. excessive smoke is itself an emissions problem that requires attention, and
2. excessive smoke is a good indicator that some component or components in the engine are malperforming.

In contrast, gaseous emissions of HC, CO and NOx from diesel engines have not received much attention. This is partly due to the fact that the pollutant concentrations (not the total quantity emitted) in exhaust are low, since diesel combustion occurs at lean air-fuel ratios. In addition, the concentrations can vary significantly between engines which are operating properly, depending on the operating air-fuel ratio that the manufacturer has chosen. Emission tests designed to mimic or correlate with the engine certification test have been developed in Europe and Australia [*15*], but these tests are difficult to conduct in the context of an emissions inspection program with any significant throughput of trucks. The tests also require the use of a large chassis dynamometer, which is typically quite expensive. This report focuses on the less expensive smoke-based inspection options.

Smoke emissions are generally measured in terms of opacity, which is simply the percent of light blocked by the smoke plume. A variety of smoke measurement instruments exist, and a correlation of their measured opacity values suggests that some of these instruments can be used reliably with proper adjustment of pass/fail criteria.

The heavy-duty diesel truck inspection test procedure must have specified methods for:

- Measurement of smoke opacity
- Test cycle which the engine must follow
- Pass/fail criteria for smoke
- Visual inspection for tampering, if applicable, and pass/fail criteria

The detailed specification of these four items provides the inspection procedure that can be used by inspectors in the field. Selection of appropriate procedures must consider the levels of test and measurement accuracy that are feasible, operational problems to be overcome in the field, and the minimization of errors of commission and omission. In particular, issues of comparability of the recommended test procedure(s) and the US Federal smoke certification cycle, as well as the comparability to the Federal Standards are important when selecting the field inspection option. A detailed discussion of these issues is provided in Appendix B.

4.3.1 Canadian Heavy-duty Inspection Maintenance Code of Practice

The Provinces, in conjunction with Environment Canada, have been developing a recommended code of practice for heavy-duty vehicle I/M programs [5] which outlines program design options. Also contained in the code are recommendations and suggestions on operational issues including quality control, fees and fines, testing conditions, and records and reporting.

The ACOR design of a vehicle pre-selection based on random roadside estimation of visible emissions followed by a J1667 smoke test meets the “minimum requirement” suggested by the Code. Other program design choices mentioned in the code but not included in the current ACOR program are listed below.

Inspection Location/Period:	Mandatory periodic (annual) testing at either at centralized or decentralized inspection centres.
Included population	Non-diesel vehicles
Inspection Test:	Two speed idle test for non-diesel vehicles Dynamometer-based tests for smoke and gaseous emissions either steady-state, lug-down or transient loaded-mode On-board Diagnostic Links – not presently available Remote sensing – not presently fully developed

The code does not contain any cost-effectiveness analysis of the various program designs and makes no recommendations on which of the options offer the best level of compliance. It do recommend the use of the 40/55 standards for the J1667 test but notes that there are no currently accepted common standards for the dynamometer-based tests.

4.3.2 Inspection Tests Evaluated

Based on the analysis of the optional testing protocols, this study developed estimates for the emission reduction effectiveness of the following two testing options:

Random Inspection Based on SAE 1667

This is continuation of the current program but with modifications to the failure standards, organizational and enforcement structures to increase the capture rate and decrease the program costs. Also, it is probable that the addition of some minor – but emission significant – physical inspections for failed or tampered components could be a cost-effective addition to the program.

Annual Inspection Using A Lug Down Test On A Dynamometer

The use of dynamometers to load up the engine while checking for opacity is in use in a number of US and European jurisdictions. The test is capable of assessing emission faults beyond those of the SAE 1667 test and thus can increase the total reduction of emissions of PM and NOx. This test option would require the certification of local diesel dealers that have appropriate dynamometers or the installation of the dynamometers at AirCare stations or some other contractor operated sites.

4.4 Emission Calculation Methodology

The methodology to evaluate the emission benefits of the inspection program for HDDV relies on the malperformance model originally developed for ARB in 1986 by Radian Corporation [*16*]. The model was updated by Energy & Environmental Analysis Inc. (EEA) during the 1990s, and has been validated on a limited basis for pre-1994 engines by EEA. No validation has been attempted on 1994 and later engines' emissions, since there is very little in-use emissions data from such engines. The malperformance model is required for two reasons:

1. The EPA MOBILE5A, 5C and 6 models all assume zero deterioration of emissions for most modern HDD engines, thereby implying no benefit for I/M.

2. The links between emissions, malperformance and inspection are direct in the Radian model.

Emission increases from diesel engines, with age or mileage, are associated primarily with a range of component malperformances. This implies that a well-maintained engine should have near zero emissions deterioration over its useful life, and this implication has been confirmed using certification data from engine durability tests. This result will remain true as long as engines do not utilize high efficiency aftertreatment devices, such as catalysts, which lose emission conversion efficiency with age. To date, very few HDD engines employ any aftertreatment devices (some have low efficiency oxidation catalysts to reduce PM by about 20 to 30 percent), and this is likely to be the case to at least 2008. As a result, the basic premise of the model is correct for the near term to 2008.

4.4.1 Malperformance Concept

The Radian model has a comprehensive list of malperformances that has been developed using direct repair evidence from ARB repair studies, and by consultation with engine manufacturers. The rate at which they occur is based on the ARB repair studies and is designated as r_k for each malperformance type, k. Each malperformance type has an effect on the emissions of pollutant i, that is labelled ΔE_{ik}, which represents the incremental emission effect (either as a percent of baseline emissions or as an absolute number) due to the presence of malperformance type k. The values of ΔE_{ik} utilized have been derived from data generated by testing engines with intentionally induced malperformances, and from data on in-use engines tested, diagnosed, repaired and retested.

Hence the excess emissions are given by

$$\Delta E_i = \Sigma\, r_k \cdot \Delta E_{ik.}$$

The Radian model data on malperformance types, rates of occurrence and emission increases is documented in Appendix C as a series of three spreadsheets, for light-heavy, medium-heavy and heavy-heavy-duty engines, and ΔE_{ik} is reported as a percent increase in emissions from the zero-mile level. Here, the rates (r_k) of malperformance are fleet averages, and are associated with the rate at the mid-point of a vehicle's useful life. The useful life estimates are about 180,000 miles for light-heavy engines, 300,000 miles for medium-heavy engines, and 500,000 miles for heavy-heavy-duty engines. Using the VMT weights implied in MOBILE5A, the average mid-point of the useful life is 190,000 miles for the fleet.

The Radian model directly indicates the percentage increase in emissions at the mid-point of HDDV useful life, and it is assumed that the deterioration occurs linearly with mileage, as is common in all EPA emission inventory models. The impact of inspection and repair is modelled as a reduction in the rate of occurrence (r_k) of malperformances. This reduction is calculated from the malperformance identification rate, which is a function of the test and standard used, and a repair rate that represents the percent of properly repaired vehicles.

The identification rate of each malperformance has been developed in earlier studies by EEA for the California Bureau of Automotive Repair at only one cutpoint (55 percent opacity for the J1667 test, and 15 percent opacity for the lug-down test). These rates are scaled by the observed failure rate at different cutpoints from the opacity distribution curves of the random sample of trucks taken in the GVRD, to obtain rates for any arbitrary set of cutpoints. It should be noted that there are several assumptions required to complete the calculations of emission benefits.

4.4.2 Malperformance Rates

The Radian model base rates of occurrence of malperformances are for a "no I/M program" situation. The presence of any type of enforced I/M has a deterrent effect that leads to better maintenance and less tampering (this effect is likely independent of test type and standard). Studies conducted in California before and after the introduction of their Heavy-Duty Vehicle Inspection Program indicated that deterrence effects reduced malperformances (and failure rates) by one-third, and this 33 percent reduction has probably already occurred in Vancouver. However, all calculations of benefits are referenced to a "no I/M program" baseline, so that all comparisons are consistent.

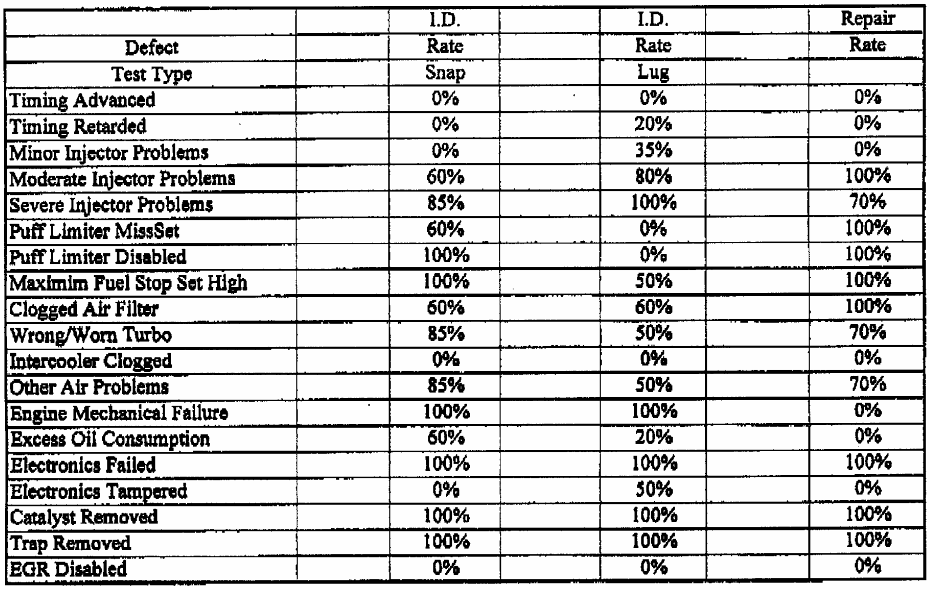
The baseline estimates of "excess" emissions using the Radian Model are obtained directly from the detailed spreadsheets in Appendix C. Actual inputs for the VMT weighted "all years" calculations require absolute emission rates and mileage accumulation rates (MAR) by model year. The "zero-mile" emission rates are derived from EPA's MOBILE5A model, while the absolute deterioration in grams/mile per 10k mile is derived from the percentage values in the detailed spreadsheets. Typically, the MOBILE5A model understates HDD NOx emissions by about 12 percent, HC emissions by 70 percent and PM emissions by over 100 percent. Although the PM excess emissions percentage appears very large, it should be noted that in 2005, the vast majority of engines in the fleet would be required to meet very low certification of standards of 0.1

g/bhp-hr, which is 80+ percent below pre-1991 engine-out emission levels. Hence, absolute increases in PM are still quite small.

As noted, a detailed analysis of the lug-down test and snap test capability to identify malperformances at the California cutpoints (55/40 percent) for the J1667 test and at the 15 percent cutpoint for lug-down test has been conducted by EEA for the Bureau of Automotive Repair. The results of that study are summarized in Table 4-3, which shows malperformance identification rates by malperformance type for the two test types. Repair rates are derived from the repair studies conducted by ARB, and are limited by the US$1,500 cost ceiling. As a result, repair of serious injector problems and replacement of turbochargers do not occur on some fraction of the fleet due to the costs exceeding the ceiling, while engine failures requiring rebuild (a US$4,000 to US$6,000 repair) do not occur at all as a result of I/M.

The identification and repair rates for malperformances are input into the Radian model to estimate excess emissions in the presence of an I/M program, where all vehicles are inspected and repaired as necessary (i.e., 100 percent compliance). The analysis also accounts for the deterrence effect of an I/M program, by assuming that malperformances occur at a rate 33 percent lower than the rates presented in Appendix C. The emissions benefits of the deterrent effect is estimated by zeroing out one-third of the malperformances, since these malperformances never happen in the first place, and are an important contributor to overall I/M program benefits. The net benefits of I/M are computed by examining these results relative to the “no-I/M” baseline.

Table 4-3 Defect Identification and Repair Rates



Defect		I.D. Rate		I.D. Rate		Repair Rate
Test Type		Snap		Lug		
Timing Advanced		0%		0%		0%
Timing Retarded		0%		20%		0%
Minor Injector Problems		0%		35%		0%
Moderate Injector Problems		60%		80%		100%
Severe Injector Problems		85%		100%		70%
Puff Limiter MissSet		60%		0%		100%
Puff Limiter Disabled		100%		0%		100%
Maximim Fuel Stop Set High		100%		50%		100%
Clogged Air Filter		60%		60%		100%
Wrong/Worn Turbo		85%		50%		70%
Intercooler Clogged		0%		0%		0%
Other Air Problems		85%		50%		70%
Engine Mechanical Failure		100%		100%		0%
Excess Oil Consumption		60%		20%		0%
Electronics Failed		100%		100%		100%
Electronics Tampered		0%		50%		0%
Catalyst Removed		100%		100%		100%
Trap Removed		100%		100%		100%
EGR Disabled		0%		0%		0%

Since 1994, the majority of engines in the heavy-heavy fleet utilize electronic fuel injection control, and this has extended to the medium-heavy and light-heavy engines since 1998. Hence, many malperformances such as the mis-setting or disconnection of the puff-limiter and maladjustment of the maximum fuel stop are no longer possible, and are set to zero malperformance rates (or very low levels for the few remaining mechanical systems). In addition, engines and injectors are becoming more reliable due to advances in materials technology and manufacturing. Based on anecdotal estimates from the manufacturers, we have reduced the malperformance rate by 50 percent for specific malperformances in the post-1993 period relative to pre-1994 malperformance rates.

New technologies to reduce emissions in the 2002-2007 and 2008+ time frames are primarily related to EGR and to NOx catalyst/PM traps, respectively. Obviously no data is available to estimate malperformance rates for such technologies in a “no-I/M” situation, and we have utilized a three-percent malperformance rate, similar to that observed for electronics tampering now. The baseline malperformance rates are coupled to estimates of emission increase due to failure or removal, based on known technology efficiency factors. For example, PM traps will have a PM trapping efficiency of 90 percent, so that their removal will cause PM emissions to increase by 900 percent.

Based on these factors, we estimated that excess NOx, HC and PM emissions will decrease on a percentage basis until aftertreatment technology is introduced. The large percentage increase in emissions associated with disablement of aftertreatment systems cause the excess emission estimates to increase sharply in percentage terms in the post-2007 time frame, but absolute excess emissions will still decline due to the high efficiency of aftertreatment.

I/M program effects are modelled based on the ability of specific test/cut point combinations to identify malperformances. Again, these data are based on studies conducted for the ARB in the early-to-mid-1990s, and their application to newer trucks is based on technology similarity. Failures of EGR, particulate traps and NOx catalysts are relatively easy to detect due to the large increase in tailpipe emissions relative to a well-maintained vehicle’s emissions.

The I/M test scenarios are based on stable programs after the initial high failure rate phase is complete. A key assumption is that any I/M program that has a high probability (perceived) of detecting a vehicle with malperformances will result in a deterrent effect. Again, based on studies conducted in California in the mid-1990s, we assume that a third of all malperformances disappear due to improved maintenance, within two years of program inception. This is the source of significant benefits that is assumed to be unrelated to the specific test employed or the pass/fail criteria used.

4.5 Standards For Pass/Fail On The Snap Test

The setting of pass/fail cutpoints on the snap test for smoke opacity relies on the standard methodology of maximizing detection of high emitters while minimizing errors of commission. In the case of the snap test, the results are linked only through malperformances, not gaseous or particulate emissions. In other words, an error of commission is defined as a vehicle failing a given cutpoint with no detectable malperformances, or a vehicle that cannot be properly repaired to a smoke opacity level below the cutpoint.

In addition, the EPA has a peak smoke standard on the EPA smoke test that has (unfortunately) not been revised since the early 1970s. While there is not an exact correlation between the peak smoke as measured on the certification smoke test to the SAE J1667 smoke opacity value, the J1667 value is typically within 5 opacity points of the EPA test, based on work done for the ARB in the early 1990s. The EPA peak smoke standard is set at 50 percent opacity, and this has caused truck owners to argue that in-use standards more stringent than the certification standard, and that this is unfair.

However, most modern engines have actual certification levels well below the 50 percent standard. Even for 1980 – 1990 engines, median certification levels were in the 25 to 30 percent opacity range, but several engine models including some relatively popular ones were certified at levels in the 40 to 45 percent opacity range. The California 55 percent opacity cutpoint was set to account for the fact that not all engines within a model line are identical (production variance) and that there is some variation between J1667 smoke and the EPA test cycle smoke tests. In addition, repairs performed on 80 trucks that failed the J1667 test showed that three continued to have smoke levels of 45 to 50 percent after multiple repairs. Hence, the 55 percent cutpoint was set as the limit to prevent excessive errors of commission.

No similar detailed repair studies of post-1990 trucks have been conducted for an analysis of errors of commission and omission. However, peak smoke on the certification cycle for 1991 – 1993 engines declined to a median value of 15 to 18 percent opacity. Peak smoke values for 1994 and later engines have declined to a median value of about 10 to 11 percent opacity.

Detailed analysis of certification smoke data revealed that the distribution of certification smoke values is close to the expected log-normal shape. Figure 4-1 shows the distribution of certification peak smoke for model year 2000 heavy-duty engines, with each certification value counted as a data point without sales weighting. It is noteworthy that a large number of certification values of over 30 percent opacity are observed. Detailed examination of the engines reporting certification values over 30 percent opacity revealed that, with only two exceptions, they are engine models that continue to offer mechanically controlled fuel injection systems, and virtually all are low sales volume, medium-heavy or light-heavy diesels. (Many are also offered with electronic fuel injection as an option.) We have not been able to obtain detailed sales data at the certification family level, but anecdotal data from engine manufacturers supports the likelihood that these engines account for less than ten percent of the on-highway truck fleet from the 2000 model year (estimates ranged from four to seven percent).

Hence, a considerably more stringent snap smoke standard is possible if some exemptions are granted for specific low sales volume engine models. ARB has followed this approach in setting the 40 percent standard, by providing exemptions to certain engine lines incapable of meeting the post-1990 standard of 40 percent.

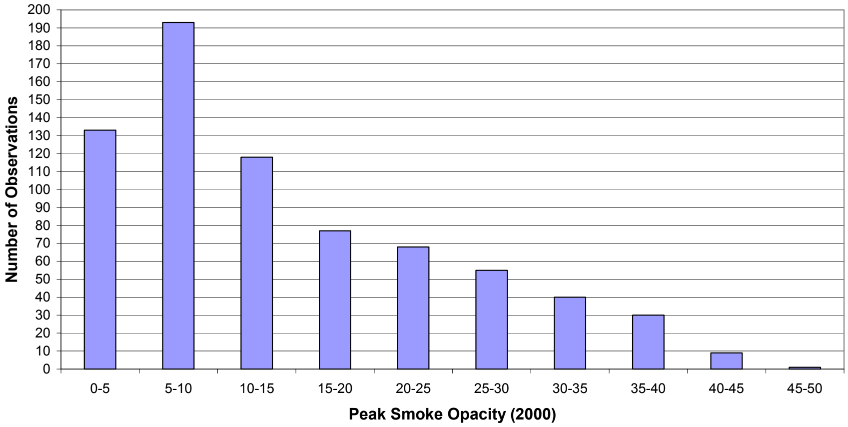


Figure 4-1 2000 EPA Certification Smoke Test Data

In the absence of hard data on errors of commission and omission, the testing approach has been to set a standard at twice the median certification level, rounded upwards to the nearest five percent opacity. The current median levels of 11 percent opacity suggests a standard on the snap of 25 percent; of course, exemptions may have to be provided for most engines with mechanically controlled fuel injection systems where the existing standards of 40/55 can be maintained. We believe that these exemptions would have a minimal effect on compliance since the affected market share is so low.

More detailed analysis presented in the Appendix B shows that much of the benefit from I/M is from older, pre-1988 trucks. Tightening the cutpoint may fail more trucks but will significantly increase the error of commission rate, and is also subject to challenge by truck owners in court

In this analysis, three cases were modelled:

1. The continuation of the current program, using the same cut points (55 percent and 40 percent);

2. a program resembling the current program but with a more stringent cutpoint (25 percent) for 1994 and later vehicles; and

3. a program with both the snap and lug down tests. In the lug down test, both smoke and gaseous emissions would be measured.

The assumed cutpoints are:

Snap	55%	Pre-1990 engines
	40%	1991-1993 engines
	25%	1994+ engines
Lug Down	15%	Pre-1990 engines
	10%	1991-1993 engines
	7%	1994+ engines

In addition, we have used an assumed NOx emissions cutpoint that is currently unspecified, but the very good correlation of NOx measured on the EPA transient test and the lug down test suggests that a cut point with good discrimination could be developed.

4.6 Program Effects on Emission Rates

Analyses of the reductions show that even a “snap test only” program has some NOx emissions benefit due to the deterrence effect. Excess NOx emissions range from 9.5 percent for the pre-1988 fleet to 4.2 percent for the 1994-2001 fleet, increasing to 23.2 percent of the post-2007 fleet. Even a snap only program reduces the excess emissions by one-third from the deterrence effect, and a little higher in the future due to the fact that the snap test can detect some fraction of catalyst malperformances.

NOx benefits with the lug down test are very high due the capability of the test to detect most high NOx emitters. Typically, the lug down can identify up to 90 percent of high NOx emitters, reducing excess emissions to 0.5 percent for pre-1988 vehicles and to 2.9 percent for post-2007 vehicles. We caution ACOR that these benefits are contingent on the development of NOx cut points (which may need to be specified as a NOx/CO_2 ratio).

PM benefits from the snap test are very high. Excess PM emissions range from 115 percent for pre-1988 vehicles to 14 percent for the 2002-2007 vehicles, and the snap test can typically identify 70 to 80 percent of excess PM. Combining the snap and lug down test is useful since the lug test can identify moderate injector problems and a larger percentage of catalyst problems in the future.

The snap idle test, however, has decreasing benefits, since many of the malperformances it can detect are no longer relevant to engines with electronic fuel injection. In addition, it is difficult to reduce the smoke opacity cutpoint on the snap test to very low levels because some engines have peak smoke on the snap in the 20-25 percent range of the current certification level. Lug down smoke levels are very low (less than five percent opacity) now, so that stringent cutpoints for continuous smoke are possible. Hence the lug down test is preferable to the snap test for current and future tests; however, the test cannot be performed at the roadside like the current snap test.

For each of the program options, the EEA malperformance model was used to estimate the percentage increases in emissions from certification emission levels at the vehicles' mid-life. The estimates are provided in Table 4-4.

These values were then applied to the zero kilometre emission rates contained in Mobile 6 and AP-42. This produced a model year specific emission factor for each pollutant. The individual emission factors were then arithmetically weighted by the vehicle age population percentage for that model year in the calendar year under assessment. Seven calendar year estimates were calculated for 1995 through to 2025 in five year steps.

The individual model year weighted values can also be expressed as a percent of the total emission rate factor, thus providing an estimate of the relative portion that an individual model year cohort's contribution makes to the entire HD diesel fleet emissions. See Section 4.10 for details. This is plotted in Figure 4-2, and indicates that a disproportionately large share of the total emission rate is being generated by pre-1990 vehicles. They constitute 37 percent of the population but produce an estimated 68 percent of the PM and 45 percent of the NOx.

Table 4-4 Estimates of Malperformance Relative Emission Increases

Pollutant	Testing Option	1960-87	1988-90	1991-93	1994-01	2002-07	2008+
PM	No Program Baseline	114.7%	55.8%	50.4%	28.7%	14.76%	45.77%
	Snap (55/40)	30.2%	14.9%	16.0%	16.1%	9.1%	10.2%
	Snap (55/40/25)	30.2%	14.9%	16.0%	7.1%	4.9%	5.5%
	Lug + Snap	32.1%	16.6%	14.2%	5.7%	4.2%	4.5%
HC	No Program Baseline	57.1%	29.8%	25.2%	10.6%	5.8%	5.8%
	Snap (55/40)	15.9%	29.8%	15.2%	10.6%	3.8%	3.8%
	Snap (55/40/25)	57.1%	29.8%	25.2%	10.6%	5.8%	5.8%
	Lug + Snap	15.9%	8.5%	7.9%	3.5%	2.3%	2.3%
NOx	No Program Baseline	9.5%	11.8%	8.1%	4.2%	6.5%	23.2%
	Snap (55/40)	6.3%	7.8%	5.4%	3.5%	5.4%	16.5%
	Snap (55/40/25)	6.3%	7.8%	5.4%	2.8%	4.3%	9.9%
	Lug + Snap	0.6%	1.6%	1.4%	0.7%	0.9%	2.9%

Percent increase at vehicle mid-life from a reference of new vehicle certification levels

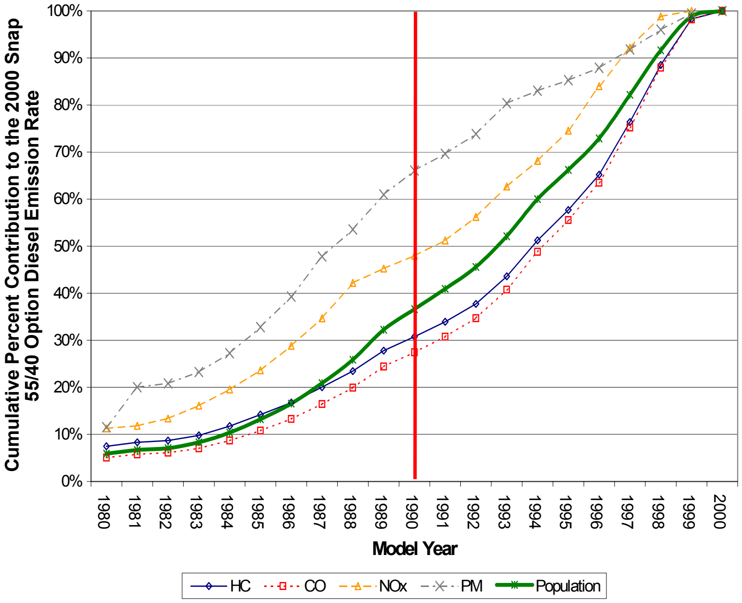


Figure 4-2 2000 HD Diesel Emission Contribution By Model Year

The composite fleet emission factor at each calendar year was computed by adjusting the vehicle age pool in time. The summary estimates are presented in Table 4-5 by calendar year and testing option. These forecasts have been transformed into ratios to the 2000 rates so that the future decreases in emission rates can be seen more clearly. These forecasts by pollutant are presented in Figure 4-3, Figure 4-4, Figure 4-5 and Figure 4-6 for HC, CO, NOx and PM, respectively.

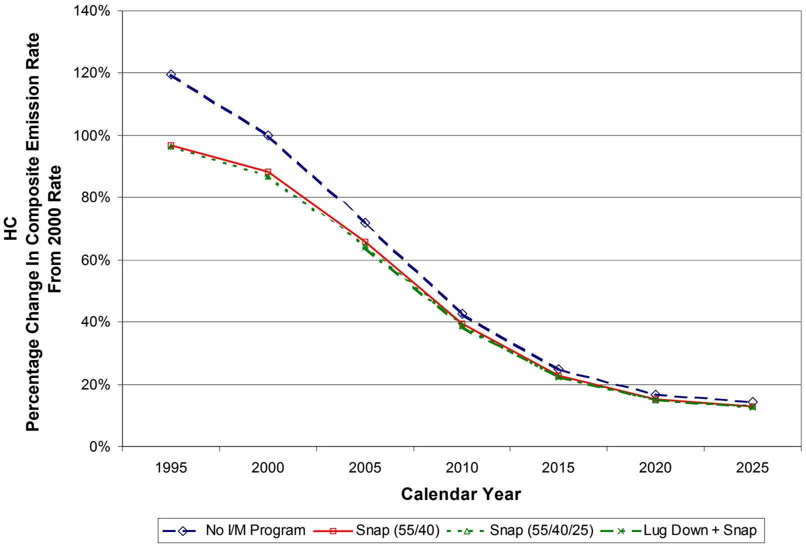


Figure 4-3 Forecast of Relative Average Emission Rates – HC

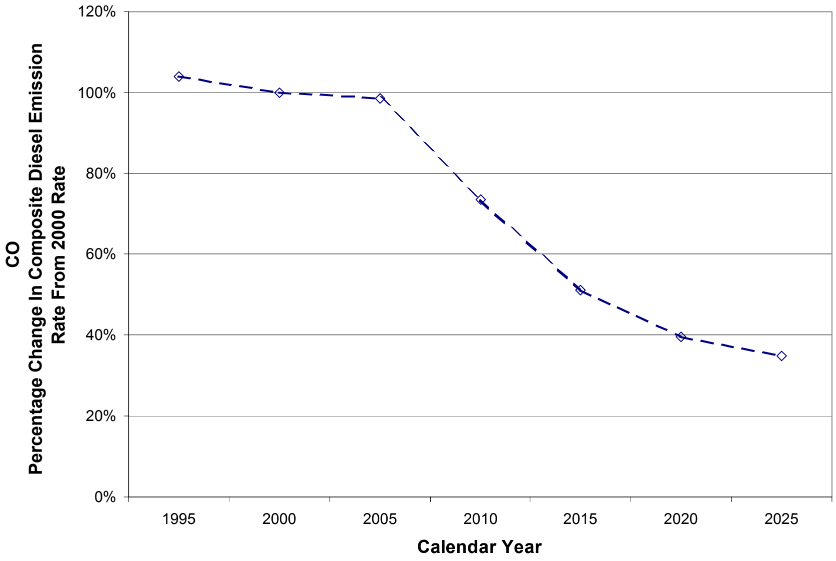


Figure 4-4 Forecast of Relative Average Emission Rates - CO

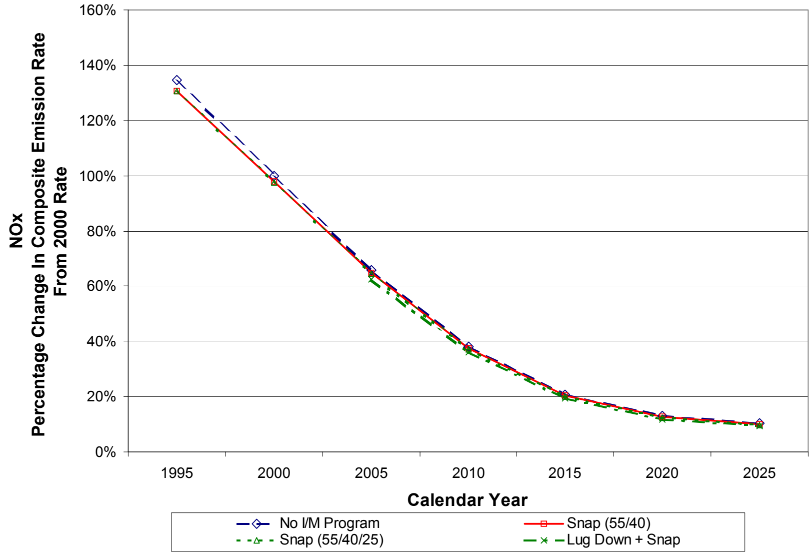


Figure 4-5 Forecast of Relative Average Emission Rates - NOx

Table 4-5 Composite Emission Factor Estimates by Calendar Year and Test Option

Pollutant	1995				2000				2005				2010				2015				2020				2025			
	No I/M Program	Snap (55/40)	Snap (55/40/25)	Lug Down + Snap	No I/M Program	Snap (55/40)	Snap (55/40/25)	Lug Down + Snap	No I/M Program	Snap (55/40)	Snap (55/40/25)	Lug Down + Snap	No I/M Program	Snap (55/40)	Snap (55/40/25)	Lug Down + Snap	No I/M Program	Snap (55/40)	Snap (55/40/25)	Lug Down + Snap	No I/M Program	Snap (55/40)	Snap (55/40/25)	Lug Down + Snap	No I/M Program	Snap (55/40)	Snap (55/40/25)	Lug Down + Snap
HC	3.3	2.6	2.6	2.6	2.7	2.4	2.4	2.4	2.0	1.8	1.8	1.8	1.2	1.1	1.1	1.1	0.7	0.6	0.6	0.6	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3
CO	11.0	11.0	11.0	11.0	10.6	10.6	10.6	10.6	10.4	10.4	10.4	10.4	7.8	7.8	7.8	7.8	5.4	5.4	5.4	5.4	4.2	4.2	4.2	4.2	3.7	3.7	3.7	3.7
NOx	14.7	14.3	14.2	13.5	10.9	10.7	10.7	10.3	7.2	7.1	7.0	6.8	4.1	4.1	4.1	3.9	2.3	2.2	2.2	2.1	1.4	1.4	1.3	1.3	1.1	1.1	1.1	1.0
PM	0.85	0.56	0.56	0.56	0.40	0.30	0.27	0.28	0.22	0.20	0.16	0.16	0.11	0.09	0.09	0.09	0.08	0.06	0.05	0.05	0.06	0.04	0.04	0.04	0.05	0.03	0.03	0.03

HC,CO,Nox in g/mi   PM in g/BHP-hr

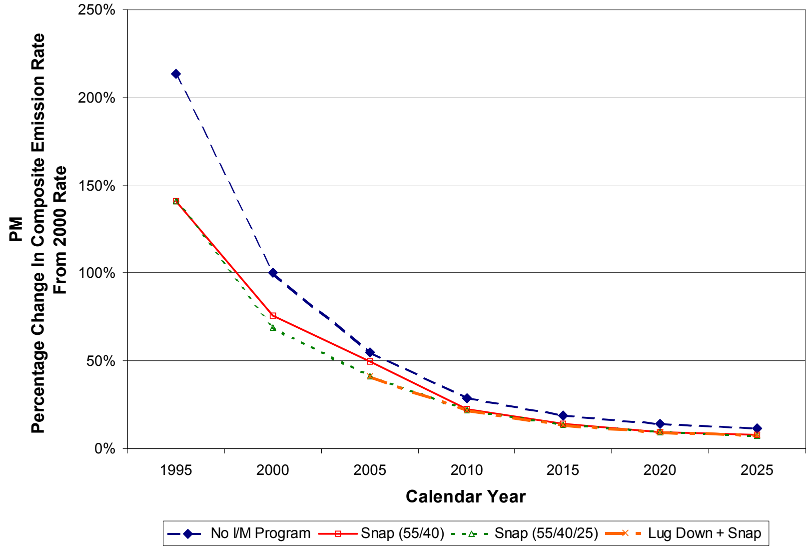


Figure 4-6 Forecast of Relative Average Emission Rates – PM

The estimates show that for the baseline (no program) case relative emission rates:

- HC declines steadily to reach about 17 percent of the 2000 rate by 2020;
- CO drops after the introduction of aftertreatment devices in 2007 and decreases to under 40 percent of its 2000 rate by 2025;
- NOx has a continuous decline through to 2015 when the rate of decrease will slow and reach an emission rate of 10 percent of its 2000 rate by 2025;
- PM drops significantly through to 2010 where it levels out at approximately 10 percent of the 2000 rate.

These forecasts clearly show that that major air quality improvements will occur in the LFV even if no in-use inspection program is in place. However, it should be noted that as the emission control stringency and complexity of controls increases, there will be an increased risk of tampering. Because of the unknown incidence and effect of this tampering, it is not modelled in the baseline scenario.

4.7 Emission Inventory Impacts

To estimate changes in the inventory emissions, the 1999 LFV inventory estimates [*17*] were used as a reference. The values were then adjusted to account for the estimated growth rate in the vehicle population (3.3 percent/annum). These “base” values are without any correction for changes in emission base rates. The “base” estimates were then corrected for the relative change in the emission factors from the 2000 estimate for each of the baseline, current snap, increased stringency snap and lug-down set of test options. The results of these calculations are provided in Table 4-6, Table 4-7,

Table 4-8, and Table 4-9.

Table 4-6 Baseline (no I/M) Inventory Estimates (tonnes)

Pollutant	1995	2000	2005	2010	2015	2020	2025
HC	845	832	702	491	337	267	268
CO	48544	57100	67165	79003	92928	109306	128572
NOx	6437	5630	4364	2960	1907	1397	1331
PM10	631	348	224	139	107	93	90
PM2.5	554	306	197	122	94	81	79

Table 4-7 Current Snap-acceleration Test (55/40) Option Inventory Estimates (tonnes)

Pollutant	1995	2000	2005	2010	2015	2020	2025
HC	684	733	644	454	308	241	242
CO	48544	57100	67165	79003	92928	109306	128572
NOx	6255	5516	4296	2916	1866	1355	1260
PM10	417	263	203	108	79	64	60
PM2.5	366	231	179	95	69	56	53

Table 4-8 More Stringent Snap-acceleration Test (55/40/25) Option Inventory Estimates (tonnes)

Pollutant	1995	2000	2005	2010	2015	2020	2025
HC	682	721	632	446	304	238	239
CO	48544	57100	67165	79003	92928	109306	128572
NOx	6252	5500	4274	2895	1845	1334	1237
PM10	416	241	168	105	77	63	59
PM2.5	366	211	148	92	68	55	52

Table 4-9 Lug-down Test Option Inventory Estimates (tonnes)

Pollutant	1995	2000	2005	2010	2015	2020	2025
HC		715	626	442	302	237	238
CO		57100	67165	79003	92928	109306	128572
NOx		5291	4132	2798	1770	1267	1166
PM10		242	168	105	77	63	59
PM2.5		212	148	92	68	56	52

The differences from the baseline estimates are the measure of the potential emission benefits of the I/M inspection options and these values are shown in Table 4-10. It can be seen that there is a general decrease in the total tonnes of pollutant removed by all of the options through to 2015-2020.

Table 4-10 Estimated Changes in Total Emissions (tonnes/year)

Pollutant	Calendar Year						
	1995	2000	2005	2010	2015	2020	2025
Snap (55/40)							
HC	-161	-99	-59	-36	-29	-26	-27
CO	0	0	0	0	0	0	0
NOx	-183	-113	-69	-45	-42	-43	-71
PM10	-215	-85	-21	-31	-28	-28	-30
PM2.5	-189	-75	-18	-27	-25	-25	-26
Snap (55/40/25)							
HC	-164	-110	-70	-45	-33	-29	-29
CO	0	0	0	0	0	0	0
NOx	-186	-130	-90	-66	-62	-64	-95
PM10	-215	-108	-56	-34	-30	-30	-31
PM2.5	-189	-94	-49	-30	-27	-26	-27
Lug Down + Snap							
HC			-76	-48	-35	-30	-30
CO			0	0	0	0	0
NOx			-232	-162	-138	-130	-165
PM10			-56	-34	-30	-29	-30
PM2.5			-49	-30	-27	-26	-27

4.8 Program Cost Estimates

All cost estimates are calculated using current 2002 dollar values, which implies an assumption that all costs will inflate over time at an equal rate. The assumptions and results of the cost model are described below segmented by program testing and the truck industry's repair costs.

4.8.1 Testing Costs

Estimates for the testing costs are based on a costing model that contains the following assumptions and data:

1. The snap-acceleration test model continues with a random roadside structure, however, with a decreased program cost through the use of the two one-person enforcement vehicles.
2. Assumes that the lugdown testing is a mandatory annual test requirement. We have assumed that it is integrated into the AirCare LDV program and that sheltered external inspection lanes are constructed at selected testing centres.
3. It also assumes that the present contractor-run delivery method can accommodate the addition of HDV inspections.
4. The capital costs for the physical changes are estimated at $400,000 per station with a further $100,000 per station for test equipment.
5. Estimates of the number of stations required are based on vehicle population, time per test and operating hours per year.
6. Capital costs were amortized over 10 years at a real interest rate of 2 percent.
7. Labour costs are estimated on the basis that the test lane is integrated with the current AirCare test centres and that one person is required for the test. Costs are based on the current AirCare test technician hourly rate ($14.75/hour). A multiplier of 1.3 is used to inflate this hourly rate for overhead costs (training, etc.) and direct testing costs (repairs, maintenance, etc.).
8. The estimate of the number of stations is based on an assumption that the lugdown test requires 0.3 hours to complete (similar to the current Arizona experience) and that the operating hours are the same as the current AirCare program. Only integer values of stations are used (i.e., a calculated need of 4.3 stations would be rounded to 5).

4.8.2 Repair Costs

Repair costs are based on estimates of the failure rate for each option by calendar year. The current ACOR random program's failure rate was used as the basis for the “snap” option. Plus, it was assumed that the more severe test standards would move the overall failure rate up to 0.6 percent in 2005 and that this would decline to 0.3 percent by 2010 and remain steady thereafter. The lugdown test is estimated from the malperformance model to have an initial failure rate in 2005 of 6.8 percent, which declines to 2.4 percent in subsequent years. Average repair costs for both testing options are estimated to be the same as those incurred by the current program ($870).

4.8.3 Cost Effectiveness

The overall benefit value of these emissions reductions may be estimated by applying current monetary values from welfare economics analyses (environmental externalities) that have been carried out for the Lower Fraser Valley and elsewhere in North America. In a recent report entitled “Greater Vancouver and Fraser Valley Air Quality Management Plan Phase 2 Final Report: Harmonized Measures for Reducing Greenhouse Gases and Air Pollution in the LFV” [*18*], a set of damage cost weightings was provided. These can be used to weight the benefits of each pollutant into a generalized damage cost estimate. The previous study's values are presented in

Table 4-11. The relative weights of this analysis were used to calculate the total benefit from the various inspection options expressed as damage or impact-weighted tonne reduced using the equation:

$$\text{Impact-weighted Emissions} = 25*PM+NOx+HC+CO/7+3*SO_2$$

Table 4-11 Summary of Indicative Damage Cost Values Used for Evaluation Purposes

Value	PM ($PM_{2.5}$)	SO_2	VOC	NOx
Nominal Current C$/tonne				
Damage cost value, LFV	45,000	5,750	2,000	2,000

The relative value for CO is taken from other work in which it has been customary to apply a 1/7 impact weighting to CO to reflect its relative direct and indirect effects. Since CO reductions are not predicted by the model used here, it does not enter into the benefit estimates.

The results of the emission reduction and cost estimate calculations are presented in Table 4-12. The cost-effectiveness analysis indicates that:

1. Current snap-acceleration program is estimated in 2005 to result in a $616 cost per tonne (weighted) reduction. This is an increase from the 2000 estimate of $312/tonne due to the interaction of reduction in excess emission credited and the decrease in operational costs caused by the drop in repaired vehicles. The ratio drops again in 2010 as the number of trucks that fail decreases (thus repair cost drop) but the not in proportion with the emission benefits reductions.

2. If the more stringent standard is used, this cost-effectiveness ratio decreases to $395 and is the lowest cost option. In this case the program costs are not changed but the total emission reduction, especially PM, is increased.

3. The lug option has a higher cost/tonne in 2005 of $920, due principally to the much higher program costs.

4. For all options, the cost per tonne increases beyond 2010 as the emission reduction effectiveness decreases and the program costs increase with the increasing total vehicle populations.

5. As the focus of the HDV control program has been on PM and smoke reduction and assuming that this will be the regional strategy in the future, we do not see any improvement in the cost effectiveness of the program with an expansion of the program to the lugdown test option.

6. The use of more stringent cutpoints for the post-1994 vehicles will provide the lowest cost per emission reduction benefit of all the options.

Table 4-12 Estimates of Emissions Reductions and Costs

Option and Pollutant	Calendar Year					
	2000	2005	2010	2015	2020	2025
Snap (55/40)	**Emission Change from Baseline (tonnes/year)**					
HC	-99	-59	-36	-29	-26	-27
CO	0	0	0	0	0	0
NOx	-113	-69	-45	-42	-43	-71
PM10	-85	-21	-31	-28	-28	-30
PM2.5	-75	-18	-27	-25	-25	-26
Program Cost/ Year	$730,000	$395,000	$336,000	$377,000	$495,000	$539,000
Cost/tonne						
All, Impact-weighted	$312	$616	$395	$483	$634	$638
HC	$7,400	$6,700	$9,200	$13,100	$18,900	$20,200
CO						
NOx	$6,400	$5,700	$7,500	$9,000	$11,500	$600
PM10	$8,500	$19,200	$10,900	$13,200	$17,300	$18,000
PM2.5	$9,700	$21,800	$12,400	$15,100	$19,700	$20,500
Snap (55/40/25)	**Emission Change from Baseline (tonnes/year)**					
HC	-110	-70	-45	-33	-29	-29
CO						
NOx	-130	-90	-66	-62	-64	-95
PM10	-108	-56	-34	-30	-30	-31
PM2.5	-94	-49	-30	-27	-26	-27
Program Cost/ Year	$730,000	$395,000	$336,000	$377,000	$495,000	$539,000
Cost/tonne						
All, Impact-weighted	$249	$255	$347	$441	$594	$602
HC	$6,600	$5,600	$7,500	$11,300	$17,100	$18,400
CO						
NOx	$5,600	$4,300	$5,100	$6,000	$7,700	$600
PM10	$6,700	$7,100	$9,800	$12,300	$16,700	$17,400
PM2.5	$7,700	$8,000	$11,100	$14,100	$19,000	$19,900
Lug Down + Snap	**Emission Change from Baseline (tonnes/year)**					
HC	0	-76	-48	-35	-30	-30
CO						
NOx	0	-232	-162	-138	-130	-165
PM10	0	-56	-34	-30	-29	-30
PM2.5	0	-49	-30	-27	-26	-27
Program Cost/Year	$2,646,000	$1,567,000	$1,888,000	$2,196,000	$2,196,000	$2,646,000
Cost/tonne						
All, Impact-weighted		$920	$1,765	$2,365	$2,459	$2,762
HC (unweighted)		$20,600	$39,200	$62,300	$72,900	$86,900
CO (unweighted)						
NOx (unweighted)		$6,700	$11,600	$15,900	$16,800	$2,900
PM10 (unweighted)		$28,000	$54,900	$72,600	$74,900	$86,700
PM2.5 (unweighted)		$31,900	$62,500	$82,700	$85,300	$98,800

4.9 Heavy-duty Gasoline and Alternative Fuel Vehicle Testing

The population of gasoline and alternative fuel vehicles over 5,000 kg (9,837 non-electric vehicles in 2000) is currently excluded from any form of in-use inspection and constitutes approximately 22 percent of the overall HDV population. These vehicles generally have low PM and smoke emissions and thus appear “clean” to the general public. They are however, relatively high emitters of CO (see Table 4-13) with average emissions rates that are over five times that of diesel vehicles. No data on AFV emission rates from LFV vehicles have been found, but it is expected that the emission factors will be lower than the gasoline factors.

Table 4-13 Comparative Fleet Average 2000 Emission Rates

Average Emission Factor (g/mi)	HC	CO	NOx
Gasoline	3.1	57.5	5.0
Diesel	2.4	10.6	10.7

The initiation of a mandatory annual emission inspection program based on a two-speed idle exhaust concentration test would result in two outcomes.

1. The average emissions of these vehicles would be decreased.

2. The program would place additional ownership and operating costs on this fleet of old vehicles and thus provide for additional financial pressure for their replacement with a newer and cleaner technology vehicle.

4.9.1 Heavy-duty Gasoline Inspection Emission Impacts

Mobile 6 was used to model an HDGV I/M program beginning in 2004 using the following assumptions:

1. A two-speed idle test; and

2. a failure rate of 15 percent for post-1981 and 25 percent for pre-1981vehicles.

The Mobile 6 program assumes computerized testing, post-repair inspection and a waiver rate of 5 percent, with a compliance rate of 95 percent. Also included was an assumption of a gas cap and evaporative hose check, with an evaporative OBD modelled.

The aggregate emission rate (g/mi) results are shown in Table 4-14 and indicate that the benefits are about 4 percent for HC and 10 percent for CO. This low impact is likely a function of the very simplistic model contained within the Mobile 6 model and it is probable that the true effect would be higher than estimated. Because of this uncertainty, it is recommended that a small pilot program be undertaken to collect vehicle performance data in order to set cutpoints and develop better emission impact estimates based on actual repair benefits.

Table 4-14 also presents the estimates of the impact these emission rate reductions in will have on total emissions. These estimates were developed using a similar methodology as used for the HHDV model in which the 1999 inventory estimate is corrected for the relative emission rates and the population forecasts (in this case a declining population forecast).

Table 4-14 Estimated HDGV I/M Emission Impact

HDGV Emission Rates (g/mi)	1999	2005		2010		2015		2020		2025	
		Baseline	With I/M	Baseline	With I/M	Baseline	With I/M	Baseline	With I/M	Baseline	With I/M
VOC	3.41	2.14	2.04	1.31	1.26	0.87	0.84	0.62	0.59	0.56	0.53
CO	34.98	17.90	16.00	10.54	9.40	8.94	7.98	8.60	7.68	8.43	7.36
NOx	5.32	4.20	4.18	2.20	2.19	1.07	1.07	0.58	0.58	0.51	0.51
Percent of 1999 Rate											
VOC		63%	60%	38%	37%	26%	24%	18%	17%	16%	15%
CO		51%	46%	30%	27%	26%	23%	25%	22%	24%	21%
NOx		79%	79%	41%	41%	20%	20%	11%	11%	10%	10%
Inventory (tonnes/year)		**Baseline**	**Change**	**Baseline**	**Change**	**Baseline**	**Change**	**Baseline**	**Change**	**Baseline**	**Change**
Population Estimate	9255	6900		5100		3600		3600		3600	
VOC	125	59	2.6	27	1.2	12	0.5	9	0.4	8	0.5
CO	1,766	422	45	113	12	45	4.8	31	3.3	27	3.4
NOx	218	41	0.2	6	0	1	0	0	0	0	0
Impact-weighted Composite*		160	9.2	48	2.9	20	1.2	14	0.8	12	1.0
Program Cost			$539,000		$313,000		$248,000		$248,000		$248,000
Cost/tonne			$58,400		$106,100		$205,500		$301,500		$242,900

* Composite = 25*PM+HC+NOx+CO/7

The analysis indicates that the addition of a HDGV I/M program would decrease total HDGV emissions (impact-weighted composite) by 6% in each of the forecast calendar years.

4.9.2 HDGV Program Costs

Cost estimates for this program option were developed in a similar manner to the diesel test options. The basic testing time and failure rates were based on data provided by the Arizona and Ontario I/M programs. The Arizona I/M program achieves a 6 percent failure rate on an idle test with a relatively loose CO standard of 3 percent. Summary information from the Ontario program indicates a 20% failure rate with their somewhat tighter standards [*19*]. For this model, it is assumed that standards similar to Ontario’s would be used and a first year failure rate is estimated at 20 percent [i] and decreases to 10 percent in years after 2010.

Table 4-15 Program Cost Estimates for a HD Gasoline Idle Test Program

Calendar Year	# Vehicles/ Year	Total Testing Costs	Total Cost/ Test	Failure Rate	Repair Costs*	Total Costs
2002	8700	$ 94,000	$ 11	20%	$ 748,000	$ 842,000
2005	6900	$ 94,000	$ 14	15%	$ 445,000	$ 539,000
2010	5100	$ 94,000	$ 18	10%	$ 219,000	$ 313,000
2015	3600	$ 94,000	$ 26	10%	$ 154,000	$ 248,000

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[i] probably a 2 to 2.5% limit but a pilot test survey would be required to confirm this standard

2020	3600	$ 94,000	$ 26	10%	$ 154,000	$ 248,000
2025	3600	$ 94,000	$ 26	10%	$ 154,000	$ 248,000

* Repair costs estimated at $430/ repair

The program cost analysis indicates that the annualized government testing costs should be quite low, although this assumes that only one station site is used to test all HDGV vehicles[i]. If more stations were installed, then the program costs would increase by approximately $100,000 per year per station. As the total number of failures and repairs would be the same, the programs cost-effectiveness would decrease. The repair costs are based on the average repair costs obtained from the Arizona I/M program (US$280/vehicle or C$430/vehicle) and the estimated failure rates. As shown in Table 4-15, the estimated repair costs are the largest component of total program costs at approximately nine times the government testing costs. Note that this estimate excludes the owner/operator’s time cost of the having the test done and that this model assumes only one testing site, which would maximize the industry cost of access to the site.

Comparing the program costs with the estimates of emission reduction (Table 4-14) results in a cost-effectiveness ratio of $58,400/composite tonne in 2005. This value increases to $106,100, $205,500, $301,500, and $ 242,900 in calendar years 2010, 2015, 2020, and 2025 respectively.

4.10 Vehicle Age Management

An alternate emission control method is to attempt to accelerate the turnover of the vehicle stock so that lower emitting technologies enter the market faster. The recent and near-term future changes to the emissions standards means that there are large emission rate differences between vintages of vehicles. The relative (percentage change from 2001 vehicles) emissions rates (calculated at 160,000 km) for CO, HC, NOx [*20*] and PM [*21*] (based on a Class 8 vehicle) are compared in Figure 4-7 for diesel and Figure 4-8 for gasoline fuelled vehicles. These graphs illustrate the large increases in emission rates for older vehicles. For instance, one kilometre of a pre-1987 HDD truck is the PM generating equivalent of nine 2001 vintage vehicles. Gasoline technology differences indicate that a pre-1985 gasoline fuelled truck is the CO equivalent of 5 new trucks.

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[i] based on a 15 minute test and 2600 test lane hours per year.

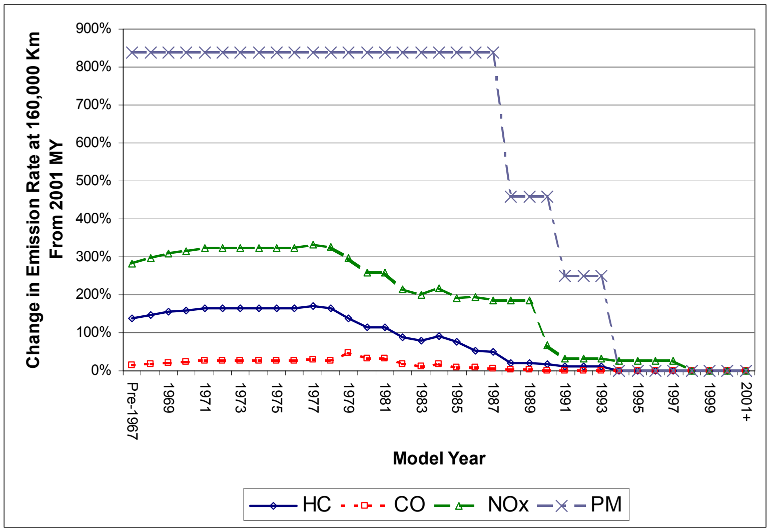

Figure 4-7 Relative Emission Rates For HD Diesel Vehicles

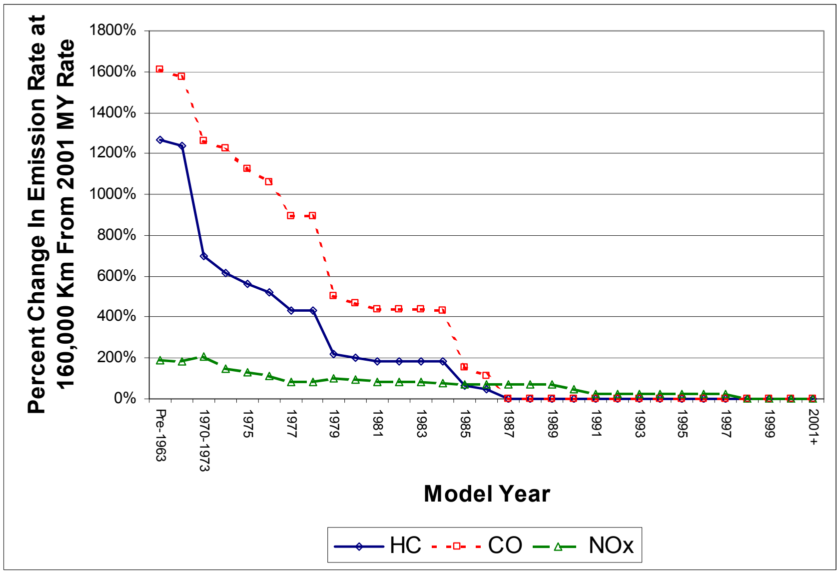

Figure 4-8 Relative Emissions HD Gasoline Vehicle

When these emission rates are applied to the fleet in proportion to their population and annual usage rates, the percentage of total emissions emitted by model year can be calculated. Figure 4-2 (see Section 4.6) and Figure 4-9 plot the relative emissions for diesel and gasoline vehicles, respectively, for the calendar year 2000. It can be seen that vehicles older than 1990 vintage contribute 68 percent of the total PM emissions and 45 percent of the NOx - this while making up only 37 percent of the population and contributing only 16 percent of the diesel HDV VKT.

Similarly with the gasoline vehicles over 5,000 kg, the large proportion of the vehicles that are older than 1990 results is close to 90 percent of all the HDG generated CO and 80 percent of the HC being emitted by these vehicles. In fact, 50 percent of the HDG CO is produced by the 35 percent of the vehicles that are model year 1980 and older.

Of course, these percentages change in time. Estimates of the contribution percentages for 2005 and 2010 for diesel vehicles are presented Table 4-16 and indicate that the disproportionate impact of these older vehicles does reduce but even in 2010, the pre-1990 diesels contribute 35 percent of the PM_{10}.

Table 4-16 Pre-1990 Vintage Diesel Vehicles Emission Contributions

	Calendar Year		
	2000	2005	2010
% Population	37%	13%	6%
% VKT	16%	6%	3%
% PM	68%	47%	35%
% NOx	45%	25%	23%
%HC	31%	16%	14%
%CO	27%	10%	7%

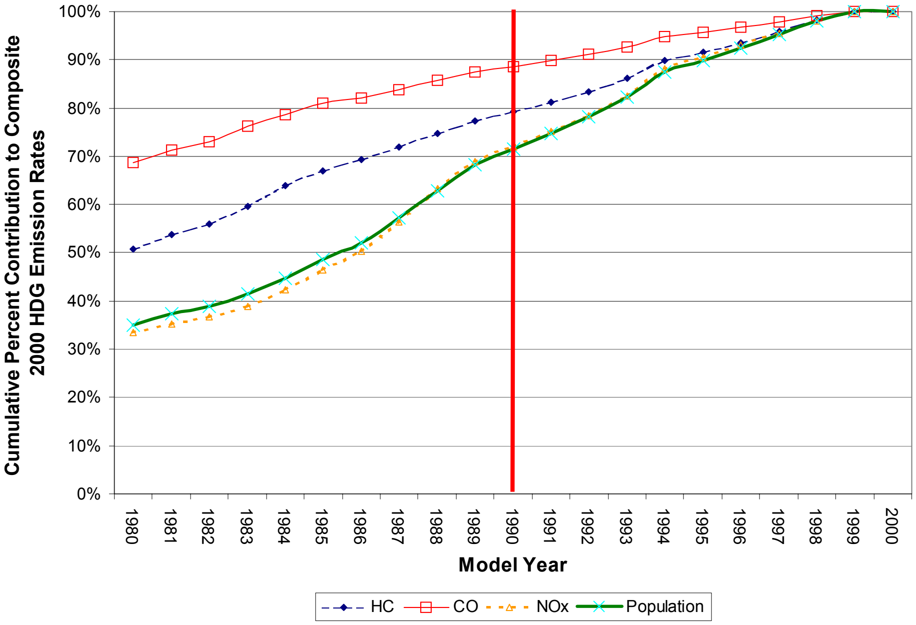

Figure 4-9 Cumulative Contribution of Model years to HDGV 2000 Emission Rate

Another important aspect of the old vehicle fleet is the large percentage that is held in public fleets, where tax-based incentives may have minimal effect. The 1998 LFV vehicle demographic data indicated, as shown in Table 4-17, that 34 percent, 16 percent and 19 percent of the AFV, diesel, and gasoline fuelled vehicles, respectively, were older than 1990 and were owned by government or transit operators. This relatively high concentration of vehicles under direct or indirect government control argues for the use of government policy directive and expenditures to instigate significant changes in the age distributions of their fleets.

Table 4-17 Government Controlled Pre-1990 Vehicles in 1998

	AFV	Diesel	Gasoline	Total
Total	722	1546	791	3059

Government	152	577	530	1259
Bus	553	742	234	1529
Garbage	17	227	27	271
Percent of Total	34%	16%	19%	19%

4.10.1 LFV Fleet Modernization

To change the emission generation nature of these old vehicles, two types of replacement programs have been used in a variety of jurisdictions. The first option is the retrofit of emission controls and the second is the replacement of the vehicles with new vintage vehicles or engines. A good recent review of these types of programs has just been published by the Manufacturers of Emission Controls Association [*22*].

The accelerated retirement of vehicles has been tried in a number of jurisdictions for light-duty vehicles and British Columbia in particular has been a leader in the area with its Scrap-It program [*23*]. While these types of programs can be politically very important, unless the “price is right” they generally only affect a very small percentage of the vehicle population. This is especially so in the HDDV market where the value of the vehicle is higher.

A number of mechanisms for achieving this replacement have been suggested or used in other jurisdictions, including:

- Retrofit or replacement grants or loans;
- increased application of accelerated capital cost allowances for trucks;
- creation of a tax credit scheme for trucks;
- mandatory age limits for truck registrations;
- operation of a purchase scheme for older trucks; and
- mandatory retrofitting of engines of a certain age.

4.10.2 Retrofit

The use of vehicle retrofit has been implemented in the US in transit bus and urban truck applications through the EPA Urban Bus and Voluntary Truck Retrofit programs, and the California truck retrofit program. All these programs have established emission retrofit standards and verification procedures that would be good models to follow if this control path were taken. Some analysis has been made in other studies [*24*, *25*], on the cost effectiveness of emission retrofits and whole engine replacements and current programs are beginning to report some actual costs. A cost survey conducted in November 2000 [25] showed that average diesel oxidation catalyst costs ranged from US$465 to US$1,750 per vehicle. Diesel particulate filters are currently being sold for about US$7,500 per installation. The cost of the filter is forecast to decrease, assuming higher sales volumes, to between US$3,000 to US$5,500 per vehicle.

The most advanced North American programs include:

U.S. EPA Urban Bus Retrofit/Rebuild Program

Begun in 1993, the program requires that urban buses operating in metropolitan areas with populations over 750,000 be equipped at the time of engine overhaul with U.S. EPA-certified retrofit pollution control devices, such as oxidation catalysts, or be rebuilt using certified low emission components. This is a legislated requirement and no financial incentive is provided by the program. To date, well over 20,000 urban buses have been retrofitted or rebuilt as a result of the program.

U.S. EPA Voluntary Heavy-Duty Retrofit Program

Announced on March 22, 2000, the objective of the voluntary initiative is to clean up in-use diesel engines in trucks, buses, and construction equipment. Under the program, if a state uses a retrofit technology approved under the program, they are eligible to receive state implementation plan (SIP) emission reduction credits. EPA received 70,000 retrofit commitments in 2001 and has set a goal of receiving 130,000 retrofit commitments in 2002. The EPA program sets up a protocol for calculating credits, the structure of a third-party verification system for approving retrofit technologies, and in-use testing requirements to ensure that the emission reduction credits claimed are achieved in the field. [i]

ARB's Carl Moyer Program

To actually achieve measurable effects on the vehicle population, large subsidy budgets are required. For instance, the California ARB funds the Carl Moyer Program [ii] which provides incentive grants, is a means to reduce emissions from heavy-duty engines. These grants cover the incremental cost of cleaner on-road, off-road, marine, locomotive and stationary agricultural pump engines, as well as forklifts, airport ground support equipment, and auxiliary power units.

In its first three years, the Carl Moyer Program has provided reductions of 14 tons per day of NOx and about 800 pounds per day of PM. Most of these emissions benefits will occur for five years (the minimum project life). However, some large engine projects will be providing emission benefits for 20 years or more. In general, the Carl Moyer Program estimates a cost-effectiveness ratio which averages at US$4,000 per ton (approximately C$5,450/tonne) of NOx reduced [*26*]. The funding level has been US$25 million for fiscal year 1998-99, US$19 million for1999-2000, US$50 million for 2000-2001, and US$16 million for 2001-2002. 48 percent of the funds went to on-road vehicles with the balance split between agricultural pumps, marine, rail, fork lifts and off-road applications.

During the first two years, air quality management districts provided US$1 in matching funding for every US$2 of Carl Moyer Program funding for engine incentives. Program funds in the first two years, including districts' matching funds for infrastructure, totalled about US$71 million. State funds for the third year program were increased to US$50 million. At the increased funding level, it was believed that districts would not have been able to provide increased matching funds. Hence, the matching fund requirement for the third year was capped at US$12 million state-wide. This is equivalent to a match of about US$1 for every US$3.68 received from state funds.

ARB's HD Retrofit Implementation

ARB is still developing their retrofit programs for both HD trucks and transit buses. At present they have developed and implemented a device certification program [iii] and are going through public hearings on program proposals requiring retrofit or replacement of public buses and solid

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[i] Information regarding EPA's Voluntary Diesel Retrofit Program can be found at: http://www.epa.gov/otaq/retrofit/

[ii] more information is available at http://www.arb.ca.gov/msprog/moyer/moyer.htm

[iii] http://www.arb.ca.gov/msprog/aftermkt/aftermkt.htm#heavyduty

waste collection vehicles starting in 2004 through 2008. Further, this program requires the use of low sulphur diesel (15ppm) starting in July 2003.

Verification Programs

For both the EPA and ARB programs, verification and certification of equipment performance have been developed. EPA maintains a list of verified technologies at their web site[i]. The California ARB is also developing a retrofit verification procedure to verify the capabilities of retrofit devices. The Air Resources Board maintains a list of verified technologies on their web site [ii].

4.10.3 Engine or Vehicle Replacement

SECAT Program

Another California program is the Sacramento Emergency Clean Air and Transportation (SECAT) program [iii], which was created as a way to help truck owners and fleet operators reduce their vehicles' emissions through a retrofit or replacement subsidy. The goal of the program is to reduce the nitrogen oxide emissions from heavy-duty vehicles in the Sacramento airshed by two tons per day by November 2002 and three tons per day by 2005. Part of the justification for the program is the ability for Sacramento to access federal transportation money, which is tied to achieving air quality objectives. If SECAT achieves its goal, then they can receive up to US$680 million in federal transportation improvements.

The total SECAT budget through to 2005 is US$70 million, of which the bulk will be expended by the end of 2002. The funding is shared US$50 million from the State and US$20 million from the Federal Congestion Mitigation and Air Quality (CMAQ) funds.

The program is a voluntary program and targets to replace the engines in 3,000 to 6,000 trucks. To date (February 2002), the SECAT program has funded over 500 projects, which have resulted in more than a half-ton-per-day of emissions reduction from diesel vehicles in the Sacramento region.

In February 2002, the SECAT program was expanded to include a new option - Fleet Modernization. Through Fleet Modernization, owners of 1983 and older diesel vehicles are offered financial assistance to acquire newer 1995-2000 vehicles. The program has had good immediate response and the program management contends that the average cost for a truck replacement will be about US$40,000, which is nominally the same cost that they had been paying for an engine replacement [iv]. They have had a number of original equipment suppliers offering to supply re-configured used equipment (with an OEM warrantee) to the program, as there is a significant glut of end-of-lease highway tractors currently on the market.

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[i] http://www.epa.gov/otaq/retrofit/retroverifiedlist.htm

[ii] www.arb.ca.gov/diesel/documents/verifieddevices.htm

[iii] more information is available at www.4SECAT.com

[iv] information provided by David Young, Senior Planner, Sacramento Area Council of Governments

4.11 Conclusions

The analysis of the effect on emissions and program costs of three sets of program options indicated that:

1. Large reductions in emissions will result as the direct effect of newer lower emitting vehicles entering the market over the next few years. By 2010, the baseline (no I/M Program) emissions will be 43%, 73%, 38%, and 29% of their 2000 inventory levels for HC, CO, NOx, and PM. By 2025, the levels will be 14%, 35%, 11% and 11%.

2. Of the inspection options, the more stringent snap-acceleration option provides the best cost per composite emissions reduced at $255/tonne in 2005. This program would reduce the emissions of HC, NOx and PM_{10} by 70, 90 and 56 tonnes per year or about 10%, 2% and 25% of the baseline emissions in 2005. By 2025, the enhanced program is estimated to have a cost-effectiveness ratio of $602/t and reduce the emitted tonnes per year by 29 (11%), 95 (7%), 31 (34%) for HC, NOx and PM_{10}.

3. The other two options, the current two-tier snap standards and the lug down test, both are effective inspection procedures but have significantly higher cost ratios for generating nominally the same amount of emission reductions.

4. The testing of the HD gasoline fleet using a two-speed idle test will result in significant emissions reductions, which are modelled by MOBILE 6 at 4% for HC and 10% for CO. The study team believes this underestimates the true reduction and suggests that a pilot survey of HDGVs be undertaken to obtain a better estimate. The costs of such a program are estimated at $554,000 ($94,000 operational and 460,000 for repair) in 2002. Over time, as the HDGV stock is reduced, the program costs would also reduce to $222,000 per year by 2015.

5. The use of emission control retrofit or vehicle upgrading programs could remove a significant portion of the vehicles older than 1990, which contributed 66% of the PM and 45% of the NOx produced by HDDVs in 2000. The existing programs in the US are good operational examples, but these programs are expensive and need large capital budgets to subsidize the changes – of the order or $C60,000 per vehicle in the case of the Sacramento SECAT program.

5. Diesel Exhaust Particulate Health Impacts

Health effects of diesel exhaust – especially diesel exhaust particulate matter (DEP) – have been reviewed in two recent reports for the Greater Vancouver Regional District (GVRD) and the Vancouver/Richmond Health Board [*27*, *28*]. These studies and other supporting research were summarized and used as the basis for recommendations of action respecting evaluation of diesel emission impacts in the region to the Vancouver City Council by the Vancouver Director of Environmental Health [*29*].

5.1 Current Ambient Air Quality

5.1.1 PM_{10} and $PM_{2.5}$

The annual average PM_{10} concentration in the GVRD and eastern LFV (little difference across the monitoring network stations) is about 12-13 $\mu g/m^3$. The estimated contributions of major source types that have been used in recent analysis of the relationships between emissions and ambient air quality in the region [*30*] are shown in Table 5-1. The methodology to which the table applies is not described in detail here. Details may be found in the reference cited in endnote 30. The table shows only the relevant data for direct PM emissions from vehicles. The full model addresses all source types.

Table 5-1 Lower Fraser Valley PM_{10} Source Apportionment Model

Source	Fraction of Ambient PM_{10}	Baseline Concentration (1997-8)	Emissions (tonnes, 1998)	K_{local} (1998)
All sources	1.00	13.30	-	-
Vehicle Direct PM_{10}	0.15	1.40	563	2.478E-03
Background	0.30	4.00	-	-

The "K_{local}" factor in the table is the estimated dispersion coefficient, equal to the ratio of a change of ambient PM_{10} concentration ($\Delta\mu g/m^3$) per tonne/year change in emissions. The estimated change is for that portion of the ambient PM_{10} that is above a background value, that is, will respond to local changes in emissions. The background value assumed in the analysis shown in the table was 4 $\mu g/m^3$. The analysis includes both primary and secondary PM. An estimate of change in annual average ambient PM_{10} concentration in the GVRD or eastern LFV may be made by multiplying an estimated change in annual emission by the appropriate K_{local} factor. Thus, a change in emission of primary PM_{10} from the vehicle fleet of 100 tonnes/year would translate to a change in average ambient PM_{10} concentration of about 0.2 $\mu g/m^3$ in either the GVRD or the LFV. As shown in a previous table (Table 4-10), such a reduction would comprise about 30 percent of the current total from the heavy-duty on-road fleet.

As shown in Table 5-1, direct emissions of PM from vehicles in the region comprise about 15 percent of ambient PM_{10}.

5.1.2 Diesel Emission Particulates

There have been no systematic measurements or estimates of the typical concentrations of DEP in Vancouver air. The Levelton report cited in endnote 27 suggests that a typical ambient DEP concentration for the GVRD region is about 1 $\mu g/m^3$ (higher adjacent to heavy use roadways). This level is similar to those measured in large US cities. We assume for the purposes of this report that this concentration is adequate to use for assessment purposes. This estimate is consistent with the fractional contribution of direct on-road vehicle emissions to ambient PM_{10} shown in the table above. Essentially all DEP is in the $PM_{2.5}$ size fraction.

5.2 Summary Of Health Impacts

DEP is associated with a variety of health outcomes – both morbidity (illness) and mortality (premature death). These are summarized in the two reports cited in endnotes 27 and 28.

Most of the conclusions about the effects of DEP in ambient air are based on its relative contribution to total fine particle (PM_{10} or $PM_{2.5}$) levels. There are few studies that identify the effects of DEP in ambient air independently. Morbidity and mortality effects on laboratory animals have been demonstrated, including evidence of carcinogenic (cancer-causing) effects. Human studies of exposed occupational groups, such as mine workers and railway workers, and a few clinical studies of human response to exposure to DEP, have indicated acute morbidity effects, increased mortality and carcinogenic effects. Among diesel truck drivers and railway workers, for example, overall analysis of many studies indicates about a 30 percent increase in cancer risk between the most exposed and least exposed groups of workers. Their exposure was to concentrations of DEP many times higher than those to which the general population is exposed. Human volunteers in clinical studies (at concentrations about 300 times those estimated to exist in Vancouver) have experienced inflammation of the lung and enhanced response to subsequently administered allergens.

Evidence that DEP may be carcinogenic comes from the occupational exposure studies and from urban epidemiological studies in which increased lung cancer rates were associated with living in areas with higher exposure to DEP. Urban-rural differences in lung cancer of about 30 percent in some studies may be related to the higher levels of DEP found in urban air, but this has not been demonstrated conclusively.

Based on the evidence available to 1998, the California Air Resources Board (ARB) found that DEP should be considered to be carcinogenic in humans [*31*]. ARB determined a risk factor of 300 per million of population per microgram per cubic meter of ambient concentration over a 70-year lifetime. That is, a person living in an area with an ambient concentration of DEP equal to 1 $\mu g/m^3$ over an entire lifetime would have an increased risk of contracting lung cancer of 300 chances in a million (0.03%). This is to be compared with the overall risk in BC of contracting lung cancer in a lifetime of about 8.8% for men or 5.3% for women (probability of 0.088 or 0.053, respectively.

5.2.1 Health Impact Risk Assessment

Cancer risk

To bring this into the local context, the overall mortality rate for all causes for the GVRD is about 6.7 per thousand people per year (overall risk of dying from any cause in a given year is 6.7 in a thousand, or 6.7×10^{-3}). That means that, for a population of roughly 1.8 million in GVRD, about 12,000 people die each year. Of those, about 3,000 will die of all types of cancer. Since the cancer risk factor for DEP refers to a lifetime exposure (nominally, 70 years), the population at risk in the GVRD can be approximated by the fraction of people ages 65 and older. Currently, there are 220,000 people 65 or older in the GVRD (GVRD population statistics, based on the 1996 census of 216,425, 11.8 percent of the population). Thus, if those people have been exposed to 1 $\mu g/m^3$ of DEP for their lives to-date, 300 in a million of them, or about 66 people, would have a (lung) cancer today attributable to their exposure to DEP. This number of people is the expected number of new (lung) cancer cases each year attributable to DEP exposure. A significant portion of those 66 people would be expected to die of their cancer. Canadian cancer statistics for 2001 show that about 2,500 new lung cancers per year occur in BC. If about half of those occur in the Lower Fraser Valley (1,250), then about 5% (66/1,250) of all new cases of lung cancer in the LFV would be attributable to DEP.

A health risk analysis done for the State and Territorial Air Pollution Program Administrators and the Association of Local Air Pollution Control officials (STAPPA-ALAPCO) provides estimates of numbers of cancer cases for large US cities that are significantly greater than the preceding analysis would indicate[*32*]. The STAPPA-ALAPCO report appears to have ignored the fact that the CARB risk factor is for a population that has been exposed to DEP for an entire 70-year lifetime and that not all members of the population are at the same level of risk. The methodology followed here appears to be a more realistic way of estimating the local incidence of DEP-related cancer.

Non-cancer mortality and morbidity

The scarcity of data on morbidity effects precludes estimating the number of DEP-related illnesses in the GVRD, but there would no doubt be an appreciable number. If it is assumed that the morbidity effects of DEP are similar to those of $PM_{2.5}$ generally (this is not necessarily accurate), we can estimate the avoided health outcomes attributable to a reduction in DEP emissions based on earlier work for this airshed, as shown in the next section.

Human exposure to airborne ambient PM (especially $PM_{2.5}$) is associated with a wide range of acute respiratory and cardio-vascular illnesses. For example, total mortality in a population is estimated to change by about 1 percent for each 10 $\mu g/m^3$ day-to-day change in ambient PM_{10} concentration. Analogous dose-response (or more accurately, exposure-response) factors have been estimated for many morbidity (disease) outcomes. Those most at risk from exposure to ambient PM are the elderly (people over 65) and children. No threshold of response to ambient PM_{10} or $PM_{2.5}$ has been found in any of the epidemiological studies upon which the response factors are based.

At current ambient concentrations of about 13 $\mu g/m^3$ (background = 4 $\mu g/m^3$), then, the excess risk of life-shortening (premature death) is estimated to be about 1 percent. This translates to an additional risk of about 70 in a million. This level of risk is comparable to the excess cancer risk of lifetime exposure to DEP described above (about 300 in a million).

Using the example given above, if a change in direct vehicle PM_{10} emissions of 100 tonnes per year produces a change in ambient concentration of PM_{10} of 0.2 $\mu g/m^3$, the emission reduction would change the risk of premature death (life-shortening by perhaps a few days to a few years) with respect to respiratory or cardio-vascular disease by about 1 in a million. The change in risk in this instance would be immediate relative to the change in emissions. The change in cancer risk would accrue over an entire lifetime and would not be immediate.

5.2.2 Effect Of Emission Reductions On DEP-Related Health Risk

Emissions

The *1999 Emission Inventory Update for the Lower Fraser Valley Airshed* [17] GVRD, 2000) shows the following breakdown of fine particle ($PM_{2.5}$) emissions for the LFV:

Emissions from diesel vehicles (a large fraction of the "heavy-duty vehicles" category) comprise 56 percent of on-road vehicle emissions and 13 percent of the total mobile source category. On-road vehicles account for 23 percent of the total mobile category. The California South Coast Air Basin estimates that 70 percent of on-road fine particle emissions come from diesel vehicles – somewhat higher than the above estimates for the LFV.

Table 5-2 1999 LFV $PM_{2.5}$ Emission Inventory Update

Sector	$PM_{2.5}$ (tonnes/year)	Percentage
Point Sources	1,790	28.6
Area Sources	2,172	34.6
Mobile Sources (breakout follows)	2,308	36.8
Light-duty On-road Vehicles	229	3.6
Heavy-duty On-road Vehicles	296	4.7
Marine Vessels	230	3.7
Railways	1,196	19
Aircraft	56	0.8
Off-road diesel	264	4.2
Off-road gasoline & small engines	36	0.5
Total All Sources	6,270	100

Emission Changes Attributable to ACOR - Air Quality and Health Benefits

Estimates developed over a number of years and presented in the report on the BC Clean Transportation Analysis Project [30] and shown in an example calculation above indicate that an emission reduction of, say, 100 tonnes of fine particles in the LFV airshed will result in a reduction of about 0.2 $\mu g/m^3$ of $PM_{2.5}$ (annual average). As shown in reference [30], the new light-duty vehicle emission standards (Tier 2) that will come into effect for model year 2004 are estimated to have the effect of reducing the average fine particle loading in the airshed by about 0.2 $\mu g/m^3$ by 2020. This reduction would be due to the secondary particulate formed from NOx and VOC emissions (nitrates and secondary organic aerosol), but the effect is the same for a reduction of direct fine particle emissions. The estimated emission reduction of PM_{10} or $PM_{2.5}$ for 2000, then, is estimated to have reduced the regional average concentration of fine particles by 0.1-0.2 $\mu g/m^3$. This is significant, since its current effect is essentially equivalent to the ultimate effect on PM_{10} of the Tier 2 standards in 2020.

The estimated emission reductions that are attributable to the existing ACOR program and possible options were developed in Section 4.7 and indicated that the emission reductions attributable to an ACOR-style program or its possible successor through the period from 2005 – 2025 would be in the following ranges:

- for PM (either PM_{10} or $PM_{2.5}$) from about 20 to 60 tonnes per year,
- for NOx from about 40 to 230 tonnes/year, and
- for HC from about 25 to 80 tonnes/year.

The NOx and HC emission reductions are not expected to have a material effect on ozone concentrations in the region. The PM reductions, however, would have a comparable impact on region-average PM concentrations to the estimates for the ultimate impact of the Tier 2 LDV/MDV emission standards. That is, the estimated PM reductions attributable to an ACOR type of program in the future are estimated to reduce regional average PM_{10} concentrations in the longer term by about 0.1 $\mu g/m^3$. This would be a significant additional benefit given the current values of PM_{10} in the region and the difficulty in the future of gaining emission reductions from other source sectors. Such a reduction is especially significant, since effectively all of the DEP is known to be in the smaller $PM_{2.5}$ size fraction that is of particular concern for both health and visibility impacts.

An estimate of the economic value of the emission reductions attributable to ACOR or its successors may be made by pro-rating the benefit estimated in a recent study for the implementation of the Tier 2 light-duty vehicle emission standards in the Lower Fraser Valley [30]. The effect of an ACOR-style program is estimated to produce 20-60% of the long-term emission reduction in ambient PM_{10} compared with Tier 2. Tier 2 was estimated to produce an annual average benefit (in terms of avoided health and welfare damage) of about $11 million (2000 CAD) over the period 2005-2020. On a pro-rated basis, therefore, an ACOR-style program would have a deemed economic benefit value of about $2-7 million/year, which significantly outweighs program costs. Based on other studies, the actual health care cost saving portion of the total health and welfare benefit is expected to be 15-25%, or $0.4-1.4 million per year – making the program cost beneficial even in this more restricted context.

5.3 Conclusions

Diesel emissions are an important factor in the impact of regional air quality on the population. The estimated emission reductions indicated in this report would be beneficial in reducing exposure of people in the Lower Fraser Valley to particulate matter, and especially to diesel exhaust particulate, which is thought to be more toxic than PM from other sources. The estimated reductions would reduce the risk of diesel exhaust-related disease by about 25% now and 10 to 20% in the longer term as cleaner technology displaces today's HDV fleet. Such a reduction would be difficult to obtain by other measures.

As demonstrated in reference 27, the impact of diesel emissions is exacerbated by the fact that the emissions occur in proximity to residential neighbourhoods and other roadside development. The elevated concentrations of particulate matter that are produced at street level fall off slowly with distance away from a street and cause significantly elevated concentrations at street-side residences or commercial buildings for the first few hundred meters from the centre of the street.

6. Recommended Actions

Based on the analysis and forecasts contained in this study, we recommend that the following programs and actions be considered:

1. The current ACOR program should be continued in its present function, but the staffing levels should be reduced. This can only be achieved if special constable status can be obtained for the inspectors.

2. The failure rate using the current ACOR pass/fail limits has been falling and is anticipated to continue to decline. To increase the severity of the test and increase the number of vehicles that will be repaired, it is recommended that a third tier opacity limit standard of 25 percent be added for post-1994 vehicles.

3. No change to the pre-1990 or 1991-1994 vehicle smoke opacity limits is recommended.

4. To minimize testing avoidance, the current refusal-to-test fine should be doubled to $150.

5. Provincial motor vehicle regulations should be modified to assure that any glider vehicles are required to pass standards appropriate for the date of manufacture of the chassis or engine, whichever is younger.

6. A fine (suggested at $300) in-lieu of repair could be applied to out-of-province vehicles that fail emission testing as a mechanism to increase the economic cost of non-compliance. This fine should be able to be waived on proof of repair.

7. There currently is a legislative gap concerning the testing of light duty vehicles for smoke and thus legislative and regulatory changes should be made to allow for the testing and enforcement of a smoke standard on light duty vehicles, similar to regulations in place in other jurisdictions.

8. Increased public information should be developed and disseminated on the ACOR program.

9. Heavy-duty gasoline, propane and natural gas fuelled vehicles should be annually inspected using a two-speed idle test for HC and CO. The testing should be integrated into the current AirCare operations and would require one, or possibly two testing stations. The study makes no recommendations on cut points for this test, as it is necessary to undertake a field survey of the current vehicles to assess their current state of compliance.

10. The initiation of a retrofit or replacement program aimed at older gasoline and diesel vehicles could be an effective way of reducing emissions, but would impose significantly higher government costs, if a subsidy program is used, than the current I/M program. It may be possible to require the mandatory upgrading of vehicles (and thus avoid direct government costs) but this requires more legal analysis. If this retrofit/replacement program is considered, then the standards, verification methods and program design should draw heavily on the existing programs developed in the US.

11. While the effects of low sulphur fuels will be seen region-wide in 2006, it may be an effective measure to accelerate the use of low sulphur fuels in high use in government-controlled fleets, since the use of low sulphur fuels results in immediate reductions in particulate formation.

12. Because of the uncertainties of the physical reliability and tampering potential of aftertreatment emission control technology and low sulphur fuels in 2007, a further

assessment of the need for and design of an in-use inspection program should be undertaken in the 2005-6 time period.

13. Continual liaison and information transfer with other jurisdictions involved in heavy-duty vehicle inspection should be maintained to allow PVTT and GVRD staff to keep apprised of technology and regulatory changes.

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APPENDICES

A. Vehicle Population Data

Table A-1 LFV HDV Population by Model Year and Fuel Type (2000 and 1998)

		2000 ICBC REGISTRATION DATA					1998 ICBC REGISTRATION DATA				
Age	Model Year	AFVs	Diesel	Gasoline	Total	Model Year	AFVs	Diesel	Gasoline	Blank	Total
20	<1982	760	1609	2670	5039	<1980	409	1347	1506	97	3359
19	1982	177	211	168	556	1980	135	374	329	24	862
18	1983	217	112	122	451	1981	148	478	289	25	940
17	1984	90	337	198	625	1982	156	270	121	8	555
16	1985	137	561	243	941	1983	206	119	81	4	410
15	1986	128	776	295	1199	1984	80	453	132	2	667
14	1987	123	906	258	1287	1985	116	608	166	3	893
13	1988	171	1192	407	1770	1986	104	811	194	6	1115
12	1989	212	1351	420	1983	1987	116	1059	193	7	1375
11	1990	172	1736	406	2314	1988	143	1241	342	5	1731
10	1991	119	1194	255	1568	1989	172	1326	354	7	1859
9	1992	49	1178	250	1477	1990	144	1844	363	9	2360
8	1993	77	1266	252	1595	1991	111	1239	233	8	1591
7	1994	59	1784	317	2160	1992	46	1305	209	9	1569
6	1995	76	2156	398	2630	1993	75	1203	248	9	1535
5	1996	68	1684	183	1935	1994	57	1656	282	15	2010
4	1997	15	1830	189	2034	1995	81	2071	412	20	2584
3	1998	57	2530	211	2798	1996	56	1680	164	4	1904
2	1999	15	2577	215	2807	1997	17	1699	205	12	1933
1	2000	5	1958	150	2113	1998	55	2009	139	14	2217
0	2001		326	3	329	1999	1	615	32	11	659
	Total	2727	27274	7610	37611		2428	23407	5994	299	32128
	% Market	7%	73%	20%	117%		8%	73%	19%	1%	100%
	% pre 1991	80%	32%	68%	43%		79%	42%	68%	66%	50%

B. Heavy-duty Vehicle In-use Test Methods and Comparisons

B.1 Smoke Test Procedure and Standards

All heavy-duty diesel engines must be certified to meet smoke standards as determined by the Smoke Test Procedure referenced in the U.S. Code of Federal Regulations 40 CFR Part 86-884. The test is conducted on an engine following a prescribed sequence of operations on an engine dynamometer. At the end of the lugging mode, the engine is returned to curb idle, and the procedure is repeated until three consecutive valid tests are obtained.

Smoke opacity is measured over the entire cycle with a light extinction type smoke meter. The three highest values of smoke opacity in any mode for each of the three cycles (total of 9) are averaged to define peak smoke. The 15 highest values in the acceleration modes over each of three cycles (total of 45) are averaged to determine acceleration smoke. The five highest values in the lug mode over each of the three cycles are averaged to obtain lug smoke. The standards are 50 percent smoke opacity for peak smoke, 20 percent for acceleration smoke and 15 percent for lug smoke. These standards have been in existence since 1974 for California and Federal engines, and have been maintained unchanged at these levels. Most pre-1991 engine families have certification smoke levels at about half the standard in all modes, and 1991 and later vehicles are certified at levels so far below the standard that these standards are largely irrelevant.

The test cycle has been derived so that acceleration modes simulate actual on-road acceleration from a stop. The initial elevation above idle speed is the start of the rolling motion, and the 5 second acceleration to 85 percent of rated RPM is typical of first gear acceleration at wide open throttle. The sharp deceleration to, and continued acceleration from, intermediate speed simulates the gearshift to second gear and continuing acceleration beyond that point. Another noteworthy point is that peak and acceleration smoke are all defined as averages of three or more instantaneous peaks.

B.2 In-use Smoke Test Procedures And Standards

The study team examined procedures that have been developed over the years for inspecting heavy-duty diesel engines. Since the basic engine design was developed over 100 years ago, there is a considerable body of literature and expertise on the types of malfunctions in diesels that cause excessive emissions, and on the methods to diagnose such malfunctions. The test procedures considered as potential options for the ACOR program were developed from diagnostic tests and included:

- Visual assessment;
- The acceleration test from standstill;
- The acceleration test from a rolling low speed condition (rolling acceleration test);
- The "snap-acceleration" test;
- The "lug-down" test

None of these tests are new or novel, and the principal focus for this study is to evaluate potential alternate methods to the EPA Method 9 and SAE 1667 used in the current ACOR program.

The tests are briefly described below.

Visual Method

The visual method using Ringelmann charts and trained observers (EPA Method 9) has been used widely to measure smoke opacity. The visual method was found to compare well with meter measured opacity when conditions were carefully controlled in tests conducted by California Air Resources Board (ARB). However, even under such conditions, it was found that 5 percent of the readings could show differences in excess of 15 percent opacity.

In the field, many other factors come into play. Viewing angle, changing ambient backgrounds and the sun angle can cause significant error. More importantly, psychological and human factors can cause large errors. The factors are related to inspection staff becoming tired when inspecting smoke continuously over the day. Any visual smoke measurement system would require staff to be very alert throughout the day, and would have to compensate for the tendency to record the same reading on repeat tests as that measured on the first test. Finally, the visual method does not provide any objective way to decide a challenge to the test. For these reasons, it is believed that the meter-based method is preferable. In addition, a visual reading also may be required to control for unusual circumstances, such as excessive condensation in the exhaust plume

Lug-down

The "lug-down" test simulates a condition representative of a loaded truck climbing a hill at full throttle. The cycle simulated is a hill climb started at a high initial engine speed, with engine speed declining under the inertia load of the truck during the climb. During the test, the inertia load is simulated with a load imposed by a dynamometer, or by the brakes of the truck. The brakes or dynamometer loads are applied (while maintaining full throttle) when engine RPM is at maximum (i.e., governed) speed. Engine RPM is then "lugged down" to 60 or 70 percent of governed speed by increasing the load. In an inspection program, one method available and recommended by Colorado is to load the engine by using the brakes. A second method is by using a dynamometer.

Snap-acceleration

The "snap-acceleration" test requires, with the transmission in neutral and the engine at normal (low) idle, the accelerator pedal be depressed to the maximum, or wide open throttle, position. The pedal is held at this position for 5 seconds or until the engine reaches maximum (governed) speed, whichever occurs first. The pedal is then released to allow the engine to return back to normal idle. Typically, peak smoke opacity, rather than average smoke opacity, is measured in conjunction with this test. This test cycle forms the basis of the SAE J1667 test. During the "snap-acceleration" test, smoke emissions can be emitted as a relatively short duration puff of smoke, and the response time of the instrument used to measure the opacity of the puff has a major effect on the measured value of peak smoke opacity. The most significant difference between the J1667 procedure and the procedure employed previously by ARB (the SAE J1243 test) is in the instrument response time specifications.

The SAE J1667 procedure differs in several key respects from the earlier J1243 procedure, specifically because it is the recommended procedure for assessing smoke emissions from in-use vehicles powered by diesel engines. The SAE J1667 incorporates:

- A specific method for performing the snap acceleration test.

- Correction factors for normalizing measured smoke opacity when measurements are made at alternative optical path lengths and non-standard ambient conditions.

- Specifications for the smoke-meter, and especially for overall instrument response time.

The defined snap acceleration test implementation in SAE J1667 is almost identical to the ARB procedure used previously. Minor modifications include revisions to the time span spent at governed speed and specifications limiting the amount of idle between successive snap acceleration cycles. The SAE J1667 requires that the throttle be held at the fully open position until the time the engine reaches governed speed, plus an additional 1 to 4 seconds. Upon releasing the throttle, the operator must allow the engine to remain at low idle for at least 5 seconds, but not more than 45 seconds, before initiating the next snap acceleration cycle. These particular time requirements were absent in the previous ARB specification. The J1667 procedure also requires at least three rather than the two preconditioning cycles required previously by ARB and for the use of correction factors for optical path length variations, and for ambient conditions

The smokemeter specifications in SAE J1667 allow the use of either partial flow or full flow smokemeters, and smoke measurement in either opacity or density scales. The SAE J1667 procedures suggest the use of a green Light Emitting Diode (LED) for the light source in the smokemeter. J1667 also specifies a reduced zero drift rate of 1 percent opacity per hour, half the previous ARB specification. However, the most significant difference is the use of an electrical filter to adjust total instrument response time to 0.5 -0.010 seconds. The SAE procedure requires a second order digital Bessel filter, and defines instrument response time as:

$$t = \mathrm{SQRT}\ (t_p^2 + t_e^2 + t_f^2)$$

where: t_p is the physical response time of the instrument sampling train

t_e is the electrical system response time

t_f is the filter response time

In a full flow end-of-line smokemeter such as the one used in the ACOR program, t_p and t_e are much smaller than 0.5 seconds so that almost all of the averaging is achieved by the Bessel filter in such cases.

Rolling Acceleration

The "rolling acceleration" test requires the vehicle to be in gear (selected to allow maximum engine speed to be reached at a vehicle speed of about 25 mph). With the truck rolling at low speed (~3 mph) the accelerator pedal is depressed to the maximum or wide open position, and held there for 6 to 10 seconds. The pedal is then released and the truck is brought to a stop.

Acceleration From A Standstill

The "acceleration from standstill" test is identical to the rolling acceleration test, with the exception that the truck is stationary when the acceleration is initiated. During both these tests, peak smoke opacity and average smoke opacity can be measured. For measuring peak smoke, it may be useful to utilize an SAE J1667 compliant smoke meter.

The Federal Smoke Test Cycle has different phases that represent various operating modes of a heavy-duty truck. The first acceleration phase from idle to (idle+200) RPM is representative of a truck engaged in first gear and moving away from a stop. At the end of three seconds, the accelerator pedal is depressed in full throttle position and the engine accelerated to 85 percent of rated speed in 5 seconds. This phase corresponds to a rolling acceleration cycle that is closely related to the rolling acceleration test, based on the throttle position and engine speed as a function of time over the five second period. From discussions with engine manufacturers it was learned that peak smoke values are highest during this phase of the Federal Smoke Test, and average acceleration smoke values also are usually (but not necessarily) highest during this phase of the test.

The last 35 seconds of the Federal Smoke Test Cycle requires that the dynamometer load be increased so that engine RPM drops from rated speed to intermediate speed (~60 percent of rated speed) in 35 seconds, while the throttle position is held at wide-open during the entire period. This phase is essentially identical to the "lug-down" test cycle in terms of the throttle position and engine RPM as a function of time. Obviously, the "lug smoke" is the value recorded during this phase of the Federal smoke cycle.

The standing acceleration test has no exact parallel in the Federal Smoke cycle, but the test is closely linked to the rolling acceleration test. Engineering analysis suggests the near equivalence of smoke opacity on the two test cycles.

The snap acceleration test cycle, currently used by the ARB Roadside Smoke Inspection Program, is not directly related to any specific mode in the Federal Smoke Test Cycle, although the engine is accelerating rapidly at full throttle, under its own inertia load. Typically, such acceleration requires about one to two seconds to reach rated speed, starting from curb idle. This contrasts to the five seconds required to reach 85 percent of rated speed in the Federal Smoke cycle. However, the test cycle has been endorsed by engine manufacturers as part of the SAE J1667 test.

The effectiveness of a test procedure can be assessed in two ways.

1. The interrelationship between the test procedures and Federal test procedures can be examined to address the comparability issue.

2. Data on failure rates and the types of malperformance identified can be examined for each of the four tests considered.

The second method is more directly relevant to an inspection program, and is described below.

B.3 Malperformances in Diesel Engines

Surveys of diesel engines in the field and the expertise of the manufacturers' service organizations have allowed a comprehensive compilation of the typical malperformances that occur in diesels which lead to high smoke or gaseous emissions. In general, malperformances in the intake air system or the fuel system are the most common causes, although an engine in very poor mechanical condition can have sufficient loss of lubricating oil or compression to cause high smoke and gaseous emissions.

Based on discussions with manufacturers, the data in Table B-1 is a comprehensive listing of malperformance in diesel engines, and their frequency of occurrence as measured in a qualitative form. In the air intake system, dusty air filters and leaky turbocharger oil seals are relatively common, while more serious turbocharger damage or problems with the intercoolers are quite rare. Valve system timing and valve leaks are also infrequently observed; if a valve leak is significant, then the cylinder can stop functioning completely due to loss of compression and the resulting vibration will make the vehicle not driveable.

Table B-1 Effect And Frequency Of Component Malperformances In Heavy-Duty Diesel Engines

Components	Effect on Emissions	Frequency
Air Filter (Dirty)	Can increase full throttle smoke considerably	Extent of blockage varies, but is relatively common
Turbocharger seals worn	Can leak oil and cause smoke/HC	Minor oil leaks are common in older engines
Turbocharger damage	Significant damage is catastrophic, but minor damage has little effect on emissions	Minor nicks on turbo are common
Intercooler internal leaks	Coolant Induction can cause white smoke	Rare
Intercooler plugged	High heat will increase smoke and NOx	Unknown
Valve Timing	Incorrect timing can have minor emissions effect	Rare
Valve Leaks	Loss of compression and high smoke. Engine is hard to start.	Relatively rare, self correcting due to poor startablilty
Governor RPM setting	Increased RPM setting can increase HC/smoke in some trucks	Common among independent trucks
Max. Fuel. Stop setting	Increased HC/smoke at full throttle	Relatively rare
Injection timing	Advance causes increased NOx retard increase HC/smoke	Relatively rare
Throttle Delay/Air-Fuel Ratio Control	Causes excessive smoke during acceleration	Common among independent trucks
Worn injector spray holes	Increase smoke/HC	Occurs in older trucks
Injector plugging	Asymmetric spray can cause increase smoke/HC	Occurs in older trucks
Injector tip cracking	Excessive smoke, but is catastrophic to engine	N/A
Incorrect injector size	Effect can vary, but HC and smoke increase with increasing injector size	Could be common in replacement of injectors
Worn piston rings	High smoke from low compression/oil leak	Relatively rare, as vehicle is hard to start
Leaking valve seals	Blue smoke from oil consumption, HC increased	Unknown
Wrong part numbers	Minor effects if mismatch Is not severe	Unknown, but could be a problem with aftermarket parts

Source: EEA report to the California Bureau of Automotive Repair “Feasibility Study for an I/M Program for Heavy Duty Vehicles”, January 1993

On the fuel system side, governor tampering and tampering with the "air-fuel ratio control" (also known as throttle delay) are widely acknowledged as the most common forms of tampering, although even these have been declining in recent years. Advancing the maximum fuel stop or advancing the injection timing is rarer as these are not easily accomplished, but advancing injection timing may occur in the 1977-1984 engines when some engines were designed to meet NOx standards by injection timing retard.

Problems with injectors vary in severity, as most injectors are replaced only once between rebuilds, if at all. Fouling of injectors or spray hole erosion may be common in older trucks but serious injector problems will, if left uncorrected for a long time, lead to serious engine damage. An incorrect injector size could be used during replacement or rebuild, but this may simply raise the maximum fuel delivered to another certified rating level (i.e., it may result in the engine producing more horsepower, but with no increase in emissions per HP produced). However, in some cases, the mismatch between the existing turbo-charger/intake system and the up sized injector may be so severe that high smoke could result.

The use of incorrect parts (i.e., incorrect size or part number) during repair or rebuild can similarly result in higher smoke in some cases, but it is believed to be relatively rare. Very worn engines with leaky valve guides, or worn piston rings, are likely to be found near the end of the engine's useful life but a certain fraction of engines on the road are always in this range of their useful life.

A qualitative estimate of the impact on air quality can be obtained by combining the frequency of occurrence and the emissions impact. This would suggest that the biggest impact on air quality would be caused by dirty air filters, worn or plugged injectors and incorrect fuel injection system setting for the governor and throttle delay. An analysis of repairs in the Denver study [1] provides detailed data on 71 trucks and Table B-2 provides the distribution of repairs observed (note that many trucks had more than one type of repair):

Table B-2 Denver Repair Frequency Data

Repair Type	Percent of Trucks
Air Filter	12.9
Turbocharger	4.3
Air Fuel Ratio Control	71.4
Injectors	37.1
Other Intake	4.0
Injection Pump Settings*	37.1
Valves/Overhead Adjustment	7.1/30.0
Worn Engine (Rebuild)	6.7
Injection Timing	5.7

*Source: Denver Regional Air Quality Council, March 1998

Of course, the observed distribution is also a function of the fact that Denver HDV I/M program uses the snap-acceleration test, which may preferentially fail certain types of malperformances. These issues are considered in more detail below.

B.4 Comparison Between Acceleration Tests

Three of the four test cycles considered are acceleration tests, where the engine RPM increases from idle to rated RPM in a time space of about 2 seconds or less for the snap idle test to 5 seconds or more for the standing and rolling acceleration tests. If there is a relationship between measured peak smoke values from the different tests, the tests can be used interchangeably, and the test utilized for the inspection program can be chosen based on convenience and other operational considerations.

Data to explore the potential relationship between the three tests are based on pilot programs conducted by ARB [2]. ARB conducted measurements with the rolling acceleration test, the standing acceleration test and the snap acceleration test using the SAE J1243 (not the new J1667) measurement method.

The ARB also conducted a repair program in conjunction with the pilot program, where trucks with relatively high smoke emissions on any or all of the tests were randomly selected for repairs. At the repair location, the selected trucks were retested using all three tests prior to any repair being performed. In these cases, the tests were conducted with mechanics or ARB personnel driving the trucks.

The roadside pilot program obtained data on 310 trucks, but many of the data records were incomplete due to errors in performing the test or due to driver non-participation, and a final data set of 256 records were obtained that contained at least one good record for both the snap idle test and the rolling acceleration test. Analysis of the data first utilized the concept of averaging

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[1] EEA Inc., Analysis of Potential Changes to the Colorado Heavy-Duty Diesel Inspection Program, Denver Regional Air Quality Council, Denver CO, March 1998

[2] EEA Inc., Proposed Roadside Smoke Test Procedures and Opacity Standards for Heavy-Duty Diesel Trucks Technical Support Document, California Air Resources Board, June 1990

two of three most consistent readings where all three test repetitions were available, so that test performance error and variability were minimized in the analysis of comparability.

In order to support the hypothesis that peak smoke opacity on the snap test was related to peak smoke opacity on the rolling acceleration test, linear regression was performed on the average of the two most consistent opacity values measured by the opacimeter on each test. If these values are labelled ASM (for Average Snap Metered) and AAM (for Average Acceleration Metered) the regression obtained was:

$$\underset{}{ASM} = \underset{(1.489)}{8.102} + \underset{(0.030)}{0.923}\ AAM \qquad (r^2 = 0.791)$$

where the numbers in parentheses are standard errors of the coefficients. The regression indicates that nearly 80 percent of the variation in rolling acceleration smoke between trucks is explained by the snap smoke.

Another data source is the repair sample, where trucks were tested before repair. Here, the acceleration test smoke was measured only visually, and the snap test smoke measured both visually and with a meter. These tests were performed under more closely controlled conditions, and the regression result was

$$ASM = \underset{(2.399)}{1.561} + \underset{(0.033)}{0.978}AAV \qquad (r^2 = 0.926)$$

where AAV corresponds to the highest rolling acceleration peak smoke measured visually. The high r^2 is indicates that a very good correlation was obtained from this sample.

Hence, it is reasonable to conclude that the peak smoke opacity measurements in the two tests are good surrogates for each other, if the potential for test error is well controlled. In particular, it appears necessary to ensure that the accelerator pedal is depressed to full throttle position as rapidly as possible during the conduct of either test. This aspect of the test offers the drivers a significant opportunity to reduce smoke by "feathering" the throttle, i.e., by not depressing it quickly and/or not depressing it to the maximum position.

The ACOR (SAE J1667) test procedure is identical to the one used in the above ARB conducted tests, but the response time specifications of smoke meters affect readings. Studies conducted by ARB and the SAE J1667 committee show that the older J1243 method based smoke opacity reading was, on average, 4 percentage points higher than the J1667 reading for pre-1991 mechanically fuel-injected engines. Tests on 1991 and later electronically controlled fuel injection system equipped diesel engines showed occasional large divergences between the two methods. It was found that electronically controlled engines could often emit a very sharp, short duration smoke puff during the snap acceleration test that registered relatively high values of opacity on the older J1243 measurement method, but were attenuated when using the J1667 method. However, there also appears to be other problems related measuring to smoke from electronically controlled systems, discussed in later sections.

B.4.1 Lug-Down Test

The lug-down test is now being used in Arizona and Colorado. Arizona performs the "lug-down" from rated speed to 80 percent of rated speed, while Colorado performs the lug-down from rated speed to 90 percent, 80 percent and 70 percent and measures smoke opacity at all three points. Both programs enforce a 20 percent opacity standard for turbocharged diesels, but Colorado has a higher 35 percent standard for naturally aspirated diesels.

However, in both programs, failure rates are relatively low; 3 percent of naturally aspirated diesels fail and 1 percent of turbocharged diesels fail the Colorado inspection (although some may use the lug-down test). At the 20 percent opacity standard in Arizona, test results from 1997 calendar year show that 4.6 percent of vehicles fail the inspection.

Since the lug-down is conducted at full-load continuous operation, it can be useful in spotting

- air filter restrictions
- injector problems
- leaking or worn valve guides and piston rings
- the maximum fuel stop set to permit overfueling.

On the other hand, the lug-down test cannot spot transient overfueling problems caused by an incorrectly calibrated fuel injection pump or by misadjustment of the throttle delay. A problem also exists with the choice of pass/fail cutpoint. The lug smoke certification standard is 15 percent opacity, but the actual certification levels are typically below 10 percent for most engines. Hence, a 20 percent standard is capable of detecting only the highest emitters, partly accounting for the low failure rate observed.

In 1991, Arizona performed a comparative analysis of the measured smoke opacity on the snap test and on the lug-down test. The procedure for the snap test was identical to the one used in California's previous roadside vehicle inspection program. Using the California standard of 55 percent opacity for the snap test, a failure rate of 25.7 percent was obtained with a sample of 1282 trucks. The lug-down failure rate for the same sample at the Arizona standard of 20 percent opacity was 7.3 percent. Interestingly, not all trucks failing the lug-down test failed the snap test. The distribution was as follows:

Table B-3 20% Standard Lug-down Test

Test Result	Pass Snap	Fail Snap
Pass Lug	69.7	23.2
Fail Lug	4.7	2.5

Nearly 2/3 of all trucks failing the lug-down test passed the snap test, indicating that the two tests identify different malperformances.

An analysis of the Arizona data was also performed using the ARB's future standard of 40 percent opacity, and the Federal lug smoke standard of 15 percent opacity. In this case, the failure rate on the snap test increases to 36.3 percent and the failure rate on the lug test to 10.5 percent and the overlap is as follows:

Table B-4 15% Standard Lug-down Test

Test Result	Pass Snap	Fail Snap
Pass Lug	57.6	31.9
Fail Lug	6.1	4.4

As can be seen, about 60 percent of trucks failing the lug test pass the snap test, indicating that the lug-down test has some incremental effectiveness even at more stringent standards. It is interesting to note that the Colorado failure rate (at 15 percent opacity standard) is about 12 percent, consistent with Arizona data.

EEA conducted a study of the effectiveness of the lug-down and SAE J1667 based snap-acceleration test in the metro-Denver area [footnote *1*]. Results from this study on 80 HDDVs tested supplemented by the Colorado School of Mines data on 16 HDDVs are even more interesting. Figure B-1 shows a scatterplot of the relationship between the Lug-down test opacity and J1667 opacity for the sample, and there is little visual evidence of any correlation. Using a J1667 test pass/fail cutpoint of 55 percent and 40 percent for pre-1991 and 1991+ model year HDDVs, and a lug test pass/fail cutpoint of 15 percent and 10 percent, the failure rates are shown in Table B-5.

Table B-5 Comparative Failure Rates

Test	Percent Failed
Snap	20
Lug-Down	12
Both	0

The complete lack of overlap between the failures on the two tests is quite unexpected but is potentially because of the small sample of 96 trucks.

There are some additional test issues related to 1991 and later trucks for either the J1667 or lug-down tests. As noted, certification smoke values are below 10 percent opacity for peak smoke and are below 5 percent opacity for lug smoke. These low levels indicate that very stringent standards may be necessary to identify malperformance in 1991 and later HDDVs. Separately, in HDDVs equipped with electronically controlled engines, the electronic control system can also be configured to detect a "snap-acceleration" and cut fuelling so that SAE J1667 based opacity may be low but actual acceleration smoke may be high.

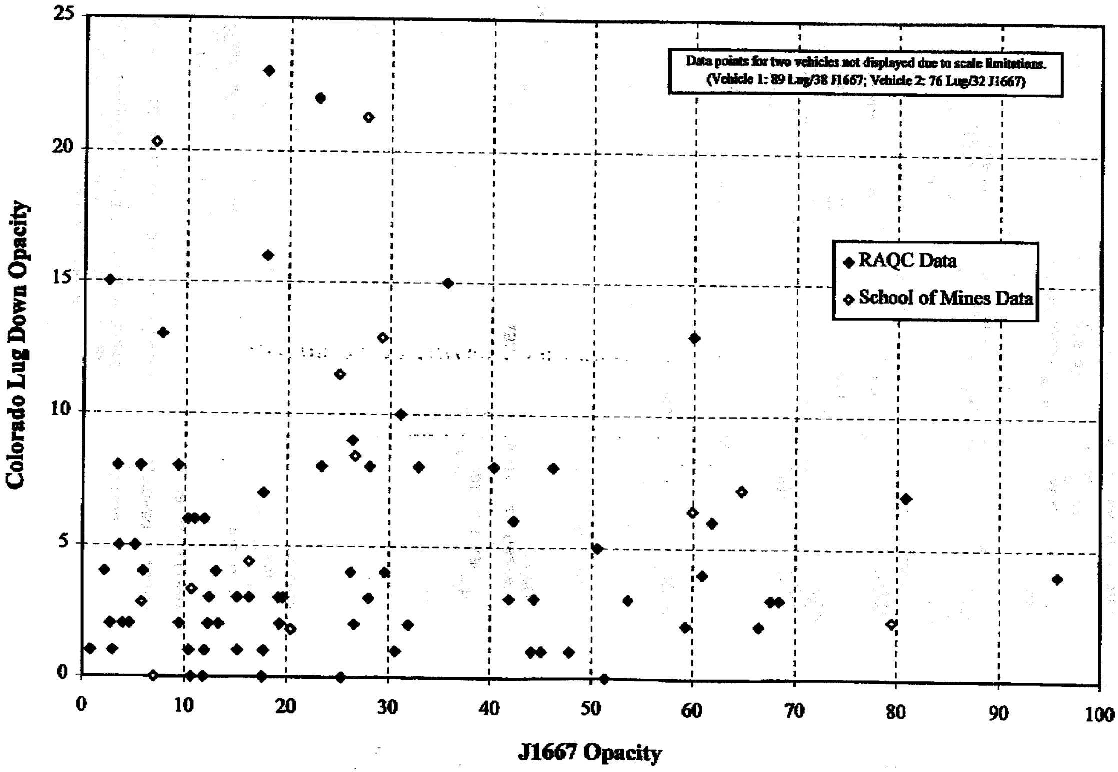

Figure B-1 Scatterplot

B.5 Visual/Functional Inspection of Components

As an alternative or a complement to the smoke tests discussed, it is possible to visually inspect some of the critical components that can malperform, or functionally check the components for malperformance. The inspection should be carried out on all of the components identified in Tables B-1 and B-2 that can malperform or be tampered with. A brief overview of the inspection process and difficulty of conducting the inspection is provided below by component. These procedures are based on information provided by the staff of Caterpillar, Cummins, Navistar, and DDC, who collectively account for over 80 percent of total market for heavy-duty diesel engines.

<u>Air Filter</u>

Blockage of the air filter cannot be visually ascertained, but a functional check is simple. The check requires a pressure drop measurement at full throttle (either no load or full load); many truck models provide a fitting to which a manometer (pressure gauge) can be attached. Most manufacturers recommend replacement of the filter if the pressure drop exceeds 15 inches of water. In general, the air filter is readily accessible in most trucks.

<u>Turbocharger</u>

A visual inspection of the turbocharger is time consuming, as it requires disassembly of the intake system ahead of the turbocharger. Once the intake system is disassembled, the turbocharger can be inspected to check:

- if the turbine wheel turns freely when rotated by hand
- if the compressor is damaged physically
- if the compressor edge is making contact with the housing
- if there is physical evidence of oil seepage on the housing wall

A competent mechanic can easily inspect for turbocharger damage or oil leakage from the seals but the visual procedure can take 45 minutes to 1 hour, mostly for intake system reassembly and disassembly. A functional check of the turbocharger can be done either at no load or full load, by accelerating the engine to rated RPM, and checking the boost on the truck boost gauge or with a manometer. However, this test does not reveal oil seal leaks.

<u>Intercoolers</u>

External plugging of the intercooler can be spotted visually, as it usually is due to dust or debris. Internal air leaks however, are difficult to spot, especially if they are small. A loss of boost pressure (see turbocharger) is a possible indication; in jacket water-type intercoolers, there may be coolant loss to the intake air system. Diagnosing these defects require disassembly of the intercooler from the engine for a separate check, which is time consuming.

<u>Governor</u>

The ability to reset the governed speed varies from engine model to engine model, e.g., it is quite difficult in a Navistar engine, but relatively easy in a Cummins engine. A visual check is not applicable. The functional check is simple - the engine can be accelerated to rated speed by holding the accelerator pedal to full throttle position with the transmission in neutral. The engine RPM can be measured directly from the truck tachometer (but this may be unreliable or incorrect) or by plugging an external tachometer into the engine if a port is available. If no port is available, engine RPM can be read from the crankshaft pulley with a strobe light. If engine RPM exceeds rated RPM + governor droop, then it can be concluded that the governor is misadjusted. Electronic governors can be checked by the internal diagnostics in the engine control unit.

Air-Fuel Ratio Control/Throttle Delay

A visual inspection is only possible to check if the cover-plate on the control has been removed (Cummins), the seals on the adjustment tampered (Caterpillar) or the entire throttle delay assembly disconnected (DDC). Any of these actions, however, can be time consuming as access can be limited depending on truck type and engine rating. For example, visually inspecting the throttle delay in DDC engines requires that the intake air system be disassembled and the valve covers removed. A detailed functional inspection is also time consuming and requires a trained technician familiar with the specific manufacturer's models.

Fuel Injection Pump Calibration

Many engine models use the "pump and line" type of fuel injection system, where all of the high pressure system controls for fuel injection are within the pump body. A check of the pump calibration and injection timing is time consuming and requires a pump calibration stand, which is generally available only in specialized repair facilities or dealerships. There are similar difficulties in the inspection or the calibration of unit injector type systems used in DDC and Caterpillar 3176 engine models, which requires removing the valve covers and checking the injector linkages ("overhead adjustment"). Hence, these types of checks cannot be included in periodic inspection.

Injectors

Checking an injector for fouling or spray hole erosion requires removal of the injector from the engine and mounting on a flow stand; no visual inspection is possible. Removal of injectors and their checking and remounting is time consuming and expensive. Hence, this check cannot be recommended as part of an inspection. However, a single plugged or non-functional injector in an engine can be spotted with a less time consuming procedure. This involves loosening the inlet line in pump and line systems or disabling the rocker arm in unit injector systems so that the injector is disabled. Electronic injection systems are now being equipped to cut off fuel flow to one injector at a time as part of the diagnostics, so that this test can be done relatively easily. If injection cut-out makes no difference to engine operation or even improves the smoothness of operation, it can be concluded that the particular injector is defective. The procedure, however, can take up to two hours for mechanically controlled engines, and is not considered suitable for an inspection program.

Electronic Controls

These controls obviously cannot be visually inspected. However, all manufacturers offering electronic fuel system controls now offer off-board diagnostic equipment that are, unfortunately, unique to each manufacturer. It is relatively simple to check the electronic system with the diagnostic equipment, but different equipment is required for each manufacturer's engines. Hence, these checks will be difficult to implement for centralized programs, but may be possible for self-certification by fleets. The EPA and SAE are working on standardized diagnostics systems, but no common system exists now.

Poor Mechanical Condition

Several checks are possible for a diesel engine. A compression check is not easy, however, as this requires removal of an injector. A blow-by check can be conducted by attaching an orifice and tube to either the crankcase breather tube or oil fill tube. The test must be conducted at rated RPM, and can be conducted at either no load or full load conditions. A high pressure drop across the orifice indicates excessive blow-by, which, in turn, indicates worn pistons/rings. The test can be conducted in 20 to 30 minutes. Another potential indicator of a worn engine is blue smoke at light loads, indicating oil burning, but it is difficult to set a standard for blue smoke. Rough engine operation or starting problems can also indicate a worn engine if the injectors and injection pump are not malfunctioning.

Table B-6provides a summary of the possibility and ease of either a visual or functional inspection. It is clear that there are some checks that can be easily carried out, while others are quite difficult.

The ARB pilot program included an inspection of the engine for evidence of tampering and also for examination of the state of the engine (dirty, oil leaks, etc.). However, the engine condition made it difficult in many cases to determine even the engine type. In a limited number of cases, the ARB field staff were unable to obtain access to the engine to perform a visual examination due to stuck hood releases or limited access "cabover" designs. In particular, difficulty in obtaining model year information has consequences for the type of standards that can be set for inspection. The frequent rebuilding of heavy-duty diesel engines and the lack of accessible engine tags lead to difficulties in establishing engine vintage and rating information.

Table B-6 Potential For Visual Or Functional Check Of Critical Components

Component	Visual	Functional	Test Mode
Air Filter	No	Easy	Pressure drop at rated speed
Turbo Seals	Easy, but requires intake disassembly	No	At rest, inspect for oil leak
Turbo Damage	Easy, in some cases	Easy	Visual: at rest. Functional; full load check of turbo boost
Intercooler Plugged	Easy	Difficult	Visual: at rest
Governor Tampering	No	Easy	No load or full load maximum RPM
Max. Fuel Stop	No	Difficult	Requires removing injection pump
Air-Fuel Ratio Control or Throttle Delay	Difficult, for presence of throttle delay only	Difficult	As above for most engines
Injectors	No	Very difficult	Requires removal of injectors
Injection Timing	Relatively easy	Difficult	Check for alignment of timing marks
Electronic Control	No	Easy if equipment is available	Requires dedicated test equipment
Engine Worn	Uncertain	Relatively easy	Blow-by check at full load

The tampering inspection focused on the injection pump seals and/or the smoke puff limiter. The puff limiter information on the inspection form focused on Cummins engines which have a cover plate for the air fuel ratio control (puff limiter in layman terms) adjustments. If the plate was bent, the engine was considered as tampered. On average, tampered vehicles had higher smoke opacity values than non-tampered vehicles.

However, the average emissions do not indicate the responses of individual vehicles within each sample subset. Many trucks classified as not tampered had high smoke emissions, while many trucks classified as tampered had low smoke emissions. It is well known that many truckers perform repairs on their trucks by themselves, and there are legitimate reasons for their removing pump seals or bending the cover plate. As a result, these visual indicators can be regarded as necessary conditions but not sufficient conditions to conclude that a truck is tampered. In addition, the inability of ARB field staff to access a very large percentage of these inspection items suggests the difficulty of including these items in a centralised inspection program, and possibly in a decentralised one.

The issues regarding governor tampering are similar. Many trucks are not equipped with a tachometer, while field staff noted that many trucks had inoperative tachometers. This accounts for much of the unavailable data on the maximum no-load RPM, while obtaining the rated RPM involved problems similar to those described above for engine type. However, smoke emissions for engines with active RPM higher than rated RPM were no higher than smoke emissions for engines where the governor was tampered. The lack of correlation is not necessarily difficult to understand, since increased engine RPM can (in some engine types) lead to increased turbocharger boost and reduced smoke. The data, therefore, does not support the viability or usefulness of a governor tampering inspection in a centralised program.

However, in a program where a mechanic can spend some time on the inspection, the following checks can all be accomplished in a 30 to 45 minute period:

- air filter pressure drop check
- turbo boost check
- governor check
- intercooler inspection
- blow-by check for worn engine
- electronic diagnostic check

In most cases, the mechanic performing the inspection must have access to engine specifications to determine the correct boost level and RPM, and have access to the correct electronic diagnostics for the particular engine model being inspected.

B.6 Conclusion on Inspection Options

The appropriate test procedure selected for the inspection program is a function of the program type, and also a function of the need to co-ordinate inspection requirements with requirements in neighbouring jurisdictions. The analysis presented in this section indicates the following:

- The rolling acceleration and snap acceleration tests provide peak smoke results that can be correlated, and are effective tests to identify a variety of common malperformances. The snap acceleration is the preferred method since the test is much easier to perform than the rolling-acceleration test.

- The lug-down test does not identify several common malperformances, but identifies some malperformances that the acceleration test and snap test do not. These malperformances are less common in the fleet but can have significant emissions impact. The lug-down test must be performed on a dynamometer, as the on-road procedure using the brakes does not appear to give equivalent results.

- Visual and functional checks of critical components that govern engine performance are possible in reasonable time (less than 1 hour) for a few components. It appears that six components with significant potential emission effects can be functionally inspected in a period of 30 to 45 minutes.

- The SAE J1667 procedure is the preferred method of implementing the snap acceleration based tests.

- A combination of two tests, such as the SAE J1667 and lug-down tests, are likely to provide more benefits than any single test.

- In the future, the advent of standardized electronic diagnostics systems may permit inspections that simply query the diagnostics for emission related malperformances. This type of inspection is not possible currently.

C. Correlation Between Opacity and Mass Emissions

Very few test programs have been conducted on in-use heavy duty trucks where emissions have been measured on both the EPA cycle and a range of short tests. The EPA chassis cycle that is arguably close to the engine certification cycle is the so called "Test D" cycle, although the lack of specificity on the truck loading requirements make the connection between certification cycles and the chassis cycle dependent on exactly how the test was set up. In 1999, the New York State Department of Environmental Conservation funded a set of tests of in-use trucks in New York City that examined the correlations between the D Test and other cycles that are easier to perform for an inspection program [[3]]. In total, the program tested 37 vehicles on 184 individual test cycles. Although there were nine distinct test cycles represented, five (the Routized Test D, the 20 mph steady state, the 40 mph steady state, the snap acceleration, and the WVU 5 Mile Route cycles) account for all but 14 of the test cycles performed. These five cycles, in conjunction with the lugdown cycle, can provide a basis for assess the link between short tests and mass emissions.

C.1 Test Cycle Relationships

The New York study employed a variety of emission test cycles, including both transient, steady state, and I/M type cycles, and thus presents an opportunity to investigate not only the influence of the specific test cycle on measured emissions, but also the ability of any included cycle to predict emission rates under one of the other included cycles.

Given the various test cycles performed for the study, comparative statistical analysis was performed for the Routized Test D (a chassis version of EPA's engine test method), the WVU 5 Mile, the 20 mph steady state, the 40 mph steady state, the lugdown, and the snap acceleration cycles. The Routized Test D cycle is employed as the "gold standard" throughout this analysis and all other cycles are evaluated in terms of their ability to predict Routized Test D emission rates. This is not meant to impart some "official standing" to the Routized Test D cycle that does not apply to the other cycles evaluated, simply that the number of analysis permutations can be controlled by assigning one cycle as the "target" cycle and evaluating all other cycles relative to this target. Should relations between any two cycles demonstrate significance with the target cycle, they can be assumed to also have a significant relationship with each other.

A simple linear regression technique was employed and provides an initial indication of not only whether a significant relationship might exist, but also the strength of that relationship. For this study all test cycle relationship analysis is based on linear regression analysis of the form:

g/bhp-hr over Routized Test D cycle = a + b (g/bhp-hr over comparative cycle)

Table C-1 presents the results of the analysis. As indicated, 19 of the 20 comparative cycle coefficients ("b") are significant at a 90 percent level of confidence. In fact, 16 of the 19 are significant at a 99 percent level of confidence. While this indicates that there is a significant directional relationship between emission species measured over the comparative cycle and the Routized test D cycle (excluding 40 mph steady state CO), the predictive ability of the comparative cycles varies substantially. The WVU 5 Mile Route cycle shows relatively good correlation for all emission species (r^2 = 0.71-0.87) indicating that an expansion of the test

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[3] EEA Inc., Documentation and Analysis of Heavy-Duty Diesel Vehicle Test Data, NY Dept. of Environmental Conservation, December 2000

program dataset to include emission rate data from other studies collected over the WVU 5 Mile Route cycle may be a viable alternative.

Conversely, both the 20 and 40 mph steady state cycles demonstrate poor correlations for all emission species. Together, the clearly significant species coefficients combined with the poor overall correlations reflect a situation where a strong directional trend exists in combination with a large degree of scatter. Therefore, while it is possible to make inferences on the overall Routized Test D cycle emission rate from emission rates generated over the steady state cycles (again excluding 40 mph steady state CO), the accuracy of these inferences will be highly uncertain for any specific truck. While it may be possible to draw broad-brush conclusions from the steady state data, enforcement type decision-making will be limited. Figure C-1 graphically depicts this situation for 40 mph steady state NO_x measurements (which exhibit the strongest correlation ($r^2 = 0.62$) of any steady state emission species).

For the lugdown cycle PM and CO, the situation is similar to that for the steady state cycles. Species coefficients are significant at 90 percent confidence, but overall correlation is poor, with r^2 values of only about 0.5. Figure C-2 graphically depicts the PM relationship, where the degree of variability is obvious. However, the situation for NO_x and HC more closely reflect that of the WVU 5 Mile Route cycle, with both relations showing strong species coefficients and good correlation (in fact, excellent correlation for HC).

Figure C-3 graphically depicts the NO_x relationship, where despite the limited sample size, the correlation of Routized Test D cycle predictions with observations is obvious. While it would be advantageous to assemble a larger dataset to confirm this relationship, it appears that the lugdown test can be used to accurately predict transient cycle NO_x emissions.

The near-zero load snap acceleration cycle behaves much like the steady state cycles, exhibiting strong coefficient significance but poor correlation. Figure C-4 depicts the relationship for PM. Interestingly, despite the poor correlation, it appears that much of the variability derives from snap acceleration measurements above 1 g/bhp-hr. It may, therefore, be possible to draw broad conclusions from snap acceleration measurements, but the usefulness of this ability is uncertain. There are currently no instances where mass emissions data are routinely collected over the snap acceleration cycle. Moreover, it seems unlikely that in instances where mass emissions data were being collected, that the snap acceleration cycle would be considered the most appropriate test cycle. Therefore, while providing additional evidence that relative emission rates exhibit a surprising degree of test load independence, further use of the snap acceleration mass emission rate data appears limited.

Table C-1 Statistical Correlations Between Test Cycles

Species	Obs	a	Sig_a	b	Sig_b	r^2	Sig_F
Routized Test D vs. WVU 5 Mile (5 Mile independent)							
PM	32	0.02	0.31	1.10	0.99	0.71	0.99
CO	32	-0.17	0.56	1.15	0.99	0.74	0.99
NO_x	32	0.10	0.13	0.89	0.99	0.71	0.99
HC	32	-0.03	0.84	0.93	0.99	0.87	0.99
Routized Test D vs. 20 mph Steady State (20 mph independent)							
PM	27	0.16	0.99	0.56	0.99	0.22	0.99
CO	27	0.69	0.81	0.47	0.94	0.14	0.94
NO_x	27	2.57	0.99	0.40	0.99	0.38	0.99
HC	27	-0.03	0.41	0.74	0.99	0.60	0.99
Routized Test D vs. 40 mph Steady State (40 mph independent)							
PM	30	0.08	0.91	0.89	0.99	0.50	0.99
CO	30	1.23	0.99	0.37	0.52	0.02	0.52
NO_x	30	1.86	0.99	0.56	0.99	0.62	0.99
HC	30	0.12	0.99	0.43	0.99	0.35	0.99
Routized Test D vs. Lugdown (Lugdown independent)							
PM	7	0.12	0.83	0.33	0.92	0.49	0.92
CO	7	-0.27	0.29	2.61	0.93	0.52	0.93
NO_x	7	1.54	0.91	0.58	0.99	0.79	0.99
HC	7	-0.04	0.94	1.70	0.99	0.99	0.99
Routized Test D vs. Snap Acceleration (Snap independent)							
PM	30	0.13	0.99	0.28	0.99	0.55	0.99
CO	30	0.26	0.72	0.18	0.99	0.64	0.99
NO_x	30	2.09	0.96	0.62	0.99	0.29	0.99
HC	30	0.12	0.97	0.10	0.99	0.22	0.99

"Sig_x" indicates the statistical significance of the parameter "x."

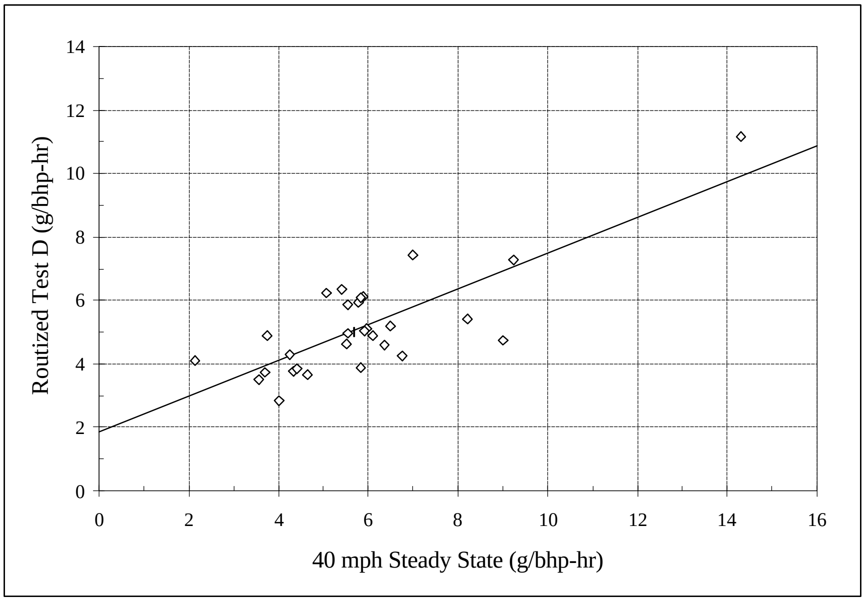

Figure C-1 Routized Test D vs. 40 MPH Steady State, NO_x

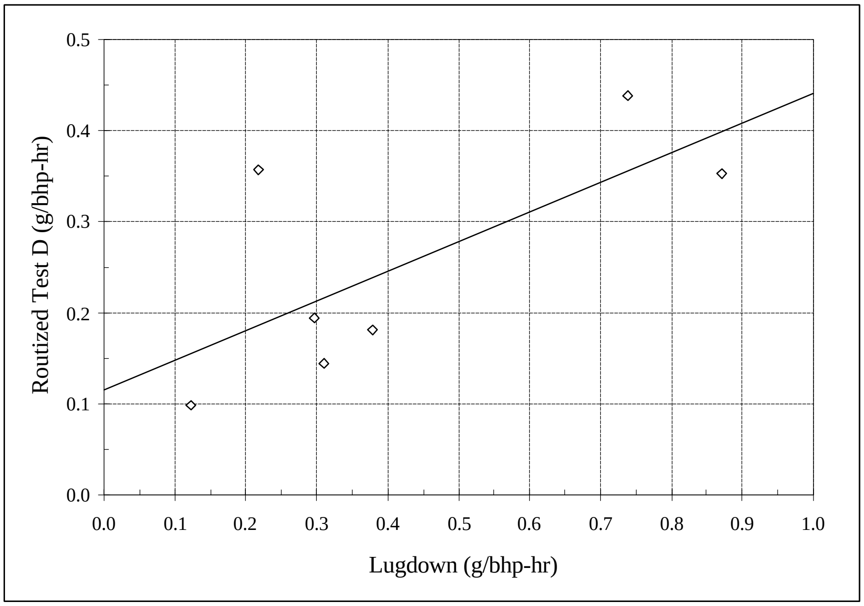

Figure C-2 Routized Test D vs. Lugdown, PM

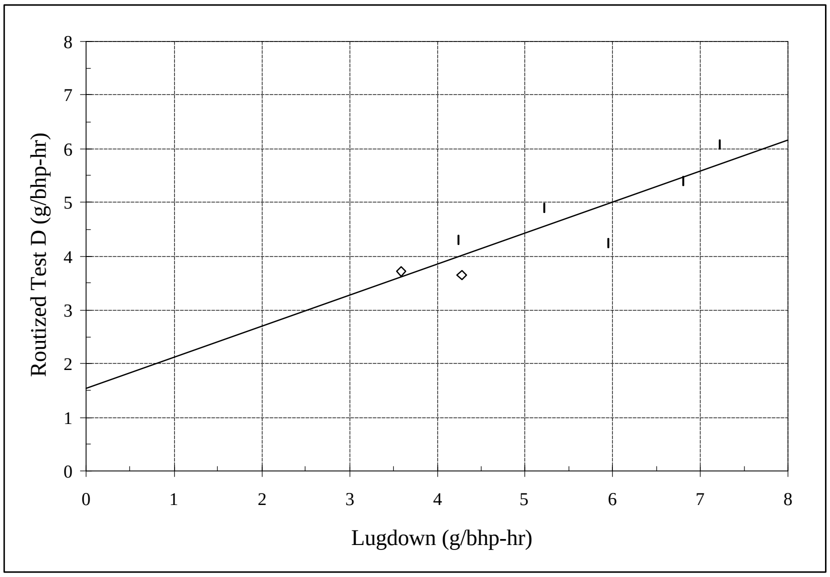

Figure C-3 Routized Test D vs. Lugdown, NOx

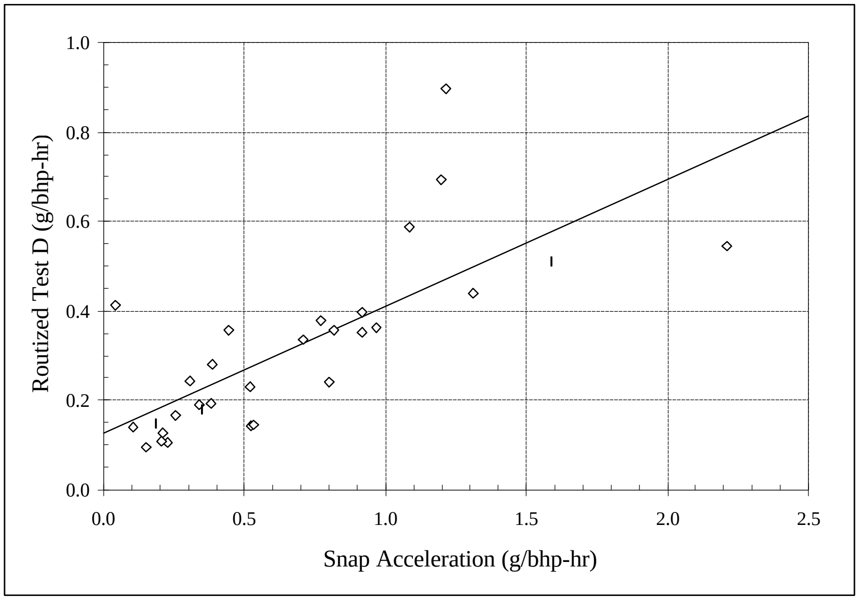

Figure C-4 Routized Test D vs. Snap Acceleration, PM

C.2 Correlation with Emissions Species

Given difficulties in the measurement of diesel PM, the question can be raised whether it is possible to predict PM emission rates using surrogate emission species such as CO. Work investigating this potential was undertaken as part of research undertaken for New York State. The program assessed the Routized Test D cycle data as well as both 20 and 40 mph steady state data. For the Routized Test D cycle, NO_x versus CO data was also examined under the premise that any relationship between PM and CO would also imply a relationship between NO_x and CO given the known relationship between PM and NO_x. Finally, the relationship between snap acceleration cycle PM and opacity data was examined to determine the potential for direct PM reductions under an opacity-based inspection program.

Table C-2 presents the results of the analysis between the measured emissions species of the Routized Test D cycle. Figure C-5 and Figure C-6 graphically present the strongest model year group relations for PM and NO_x respectively.

Table C-2 Inter-Species Relations For The Routized Test D Cycle

Model Year Group	Obs	a	Sig_a	b	Sig_b	r^2	Sig_F
PM versus CO (CO independent)							
Pre-1990	6	0.37	0.90	0.0528	0.67	0.24	0.67
1990-1993	9	0.31	0.98	0.0540	0.58	0.10	0.58
1994 and Newer	17	0.10	0.98	0.7777	0.96	0.24	0.96
NO_x versus CO (CO independent)							
Pre-1990	6	4.07	0.95	0.8948	0.90	0.54	0.90
1990-1993	9	4.05	0.99	0.3041	0.51	0.07	0.51
1994 and Newer	17	5.36	0.99	-0.4286	0.65	0.06	0.65

"Obs" indicates the number of observations in the dataset. "Sig_x" indicates the statistical significance of the parameter "x."

For PM, a significant relationship between measured CO and PM over the Routized Test D cycle was found only for the 1994 and newer model year group. The coefficient for CO was significant at a 96 percent level of confidence, but the range of variability observed in the data is extensive as shown in Figure C-5 and as indicated by the poor correlation coefficient (r^2 = 0.24) of the regression. More importantly, the variability increases with measured emissions, so that high CO emissions are not a good indicator of high PM emissions. For example, in just the 17 vehicle 1994 and newer dataset that was analyzed for this report, there is about a ±70 percent variation in measured PM for similar CO measurements at about 2 g/bhp-hr. Pre-1994 vehicles exhibit no statistical relationship between PM and CO.

As shown in Table C-2 the correlation between measured CO and NO_x over the Routized Test D cycle is at least as poor as that for PM versus CO. Only the pre-1990 model year group indicates a relationship between measured CO and NO_x at a 90 percent level of confidence. However, even for this vehicle group the variation between predicted and measured emissions is large (r^2 = 0.54), although as indicated in Figure C-6, this variation is more constant across the range of measured CO than was the case for PM versus CO. For 1990 and newer model year vehicles, NO_x and CO are statistically independent.

Table C-3 and Table C-4 present the results of the analysis of steady state cycle PM versus CO. As was the case with the Routized Test D cycle, the statistical relationship between the species over both the 20 and 40 mph cycles is poor. The lone exception is for the 1990-1993 model year group under the 20 mph cycle, where a significant relationship with reasonable correlation (r^2 = 0.84) is observed. However, from Table C-3, it is obvious that the slope of this relationship is dictated by a single datapoint (3.3 g/bhp-hr CO, 0.82 g/bhp-hr PM). Removing that datapoint reduces the significance of the apparent relationship to zero (there is only a 4 percent level of confidence that the slope is nonzero). Therefore, based on the analysis dataset constructed for the New York study, it does not appear that CO emissions are a good predictor of PM.

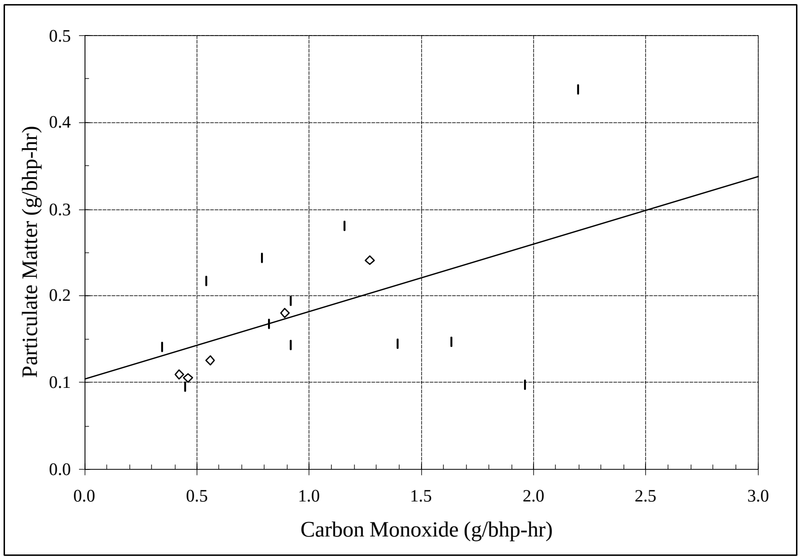

Figure C-5 Routized Test D PM vs. CO, 1994 And Newer Vehicles

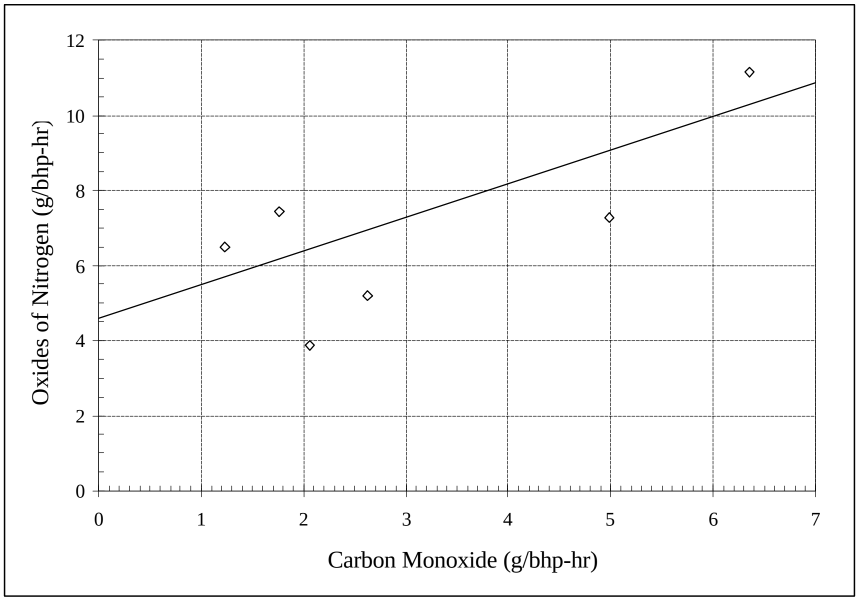

Figure C-6 Routized Test D NO_x vs. CO, Pre-1990 Vehicles

Table C-3 PM vs. CO (CO Independent) Over the 20 Mph Cycle

Model Year Group	Obs	a	Sig_a	b	Sig_b	r^2	Sig_F
Pre-1990	8	0.24	0.82	0.0351	0.41	0.05	0.41
1990-1993[1]	7	-0.34	0.96	0.3288	0.99	0.84	0.99
1990-1993[2]	6	0.17	0.76	0.0042	0.04	0.00	0.04
1994 and Newer	17	0.19	0.99	0.0039	0.10	0.00	0.10

"Obs" indicates the number of observations in the dataset. "Sig_x" indicates the statistical significance of the parameter "x."

1. Includes all data.
2. Excludes one datapoint that dominates the apparent relationships.

Table C-4 PM vs. CO (CO Independent) Over The 40 MPH Cycle

Model Year Group	Obs	a	Sig_a	b	Sig_b	r^2	Sig_F
Pre-1990	8	0.31	0.89	0.0334	0.15	0.01	0.15
1990-1993	9	0.33	0.97	-0.0189	0.14	0.00	0.14
1994 and Newer	18	0.13	0.99	0.0542	0.57	0.04	0.57

"Obs" indicates the number of observations in the dataset. "Sig_x" indicates the statistical significance of the parameter "x."

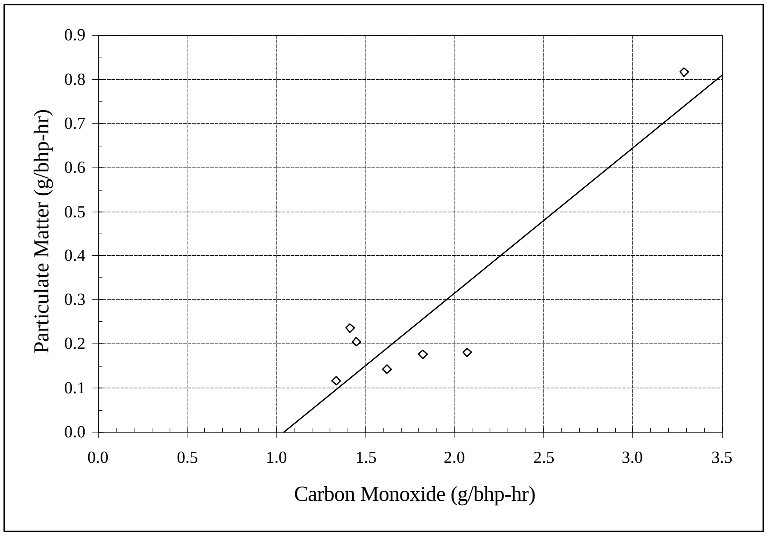

Figure C-7 20 MPH Steady State PM VS. CO, 1990-1993 Vehicles

Table C-5 presents the results of an analysis of PM emissions versus measured opacity over the snap acceleration cycle (using the J1667 "peak" measurement method). Although the study showed an interesting opportunity to investigate the direct relationship between opacity and PM mass, the importance of this relationship should not be overstated. As indicated in Table C-5 and Figure C-8, a very strong relationship between PM and opacity is evidenced for the pre-1990 (mechanically controlled) engine population. A statistically significant relationship also exists between PM and opacity for 1994 and newer engines, but variability is too high to allow accurate predictions of PM from measured opacity. These are important findings that provide a level of basic support for ongoing opacity-based efforts toward controlling PM emissions, but the statistical relationships (or more importantly perhaps the lack thereof) should be kept in perspective.

Table C-5 PM vs. Opacity Over Snap-acceleration Test

Model Year Group	Obs	a	Sig_a	b	Sig_b	r^2	Sig_F
Pre-1990	7	0.67	0.99	0.0147	0.99	0.89	0.99
1990-1993	9	0.66	0.88	0.0094	0.33	0.03	0.33
1994 and Newer	13	0.20	0.87	0.0324	0.96	0.33	0.96
"Obs" indicates the number of observations in the data set. "Sig_x" indicates the statistical significance of the parameter "x."							

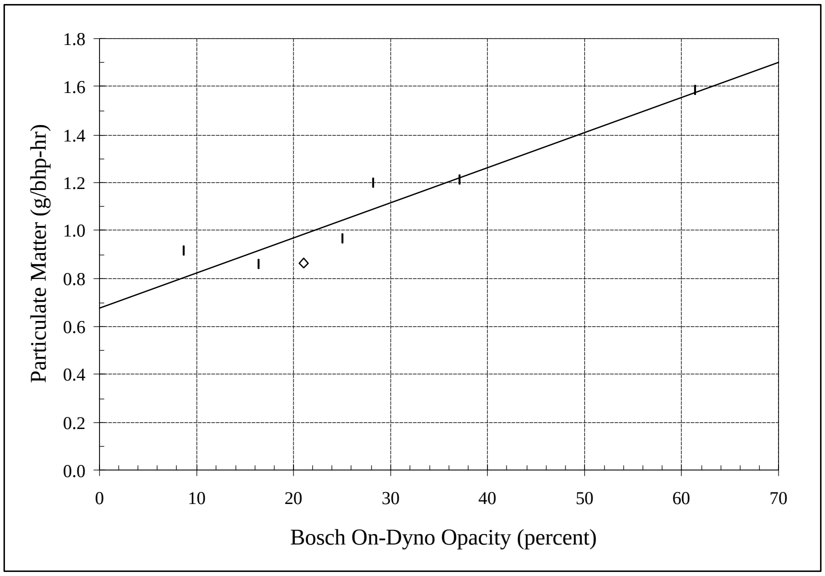

Figure C-8 Snap-Acceleration PM vs. Opacity, Pre-1990 Vehicles

Opacity-based inspection programs are not designed on the basis of any direct correlation between measured opacity and PM, but rather on the premise that opacity-based inspections can successfully identify malperforming vehicles. Depending on the specific malperformance, the level of PM reduction expected due to vehicle repair can vary, so it is not unrealistic to expect considerable variability in PM emissions across vehicles for any given opacity measurement. Nevertheless, repairs to opacity-increasing malperformances have consistently been demonstrated to reduce PM emissions (albeit at levels that vary with the specific malperformance). Therefore, the lack of a *direct* correlation between measured opacity and PM is *not* an indication that current efforts targeting the control of PM emissions through opacity-based inspection programs are misguided.

D. Malperformance Model Outputs

	Frequency of Occurance							**SNAP PASS RATE**							**LUG PASS RATE**				
Defect	1960-87	1988-90	1991-93	1994-01	2002-07	2008+	SNAP	1960-87	1988-90	1991-93	1994-01	2002-07	2008+	LUG	1960-87	1988-90	1991-93	1994-01	2002-07
														(WITH NOx)					
Timing Advanced	16.0%	20.0%	10.0%	5.0%	5.0%	5.0%	0	1.00	1.00	1.00	1.00	1.00	1.00	0.70	0.89	0.86	0.93	0.97	0.97
Timing Retarded	12.0%	8.0%	4.0%	2.0%	2.0%	2.0%	0	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00	1.00	1.00
Minor Injector Problems	20.0%	12.0%	6.0%	3.0%	2.0%	2.0%	0	1.00	1.00	1.00	1.00	1.00	1.00	0.10	0.98	0.99	0.99	1.00	1.00
Moderate Injector Problems	15.0%	8.0%	3.0%	1.0%	0.5%	0.5%	0.5	0.93	0.96	0.99	1.00	1.00	1.00	0.70	0.90	0.94	0.98	0.99	1.00
Severe Injector Problems	2.0%	1.0%	0.6%	0.3%	0.1%	0.1%	1	0.98	0.99	0.99	1.00	1.00	1.00	1.00	0.98	0.99	0.99	1.00	1.00
Puff Limiter MissSet	29.0%	21.0%	2.0%	0.0%	0.0%	0.0%	0.6	0.83	0.87	0.99	1.00	1.00	1.00	0.00	1.00	1.00	1.00	1.00	1.00
Puff Limiter Disabled	10.0%	5.0%	2.0%	0.0%	0.0%	0.0%	1	0.90	0.95	0.98	1.00	1.00	1.00	0.00	1.00	1.00	1.00	1.00	1.00
Maximim Fuel Stop Set High	10.0%	5.0%	1.0%	0.3%	0.1%	0.1%	0.5	0.95	0.98	1.00	1.00	1.00	1.00	1.00	0.90	0.95	0.99	1.00	1.00
Clogged Air Filter	22.0%	15.0%	8.0%	3.0%	3.0%	3.0%	0.5	0.89	0.93	0.96	0.99	0.99	0.99	0.30	0.93	0.96	0.98	0.99	0.99
Wrong/Worn Turbo	12.0%	6.0%	3.0%	0.5%	0.2%	0.2%	0.3	0.96	0.98	0.99	1.00	1.00	1.00	0.80	0.90	0.95	0.98	1.00	1.00
Intercooler Clogged	3.0%	4.0%	2.0%	0.5%	0.2%	0.2%	0	1.00	1.00	1.00	1.00	1.00	1.00	0.80	0.98	0.97	0.98	1.00	1.00
Other Air Problems	15.0%	7.0%	2.0%	1.0%	0.5%	0.5%	0.5	0.93	0.97	0.99	1.00	1.00	1.00	0.50	0.93	0.97	0.99	1.00	1.00
Engine Mechanical Failure	1.0%	0.5%	0.2%	0.1%	0.1%	0.1%	1	0.99	1.00	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.00	1.00
Excess Oil Consumption	5.0%	2.0%	1.0%	0.5%	0.3%	0.3%	0.5	0.98	0.99	1.00	1.00	1.00	1.00	0.50	0.98	0.99	1.00	1.00	1.00
Electronics Failed	0.0%	1.0%	0.5%	0.1%	0.1%	0.1%	1	1.00	0.99	1.00	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.00
Electronics Tampered	0.0%	5.0%	5.0%	3.0%	3.0%	3.0%	0	1.00	1.00	1.00	1.00	1.00	1.00	0.60	1.00	0.97	0.97	0.98	0.98
Catalyst Removed	0.0%	0.0%	0.0%	0.0%	0.0%	3.0%	0.2	1.00	1.00	1.00	1.00	1.00	0.99	0.80	1.00	1.00	1.00	1.00	1.00
Trap Removed	0.0%	0.0%	0.0%	0.0%	0.0%	3.0%	1	1.00	1.00	1.00	1.00	1.00	0.97	1.00	1.00	1.00	1.00	1.00	1.00
EGR Disabled	0.0%	0.0%	0.0%	0.0%	3.0%	3.0%	0	1.00	1.00	1.00	1.00	1.00	1.00	0.90	1.00	1.00	1.00	1.00	0.97
All Defects								0.49	0.66	0.88	0.96	0.98	0.94		0.51	0.61	0.79	0.91	0.90

Figure D-1 Baseline (no I/M) Malperformance Rates

I/M WITH SNAP

								SNAP PASS RATE							**LUG PASS RATE**				
Defect	1960-87	1988-90	1991-93	1994-01	2002-07	2008+	SNAP	1960-87	1988-90	1991-93	1994-01	2002-07	2008+	LUG (WITH NOx)	1960-87	1988-90	1991-93	1994-01	2002-07
Timing Advanced	10.6%	13.2%	6.6%	3.3%	3.3%	3.3%	0	1.00	1.00	1.00	1.00	1.00	1.00	0.7000	0.93	0.91	0.95	0.98	0.98
Timing Retarded	7.9%	5.3%	2.6%	1.3%	1.3%	1.3%	0	1.00	1.00	1.00	1.00	1.00	1.00	0.0000	1.00	1.00	1.00	1.00	1.00
Minor Injector Problems	13.2%	7.9%	4.0%	2.0%	1.3%	1.3%	0	1.00	1.00	1.00	1.00	1.00	1.00	0.1000	0.99	0.99	1.00	1.00	1.00
Moderate Injector Problems	5.0%	2.6%	1.0%	0.3%	0.2%	0.2%	0.5	0.98	0.99	1.00	1.00	1.00	1.00	0.7000	0.97	0.98	0.99	1.00	1.00
Severe Injector Problems	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1	1.00	1.00	1.00	1.00	1.00	1.00	1.0000	1.00	1.00	1.00	1.00	1.00
Puff Limiter MissSet	7.7%	5.5%	0.5%	0.0%	0.0%	0.0%	0.6	0.95	0.97	1.00	1.00	1.00	1.00	0.0000	1.00	1.00	1.00	1.00	1.00
Puff Limiter Disabled	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1	1.00	1.00	1.00	1.00	1.00	1.00	0.0000	1.00	1.00	1.00	1.00	1.00
Maximim Fuel Stop Set High	3.3%	1.7%	0.3%	0.1%	0.0%	0.0%	0.5	0.98	0.99	1.00	1.00	1.00	1.00	1.0000	0.97	0.98	1.00	1.00	1.00
Clogged Air Filter	7.3%	5.0%	2.6%	1.0%	1.0%	1.0%	0.5	0.96	0.98	0.99	1.00	1.00	1.00	0.3000	0.98	0.99	0.99	1.00	1.00
Wrong/Worn Turbo	5.5%	2.8%	1.4%	0.2%	0.1%	0.1%	0.3	0.98	0.99	1.00	1.00	1.00	1.00	0.8000	0.96	0.98	0.99	1.00	1.00
Intercooler Clogged	2.0%	2.6%	1.3%	0.3%	0.1%	0.1%	0	1.00	1.00	1.00	1.00	1.00	1.00	0.8000	0.98	0.98	0.99	1.00	1.00
Other Air Problems	5.0%	2.3%	0.7%	0.3%	0.2%	0.2%	0.5	0.98	0.99	1.00	1.00	1.00	1.00	0.5000	0.98	0.99	1.00	1.00	1.00
Engine Mechanical Failure	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1	1.00	1.00	1.00	1.00	1.00	1.00	1.0000	1.00	1.00	1.00	1.00	1.00
Excess Oil Consumption	1.7%	0.7%	0.3%	0.2%	0.1%	0.1%	0.5	0.99	1.00	1.00	1.00	1.00	1.00	0.5000	0.99	1.00	1.00	1.00	1.00
Electronics Failed	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1	1.00	1.00	1.00	1.00	1.00	1.00	1.0000	1.00	1.00	1.00	1.00	1.00
Electronics Tampered	0.0%	3.3%	3.3%	2.0%	2.0%	2.0%	0	1.00	1.00	1.00	1.00	1.00	1.00	0.6000	1.00	0.98	0.98	0.99	0.99
Catalyst Removed	0.0%	0.0%	0.0%	0.0%	0.0%	1.6%	0.2	1.00	1.00	1.00	1.00	1.00	1.00	0.8000	1.00	1.00	1.00	1.00	1.00
Trap Removed	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1	1.00	1.00	1.00	1.00	1.00	1.00	1.0000	1.00	1.00	1.00	1.00	1.00
EGR Disabled	0.0%	0.0%	0.0%	0.0%	2.0%	2.0%	0	1.00	1.00	1.00	1.00	1.00	1.00	0.9000	1.00	1.00	1.00	1.00	0.98
All Defects								0.84	0.90	0.97	0.99	0.99	0.99		0.76	0.79	0.89	0.95	0.94

Figure D-2 Malperformance Rates With Snap I/M

IM WITH LUG

								SNAP PASS RATE							**LUG PASS RATE**				
Defect	1960-87	1988-90	1991-93	1994-01	2002-07	2008+	SNAP	1960-87	1988-90	1991-93	1994-01	2002-07	2008+	LUG (WITH NOx)	1960-87	1988-90	1991-93	1994-01	2002-07
Timing Advanced	3.2%	4.0%	2.0%	1.0%	1.0%	1.0%	0	1.00	1.00	1.00	1.00	1.00	1.00	0.7000	0.98	0.97	0.99	0.99	0.99
Timing Retarded	7.9%	5.3%	2.6%	1.3%	1.3%	1.3%	0	1.00	1.00	1.00	1.00	1.00	1.00	0.0000	1.00	1.00	1.00	1.00	1.00
Minor Injector Problems	11.9%	7.1%	3.6%	1.8%	1.2%	1.2%	0	1.00	1.00	1.00	1.00	1.00	1.00	0.1000	0.99	0.99	1.00	1.00	1.00
Moderate Injector Problems	3.0%	1.6%	0.6%	0.2%	0.1%	0.1%	0.5	0.99	0.99	1.00	1.00	1.00	1.00	0.7000	0.98	0.99	1.00	1.00	1.00
Severe Injector Problems	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1	1.00	1.00	1.00	1.00	1.00	1.00	1.0000	1.00	1.00	1.00	1.00	1.00
Puff Limiter MissSet	19.1%	13.9%	1.3%	0.0%	0.0%	0.0%	0.6	0.89	0.92	0.99	1.00	1.00	1.00	0.0000	1.00	1.00	1.00	1.00	1.00
Puff Limiter Disabled	6.6%	3.3%	1.3%	0.0%	0.0%	0.0%	1	0.93	0.97	0.99	1.00	1.00	1.00	0.0000	1.00	1.00	1.00	1.00	1.00
Maximim Fuel Stop Set High	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5	1.00	1.00	1.00	1.00	1.00	1.00	1.0000	1.00	1.00	1.00	1.00	1.00
Clogged Air Filter	10.2%	6.9%	3.7%	1.4%	1.4%	1.4%	0.5	0.95	0.97	0.98	0.99	0.99	0.99	0.3000	0.97	0.98	0.99	1.00	1.00
Wrong/Worn Turbo	1.6%	0.8%	0.4%	0.1%	0.0%	0.0%	0.3	1.00	1.00	1.00	1.00	1.00	1.00	0.8000	0.99	0.99	1.00	1.00	1.00
Intercooler Clogged	0.4%	0.5%	0.3%	0.1%	0.0%	0.0%	0	1.00	1.00	1.00	1.00	1.00	1.00	0.8000	1.00	1.00	1.00	1.00	1.00
Other Air Problems	5.0%	2.3%	0.7%	0.3%	0.2%	0.2%	0.5	0.98	0.99	1.00	1.00	1.00	1.00	0.5000	0.98	0.99	1.00	1.00	1.00
Engine Mechanical Failure	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1	1.00	1.00	1.00	1.00	1.00	1.00	1.0000	1.00	1.00	1.00	1.00	1.00
Excess Oil Consumption	1.7%	0.7%	0.3%	0.2%	0.1%	0.1%	0.5	0.99	1.00	1.00	1.00	1.00	1.00	0.5000	0.99	1.00	1.00	1.00	1.00
Electronics Failed	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1	1.00	1.00	1.00	1.00	1.00	1.00	1.0000	1.00	1.00	1.00	1.00	1.00
Electronics Tampered	0.0%	1.3%	1.3%	0.8%	0.8%	0.8%	0	1.00	1.00	1.00	1.00	1.00	1.00	0.6000	1.00	0.99	0.99	1.00	1.00
Catalyst Removed	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	0.2	1.00	1.00	1.00	1.00	1.00	1.00	0.8000	1.00	1.00	1.00	1.00	1.00
Trap Removed	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1	1.00	1.00	1.00	1.00	1.00	1.00	1.0000	1.00	1.00	1.00	1.00	1.00
EGR Disabled	0.0%	0.0%	0.0%	0.0%	0.2%	0.2%	0	1.00	1.00	1.00	1.00	1.00	1.00	0.9000	1.00	1.00	1.00	1.00	1.00
All Defects								0.74	0.83	0.95	0.99	0.99	0.99		0.87	0.90	0.95	0.98	0.98

Figure D-3 Malperformance Rates With Lug Down I/M