AirCare®

Results and Observations Relating to the First Eight Years of Operation (1992-2000)

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Foreword

This report represents a comprehensive analysis of the first eight years of AirCare. Since its start-up in 1992, the program has experienced growing pains, interruptions and controversies. Nevertheless, the program has succeeded in achieving a 30% reduction in emissions from light-duty vehicles and enjoys the support of a majority of Lower Fraser Valley residents.

Vehicle emission testing programs impact the public more directly than virtually any other environmental regulation. Although most vehicle owners accept that their driving contributes to air pollution, it is sometimes difficult for them to understand that their own vehicle can make a difference. It is commonly believed that visible emissions from large trucks, industrial smokestacks, locomotives and aircraft are most responsible for poor air quality. However, the emission inventory for the Lower Fraser Valley shows that light-duty vehicles continue to account for more of the total smog-forming emissions released into the region's air than heavy-duty trucks, aircraft and rail combined.

AirCare works by counteracting the degradation of vehicle emissions due to a lack of preventative maintenance or the failure of emission control systems. If all vehicle owners conscientiously followed recommended service schedules, and repair facilities were diligent in checking for and correcting any problems found with the engine or emission controls, there would be no need for an emissions inspection program. However, this is not the case in practice. Often, maintenance is deferred until a serious problem develops. Similarly, causes of high emissions are frequently overlooked as long as the engine has no noticeable performance deficiencies. Inspection programs, like AirCare, identify vehicles with emission defects. Ensuring that these defects are corrected is the responsibility of the repair industry and the motoring public.

From the beginning, the AirCare program has employed state-of-the-art testing methods to identify excess-emitting vehicles. Once identified, the degree to which a vehicle's excess emissions can be reduced depends on the willingness of the owner to pay for repairs and the ability of the repair industry to isolate and correct any problems. These factors are critical to the success of the program but are beyond the ability of the program administration to control. Studies of inspection programs in other jurisdictions point to the same concerns about the response of the motoring public and the repair industry to emissions inspections.

On September 5, 2000, the AirCare program embarked on a new phase of its existence. Significant changes to the inspection centres, testing equipment and computer systems were completed over a 12-month period, while still providing the public with emission testing. As AirCare enters this second era, the inspection process has been improved yet again. More effort will be devoted in the coming years to ensuring that all high emitting vehicles are identified, and that the repairs performed are as effective as possible. In this way, the program will continue to be one of the best of its type in the world.

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1.0 EXECUTIVE SUMMARY

The AirCare vehicle emissions inspection and maintenance (I/M) program has been in operation in the Lower Fraser Valley since September of 1992. It was implemented by the provincial government on behalf of the Greater Vancouver and Fraser Valley Regional Districts as one of 54 emission reduction measures proposed in a comprehensive regional Air Quality Management Plan (AQMP). According to the 1990 emissions inventory, light-duty motor vehicles were estimated to account for 90% of the carbon monoxide, 35% of the oxides of nitrogen, and 43% of the volatile organic compounds released annually into the Lower Fraser Valley air shed. Thus, a vehicle emissions inspection and maintenance program was considered to be one of the most cost-effective approaches to reducing smog-forming pollutants in the region.

The AirCare program was designed according to a centralized, contractor-operated model. A private company, Ebco-Hamilton Partners, was contracted to build, staff and operate 12 inspection centres, located strategically throughout the region, with the capacity to perform up to 1.2 million inspections per year. A total of 42 lanes, each with identical testing equipment and lane operating software, were provided. The testing process was automated, with all the test data being transmitted electronically to a central database. The objective was to provide consistent and accurate tests, independently of the automotive repair sector. Since the inspection contractor would have no interest in the outcome of the inspection, the AirCare program would avoid the potential for conflict of interest that occurs in decentralized programs, where the person that does the test is the same one that repairs the vehicle if it fails. By separating the two functions, the testing contractor was able to focus on delivering quality inspections, leaving the repair industry to concentrate only on fixing vehicles with emission-related problems.

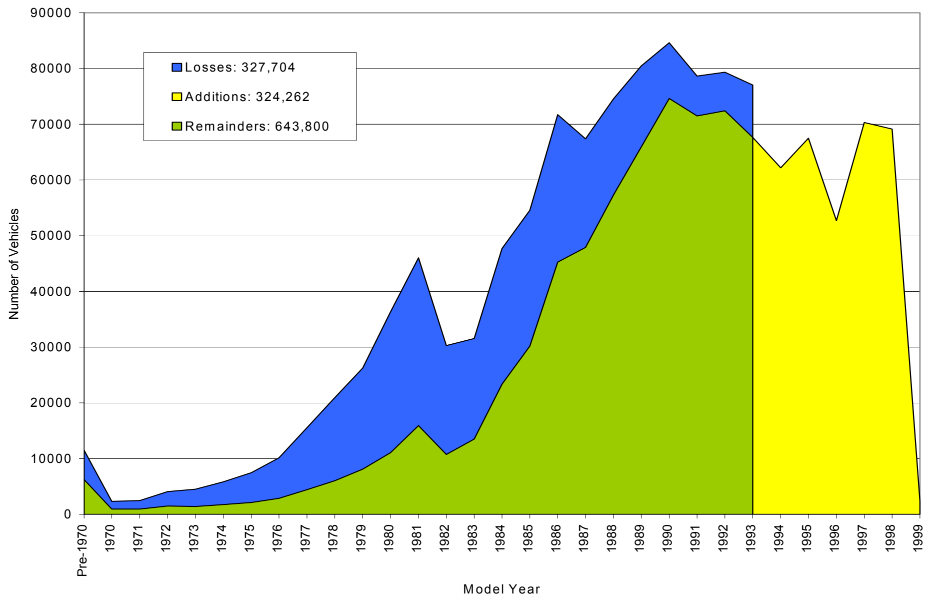
The first AirCare contract was for a period of seven years and expired on August 31, 1999. A renewal was negotiated with the same company, now called Envirotest Canada, in 1999. The new contract expires on August 31, 2006.

This report represents a review of the first eight years and four months of testing, from September 1, 1992 through December 31, 2000. Areas of analysis include changes in fleet composition, general inspection statistics, characterization of the failing vehicle fleet, discussion of the indicated effectiveness of repairs to failed vehicles and a calculation of estimated program benefits.

1.1 FLEET PROFILE

Approximately 1.2 million passenger cars and light trucks are registered in the Lower Fraser Valley of British Columbia. The age profile of the vehicle fleet changes over time as new vehicles are purchased and older vehicles are retired from use. In addition, used vehicles change hands, some vehicles move into the area from outside the region and some vehicles move out of the region. According to inspection data, about 75,000 new vehicles were introduced to the AirCare-tested fleet each year. This number has fluctuated since 1992 but has been showing a generally upward trend since 1996. The 1996 model year appears to have been a particularly poor sales year with only about 56,000 vehicles being added to the AirCare-tested fleet from that model year. The AirCare-tested fleet grew from 974,720 vehicles in 1994 to 1,047,969 in 1999. This represents a total growth of 73,249 vehicles in 5 years, or approximately 1.4% per annum. The change between 1997 and 1998 was 1.9% and the growth between 1998 and 1999 was 1.7%.

The figure below illustrates the age profile of AirCare-tested fleet in calendar year 1994 (the first full year of testing) compared to calendar year 2000.



Age Profile of the Fleet in Calendar Year 1994 and 2000

327,704 vehicles disappeared from the fleet in 6 years. In the meantime, 324,262 vehicles were added, this number made up almost entirely of new vehicles.

There is a general trend towards a higher proportion of trucks in the active fleet. The fleet is dominated by the General Motors, Ford and Chrysler, particularly in the truck segment. The import brands with the highest market share were Honda and Toyota. Overall, these five manufacturers account for almost 80% of all the vehicles on the road in the AirCare testing region.

Approximately 18,000 diesel-powered light-duty vehicles are registered in the program area. Although the number has remained relatively constant, the composition of the diesel fleet has changed from mostly cars in 1992 to mostly trucks in 2000.

The propane and natural gas-powered fleet has decreased in size and increased in age since 1992. There are very few newer model-year vehicles being converted to operate on these fuels.

1.2 VEHICLE ANNUAL MILEAGE

Odometer readings are collected at the time of inspection, providing a means of tracking annual mileage. Since this has a direct influence on the amount of emissions generated by a vehicle in a year, it is an important piece of information. Analysis of inspection data suggests that the median annual kilometres travelled ranges from 18,000 km for the newest vehicles on the road to about 10,000 km for 16 year-old vehicles. AirCare data suggest that vehicles used for daily transportation continue to accumulate significant annual mileages, despite increasing age.

1.3 INSPECTION STATISTICS

1.3.1 Annual Test Volumes and Frequency of Inspection

In the first 8 program years, the total number of inspections performed was 8,534,984. There were 1,876,123 individual vehicles tested at least once. The table below shows the number of vehicles tested in each program year compared to projected volumes based on an initial fleet size of 950,000 vehicles and a 3% annual growth rate.

Projected and Actual Number of Vehicles Inspected by Program Year

Program Year	Projected	Actual
1992-1993	950,000	507,616
1993-1994	978,500	1,016,528
1994-1995	1,007,855	1,002,566
1995-1996	1,038,091	550,668
1996-1997	1,069,233	1,060,344
1997-1998	1,101,310	1,022,874
1998-1999	1,134,349	1,042,874
1999-2000	1,093,379*	999,007
Total	**8,372,717**	**7,202,477**

* Adjusted to reflect exemption of 1999 model year vehicles

Start-up adjustments and a labour dispute that lasted from April through July of 1993 make it impossible to compare the first program year to any others. A second labour dispute in 1996 resulted in nearly 500,000 vehicles being exempt from testing in program year 4. The program has operated without interruption since September of 1996.

1994 was the first full calendar year for the AirCare program. Of the 974,720 vehicles tested in that first full calendar year, 97,100 were never seen again in any subsequent year. Of these, 75.7% passed the inspection. It is not known where these vehicles went or why they did not re-appear in later years.

Of the 1,876,123 vehicles tested at some point during the review period, 425,436 were tested in 1994 and have been seen in every year since then. Another 454,803 have missed only one year since 1994, mostly due to the strike in 1996. There have been 211,669 that have missed two years and 130,734 that have missed three years.

The table below shows the irregularity of inspection frequency for calendar years 1992 through 2000.

In every year, there are large numbers of vehicles that appear for the first time, made up mostly of new vehicles that have become eligible for testing for the first time. There appear to be about

200,000 vehicles that skip inspection in any given year, however, this number is offset by approximately 100,000 vehicles not seen in the previous year that return to the program.

Irregularity of Inspecton Frequency

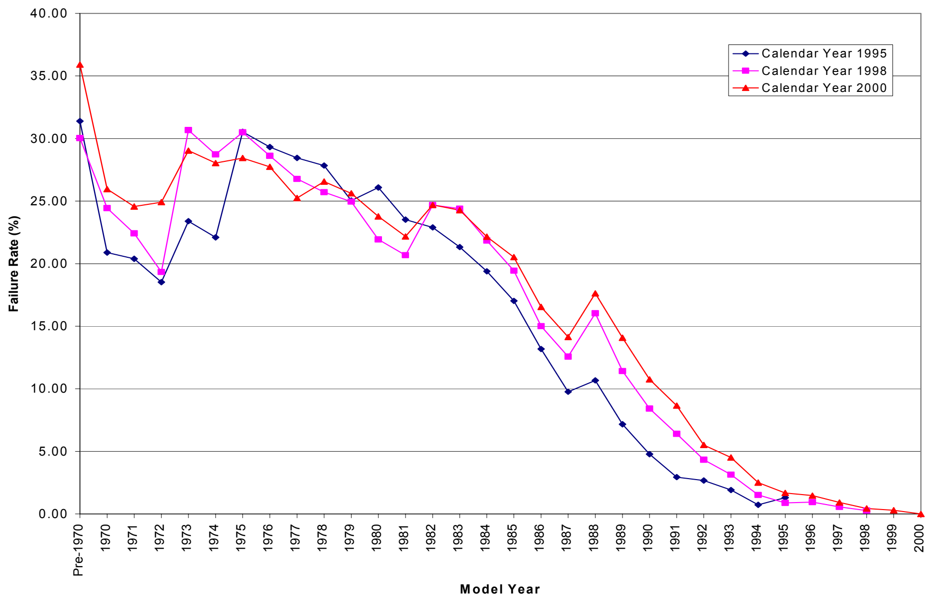
Calendar Year	# Vehicles Tested	# Seen First Time	# Tested in Previous Year but Not Seen in Current Year	# Returning for Annual Inspection as Expected	# Tested at Some Point Prior to Previous Year
1992	244,823	244,823	N/A	N/A	N/A
1993	751,755	599,917	92,985	151,838	N/A
1994	974,720	380,917	205,077	546,678	47,125
1995	1,002,604	141,529	212,372	762,348	98,727
1996	644,611	80,822	494,707	507,897	55,802
1997	1,011,112	142,614	164,154	480,457	388,041
1998	1,030,648	119,325	209,294	801,818	109,505
1999	1,047,969	112,527	203,779	826,869	108,573
2000	968,135	53,659	237,240	810,729	101,747

The reasons for irregularity in testing frequency are not evident from the data but it is suspected that change-of-ownership may account for much of it. According to DesRosiers [1], the annual used car sales volume range from 2.5 to 3.0 million, which corresponds to between 16% and 19% of the total vehicle population. This would suggest 160,000 to 190,000 sales transactions in the AirCare fleet. These transactions usually alter the vehicle's license renewal date, placing it on a different inspection cycle.

1.3.2 Inspection Results

The purpose of inspecting the in-use fleet is to identify vehicles with abnormally high emissions. The AirCare test procedure subjects vehicles to a loaded dynamometer test to measure HC, CO and NO_x emissions, followed by an idle test that checks tailpipe levels of HC and CO. Vehicles whose emissions exceed specified "cut points" fail the inspection and must be repaired. The cut points are established from the analysis of AirCare test data and are set so that any vehicle exceeding them would have emissions higher than certification standards if it were tested according to the Federal Test Procedure (the official test that must met before a new vehicle can be sold). Studies of in-use vehicles suggest that a minority will have excess emissions compared to the normal group and a subset of the high-emitter group will have very high emissions. It has been reported that 10% of vehicles account for 50% of pollutants [2].

AirCare inspection data confirm an increasing failure rate with vehicle age, ranging from less than 1% for the newest vehicles tested to 30% or more for older vehicles. The rate of increase in the failure rate appears to be much lower for vehicles less than 5 years old, otherwise the rate increases with age to a maximum of about 30%. The next figure shows the trend in failure rate vs. model year for all vehicle types for three calendar years.



Vehicle Failure Rate vs. Model Year for All Vehicle Types

The next table shows the average Passing and Failing Idle and ASM test results for four different age groups of vehicles based on data from program year 8.

Average Inspection Results by Age Group

		Idle		ASM		
Result	**Age Group**	**HC (ppm)**	**CO (%)**	**HC (ppm)**	**CO (%)**	**NO_x (ppm)**
FAIL	pre -1975	856	5.14	289	3.16	805
	1975 - 1987	419	2.60	180	1.75	1234
	1988 - 1993	214	1.21	122	1.19	946
	1994 and later	156	0.80	81	0.80	620
PASS	pre -1975	297	2.40	108	1.20	1110
	1975 - 1987	85	0.58	68	0.38	1022
	1988 - 1993	25	0.06	25	0.11	345
	1994 and later	10	0.03	13	0.06	135

The data show that advances in emission control technology over time have measurably improved emissions performance. The substantial reduction in NO_x emissions for passing vehicles in the 1988 and 1994 model years coincide with changes in the federal standards. In fact, the average ASM readings for 1994-and-later model year vehicles that fail are better than the average passing readings for pre-1975 vehicles. The emissions of failing vehicles are higher than passing vehicles in all age groups except for NO_x for the pre-1975 age group. This is expected, as NO_x and CO emissions are inversely related and most pre-1975 vehicles fail for excessive CO emissions. The failing vehicles therefore have suppressed NO_x levels relative to normal vehicles in their age group.

1.3.3 Inspection Accuracy

Throughout the review period, the program administration audited all of the inspection centres and test lanes at least once per month using certified reference gases traceable to the National Institute of Science and Technology (NIST). Although on occasion, the analyzer reading for one of the three gases fell outside the permitted ±5% tolerance from the stated gas bottle value, the errors were in the negative direction in all but 3 cases out of more than 3000 audits.

Vehicle variability is an unavoidable phenomenon in all emission testing programs. Although a vehicle in good mechanical condition with all of its emission control devices operating properly will produce fairly consistent results when tested repeatedly, vehicles with emission-related defects can produce very different results in back-to-back testing. Due to this effect, some portion of the failing vehicle fleet has been able to achieve a passing result without repairs simply by attempting another test. The exact number is impossible to determine from the inspection data.

1.4 VEHICLES THAT FAILED INSPECTION

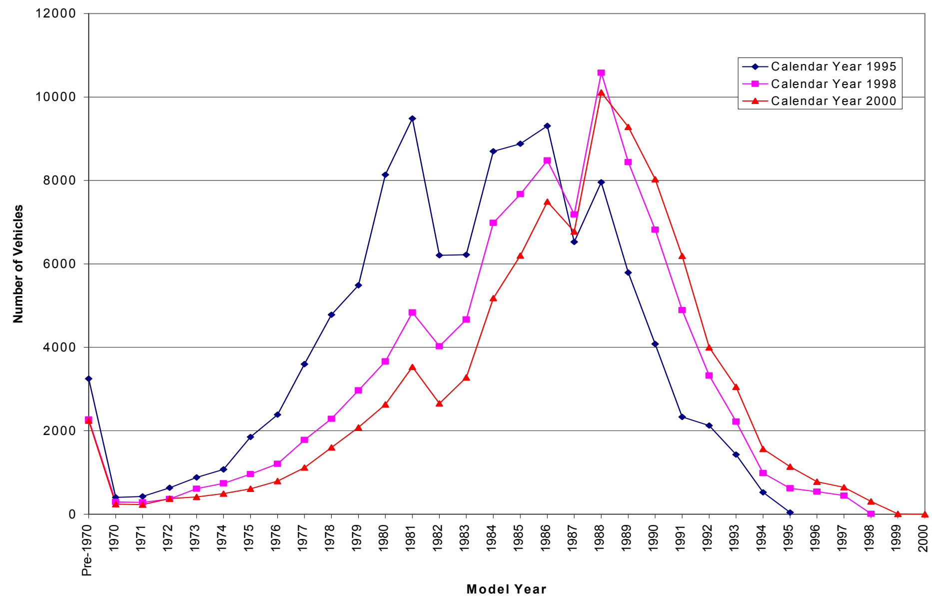
During the review period, the failure rate on initial inspection ranged from 9.64% to 14.72%, representing between 100,000 and 150,000 excess-emitting vehicles per year.

During periods when the pass/fail limits remained constant, the failure rate decreased from year to year. Significant changes were made to the pass/fail limits in September of 1995 and again in September of 2000. The failure rate increased noticeably following each of these changes. In 1995, the changes caused the failure rate to increase from 9.8% to 15%. However, by the end of August 2000, the failure rate had once again dropped to 10%.

The next figure shows the distribution of failed vehicles by model year. Most of the failing vehicles fall into the 1980-1992 model year range. The 1988 model year produced the most failures in calendar years 1998 and 2000. The number of failures of vehicles older than 1988 is decreasing over time. The number of failures among vehicles newer than 1988 is increasing.

Of the 1,876,123 individual vehicles tested at some point during the review period, there were 509,242 vehicles that failed at least once. Of these, 56.2% failed in only one annual cycle.

239,997 of the vehicles that failed did so on their first ever inspection. Another 66,130 failed the second year they were inspected. Investigation revealed that most of these “first-time-failures” (that were not during the programs start-up years) occurred on vehicles that were new to the area. This suggests that the vehicles operated within the AirCare region are better maintained than vehicles operated in areas with no inspection programs.



Number of Failed Vehicles vs. Model Year for All Vehicles Types

Each year, between 6.5% and 8.5% of failing vehicles did not return for any form of re-inspection. Overall, it is estimated that the number of "disappeared" failing vehicles was 79,000 during the review period, or 15.5% of the total number of vehicles failed.

In calendar year 1999, the top six failure modes were:

	Failure Mode
1	ASM NO_x Only
2	Idle HC Only
3	ASM CO Only
4	Idle CO Only
5	Idle HC and CO
6	ASM HC Only

These six failure modes accounted for 70.65% of all failures.

1.5 Repairs To Failing Vehicles

The process of testing vehicles and failing excess emitters does not, in itself, produce any emissions benefit. In order to produce emission reductions, excess-emitting vehicles must be competently repaired. The designers of the AirCare program were well aware of the importance of the repair industry to its success. As a result, a repair industry certification and monitoring program was devised and put in place alongside the inspection process. The objective was to provide the motoring public with access to a well-trained and well-equipped repair industry that could repair emission-related problems with maximum effectiveness at minimum cost.

Collecting repair data from these facilities would also allow for better understanding of the types of faults responsible for excess emissions in the in-use fleet.

There were two key incentives for motorists to choose a certified shop over a non-certified one:

1. Repairs could be limited to a total cost defined by a set of repair cost limits established by government. The intent of repair cost limits was to ease the financial burden on motorists facing high costs to bring their vehicles into compliance with AirCare limits.

2. Regardless of the amount spent on repairs, any vehicle submitting a completed repair data form at the time of re-inspection was automatically eligible for a Conditional Pass, allowing the vehicle owner to re-license their vehicle for up to a year, even though it still didn't pass.

1.5.1 Certified Repairs

In any given program year, fewer than half of the vehicles that failed returned for re-inspection with completed Repair Data Forms, suggesting an unexpected preference for non-certified shops by the motoring public.

Overall, 367,154 Repair Data Forms were endorsed by certified repair facilities and turned in at the time of re-inspection through August 31, 2000. Of these repairs performed by certified shops, 108,056 (29.43%) resulted in a Conditional Pass at the time of re-inspection.

There were 86,559 vehicles that received a Conditional Pass at some point, representing 17% of all failing vehicles. Most of the vehicles that received a Conditional Pass received only one. Only 1 vehicle received the maximum possible 8 Conditional Passes and only 3804 vehicles have received more than 2 Conditional Passes, suggesting that this provision is not widely used as a means of avoiding complete repairs.

Approximately 500 repair shops have been AirCare-certified in any given year. In total, 942 auto repair businesses have been certified at some point during the review period, but many decided not to renew their certification. A total of 228 shops have been certified continuously since September 1992.

The number of active AirCare-certified technicians has remained relatively stable at about 1200. There are 1900 technicians that were certified at one time but have allowed their certification to lapse.

The rate of return of Repair Data Forms has been declining in recent years. The reason for this is not clearly understood. It may be that technicians are hesitant to have certain repairs count towards their average REI and therefore do not complete and endorse the forms or it may be that fewer motorists are patronising AirCare-certified repair shops.

In the first few years of operation, the most commonly-reported parts replacements concerned basic tune-up items such as air filters, spark plugs, distributor caps and ignition wires. In more recent years, there has been a trend towards the replacement of more substantive components such as oxygen sensors and catalytic converters. As far as repair actions are concerned, carburetor air-fuel mixture adjustments and idle speed adjustments tend to dominate, even in the most recent program year. This reflects the high proportion of carbureted vehicles among vehicles that fail the test.

The Repair Effectiveness Index (REI) introduced in 1996 has indicated that the effectiveness of repairs performed to vehicles that fail an AirCare inspection has been improving. The average REI for the overall certified industry has increased from 0.29 to 0.37 between 1996 and 2000.

1.5.2 Non-Certified Repairs

The AirCare program was designed to encourage motorists to use certified repair facilities. Therefore, the database was designed in such a way that only those tests involving a completed RDF were designated as re-inspections. All other tests were designated as initial tests. As a result, it is difficult to identify non-certified re-inspections within the database. Also, because there is no repair data submitted in these cases, it is impossible to determine what repairs, if any, were performed. Simply trying a second test without making repairs may appear as a successful repair, even though no actual corrective maintenance was performed.

Vehicles not repaired by certified AirCare repair facilities must pass the re-inspection, regardless of the cost or number of repeat attempts required. Otherwise they cannot be re-licensed in the AirCare area.

1.5.3 Overall Repair Effectiveness

The table below shows the average ASM and Idle emissions from program year 8 for vehicles repaired at certified repair shops compared to vehicles with unknown repair actions. The sample is broken down into four different age groups, consistent with the table, "Average Inspection Result by Age Group", shown earlier.

Re-inspection Results by Type of Repair

		Idle		ASM		
	Age Group	HC (ppm)	CO (%)	HC (ppm)	CO (%)	NO_x (ppm)
Certified Repair	pre -1975	435	2.92	172	2.20	912
	1975 - 1987	161	1.00	105	0.99	1000
	1988 - 1993	82	0.32	59	0.39	589
	1994 and later	51	0.16	42	0.22	359
Other Repair	pre -1975	325	2.42	115	1.44	987
	1975 - 1987	105	0.78	74	0.48	1020
	1988 - 1993	40	0.11	35	0.14	451
	1994 and later	26	0.07	24	0.11	266

The table shows that certified repairs appear to be less effective. This is a result of the 30% of vehicles that obtain Conditional Passes.

A supplementary measure of repair effectiveness is available from a sample of 957 vehicles tested according to the HOT 505 test in the AirCare Research Centre. The HOT 505 test gives a more complete picture of a vehicle's actual emissions output under normal urban driving conditions. The results are expressed in units of grams/kilometre rather than in parts per million or percent. Average pre- and post-repair HOT 505 test results are shown in the table below.

Substantial decreases in average emission output are evident in all cases but one. An increase in average NO_x emissions of 4.5% was observed among the oldest vehicles. The newest vehicles tended to show the highest percentage reductions, but the absolute emission levels from these vehicles are quite low, meaning that a small reduction appears as a large percentage.

Pre-Repair and Post-Repair Emission Levels from HOT 505 Test

		Failing (g/km)			Repaired (g/km)			% Change		
Age Group	Number	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x
Pre-1975	29	4.45	48.79	2.01	2.70	35.18	2.10	-39.3%	-27.9%	+4.5%
1975-1987	564	1.77	23.02	1.80	1.25	15.90	1.56	-29.3%	-30.9%	-13.3%
1988-1993	344	0.82	12.61	0.95	0.43	6.56	0.73	-47.6%	-48.0%	-23.2%
1994 and later	20	0.19	3.11	0.52	0.15	1.70	0.29	-21.0%	-45.4%	-63.5%

To demonstrate how these data can be used to calculate program benefits, assume the case of a 1988-1993 vehicle that experiences a reduction in HC emissions of 0.39 grams/km. If such a vehicle is driven 15,000 km per year, the act of repairing it would result in (0.39*15,000) grams of HC emission reduction, or 5.85 kg (about 7.5L of gasoline) for that one vehicle. Repeating these calculations in tens of thousands of cases yields the total annual fleet reduction.

1.6 CALCULATION OF PROGRAM BENEFITS

The effect of an emissions inspection and maintenance program may be defined as the difference between the total vehicle-generated emissions in a given geographic area with an I/M program, compared to what the total would be for the same area without an I/M program

Ideally, the calculation of the non-AirCare case would be based on a control group identical in all respects to the AirCare-tested group. This would require a control situation comprising an exact duplicate of the Lower Fraser Valley except for the AirCare program. Obviously, such a control situation does not exist, so it necessary to rely on in-program data to estimate what would have happened without a program.

The methodology used in this review is different to that used previously. It does not require many of the assumptions built into the previous assessments. Its ability to model what actually happened has been radically improved, and its modelling of the effectiveness of individual repairs is much more precise.

1.6.1 The "With-AirCare" Scenario

This is the scenario that actually happened. To assess how the inventory has decreased, it is only necessary to consider the initial condition of the fleet in each year it was inspected. The first inspection on each vehicle in each year was used to calculate what the inventory would be in that year if no further repairs were effected. This assessment does not require any model of previous repair effectiveness or longevity, or of fleet turnover or retirement rates. It simply examines what the actual emission output of the fleet was, when it was initially inspected in each year. When compared with the previous year, the actual inventory reduction can be assessed. This automatically takes into account all the causes that have contributed to the reduction, but it obviously does not enable any assessment of their comparative contributions.

1.6.2 The “Without-AirCare” Scenario

This hypothetical scenario is important because it enables comparison of what was achieved in the previous "with-AirCare" scenario, to what would have been achieved anyway. To model this scenario it is necessary to assess the amount of reduction achieved by performing repairs to excess-emitting vehicles in each year, then compare this to the total reduction that was achieved between that year and the next.

To calculate the direct AirCare-related emission reductions in a single year, the emission reduction attributable to each repaired vehicle, in grams per kilometre, is multiplied by the mileage that the vehicle would be expected to drive in a year. Subtracting the total direct-from-AirCare benefits from the year-to-year change calculated in section 1.6.1, gives an assessment of how much reduction would have been achieved without the program.

Using this method, the incremental benefits directly attributable to AirCare repairs in any given year range from 3.33% to 9.72% for HC emissions, 2.65% to 8.98% for CO and 0.91% to 2.20% for NO_x. Although the annual, incremental reductions may appear small, the cumulative effects of the program become very significant over time.

Table below shows the total inventory reductions that were achieved over the eight years, including cumulative benefits.

Total Inventory Reductions over Eight Years of AirCare

	HC	CO	NO_x
Overall 8 Years	**63.6%**	**53.2%**	**48.2%**
Due to Repairs	34.3%	38.4%	10.3%
Other	29.3%	14.8%	38.0%

By combining the three percentage reductions, weighted by their actual mass assessments in the inventory, it was estimated that the emissions attributable to the light-duty vehicle fleet declined by 57.4% due to fleet turnover, repairs related to AirCare, accelerated vehicle retirement, etc. Calculations indicate that in the absence of the AirCare program, the reduction over the same period would have been only 23.7%, indicating a significant benefit due to the program.

1.7 PROGRAM RESULTS

Over its first 8 years of operation, the program has performed millions of inspections, of which more than 1 million have generated a result of “FAIL”. Thus, it has been effective in identifying many vehicles that appear to be high emitters. On the repair industry side, the program has created a demand for emission-related repairs. The industry has responded by voluntarily becoming AirCare-certified, purchasing the necessary diagnostic equipment and reference materials. Repair technicians have responded by submitting to written exams and taking training courses to improve their skills in emissions diagnosis and repair. Prior to the start-up of AirCare, very few repair shops had exhaust gas analyzers or any experience in interpreting tailpipe emissions readings. Increased public awareness of what vehicles emit and how good maintenance is important in preventing excess emissions has also resulted from the program.

However, the AirCare inspection process cannot produce environmental benefits on its own. Once a vehicle has been identified as a high emitter in the inspection lanes, the owner must take appropriate action. The motivation could come from a strong environmental awareness but more often comes from the fact that vehicle licensing will be denied until the vehicle has passed or conditionally passed. Thus, the owners of vehicles that fail the inspection are “forced” to spend money on their vehicles to comply with the program rules. This is not popular with everyone and some may go to extraordinary means to avoid repair and re-inspection costs. Persons committed to circumventing the inspection/repair process have various means at their disposal to do so. Such means include registering their vehicle outside of the AirCare area, making temporary adjustments to achieve a passing result without really correcting the problem or trying additional tests with the hope that the vehicle may pass on its own, despite no repairs.

Hopefully, only a small number of motorists employ any of these methods of avoiding an inspection failure. However, with fewer than half of the repairs being documented, it is difficult to quantify what actions were taken on the part of motorists who simply re-appeared for a second or subsequent test without any information about what might have been done to the vehicle since the last test. A significant portion of failing vehicles simply “disappear”. Whether these vehicles are actually taken out of the program area is not certain. All that is known is that they no longer appeared for inspection.

Another potential problem concerns the repair industry. Misdiagnoses and incomplete repairs prevent all of the available emission reductions from being realized. Of the repairs that are confirmed by data, only about 70% of cases result in the vehicle achieving a passing inspection result. This is not to say that the other 30% are mistakes by the repair industry, as the existence of repair cost limits prevents them from making full repairs in all cases. However, a portion of these unsuccessful repairs is not limited by cost, pointing to incomplete or incorrect diagnoses. Sometimes, the goal of the repair is to “get the vehicle through”, rather than to restore the vehicle to FTP-passing condition. This may meet the customer demands but does not satisfy the environmental goals of the program.

To sum up, the AirCare program is more than a technical exercise of testing and repairing vehicles. Human attitudes and responses have a great deal to do with the program’s success and many of these factors are beyond the ability of program designers and administrators to control. The analysis contained in this report confirms that the AirCare program has been effective in reducing emissions from motor vehicles in its first 8 years of operation. It appears that the AirCare-attributable benefits slightly outweigh those from the introduction of new, more effective emission controls.

Improvements in effectiveness can be achieved be increasing the proportion of failing vehicles that are fully repaired to achieve their lowest possible emissions. At the moment, it is apparent that 15% of failing vehicles receive a Conditional pass rather than a full pass. Of the approximately 40% of failing vehicles that simply return for re-inspection but do not supply any repair information, some portion have either not been repaired or have been made “clean for a day”. The exact number cannot be determined from the data but anecdotal accounts of passing the test despite no repairs and making temporary adjustments to “get through the test” are frequent enough to suggest that these actions do occur.

Understanding and quantifying vehicle owner's responses to I/M regulations is a very difficult task. A recently published review of inspection and maintenance program evaluation techniques identified the inability to quantify human response as a common deficiency in all I/M program and concluded that further study is required to determine the extent of old-vehicle-scrapping in response to I/M, and of program avoidance and other types of non-compliance among different socioeconomic groups. [5]

2.0 INTRODUCTION

It has long been recognized that motor vehicles play an important role in the problem of urban air pollution. In 1952, researchers in California first identified the mechanism by which certain hydrocarbons (HC) reacted with oxides of nitrogen (NO_x) in the presence of sunlight to form photochemical smog. Photochemical smog is a frequent air quality problem in cities and motor vehicles are a significant source of its precursor emissions. Another well-known air contaminant is carbon monoxide (CO), a toxic gas that has long been linked with vehicle exhaust. Faced with the task of improving ambient air quality to protect public health, governments identified emissions from motor vehicles as one of the first targets for reduction.

In the 1960's the U.S. federal government established regulations for controlling emissions from light-duty vehicles (less than 6000 lbs. Gross Vehicle Weight). California had already enacted its own legislation as a result of serious air quality concerns in the Los Angeles basin. Federal standards affecting vehicles in the remaining 49 states took effect with the 1968 model year. In 1970, the Federal Clean Air Act was enacted and the Environmental Protection Agency became responsible for establishing test procedures and emission standards for vehicles sold in the U.S. 49 States. The goal of federal standards for vehicles was to reduce hydrocarbon and carbon monoxide emissions from vehicles by 90% from 1970 levels by the year 1975. Oxides of nitrogen emissions were to be reduced by 90% of 1971 levels by 1976. Due to technological challenges and concerns over fuel efficiency, numerous extensions were granted to the auto industry. The targets for HC and CO were not met until 1980. The NO_x target was revised in 1977 and reached with the 1981 models. In 1990 the Clean Air Act was amended once again, calling for further HC and NO_x reductions and requiring passenger vehicles to meet the standards for 10 years or 100,000 miles, as of the 1996 model year compared to the previous requirement of 5 years or 50,000 miles. More recently, additional requirements have been added, seeking to limit the emissions from new motor vehicles under all conceivable modes of operation. Engineers in the automotive industry are now working at almost eliminating the remaining emissions from vehicles.

In Canada, emission standards for light-duty vehicles became law in 1971 under the Motor Vehicle Safety Act, administered by Transport Canada. Environment Canada was given the responsibility of advising Transport Canada on policy issues pertaining to vehicle emissions and shared in the role of testing vehicles to ensure that they met the new-vehicle regulations. Initially, Canadian standards mirrored those of the U.S., however, in 1975, less stringent standards were imposed and remained in effect through 1987. In 1988, the Canadian standards were once again harmonized with those of the U.S. and they have remained essentially identical since then.

Ideally, if all vehicles manufactured and sold in Canada since 1971 had remained in compliance with new-vehicle standards throughout their operating lives, air quality would not be an issue anywhere in Canada. However, given that improvements in ambient air quality have not occurred in proportion to the rate of improvement in new-vehicle emission performance, it must be concluded that the full potential of the emission controls applied to new vehicles has not been achieved in practice.

Soon after the introduction of pollution control systems on vehicles, researchers began to investigate why the predicted improvements in ambient air quality were not being achieved. What they found was that vehicles sitting in new vehicle showrooms were capable of meeting the FTP standards when tested. However, after only a year or two of use, a significant portion of vehicles were no longer able to meet the standards they were designed to. Examination of these high-emitting vehicles identified the following causes:

1. Failure to adhere to manufacturer's recommended maintenance schedule.

2. Improper adjustment of fuel mixture, spark timing or other emissions-critical engine parameters.

3. Premature failure of emission control devices or emission-related devices.

4. The deliberate removal or disabling of the emission control devices installed by the manufacturer.

To counteract these effects, the idea of inspection and maintenance (I/M) was conceived. The objective was to inspect vehicles periodically to identify those that had high emissions due to neglect, improper maintenance or tampering. Once identified, these high-emitters would then be required to undergo corrective maintenance. The result would be a reduction in overall fleet emissions as a result of restoring defective vehicles to their proper level of emissions performance. It was also believed that the need to pass a periodic emission inspection would deter vehicle owners from removing emission control hardware, thus preventing excess emissions due to tampering.

The first inspection and maintenance (I/M) program was established in New Jersey in 1974. In the early 1980's, as many U.S. cities remained in non-attainment of federal ambient air quality standards, I/M programs were implemented in many jurisdictions, the number of programs expanding from 16 in 1983 to 30 by 1985. Some of these programs have since shut down as a result of attaining compliance with air quality standards, notably in Michigan and Minnesota, but there are currently more than 35 programs still operating in the United States.

The AirCare program was the first I/M program to be implemented in Canada when it began operation in 1992. Ontario implemented a program in 1999, and Quebec has made some recent announcements about the possibility of a program there in 2002.

2.1 I/M Testing Procedures

Federal emission regulations define performance standards for various categories of vehicles. In order to establish a basis for comparison, a standardized test is needed. For North America, the certification test used since 1972 has been based on a typical commuter drive cycle called the LA-4. In its current configuration, the test is called the Federal Test procedure (FTP), or the EPA-75.

The federal rules state that when a vehicle is driven according to the EPA-75 test procedure and the exhaust gases are sampled, the vehicle should not emit more than a set amount of each pollutant per unit distance traveled. The manufacturer is free to use any method they wish to comply with the standard. Therefore, the type of emission controls used are not mandated by regulation, only the levels of emissions. The flexibility afforded by this structure of the regulations has resulted in a proliferation of emission control technologies, particularly in the early days of emission controls in the 1970's. Since the late 1980's all manufacturers have tended to use electronic fuel injection with closed-loop fuel control and three-way catalytic converters, but there are still variations on that central theme.

It can be confidently assumed that vehicles certified to meet a particular FTP standard were capable of meeting that standard at the time they rolled off the assembly line. In fact, engineers typically designed to levels much lower than the standards to account for production variability. Therefore, the FTP regulations establish a logical reference point for in-use vehicle testing. A vehicle that produces more emissions than the standard it was designed to meet must be defective because it has the inherent capability of meeting the standard. Fixing the defect should bring the vehicle back into compliance.

On the other side of the coin, it is not reasonable to expect a vehicle to perform better than it was originally designed, so vehicles capable of meeting FTP standards should pass an I/M test.

The FTP test is the "gold standard", and should therefore be the yardstick for determining which vehicles are normal emitters and which are high emitters. However, the FTP has one major drawback – it takes about 18 hours to perform the test. In order to test every vehicle on the road according to an FTP test, a huge number of emission-testing facilities would be needed. Therefore, it was necessary to develop a short test that could be performed quickly and conveniently that could provide an indication of how a vehicle might perform on the FTP.

There have been a number of short test procedures devised for testing gasoline-powered vehicles in inspection and maintenance programs. These include the Idle Test, the Two-Speed Idle Test, the Acceleration Simulation Mode Test and the IM 240 Test. All have some degree of correlation to the FTP, the correlation improving as the test becomes more similar to the FTP itself. Idle tests are the simplest to perform, as there is no need for a chassis dynamometer to operate the vehicle under load. The idle test can be done in any garage or test lane with a gas analyzer that measures HC, CO, CO_2 and O_2. The same is true for the two-speed idle test. This is the same as the idle test except for a supplementary measurement at a steady engine speed of 2500 rpm. This is a bit better than the idle test alone as it provides an assessment of off-idle operation and may identify fuel system or ignition problems not evident at idle. Dynamometer tests are preferable to either of the two unloaded tests just described. Loaded tests put the engine/emission control systems under loads more typical of real driving and allow for the measurement of NO_x emissions. The Acceleration Simulation Mode (ASM) test is a relatively simple steady-state test that has shown a fairly good correlation to the FTP. The best test, however, is the IM 240 test, a four-minute test that is very similar in nature to the FTP. Correlation between the FTP and the IM 240 is very good, making it possible to confidently identify marginally high emitters in the tested fleet, rather than just the highest emitters.

The AirCare program used the ASM 2525 steady state dynamometer test with a supplementary idle measurement. It was the first program to use the ASM test and the first to fail vehicles for excessive NO_x emissions. Vehicles unable to be tested according to the ASM test were given an idle inspection only. A complete description of the ASM/Idle test and Idle Test is provided in Appendix B. The ASM 2525 test is performed at a steady speed of 40 km/h (25 mph). The load applied to the vehicle varies by weight and approximates climbing a 3% grade at the test speed.

Diesel-powered vehicles account for less than 2% of the vehicles eligible for AirCare testing. Many programs exclude diesels from testing because there are few of them and testing them poses some difficulties. For one, diesel vehicles produce a certain amount of soot that can foul the sample lines, filters and gas analyzers. Due to the public perception that diesel vehicles are "dirty", it was a policy decision that they should be included in the AirCare program. The test used was a steady-state dynamometer test at a fixed speed of 50 km/h and a load of 10.0 hp. Exhaust gases were not sampled. Instead, an opacity meter was used to assess the amount of smoke being produced. Opacity meters shine a light beam through a smoke plume. Complete obliteration of the light by the smoke equates to 100% opacity. Logically, no visible smoke corresponds to 0% opacity. The AirCare procedure assessed the average smoke level produced over a 5-second period following 25 seconds of stable operation at the test speed and load.

2.2 PASS/FAIL LIMITS

As stated earlier, the goal of a short test is to identify those vehicles that would fail an FTP test while allowing any vehicle that would pass an FTP to receive a clean bill of health. Due to the constraints imposed by using a short, simple test to predict what the FTP result might be, and to avoid wrongly failing normally operating vehicles, the pass/fail limits are typically set well above the range of normal readings.

As a result, vehicles that are not operating to their full potential can pass an I/M test, thus sacrificing a certain amount of potential benefits. This is an unfortunate necessity if the objective of avoiding false failures is to be achieved. A typical problem concerns the state of the vehicle when it arrives for an emissions test. If it has been driven only a short distance to the inspection or has waited a long time in line prior to the test, its emissions may be higher than usual, simply because the catalytic converter has stopped operating efficiently. It might be necessary to operate the vehicle under load for 3 or 4 minutes in order to restore full catalytic converter efficiency. This, however, would reduce lane throughput and exacerbate the preconditioning problem. A happy medium includes some amount of preconditioning coupled with lenient pass/fail standards.

2.3 BACKGROUND TO THE AIRCARE PROGRAM

The AirCare vehicle emissions inspection and maintenance program was implemented in 1992 as the principal emission reduction measure in the Air Quality Management Plan (AQMP) for the Greater Vancouver Regional District (GVRD). The overall goal of the plan was to reduce the inventory of emissions of five common air contaminants; Volatile Organic Compounds (VOC's), Carbon Monoxide (CO), Oxides of Nitrogen (NO_x), Sulphur Oxides (SO_x) and Particulate matter (PM), by 38% in the year 2000 relative to the baseline year of 1985.

At the time the AQMP was devised, regional planners expected to see considerable growth in the human and vehicle population in the Vancouver metropolitan region and the communities in the Lower Fraser Valley over the next twenty to thirty years. Projections anticipated a doubling of the human population between 1990 and 2021 to approximately 3 million. It was also expected that the growth in the vehicle-kilometres-traveled would exceed the population growth rate. Although vehicle emission rates on a per-vehicle basis were going down as a result of new emission control technology, it was felt that the increase in the number of vehicles and the number of kilometres driven each year would eventually overcome the gains made by new technology. This would result in an increase in vehicle-generated pollutants after 2005.

According to the 1990 emissions inventory, light-duty motor vehicles were estimated to account for 90% of the carbon monoxide, 35% of the oxides of nitrogen, and 43% of the volatile organic compounds released annually into the Lower Fraser Valley air shed. Thus, a vehicle emissions inspection and maintenance program was considered to be one of the most cost-effective approaches to reducing smog-forming pollutants in the region.

Planning for the AirCare program had begun in the 1980's, culminating in a report from a task force outlining recommendations for the implementation of a testing program in the

Vancouver/Lower Fraser Valley region. In 1990, the Canadian Council for Ministers of the Environment (CCME) issued a recommendation that three specific regions of Canada with air quality problems (Lower Fraser Valley of B.C., Windsor-Quebec City Corridor and St John, New Brunswick) should implement vehicle inspection and maintenance programs by 1992. British Columbia was the only jurisdiction to comply with this recommendation.

In Canada, jurisdiction over in-use vehicles is provincial, rather than federal. As a result, it was necessary for action to occur at the provincial or even municipal level to start up an I/M program. AirCare evolved as a result of action by the GVRD to request a program for the Greater Vancouver Regional District. The provincial government agreed to implement a program on their behalf as the legislative authority over motor vehicles rested with the province. The AirCare administration office was initially part of the Ministry of Attorney General, but was moved to the Ministry of Transportation and Highways in 1994. In 1997, the program was moved to the Insurance Corporation British Columbia (ICBC). It remained there until September 1999 when it was moved to a new agency called Translink. Although created by provincial legislation, Translink is governed at the municipal level.

2.4 GOAL OF THE AIRCARE PROGRAM

From its name, it is clear that the AirCare program is intended to address ambient air quality. However, it has been difficult to communicate to the public just how the program is supposed to achieve its goal.

To some people, things that produce visible emissions are the most responsible for air pollution. These include diesel trucks, aircraft, locomotives, ships and industrial smokestacks. For these people, the AirCare program should concentrate on these sources before dealing with the private vehicle. Even those who can accept that vehicles are part of the problem often point to vehicles emitting visible smoke as the chief culprits. To these people, AirCare should focus on getting smoking vehicles off the road and have nothing to do with vehicles that don't smoke or smell.

Others believe that the program should encourage the use of public transit by being an obstacle to driving a private motor vehicle. Others think that the solution is to get the older vehicles off the road and leave the newer vehicles alone. Many believe the program to be a tax grab or some venture endorsed by government that profits the testing contractor at the public's expense.

The actual goal of the program is to identify vehicles with emission-related problems, preferably in the early stages, and ensure that these vehicles get repaired. The objective is to ensure that the entire in-use fleet operates with emissions at or below the FTP standards applicable to their production year and vehicle type.

3.0 AIRCARE FLEET PROFILE AND TRENDS

By provincial regulation, vehicles registered in ICBC Rating Territories D, E or H must submit to an emissions inspection as a condition of licensing. During most of the period covered by this report, vehicles whose model year was equal to or greater than the calendar year were exempt from testing. All other vehicles, with the exception of Collector, Antique and Agricultural Plate vehicles, were required to be tested annually. As of January 1, 2000, the exemption for newer vehicles was extended to two years. Consequently, the newest model year represented in this analysis is 1998.

In 1992, the population of passenger cars and trucks in the AirCare operating region with a Gross Vehicle weight Rating of 5000 kg. or less was estimated to be slightly less than 1 million. This population was expected to grow at the rate of about 3% per year in accordance with long-term growth trends for the overall fleet.

Table 1 shows the actual number of vehicles tested in each Program Year compared to the projected number of vehicles based on an assumed initial fleet size of 950,000 (1 million minus 50,000 current-year vehicles).

Table 1. Projected and Actual Numbers of Vehicles Inspected

Program Year	Projected	Actual	% Changed from Previous Year	Actual as a % of Projected Number
1 (1992-1993)	950,000	507,616	N/A	53.43%
2 (1993-1994)	978,500	1,016,528	100.26%	103.89%
3 (1994-1995)	1,007,855	1,002,566	-1.37%	99.48%
4 (1995-1996)	1,038,091	550,668	-45.07%	53.05%
5 (1996-1997)	1,069,233	1,060,344	92.56%	99.17%
6 (1997-1998)	1,101,310	1,022,874	-3.53%	92.88%
7 (1998-1999)	1,134,349	1,042,179	1.89%	91.87%
8 (1999-2000)	1,168,379	999,007	-4.14%	85.50%

It is apparent from the table that the rate of growth in the actual number of vehicles tested has not kept pace with fleet growth projections. There are also some erratic results in years 1992/93 and 1995/96. The anomalies are due to three separate events. The first occurred in 1992-1993 when 1986-and-newer vehicles were exempted from testing during the period between September 19, 1992 and February 28, 1993. This reduced the inspection volume by approximately 50% and was necessary to alleviate unacceptably long wait times and line-ups at AirCare inspection centres. An estimated 300,000 inspections were lost as a result of this temporary exemption. The second problem occurred shortly after testing of the full fleet was re-introduced in March of 1993. The inspection centre workers went on strike from mid-April to late July of 1993, resulting in the loss of approximately 250,000 inspections. The third significant event took place in 1996 when the inspection centre staff went on strike for 5 months, affecting the months of February, 1996 through July of that year. Somewhere between 450,000 and 550,000 vehicles were able to re-license without AirCare inspections as a result of the strike.

During the first seven years of operation, the number of inspections performed fell short of the initial projection of 8.4 million by more than 1 million tests.

3.1 FLEET DYNAMICS

One characteristic of a vehicle fleet is that it is in a state of constant change. New vehicles are continually being purchased, old vehicles are being scrapped and used vehicles are constantly changing hands. As a result, the mix of vehicles appearing for AirCare inspections has changed radically in composition over the first eight years of operation.

3.1.1 New Vehicle Sales

Each new model year of vehicles contributes an average of about 75,000 vehicles per year to the fleet. Although AirCare inspection data give an indication of the number of new vehicles added to the fleet, the fact that the AirCare program year runs from September to August creates a few difficulties in accounting for new vehicle sales. New vehicle models are traditionally introduced in September/October of each year. Vehicles of the 1998 model year, for example, went on sale in the fall of 1997. However, according to AirCare rules, a 1998 vehicle did not require AirCare inspection until its first renewal of licensing in calendar year 1999. For a 1998 model year vehicle purchased in December of 1997, it would be possible to re-license in December of 1998 without an AirCare inspection. Thus, such a vehicle would be two years old before being tested in December of 1999. Conversely, a late-production 1998 vehicle that was purchased in December of 1998 would require an AirCare inspection prior to any licensing transaction performed in 1999. In some circumstances, this would require that the vehicle be tested after only a few months of operation.

Due to the fact that “new” vehicles do not appear in the AirCare test fleet until January, only 8 months of testing is captured within a program year. This means that only about two-thirds of “new” vehicles are accounted for in any given program year. Therefore, it takes more than one inspection cycle to get an indication of how many vehicles of a given model year have entered the fleet. A solution for this is to use calendar years as a basis for the analysis. This results in 12 months of data for each new model year, but it also limits the analysis for 1992 to 4 months.

Figure 1 shows the distribution of vehicle population by model year for passenger cars in calendar years 1995, 1997 and 1999. Figure 2 shows the trend lines for light-duty trucks.

These figures illustrate three similar trend lines. It is significant that, for vehicles of the 1990 model year and older, there was a marked decrease in the population between 1995 and 1999. This would be caused by vehicle retirement. The trend lines also show a decreasing population of passenger cars throughout the 1990’s. This reflects the increasing popularity of sport utility vehicles and light trucks with vehicle purchasers. The trend lines of light duty trucks show less population loss between 1995 and 1999, possibly due to the greater durability of trucks relative to passenger cars. There is a pronounced dip in the population line at the 1996 model year for both cars and trucks, suggesting that this year was a poor year for vehicle sales in the Vancouver region. The population of 1997 and 1998 model year light-duty trucks exceeds 30,000, about 10,000 less than the corresponding passenger car population.

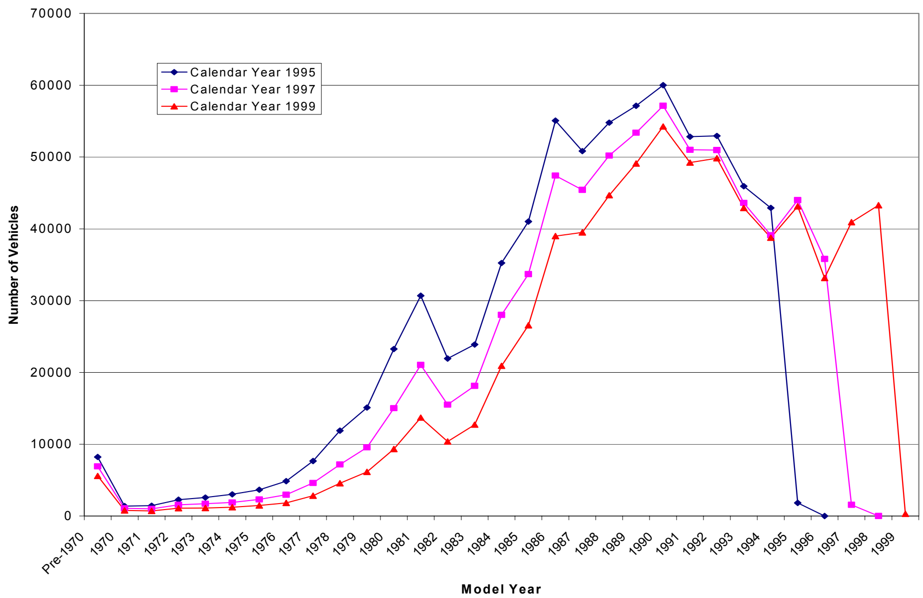


Figure 1. Model Year Distribution of Passenger Vehicles by Calendar Years

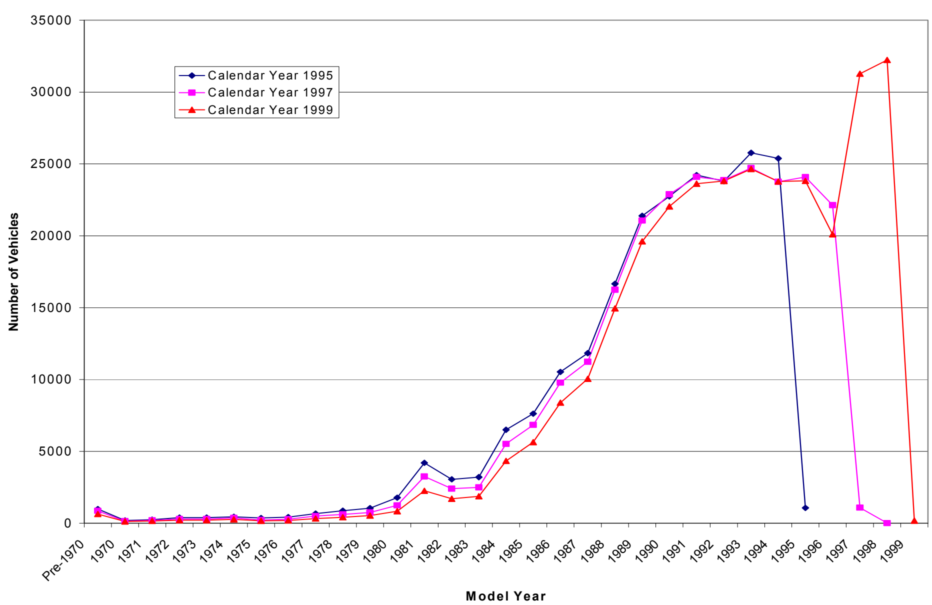


Figure 2. Model Year Distribution of Light Duty Trucks by Calendar Years

Figure 3 illustrates the population distribution data for heavy-duty trucks. For the purpose of this report, a vehicle is classified as a heavy-duty truck if its Gross Vehicle Weight Rating (GVWR) exceeds 2722 kg. (6000 lbs.) for model years up to 1988, and 3850 kg. (8500 lb.) for model years 1988 or newer.

It shows that heavy-duty trucks comprise only a fraction of the light-duty truck population. Higher populations of heavy-duty-classified trucks evident prior to 1988 reflect that fact the lower gross weight cut-off during that period. After 1988, vehicles of a gross weight rating that would have previously been identified as heavy-duty appear in the light-duty segment.

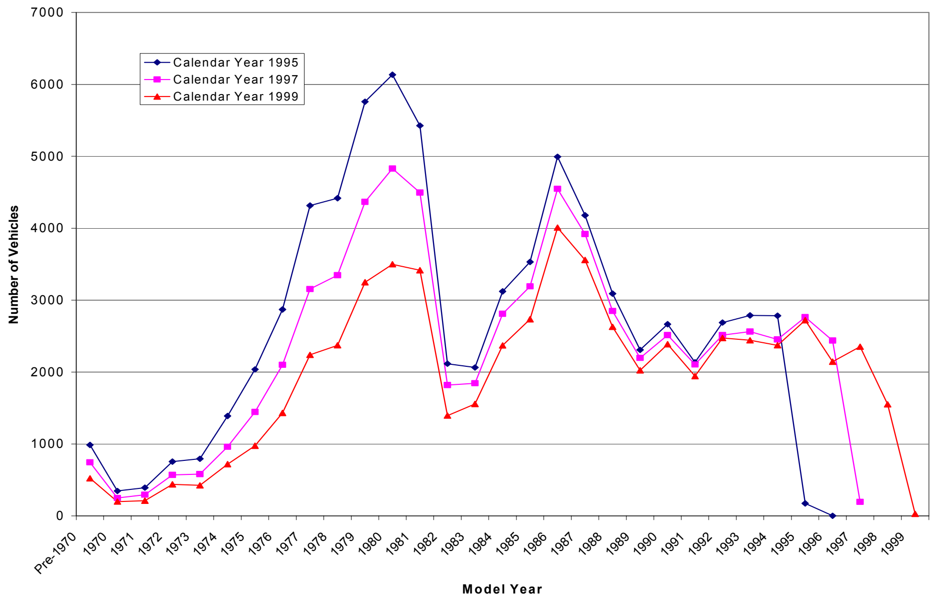


Figure 3. Model Year Distribution of Heavy Duty Trucks by Calendar Years

In common terms, a light-duty truck would be called a half-ton truck. Prior to 1988, a three-quarter ton truck would be considered heavy-duty. Commencing in 1988, most three-quarter-ton trucks became light-duty trucks as far as emissions certification was concerned.

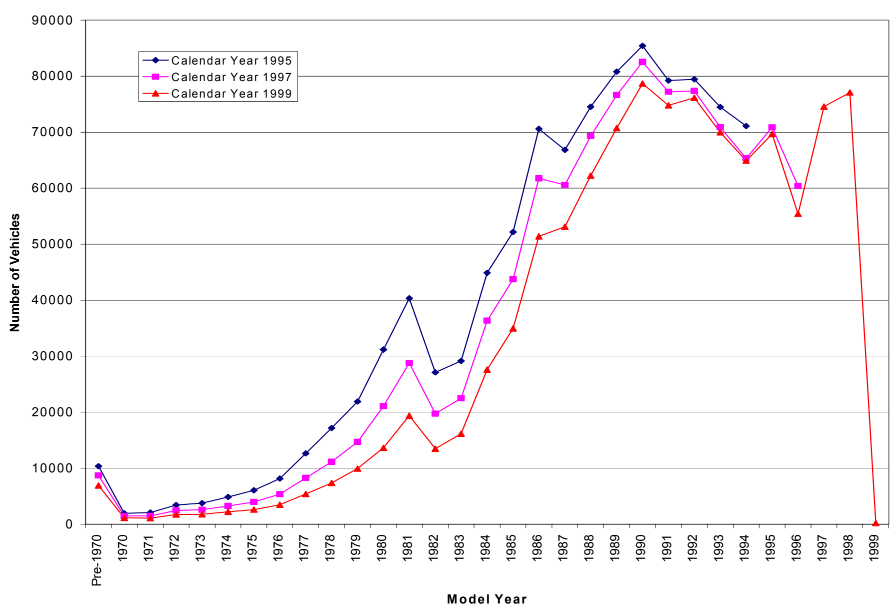


Figure 4. Model Year Distribution of All Vehicle Types by Calendar Years

Figure 4 illustrates a combination of all the population groups. The loss of population between 1995 and 1999 is evident in all model years up to and including model year 1994. Overall, a declining trend in population-per-model-year is evident for model years 1991 and newer, reaching a minimum with the 1996 model year. The data suggest that here are only 55,000 to 60,000 1996 models in the AirCare-eligible fleet, far less than the 1990 model year, that has ranged from 85,000 in 1995 to about 78,000 in 1999. It appears that vehicle sales surged in the 1997 and 1998 model years, showing population levels more like those seen in the early 1990's.

It cannot be overlooked that the AirCare data represent only those vehicles that have been presented for inspection. Comparing the data to vehicle sales or registration data for the AirCare operating region would validate the suggested trend of decreasing vehicle population between 1995 and 1999. It has not been possible to obtain such data, however. Records of new vehicle sales for the Lower Fraser Valley only are not kept and sources such as the Insurance Corporation of British Columbia track only the number of insurance policies in effect at any given time. Historical records are not available and vehicles that are not insured (i.e. in storage) are not included. It is unfortunate that this data is not available, as it would be valuable to determine if the number of vehicles in the fleet is actually declining or if it is simply the number of vehicles reporting for AirCare inspection that is diminishing.

3.1.2 Addition of Vehicles from Outside the Program Area

In-use vehicles are continuously added to the fleet from outside the program area, and each year, vehicles of all model years appear for inspection having never been through the process before. For example, in 1995, AirCare inspection would have been required for all vehicles of 1994 model year and older. If all of the vehicles meeting this age profile were inspected in 1995 and there were no additions, one would expect to see each of those vehicles again in 1999. When we look at the inspection data for 1999, we find that some of the vehicles that were seen in 1995 have disappeared, probably due to being taken out of the program area or destroyed in an accident. What we see as well is that the 1999 data set contains vehicles from the 1994 and older model years that were not present in 1995. Presumably, these additional older vehicles were brought into the program area from other provinces or countries.

Table 2. Number of First-Time-Tested Vehicles by Calendar Year

Calendar Year	Total Number of Vehicles Tested	Number of First-Time-Tested Vehicles
1992	244,823	244,823
1993	751,755	599,917
1994	974,720	380,917
1995	1,002,604	141,529
1996	644,611	80,822
1997	1,011,112	142,614
1998	1,030,648	119,325
1999	1,047,969	112,527
2000	968,135	53,659

The data in Table 2 suggest that the exemption of 1986-and-newer vehicles from September, 1992 through February of 1993 and the ensuing strike that closed inspection centres for about 3 months, resulted in a significant number of vehicles having their first test deferred until 1994. The second labour dispute in 1996 also affected the flow of testing by allowing almost half the fleet to avoid testing in that year. Also, the number of new vehicles tested in 1996 was significantly less than previous year. Due to the fact that the program has remained in continuous operation since August of 1996, the fluctuations in test volumes have smoothed out somewhat. The number of vehicles seen for the first time in recent program years seems to correspond reasonably with the number of “new” vehicles coming into the program in their first year of eligibility. The drop in calendar year 2000 reflects the extension of the new-vehicle exemption to 2 years, meaning that the 1999 model year vehicles were not tested. Assuming a normal sales volume of 75,000 units, the “first-time-seen” total for 2000 would have been increased to about 128,000 vehicles, comparable to the levels in 1997, 1998 and 1999, if the 1999 model year vehicles had been included.

3.1.3 Vehicles Retired From Use

As a rule, motor vehicles have a finite life span. Although some vehicles are preserved as a result of features that make them collectible (low production, high performance, prestigious brand name, etc.), most vehicles do not last more than 20 years. At that point, most vehicles are significantly worn, parts are hard to find, and the cost of repairing them may exceed their values. Previous figures show a significant drop-off in the vehicle population after 10 years of age. According to Figure 4, more 1990 model year vehicles were presented for testing than any other model year in each of the case years. For vehicles older than 1990 model year, however, the population declines rapidly. In 1995, there were 317,111 vehicles of model year 1985 or older presented for inspection. In 1999, that number declined to 168,767, a drop of almost 50% in four years. This is likely due to natural retirement of vehicles as they wear out. Vehicles older than 20 years tend to be those preserved by collectors and are typically no longer used for daily transportation. The population of vehicles of this type remains fairly stable, or may even increase due to the importation of collector-type vehicles from outside the AirCare program area.

3.1.4 Fleet Profile

In general, the average age of vehicles on the road in Canada is increasing. The improved quality and durability of modern vehicles makes it possible to keep them in operation for much longer than vehicles manufactured in the 1970’s. According to the Canadian Vehicle Survey [3], the average age of a vehicle in British Columbia in 2000 was 9.33 years, compared to a national average of 7.99 years. The median ages were 8 years in British Columbia, and 7 years nationally. British Columbia's overall share of registrations was 13.3% of the national total, but was much higher for older model years, (27.3% of 1981 model year vehicles, and 23.5% of 1980 and older).

Figure 5 shows the numbers of vehicles inspected by AirCare in 2000 as well as total registrations for British Columbia and for Canada. In 2000 AirCare inspected 6.6% of all light-duty vehicles registered in Canada up to model year 1998. The fourth line shows AirCare vehicle numbers multiplied by the reciprocal of 6.6%, and its co-incidence with the national registrations line illustrates that this percentage is very consistent across all model years. Although British Columbia has higher than average numbers of older vehicles, most of these older vehicles are not in the AirCare fleet. Because 1999 and 2000 model years were exempt from testing in 2000, the average age of vehicles inspected by AirCare in 2000 was 9.45 years (median 8 years). However, if estimates for exempt vehicles are included, the fleet average age for the region can be calculated as 8.55 years (median 7 years), which is much closer to the national average than to the British Columbia average.

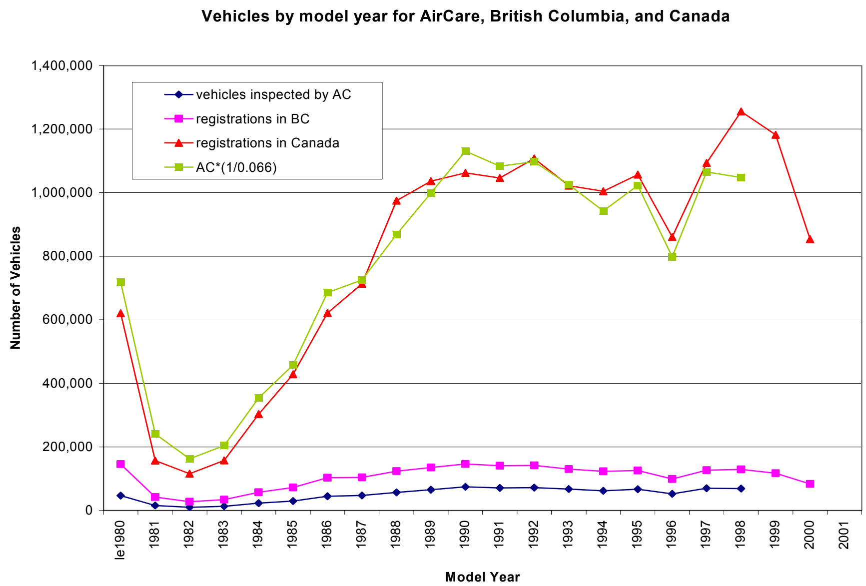


Figure 5. Vehicle Registrations in Canada, British Columbia and AirCare Region in 2000

The nominal vehicle subject to AirCare testing in 1999 was very different from the nominal vehicle in 1992. The active fleet in 1992 would have consisted of 50% vehicles of model year 1985 or older and the best available technology would be represented by the 1992 model year. By calendar year 1999, however, many of the vehicles in operation in 1992 were no longer in the fleet, having been replaced with vehicles of the 1994, '95, '96, '97, '98, and '99 model years. The majority of these new vehicles were manufactured to comply with U.S. EPA Tier 1 emission standards, which prescribed lower HC (0.16 g/km vs. 0.25 g/km) and NO_x (0.25 g/km vs. 0.62 g/km) limits. As such, the new vehicles added to the fleet since 1992 have been better performers from an emissions standpoint than the vehicles they replaced, regardless of the effects of age and mileage. The median model year of the AirCare fleet in 1999 was 1993. Analysis of program data over the years indicates that the median age of vehicles has remained about 7 years older than the most recent model year. Thus, each year, the median model year advances by one year.

In addition to changes in fleet population and emission control technology, the composition of the fleet has been changing as well. In the 1990's vehicle purchasers have had a greater tendency to purchase trucks as family transportation. This phenomenon has seen the sales of passenger cars decline while sales of trucks have increased. This trend will be discussed further, and the effect on emissions performance is potentially significant.

Trucks are subject to different emission standards than passenger cars. The reason for this is that these vehicles are larger and heavier than passenger cars and are built to different design constraints as a result of their ability to carry heavy loads or tow large trailers. Government set more lenient standards for trucks in recognition of these significant differences. While the difference in standards suggests that trucks are much greater polluters than passenger cars, it must not be overlooked that trucks are required to meet these standards for a significantly longer time and mileage; 11 years or 193,000 km compared to 5 years or 80,000 km for a passenger car. With the advent of Tier 1 standards, that were phased-in beginning in 1994, the durability requirement for passenger cars was extended to 10 years or 160,000 km. At the same time, four new emissions standards categories were created for trucks with Gross Vehicle Weight Ratings below 3856 kg. These were:

- LDGT1 – Light, light-duty gasoline truck
- LDGT2 – Heavy, light-duty truck gasoline truck
- LDGT3 – Light, heavy-duty gasoline truck
- LDGT4 – Heavy, heavy-duty gasoline truck

With these new definitions, LDGT1's were made equivalent to passenger cars in terms of emissions design standards. Durability requirements for LDGT1 and LDGT2 were set at 10 years, 160,000 km. The durability requirements for LDGT3 and LDGT4 remained at 11 years, 193,000 km. The emission control systems used on trucks manufactured since 1988 are basically equivalent to those used on passenger cars – electronic fuel injection with three-way-catalytic converter. Although the standards for LDGT2, 3 and 4 are more lenient than passenger cars, the actual emissions output of cars and light-duty trucks are more similar.

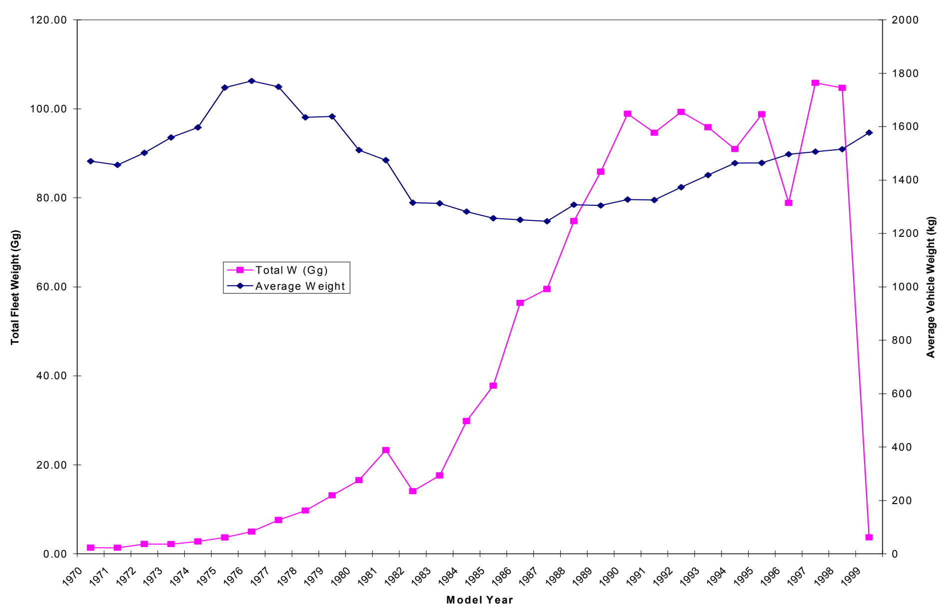


Figure 6. Total and Average Weights of the Fleet in 2000

Another trend in the fleet composition is to higher net vehicle weights. Figure 6 shows the trend in average net weight by model year. Not surprisingly, vehicle weights were higher in the 1970's, prior to the advent of fuel economy legislation. The highest average weight occurs with the 1976 model year. A decrease in average weight is evident throughout the 1980's but the trend begins to move upward again in the 1990's due to the greater proportion of truck sales.

Trucks tend to have larger displacement engines than passenger cars. According to the data, the average engine displacement for passenger cars in 1993 was 2.7L. This actually decreased between 1993 and 2000 to less than 2.5L. The average engine displacement for light-duty trucks was fairly stable at about 3.6L during the same period. For heavy-duty trucks (GVWR greater than 3856 kg. and less than 5000 kg.) the average engine displacement was 5.73L in 1994 and 5.83L in 2000. The fleet total engine displacement (the sum of all the individual engine displacements) increased from 2967 kL in 1994 to more than 3148 kL in 1999, essentially because of the increased popularity of trucks.

Representation by manufacturer has also changed over time. For this analysis, two case years were chosen, 1995 and 2000. Figure 7 and Figure 8 show the representation by manufacturer of the passenger car fleet in the two case years.

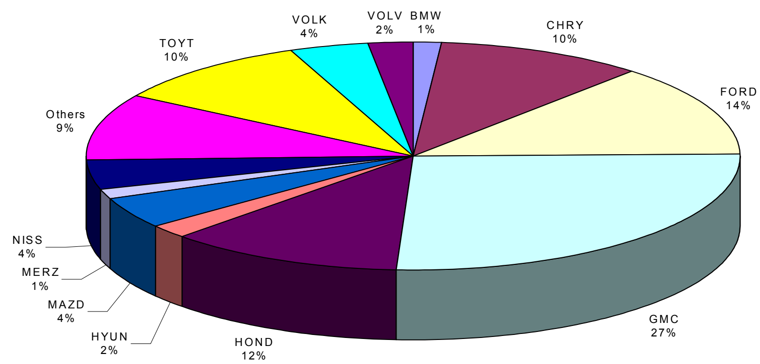


Figure 7. Distribution by Manufacturer of Passenger Vehicles in 1995

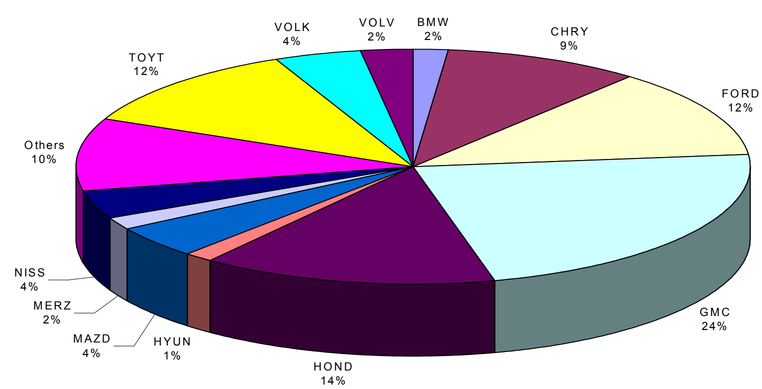


Figure 8. Distribution by Manufacturer of Passenger Vehicles in 2000

The figures show a decrease in the proportion of the passenger car fleet accounted for by the "Big Three" – General Motors, Ford and Chrysler. These three manufacturers held 51% of the car fleet in 1995, but dropped to 45% in 2000. The losses experienced by the domestic manufacturers were offset by gains from import nameplates. Honda and Toyota each gained 2 percentage points, resulting in their combined share increasing from 22% in 1995 to 26% in 2000. The Vancouver area car fleet is clearly dominated by 5 principal manufacturers, GM, Ford Chrysler, Toyota and Honda.

Figure 9 and Figure 10 show the distribution by manufacturer for light-duty trucks.

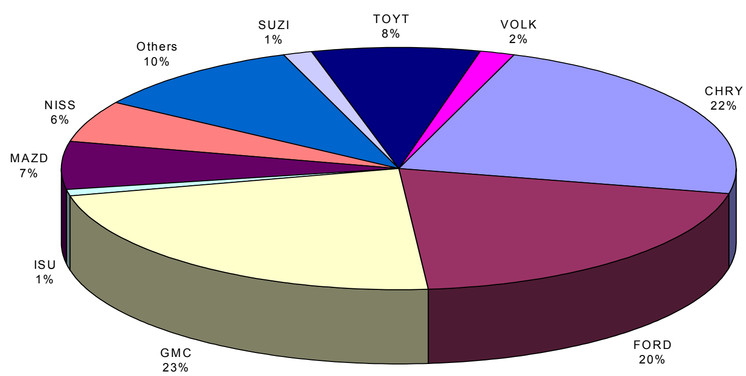


Figure 9. Distribution by Manufacturer of Light Duty Trucks in 1995

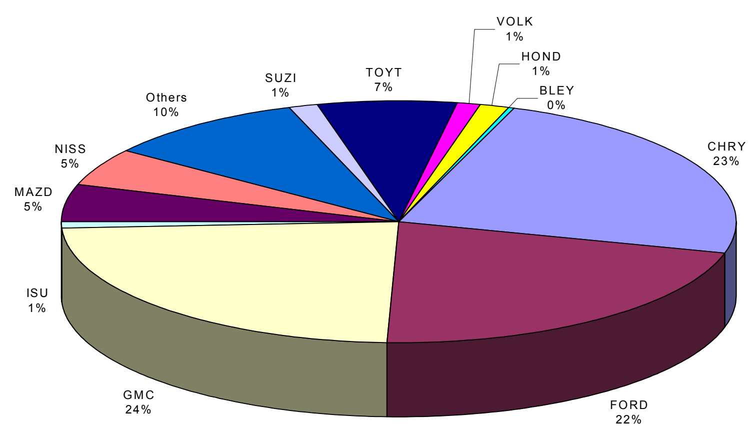


Figure 10. Distribution by Manufacturer of Light Duty Trucks in 2000

For this type of vehicle, the “Big Three” have a much greater share of the pie. GM, Ford and Chrysler combined formed 65% of the light truck fleet in 1995, increasing to 69% in 2000. The largest representation among import nameplates was from Toyota, Nissan and Mazda. All three experienced a slight decline from 1995 to 2000.

Figure 11 and Figure 12 relate to heavy-duty trucks (GVWR greater than 3856 kg.). In this segment of the fleet, the “Big Three” have a virtual monopoly with 99% of the vehicles tested being manufactured by either GM, Ford or Chrysler. GM is the biggest player in the segment with Ford a close second. GM and Ford had a combined 81% share of the heavy-duty truck fleet in the year 2000.

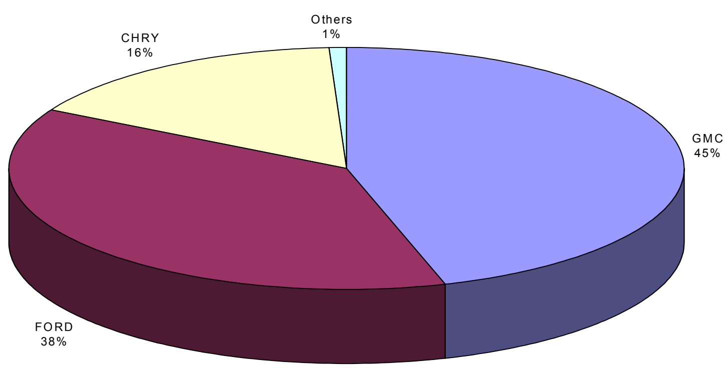


Figure 11. Distribution by Manufacturer of Heavy Duty Trucks in 1995

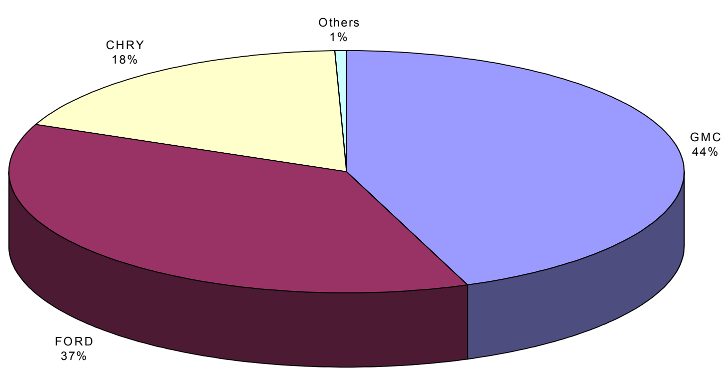


Figure 12. Distribution by Manufacturer of Heavy Duty Trucks in 2000

3.1.5 Diesel Vehicles

The number of diesel-powered vehicles presented for AirCare inspections has remained relatively stable over the first 8 years of program operation. Like other vehicles in the fleet, the diesel fleet has been changing in composition due to the introduction of new vehicles and the retirement of older vehicles. In 1993, which was a low-volume year, 12,682 diesel vehicles were tested. These vehicles were predominantly passenger cars. In 1999, the fleet size was comparable at 18,245 vehicles, but the dominant vehicle type had changed from passenger cars to trucks. Figure 13 shows the trends in population for diesel cars and trucks between 1992 and 1999.

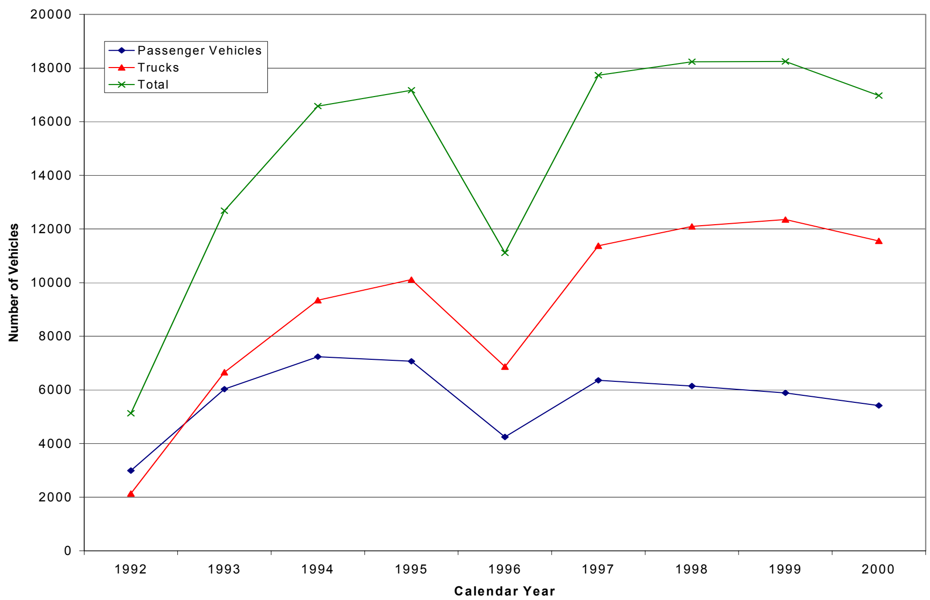


Figure 13. Number of Diesel Passenger Cars, Trucks and All Vehicles

During the early 1980's there was a move towards more diesel engines in passenger cars and light trucks in response to higher gasoline prices. When gasoline prices stabilized and even decreased later in the decade, the demand for diesel engines in passenger cars declined as well. When stringent standards for particulate matter were enacted in the early 1990's, most manufacturers dropped out of the North American diesel passenger car market, with the exception of Volkswagen who have continued to offer diesel engines. On the truck side, diesel engines have increased in popularity but still represent a small fraction of the overall fleet. Perhaps in response to stringent particulate matter standards, diesel engines tend to be offered in the heavy-duty range of trucks with GVWR's greater than 3856 kg (8500 lbs.). These engines are subject to Heavy-Duty Transient Engine Test standards that are measured in grams per brake horsepower hour (g/bhp-hr) or grams per MegaJoule (g/MJ).

3.1.6 Alternative Fuel Vehicles

Vehicles converted to operate on either propane or natural gas have been part of the Vancouver-area vehicle fleet since the early 1980's when government subsidies were made available to encourage vehicle owners to shift from gasoline, thereby reducing demand for imported crude oil. Since the inception of the AirCare program in 1992, the population of vehicles capable of operating on natural gas or propane has declined steadily. This is because older vehicles continue to be retired while very few new vehicles are undergoing alternative fuel conversions. Although some new-vehicle manufacturers offer natural gas-powered units from the factory, the market penetration of these OEM alternative fuel vehicles has been minimal. Due to their perceived "green" characteristics, these vehicles have been examined separately as part of every AirCare data analysis. This report will also include a discussion of these vehicles, but it should be kept in mind that conversions represent an ever-decreasing share of the vehicle fleet. Based on past indications of emissions performance, a decrease in the population of alternative-fueled vehicles will produce an emissions benefit, rather than a loss of emission reductions

3.1.7 Disappearing Vehicles

As previously discussed, retirement is a natural stage in the life cycle of a motor vehicle. Therefore, from one program year to the next, it would be expected that some of the vehicles seen in the previous year would not show up in the following year. There are factors other than vehicle retirement, however, that affect the number of vehicles presented for inspection each year. Human behaviour is an important consideration when looking at trends in fleet composition and in the calculated program effects. There are a number of reasons why a vehicle tested in a given year may not appear the next:

- Removed from use, due to age or destroyed in accident.
- Moved away from program area
- Vehicle sold to new owner on a different license renewal cycle
- Vehicle purposely re-registered outside the program area to avoid testing.
- Purchase of 23 months license and insurance on the basis of one AirCare inspection.
- Vehicle was exempted from testing due to labour disruption.

Some of these mechanisms require deliberate action on the part of a vehicle owner to evade program requirements. Some are unintentional. Selling the vehicle is one of these "unintentional" mechanisms. When an AirCare test results in a PASS or CONDITIONAL PASS, an expiry date is set 363 days into the future. Within the timeframe between the test date and the expiry date, licensing and insurance can be purchased for up to 12 months. Therefore, if a vehicle has been tested within the previous 363 days, it can be licensed for another year. Owners may take advantage of this without selling their vehicle, but they do have to cancel their existing license and insurance and then renew for a further 12 months, incurring surcharges in the process.

In order to assess the degree to which the above-mentioned factors affected the inspection process, an analysis of the entire data set was undertaken. There were a number of different ways of approaching this task. After considering the options it was decided that we would look at each calendar year as a separate group and identify the number of vehicles that appeared for the first time in each year and the number of vehicles seen in the previous year that did not appear the next. Table 3 illustrates the results of this analysis.

From Table 3, it is apparent that the effect of labour disruptions and other causal factors has been significant. Because there were fewer vehicles being tested in 1996, the number of vehicles that were tested in 1996 and not seen in 1997 was significantly smaller than any other year. Also note, a number of vehicles which did not show up from the previous year might reappear in the following year, and therefore they are included in the remaining fleet in the following year. The number for returning vehicles clearly shows that many vehicles skipped their 1996 inspection and returned in 1997. An interesting statistic is that only 425,436 of the 974,720 vehicles that received an AirCare inspection in 1994 have appeared each year since.

Table 3. Irregularity of Inspecton Frequency

Calendar Year	# Vehicles Tested	# Seen First Time	# Tested in Previous Year but Not Seen in Current Year	# Returning for Annual Inspection as Expected	# Tested at Some Point Prior to Previous Year
1992	244,823	244,823	N/A	N/A	N/A
1993	751,755	599,917	92,985	151,838	N/A
1994	974,720	380,917	205,077	546,678	47,125
1995	1,002,604	141,529	212,372	762,348	98,727
1996	644,611	80,822	494,707	507,897	55,802
1997	1,011,112	142,614	164,154	480,457	388,041
1998	1,030,648	119,325	209,294	801,818	109,505
1999	1,047,969	112,527	203,779	826,869	108,573
2000	968,135	53,659	237,240	810,729	101,747

Table 4 shows the number of vehicles that have missed 0,1,2,3, and so on years of inspections between 1994 and 1999.

Table 4. Number of Inspections Missed between 1994 and 1999

Number of Years Missed	Number of Vehicles
0	425,436
1	454,803
2	211,669
3	130,734
4	143,668
5	138,581
6	111,374
7	39,519

It is important to remember that there are only so many vehicles in the data set that were eligible for testing for all eight years since 1992 and were actually kept in use in the program area throughout that period. During the first three calendar years of the program, many vehicles were inspected for the first time. Given that the program was shut down completely for almost 3 months in 1993 and that 1986-and-newer vehicles were exempt from testing for six months, it took more than two years for all of the vehicles that should have been tested in the first year to appear. Throughout this period, the normal rate of vehicle scrappage continued meaning that some vehicles seen in 1992 did not appear in 1993 and so on. Vehicles from the 1992 model year were not added to the AirCare eligible fleet until March 1, 1993 but were very soon affected by the strike which started in April 1993. The 1993 models became eligible for testing on January 1, 1994. Therefore, the data set for the Table 4 starts from 1994 rather than 1992 or 1993.

A more in-depth analysis shows an major loss of vehicles in calendar year 1995 relative to the previous year. There were 192,247 vehicles that were inspected in 1994 that did not return for inspection in 1995. While some of this loss would be expected as a result of normal vehicle retirement, the magnitude of this loss greatly exceeds the attrition rate evident in later years. While it is known that factors such as re-sale and short-term licensing can allow extension of the period between inspections, one would expect that the vehicles that did not re-appear in 1995 would eventually show up in 1996 or 1997. However, this is not the case. In fact, 97,100 of the vehicles that were tested in 1994 have never been through the test again since. This represents almost 10% of the vehicles tested in that year.

To investigate the possibility that some of these vehicles were deliberately avoiding the program, a mini-analysis of this group was performed. A random sample of 500 vehicles was selected and the current licensing status was checked for each one. What the survey revealed was that 30% of the vehicles were no longer in the program area and over 50% were no longer licensed for use. This suggests that deliberate program avoidance may not be the explanation for this loss. However, this survey was conducted in 2001, not 1995 and it was not possible to discern what the status of those vehicles was in 1995. As a result, deliberate avoidance cannot be ruled out as a factor in the loss of these vehicles.

On a positive note, virtually all of these “disappeared” vehicles had passed inspection when they went through the test. This would suggest that avoidance of repair costs was not the motive for not returning the following year. In some cases, vehicles that disappeared in one year re-appeared two or three years later.

3.2 CONCLUSIONS REGARDING FLEET PROFILE

It is important to recognize that the vehicle fleet is an ever-changing entity. The replacement of older, high-emitting vehicles with new, cleaner vehicles occurs continuously, resulting in improved emissions performance, regardless of the impacts of the inspection process. To some degree, the trends seen in the AirCare test results mirror vehicle sales trends. The shift to a higher proportion of trucks is one obvious trend, and the low numbers of 1996 model year vehicles is also shown in national registration data.

It is likely that used-vehicle re-sale has had a significant impact on the fleet inspection pattern. According to a study by DesRosiers [1], the annual used car sales volume range from 2.5 to 3.0 million, nationally, which corresponds to 16% to 19% of the total vehicle population. What this means is that a minority of vehicles going through the AirCare inspection process have remained in the ownership of one person for the whole 8 years. There is a very high probability that the sale of a vehicle extends the period of time between inspections as owners tend to transfer their existing license plates to the newly-purchased vehicle. It is significant that the

AirCare-eligible fleet during this period has remained fairly constant in size at about one million vehicles, suggesting that 800,000 have been retired from use at some point.

The constantly changing composition of the in-use vehicle fleet makes it very difficult to isolate all of the factors that contribute to overall emissions to the regional air shed. The fact that the AirCare program is limited to one geographical area makes it possible for vehicles to migrate in and out of the program over time, making it difficult to accurately predict trends.

4.0 VEHICLE USAGE PATTERNS

The total emissions output of a fleet of vehicles depends mostly on the number of vehicles in operation and the annual distance they are driven. Traffic patterns also have a strong influence on emissions output. Emission inventory models rely on emission rates expressed in terms of grams per kilometre for various vehicle types and model years. Total emissions output can be calculated by multiplying the nominal emission rate for a case year by the number of vehicles and the average distance traveled.

4.1 VEHICLE DRIVING CYCLE

The way in which a vehicle is used has a dramatic effect on emissions output. Operation in a steady-state mode such as sustained highway driving tends to produce low emissions. City driving, with its attendant stops and starts, idling and generally low-speed operation results in much higher emissions production.

The driving cycle for emissions certification in North America is called the Urban Dynamometer Driving Simulation (UDDS). This driving cycle is representative of a commuter trip in a typical city in the U.S. or Canada. The cycle covers a distance of 17.89 km in just over 31 minutes of driving resulting in an average speed of 34.1 km/hr. The test is made up of 23 modes, each separated by an idle period. The peak speed is 92 km/hr, reached in the second and 20th mode, respectively. The test is divided into 3 phases, the Cold Transient (Phase 1), Cold Stabilized (Phase 2) and Hot Transient (Phase 3).

The emission certification driving cycle was developed in the early 1970's. The first version of the cycle, called the LA-4, was used for emissions certification testing beginning with the 1972 model year production. The UDDS, used since 1975, was derived from the LA-4, by adding a hot-start phase, preceded by a 10-minute engine-off period. The hot-start phase is a repeat of Phase 1. The test results are calculated on the basis of 43% Phase1 and 57% Phase 3 added together with the emissions from Phase2 and divided by the LA-4 distance of 12.07 km.

Given that the UDDS is a good representation of real-world driving, the emissions measured from a vehicle when operated over this cycle should reflect what that vehicle would produce in actual driving. Thus, it would be expected that this data could be used for inventory modeling. However, this is not really a fair use of the cycle because it was developed more as an enforcement tool than a tool for inventory modeling. The certification test was intended to provide a reference point for establishing emission reduction goals. Although every effort was made to replicate real-world conditions, traffic flows are so variable that it is very unlikely that a vehicle will experience the same speed vs. time profile in any two trips. Added to this are other factors not included in the UDDS test. These include temperatures colder than 20 degrees Celsius or warmer than 30 degrees Celsius, speeds in excess of 92 km/hr, accelerations at a greater rate than those prescribed in the test cycle, and so on.

Researchers have developed correction factors that can be applied to UDDS data to account for variations in temperature, speed, humidity and so on. These factors assist in making UDDS data more representative of real-world performance, but they cannot be rigorous enough to exactly model all types of vehicles under all types of driving conditions. Although it would be nice if models could be absolutely accurate, their use is better limited to the comparison of alternative scenarios when varying one or more known parameters.

For the purpose of this report, the data used for analysis were taken from lane inspections and then compared to a sample of HOT 505 tests. The HOT 505 is essentially Phase 3 of the UDDS which happens to be a 505 seconds long. Since Phase 3 is a hot start test, HOT 505 data does not include the effects of engine warm-up on emissions. Since emissions immediately after start-up are higher than during warmed-up operation, HOT 505 emission results give an optimistic sense of a vehicle's actual emissions output.

For the purpose of evaluating the AirCare program's effectiveness, it has been assumed that the effect of corrective maintenance occurs in the same proportion in all engine operating modes. Thus, if the repairs made to a vehicle following an AirCare failure produce a 35% reduction in hydrocarbon emissions under HOT 505 driving conditions, it is assumed that emissions of hydrocarbons are reduced by 35% in all types of driving. This assumption is justifiable, but does have a few shortcomings. For example, if a vehicle fails an AirCare inspection and is found to have a defective oxygen sensor, replacing the sensor will cause a reduction in emissions by restoring proper control of the air-fuel ratio. However, the impact will occur only under conditions in which the oxygen sensor signal is a critical input to the engine management computer. Under conditions where the oxygen sensor is not a factor in determining the engine's operating parameters, there would be no expected impact on emissions output. The issue comes down to the amount of time that the vehicle spends in oxygen-sensor-dependent mode. The reduction in emissions should be discounted proportionally. On the other hand, a misfiring cylinder will affect emissions output in all operating modes, meaning that an across-the-board emissions reduction is a valid assumption.

Whatever the drawbacks of the use of HOT 505 emission data, at least they are applied in a consistent manner, meaning that results from year-to-year are valid on a comparative basis, if not in an absolute one. The only truly accurate calculation of total fleet emissions would require a trip-by-trip quantification of emissions output for every vehicle, every day of the year. Therefore, although deficiencies can be identified in the use of HOT 505 data to represent nominal emissions performance, any assumption would be flawed in some respect.

The effects of cold weather, humidity and differing average speeds are accounted for in the computerized emissions inventory model. Transferring the HOT 505-based emission reductions to the inventory model calculation results in some adjustment for these extraneous factors. Suffice to say that the HOT 505 driving cycle is a reasonable representation of actual city driving and is therefore representative of real-world emissions output under the same environmental conditions. Emission reductions evident from a HOT 505 test are real reductions and should translate to a reduction in over-the-road emissions. The only question concerns the magnitude of this reduction. In some cases, the effect may be larger than predicted from the HOT 505 test while in others, it may be smaller.

4.2 ANNUAL MILEAGE ACCUMULATION

The number of kilometres driven each year is an important factor in assessing the emissions output of a vehicle. This data is available for vehicles tested at AirCare as a result of recording the odometer reading at each inspection. The increment in odometer reading over time gives an indication of the annual mileage accumulation.

This data has been analyzed and discussed in an SAE Technical Paper [4]. A significant outcome of this study was the development of a "vehicle tracking method" of determining annual mileage accumulations. In essence, this method takes consecutive odometer readings for an individual vehicle at different times and uses this information to calculate the mileage accumulated in a twelve-month period. Due to the fact that the time between AirCare inspections can be longer than one year or even less than one year, it is necessary to normalize the data.

Figure 14 below shows the results of this 1996 study.

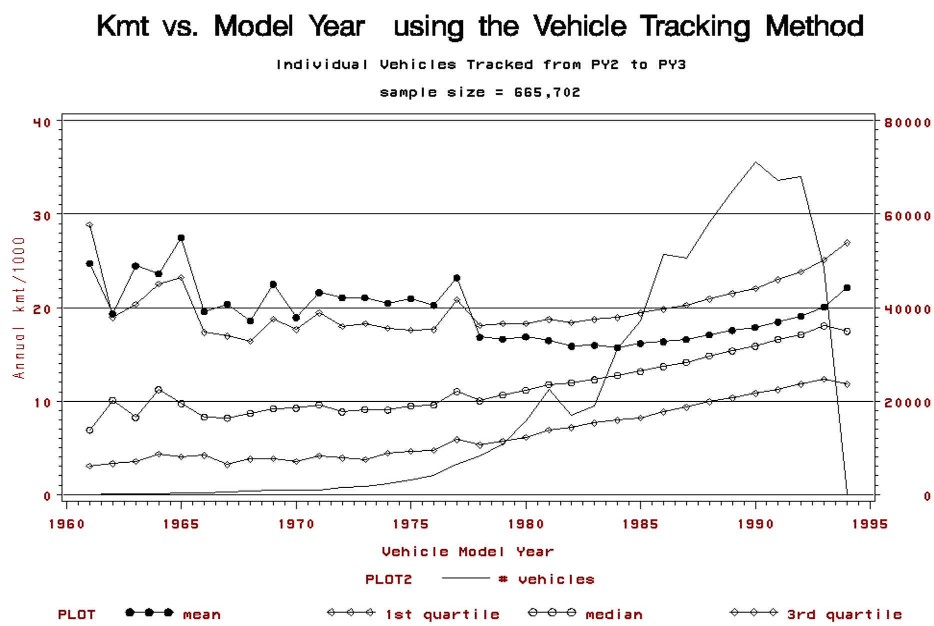


Figure 14. Kilometre vs. Model Year using Vehicle Tracking Method

According to this figure, the mean annual distance traveled for the newest vehicles in the fleet was about 22,000 km. The distance decreases slightly with each year of age but then starts to increase again, particularly pre-1978 when the odometer readings are converted from miles to kilometres. The mean may not be the best parameter to look at in order to determine the annual distance traveled, particularly in the older model years where the sample size is small and errors in the data can have a significant effect on the mean.

Median annual miles traveled shows a more reasonable trend, starting at about 18,000 km/yr for the newest vehicles, declining steadily to a value of 10,000 km/yr at 18 years. From then on, the line is fairly stable, at just below 10,000 km/yr.

The findings of the study confirmed some common beliefs about annual mileage. One is that the distance driven per year diminishes with vehicle age. Inventory models typically assume that vehicle emission rates increase with age due to normal degradation. This effect, however, is offset to some degree by the fact that, although older vehicles emit more per unit distance traveled, they tend to be driven less than newer vehicles. This assumption is not completely supported by the AirCare analysis. Although it is apparent that the newest vehicles are driven a greater distances per year than older vehicles, the rate does not decrease continuously. While this finding seems to contradict conventional beliefs, it is logical to assume that a vehicle in daily use will not experience a reduction in annual mileage just because it is getting older. If it is being used to transport its owner to and from work and for other trips in the city, it makes sense that the annual distance traveled will remain relatively constant. In a multiple-vehicle family, the older vehicle may not be used for vacations or long trips, but an accumulation of 10,000 km/yr. seems quite achievable simply from daily commuting.

5.0 INSPECTION STATISTICS

5.1 TOTAL INSPECTIONS

During the period from September 2, 1992 to August 31, 2000, 8,534,984 inspections were performed on 1,876,123 individual vehicles.

Figure 15 illustrates inspection volumes by calendar year. Inspection volumes were significantly reduced in 1996 when the inspection centres were closed for almost six months. Volumes were also reduced in 2000, when an additional year of AirCare exemption came into effect for the 1999 model year vehicles. This effectively reduced the size of the AirCare-eligible fleet by about 70,000 vehicles.

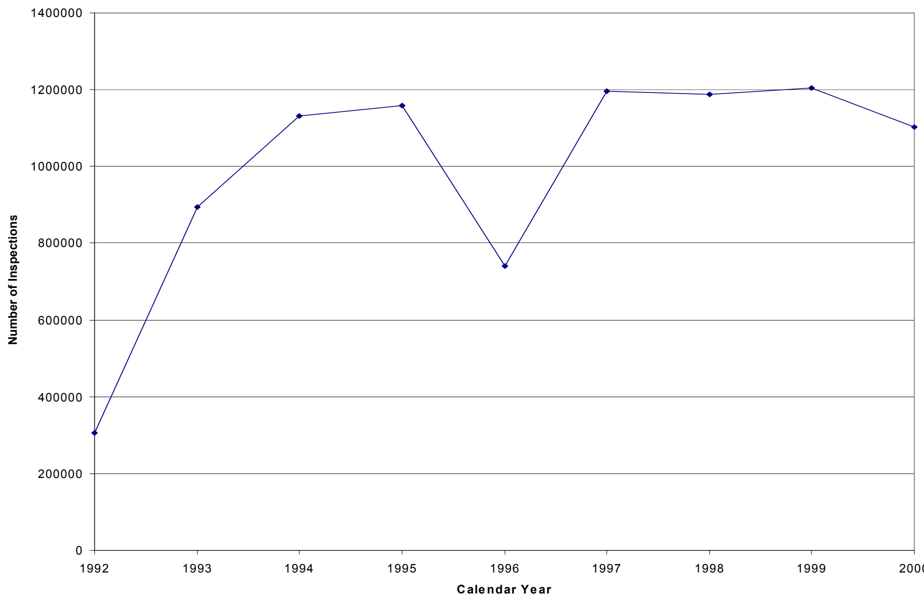


Figure 15. Total Number of Inspections by Calendar Year

Figure 16 shows the annual trends by each of the 12 inspection centres. All follow basically the same profile with a pronounced dip in 1996, coinciding with the strike of that year. The busiest AirCare inspection centre is Centre 12, the South Vancouver location. This is a centrally located, 5-lane centre that accounts for about 160,000 inspections annually. The least busy inspection centre is Centre 11, in Chilliwack. This facility is a two-lane centre that serves the eastern Fraser Valley and accounts for about 45,000 inspections annually.

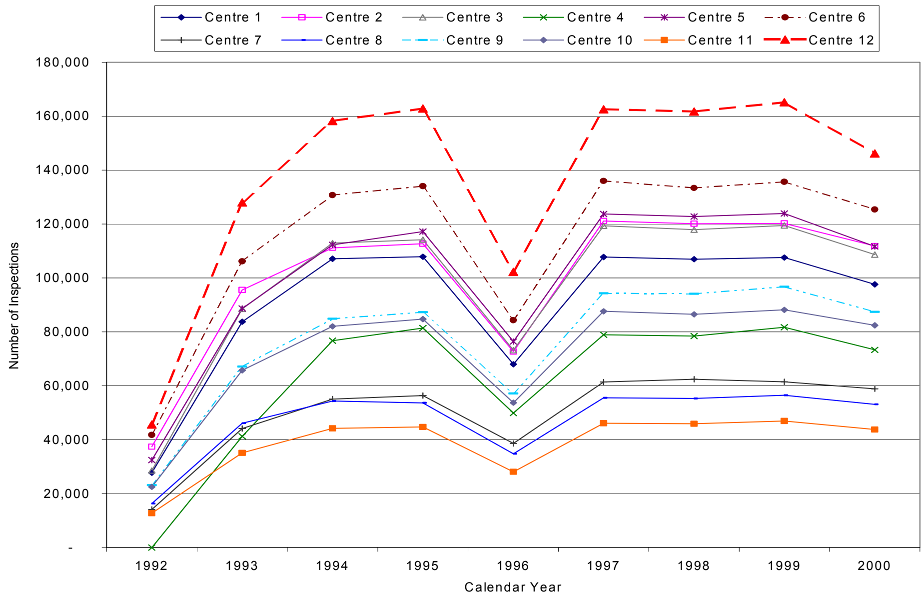


Figure 16. Number of Inspections by Centre

5.2 VOIDED INSPECTIONS

Occasionally, it is necessary to void an inspection due to a procedural or data entry error. A low rate of voided tests is an indicator of test accuracy and good customer service. Table 5 below shows the number of voided tests each calendar year and the percentage of voided tests vs. total.

Table 5. Number of Voided Tests by Calendar Year

Calendar Year	Number of Void Tests	% Void Tests
1992	2,914	0.95%
1993	1,834	0.21%
1994	1,181	0.10%
1995	1,058	0.09%
1996	742	0.10%
1997	1,034	0.09%
1998	759	0.06%
1999	816	0.07%
2000	699	0.06%

5.3 TWO SPEED IDLE(TSI) TESTS

The AirCare inspection procedure during the period covered by this report consisted of two modes – an ASM 2525 driving test and an idle test. In some cases, it was not possible to operate the vehicle on the dynamometer to perform the driving portion of the test. Typical cases included all-wheel drive vehicles, vehicles with non-defeatable traction control, vehicles with lowered chassis, vehicles too wide to fit on the dynamometer, vehicles fitted with studded snow tires (October through April), trucks with cut-off exhausts dumping ahead of the rear axle, and vehicles equipped with handicap controls. In these cases, the vehicle was tested according to a Two-Speed Idle(TSI) procedure. In this test, the engine is operated in two modes, 2500 rpm and curb idle, with the transmission in neutral or PARK. The emissions readings for hydrocarbons and carbon monoxide are captured in both modes but only the curb idle values are compared to pass/fail standards. The two-speed idle test does not include a measurement of NO_x emissions or of HC and CO emissions during normal driving. For this reason, a minimal number of idle tests should be maintained to enhance program effectiveness. Table 6 below shows the number of non-dynamometer tests each year and the percentage of these tests compared to the total inspection volume.

Table 6. Number of Two Speed Idle Tests by Calendar Year

Year	Number of Two-Speed Idle Tests	% TSI vs. Total
1992	11,072	3.62%
1993	46,456	5.20%
1994	56,969	5.03%
1995	60,246	5.20%
1996	41,804	5.64%
1997	67,366	5.63%
1998	75,556	6.36%
1999	84,160	6.98%
2000	73,612	6.68%

5.4 ABORTED INSPECTIONS

Sometimes, it is not possible to complete the inspection of a vehicle. In these cases, the test is aborted, no fee is charged and the customer is requested to return with the vehicle in a testable condition. Typical reasons for aborting a test include the following:

- Exhaust System Leaks
- Idle RPM Too High
- Vehicle Overheating
- Excessive Fluid Leaks
- Tires Excessively Worn/Unsafe

- Malfunctioning Parking Brake (Front Wheel Drive Vehicles)
- Unable to Confirm Vehicle Match to Registration Number

The incidence of aborted tests was highest in the first 3 months of program operation in 1992. Since then, the rate has remained relatively stable at about 2%.

5.5 INSPECTION OF DIESEL-POWERED LIGHT-DUTY VEHICLES

The AirCare program adopted opacity measurement as the method for testing diesel engines right from start-up in 1992. Because the diesel failure rate was very low, the numbers of inspections in a year are almost the same as the numbers of vehicles shown in Figure 13. Table 7 shows the actual number of diesel inspections in each year.

Table 7. Number of Diesel Inspections by Calendar Year

Calendar Year	Number of Inspections
1992	5,434
1993	12,366
1994	17,233
1995	17,703
1996	11,427
1997	18,285
1998	18,896
1999	18,970
2000	16,312

6.0 AUDITING AND QUALITY ASSURANCE

As mentioned previously, more than 8 million inspections were performed during the review period. In order to ensure that each of these inspections was performed according to the proper procedures and that the measurement of exhaust gases was accurate, comprehensive calibration and auditing procedures for the test analyzer system and dynamometer were devised. Despite the best efforts of the program contractor and the Program Administration Office, however, public confidence in the accuracy of the inspections has been uncertain. Local media have frequently published or broadcast stories about individuals who have failed an AirCare inspection and then passed a subsequent test, despite no repairs having been performed. The conclusion drawn by the public from this sequence of events is that the test equipment is inaccurate and will wrongly fail vehicles that are not in need of repair. This is not the case, however, as the analyzers simply measure the emissions produced at the time of the test. Since the vehicle itself is not a controlled variable, it is possible for it to change its emissions output between tests. In both cases, the analysis is correct, but the test results are different. As the vehicle owner desires a passing result and doubts the validity of the failing test (thereby prompting them to attempt another test), if a passing result is achieved on a second or subsequent attempt, their suspicion about the accuracy of the test system is confirmed in their mind. The strategy of attempting another test in a different lane or at a different inspection centre thus becomes part of local folklore and is successful often enough to sustain the myth.

The phenomenon of failing an emissions inspection and passing without any work being performed occurs in all inspection and maintenance programs. It is unavoidable, in fact, because vehicles with emissions high enough to exceed pass/fail limits may have intermittent defects that can cause wide swings in emissions output. Vehicles that are operating as designed and with no emission-related defects will pass an I/M test quite easily and consistently. But multiple tests of passing vehicles tend not to occur because one passed test is sufficient to allow re-licensing and satisfies the vehicle owner’s needs. Therefore, the only vehicles that undergo multiple tests are failing vehicles that are, by definition, abnormal. The conclusion drawn by the lay person from cases of “fail-then-pass” is that the analytical system was inaccurate or that the lane inspector performed the test incorrectly. The owner assumes that the vehicle emissions are not subject to change and therefore any variation in the test results must be attributable to the gas analyzers.

The accuracy of the gas analyzers cannot be properly checked using a vehicle, especially one that has emission-related defects. Instead, gas analyzer accuracy must be verified using known concentrations of calibration gas. In this way, variance in the concentration of gas being presented to the analyzer for measurement can be avoided. Therefore, if the analyzer is able to read the concentration of the gas supplied within a specified tolerance, it is operating correctly.

6.1 DESCRIPTION OF ANALYTICAL SYSTEM

During the review period, all 42 AirCare inspection lanes were equipped with an Emissions Measurement System (EMS), consisting of a Sensors Inc 3-Gas infra-red analyzer for HC, CO and CO_2 measurement as well as a HORIBA VIA-300 infra-red analyzer for NO_x. The EMS also contained the EMS PC computer and the dynamometer controller computer as well as two sample pumps, a water trap, filter, flow meters, solenoids and regulator valves. A ventilator unit was supplied to maintain a consistent temperature inside the cabinet. The cabinet completely enclosed the analyzer system and was fitted with locking doors. Only a station manager or authorized technician could access the analyzers or the flow adjustments. Therefore, it was not possible for vehicle owners or lane inspectors to access the analyzers or to interefere with the system operation during the test. Two sample pumps were used in order to increase the flow rate and therefore optimise system response time. Between tests, one pump supplied room air to the gas anayzers while the other one pumped air back through the sample hose and out the probe tip. This purge mode allowed trapped water to be expelled from the sample hose, reducing the potential for hydrocarbon hang-up.

The analyzer manufacturer supplied accuracy tolerances for each gas and each range of detection. The manufacturer's stated accuracy for the HC, CO and CO_2 analyzer is shown below:

HC	0 to 400 ppm, ±12 ppm
	401 to 1000 ppm, ±30 ppm
	1001 to 2000 ppm, ±80 ppm
CO	0 to 2.00%, ±0.06 %
	2.01% to 5.00%, ±0.15 %
	5.01 to 15.00%, ±0.40 %
CO_2	0 to 10.0%, ±0.3 %

For the NO_x analyzer, the accuracy was stated as:

NO_x	0 to 1000 ppm, ±32 ppm
	1001 to 2000 ppm, ±60 ppm
	2001 to 4000 ppm, ±120 ppm

The analyzers and ranges selected were chosen specifically to include the range of values that would be expected in ASM and Idle testing of a wide range of vehicles from those with no emission controls to the most advanced technology. In order to check the accuracy of the EMS in its typical operating mode, a tailpipe simulator was used to introduce sample gas to the analayzers. In this way, any leaks or problems associated with the probe, sample hose, filters and sample pumps would be identified during the audit. In other words, the compressed gas from cylinders would be introduced to the sampling system in exactly the same way as the tailpipe exhaust gases. Although the analyzer train had the provision for introducing calibration gas directly to the analyzers, this method would not be as representative as checking with a tailpipe simulator.

6.2 Contractor Procedures

As part of the agreement between the province and the AirCare contractor, certain testing equipment calibrations were required on a daily, weekly, monthly or semi-annual basis. The testing system was designed in such a way that any lane that failed to meet acceptance criteria would be locked out until the necessary repairs and/or adjustments were completed. The checks are outlined below:

Between Inspections

- Successful Auto Zero and Health Check Pass

- Opacity Meter Zero and Span for Diesel Tests
- Successful Purge of Sample System (HC < 20 ppm)

Daily

- HC, CO and CO_2 calibration gas span
- NO_x calibration gas span
- Sampling System Leak Check
- Opacity Meter Calibration with Certified Filters

Monthly

- 4-Point Analyzer Curve Checks
- Interference gas Checks
- Static Dynamometer Calibration (Load Cell)
- Check Dynamometer Speed Sensor

Every 6 Months

- Dynamometer Coast Downs (Dynamic Calibration)

Any piece of testing equipment unable to meet the accepted calibration criterion was locked out from use until corrective maintenance was performed and the calibration test passed. To maintain accurate records, details of each mandatory calibration were kept electronically in a database. For the gas analyzer calibrations, the span gas was introduced prior to any analyzer adjustment and the readings were noted compared to the stated bottle concentrations. If necessary, the analyzer span was adjusted to correct for any drift. The degree to which the analyzer reading changes from day to day reflects drift. Analyzers exhibiting abnormal drift between calibrations were flagged for maintenance.

6.3 Inspection Centre Emissions Measurement System (EMS) Audit

In addition to the routine checks performed by the AirCare contractor, the Program Administration conducted its own audits. As mentioned previously, these audits were designed to assess the accuracy and repeatability of the tests performed in the lanes and to test the equipment under actual inspection conditions. Following is a description of the audit performed at least once a month for each of the 42 lanes:

The audits began with a regular vehicle inspection of an audit vehicle in each lane. During the review period, a 1992 GMC Safari and a 1993 Plymouth Voyager were used as audit vehicles. Immediately after the ASM 2525 and idle tests were completed, the EMS sampling system was manually enabled and the ambient airflow rate readings observed and recorded (i.e. system in purge mode). Certified compressed gas was then introduced through the EMS sample probe using a tail pipe simulator and, once stabilized, the readings were recorded and compared to allowable tolerances. The audit gas blends most commonly used were low and mid blends.

Blends were chosen to represent the most critical levels of emissions measurement, right in the vicinity of the pass/fail limits.

Table 8. Audit Gas Specifications

Audit Gas	Low Range Concentration	Mid Range Concentration
Propane	150 ppm	500 ppm
Carbon Monoxide	0.25 %	1.45 %
Carbon Dioxide	5.0 %	14.0 %

Allowable tolerances for auditing purposes were set at ±5% of the value specified by the audit gas blender. The program administration purchased its audit gas from Scott Specialty Gases, of Plumsteadville, PA. The gas purchased for auditing had a stated accuracy of ±1%, traceable to NIST (National Institute for Science and Technology) standards. NIST is the North American reference for materials such as calibration gases and can be considered absolutely accurate.

If, after performing an audit check, the analyzer readings were found to fall outside of the ±5% tolerance, the analyzer was immediately calibrated and the test performed again. If the calibration did not succeed in bringing the analyzer into compliance, the lane was closed and a service technician called in. No inspections were performed until after the repair was complete.

The ±5% tolerance was designed to catch a problem in its early stages where non-compliance would have little to no effect on the outcome the actual emissions inspection. It should be noted that the ±5% tolerance was actually stricter than the gas analyzer manufacturer's stated tolerances for some ranges. Although this was a concern to the AirCare contractor, practical experience showed that this limit was achievable within any range of measurement, provided that the analyzer was properly calibrated and operating normally. Concentrations of the audit gas were varied routinely by the Program Administration to provide a random test of the system. During the eight years of auditing, 116 cylinders of certified gases were consumed in the auditing process.

In any cases where non-compliance was detected, the testing contractor was advised and any inspections that were performed in that lane were reviewed to determine if there had been any potential for false failures. Even though the AirCare pass/fail limits are chosen to be well above the normal range of vehicle performance, it was decided that if the gas analysis was found to be high by a certain amount, then any vehicle that had failed by less than that amount should be considered a pass. Inspection records covering the period during which the analyzer problem existed were then checked and any owners whose vehicles would have passed were notified and compensated appropriately. It should be emphasized that vehicles very close to the pass/fail standard would hardly be considered a normal emitter, but it was undeniable that the vehicles in the marginal zone would have passed had the analyzer read correctly.

It will be pointed out later in this section, how many times the gas analyzer audit revealed an out-of-specification condition. It should be noted, though that the cases of non-compliance were almost always in the direction where the error caused lower-than-actual readings. As a result, the effect of these errors was to pass vehicles that should have failed. Although careful effort was expended to contact owners of any vehicles that were wrongly failed, the owners of vehicles that wrongly passed were able to retain the benefit from their windfall. It should also be pointed out that the magnitude of errors detected was typically minimal – rarely more than 5%

error. Despite the public perception of errors in orders of magnitude, scientific auditing of the system never found any errors of this sort.

6.3.1 Dynamometer Load Application Audit

AirCare was one of the first programs to incorporate loaded mode testing of virtually every vehicle and was the first program to make use of the ASM 2525 test on a mandatory, rather than experimental basis. In order to perform loaded mode testing, it is necessary to use a dynamometer to apply a load to the driving wheels of the vehicle being tested. For the purpose of the ASM test, the load applied is proportional to the weight of the vehicle being tested and can range from about 6 horsepower to just over 20 horsepower, at a constant 40 km/hr.

To ensure that the load application was correct an audit procedure for the lane dynamometers was developed. The goal of the audit was to ensure that there were no substantial inaccuracies in the measured road speed or in the magnitude of the actual load applied to the vehicle during the ASM test. This audit was performed at least once a month on each dynamometer. The audit consisted of the following steps:

Using a scan tool connected to the audit vehicle's on-board computer, critical engine operating parameters were monitored and recorded during a regular AirCare inspection. A snapshot portion of the test was recorded while the vehicle was operating within the speed window of 40 ±3 km/hr. From time to time different weights were entered to simulate smaller / larger vehicles. The audit vehicle has been tested numerous times and the throttle position percentage reading has proven to be a most consistent and accurate way of testing the dynamometer load.

The audit vehicle has been observed to maintain a 20% throttle opening at 40 km/hr based on its weight of 1475 kg and correct load application for an ASM test. If the throttle position deviates from 20% by more than ±2% the lane is immediately closed pending repair. No inspections can be performed until after the defect is corrected. In every case where abnormal throttle position values were noted during the review period, subsequent checking of the suspect dynamometer revealed a calibration fault. As in the case of gas analyzer audits, problems were found very infrequently and were usually not enough to cause an improper inspection failure. Given that the audit van was undergoing emission testing while the dynamometer checks were being conducted, it was possible to assess the effect of the dynamometer loading on the emissions output. Because the van was used to simulate much larger vehicles on occasion, test results were available for a broad range of dynamometer loads. From this data, it was noted that even extremely heavy dynamometer loads were incapable of making this particular vehicle fail the test, even up to more than double the correct value for the van. This experience suggests that a properly-functioning vehicle is somewhat insensitive to dynamometer loading up to the point where fuel enrichment occurs in response to increased engine load. For vehicles with closed loop fuel control, this makes sense as the catalytic converter would be able to deal with the emissions as long as the correct window of operation was maintained. It is not possible to say with any certainty how excessive loads would affect vehicles with carburetors, because these devices are dependent on manifold vacuum to control enrichment circuits.

In any cases where the noted throttle position values were out of range, all vehicle inspections that were performed in that lane were reviewed to determine if there was any potential for false failures. If so, the contractor was instructed to notify vehicle owners and compensate them appropriately. As noted above, experience indicated that load deviation had little to no effect and rarely affected the result of the inspection.

6.3.2 Audit Results

Table 9 shows the number of inspection centre audits conducted in each program year. With only one staff person available to perform audits, a realistic goal of one audit per inspection lane per month was set. This would correspond to 504 audits per year. Factors such as strikes reduced the number of audits performed in year 1992-93 and 1995-96, but the target was achieved in 1994-95 and other years came close.

The column headed “Failures” indicates the number of instances where one of audit item results did not fall within allowable tolerances. While the percentage failure rate (9.1% of all audits performed) is not insignificant, in virtually every case where a failure was detected, the effect on the test results was in a direction that caused vehicles to pass more easily rather than failing them incorrectly. Furthermore, in every case where there was an indication that vehicles could have been incorrectly failed, all owners of such vehicles were contacted and restitution was provided as necessary.

Table 9. Number of Audits by Program Years

Program Year	Audits	Failures	%
1992-1993	196	24	12.24%
1993-1994	441	64	14.51%
1994-1995	504	35	6.94%
1995-1996	342	25	7.31%
1996-1997	478	36	7.53%
1997-1998	383	27	7.05%
1998-1999	487	57	11.70%
1999-2000	401	52	12.97%
2000-2001	406	12	2.96%
Total	**3638**	**332**	**9.13%**

The test analysis system was designed with sufficient safeguards to make it unnecessary to increase the frequency of audits. The main effect of the inspection system audits was to identify the potential for not identifying excess-emitting vehicles and thus reducing program effectiveness. Also, as pointed out elsewhere in this report, the pass/fail limits used at AirCare throughout the review period were sufficiently lenient to say that any vehicle that was failed solely because of a measurement error was probably a bona-fide excess emitter at any rate. Overall in the eight years, 2.57% of all inspections included readings within 8% of the pass/fail cut-points. Only these would be affected by analyzer errors, so the maximum potential for errors-of-omission (false passes) was 0.239% of all inspections. However, the program administration took the position that any known problem with the test accuracy that could cause false failures (i.e. vehicles should have received a marginal pass rather than a fail) would require corrective action. In every case where a failure of an audit was noted, the affected lane was repaired and re-calibrated prior to allowing the publics’ vehicles to be tested. In all but 4 cases, the effect of the audit failure was to produce test results that indicated the vehicle to be cleaner than it actually was.

7.0 INSPECTION FAILURES

An inspection and maintenance program is intended to identify excess-emitting vehicles and require that they be repaired. As a result, the failure rate is a very important statistic for program evaluation. In this section emphasis will be placed on the minority of the vehicle population that has been identified as a failure at some point during the review period.

7.1 RATES BY VEHICLE TYPE AND MODEL YEAR

Not surprisingly, the probability of failure increases as vehicles age. This is logical result, given that the engine and the emission control systems installed at the time of manufacture are subject to normal wear and degradation with use, and all mechanical or electrical components have a finite service life. The reason for inspecting vehicles at regular intervals is to identify those that have experienced a component failure since their last inspection or servicing Figure 17 below illustrates the relationship of failure rate and vehicle model year.

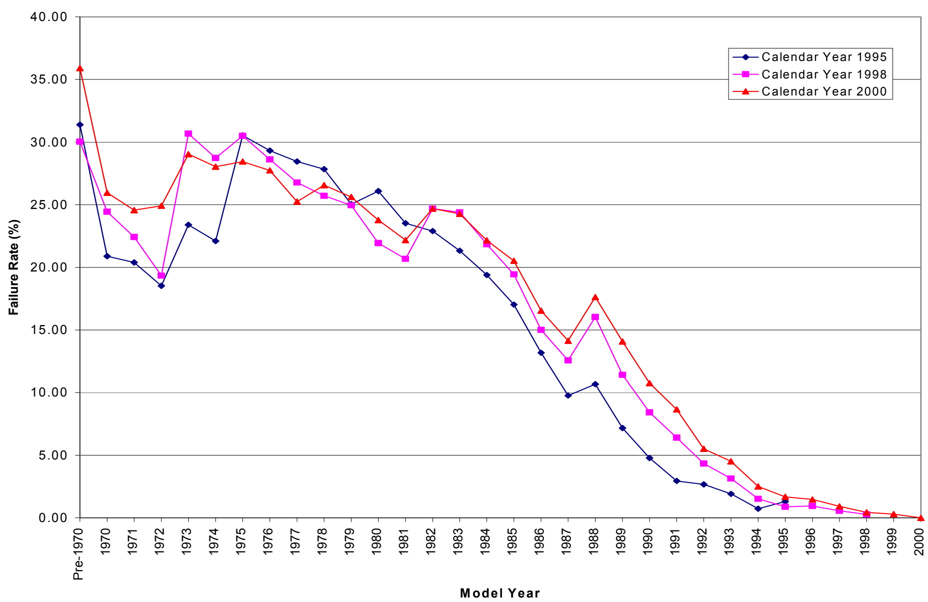


Figure 17. Vehicle Failure Rate vs. Model Year for All Vehicle Types

Figure 17 shows that the improvements in vehicle engine control technology that occurred during the 1990's has resulted in a low failure rate for vehicles less than 8 years old. The failure rate increases considerably beyond this point, reflecting the durability of the technology employed when those older vehicles were built as well as the cumulative effects of age and mileage. Given that vehicles accumulate approximately 16,000 km per year on average, a vehicle that is 9 years old will have traveled 144,000 km. At this point, it is not unreasonable to expect that components such as oxygen sensors could have degraded or failed. The reasons for vehicles failing an AirCare inspection will be discussed in greater detail later in this report.

Figure 18, Figure 19 and Figure 20 show the relationship between failure rate and model year, broken down by vehicle types. The trends for passenger cars and light-duty trucks are similar, but a more erratic trend is evident for heavy-duty trucks. As a rule, the failure rate for heavy-duty trucks is higher than that of either of the light-duty vehicle classifications. The reasons for this are not clear although this effect has been observed in previous analyses

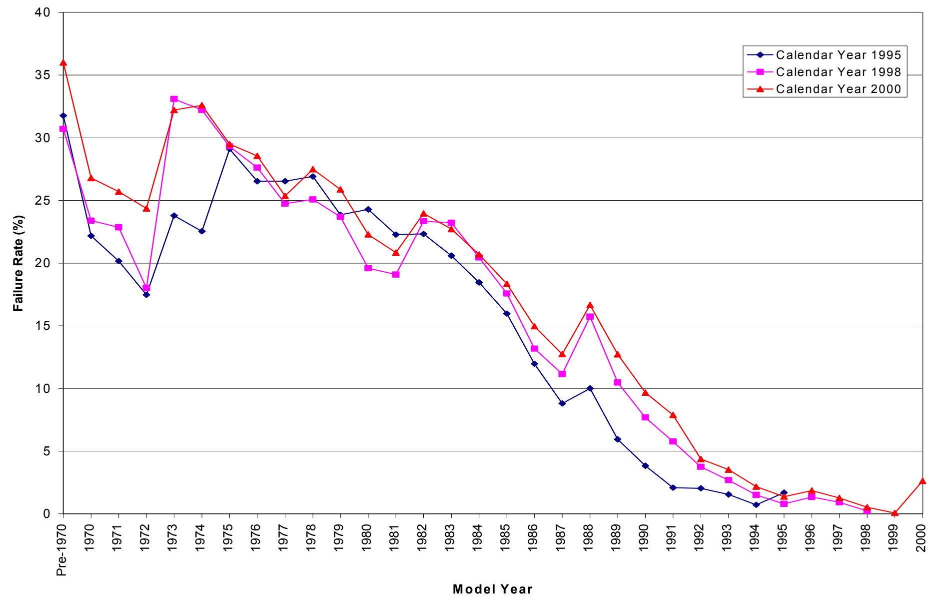


Figure 18. Vehicle Failure Rate vs. Model Year for Passenger Vehicles

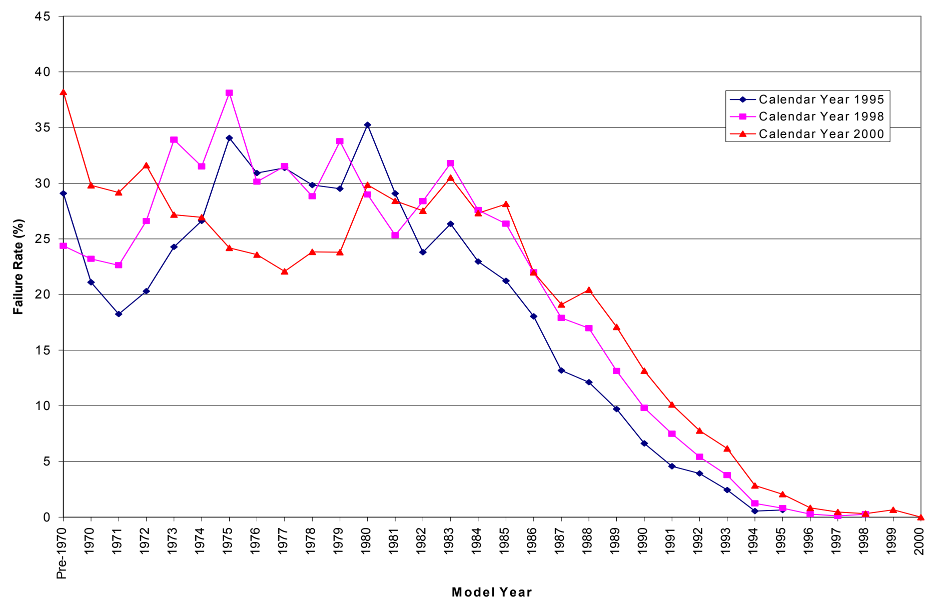


Figure 19. Vehicle Failure Rate vs. Model Year for Light Duty Trucks

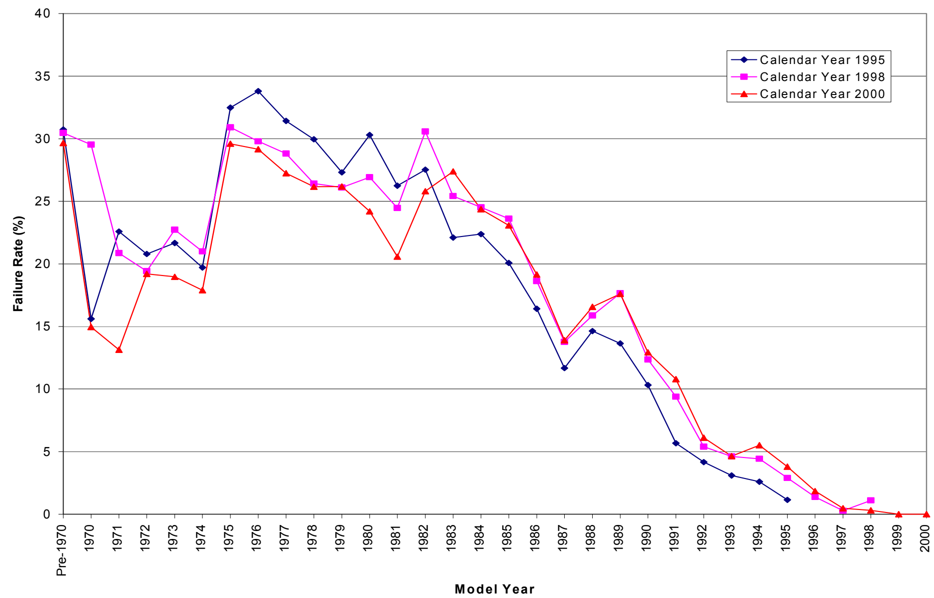


Figure 20. Vehicle Failure Rate vs. Model Year for Heavy Duty Trucks

7.2 NUMBER OF FAILURES BY MODEL YEAR

Although the analysis of failure rates by model years indicates a rapid increase in failure rate with age, the presentation of the data in this format does not necessarily give an accurate profile of the excess-emitting vehicle population. A truer representation can be found by plotting the number of failed vehicles against model year. Figure 21 below shows this relationship for all vehicle types combined.

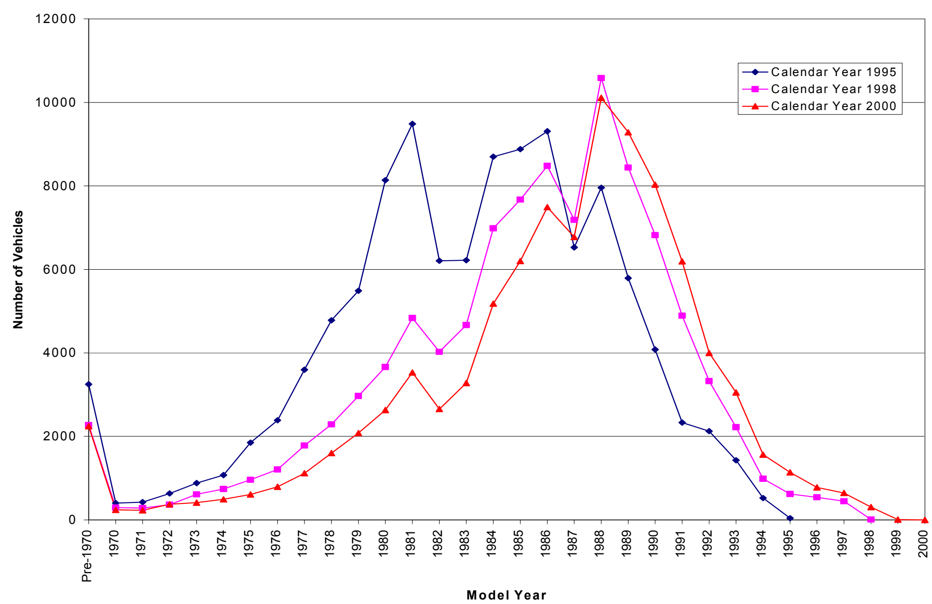


Figure 21. Number of Failed Vehicles vs. Model Year for All Vehicles Types

Figure 21 shows that, although the rate of failure of the oldest vehicles in the fleet is highest, the decreasing population of vehicles after about 15 years of age results in a distribution of failed vehicles that resembles a normal distribution curve. There are relatively few failures on the newer side of the distribution because these vehicles are equipped with the most effective emission control hardware and have not been in service long enough to degrade significantly or to experience component failures. On the left side of the curve, there is a similarly low number of failing vehicles, not because the failure rate is low, but because the number of these vehicles remaining in use is much lower. Essentially, what the analysis reveals is that most vehicles with excess emissions range in age from 8 to 20 years old.

Figure 22, Figure 23 and Figure 24 show the distributions for passenger cars, light-duty trucks and heavy-duty trucks separately.

It is interesting to note that in all of these distributions, there is a pronounced dip in the number of 1982 and 1983 model year vehicles. This dip has been evident in all analyses of AirCare data since the program began and reflects low sales of these two years when they were new. The data also show that the failing vehicle population is dominated by passenger cars as opposed to trucks.

Figure 22. Number of Failed Vehicles vs. Model Year for Passenger Vehicles

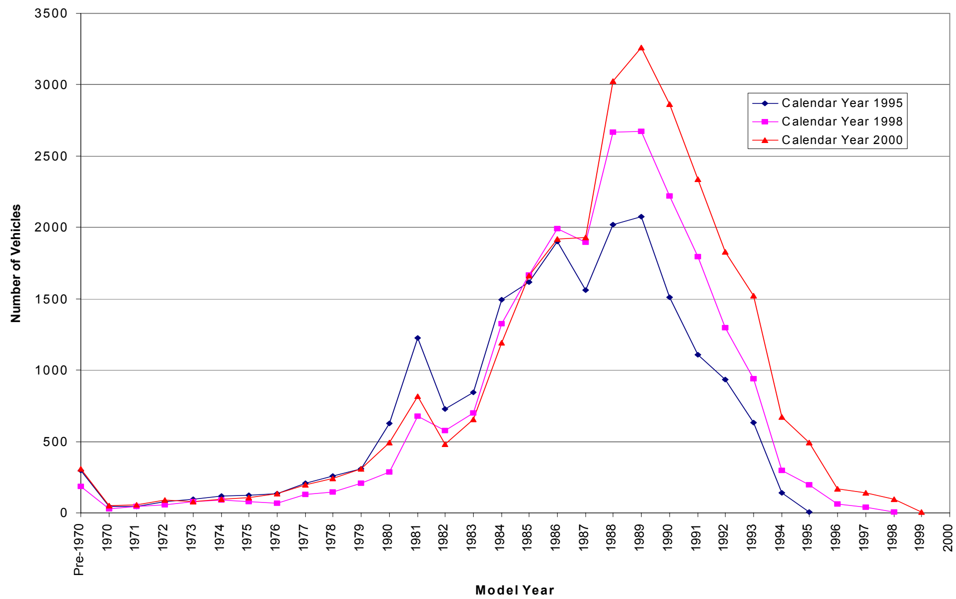


Figure 23. Number of Failed Vehicles vs. Model Year for Light Duty Trucks

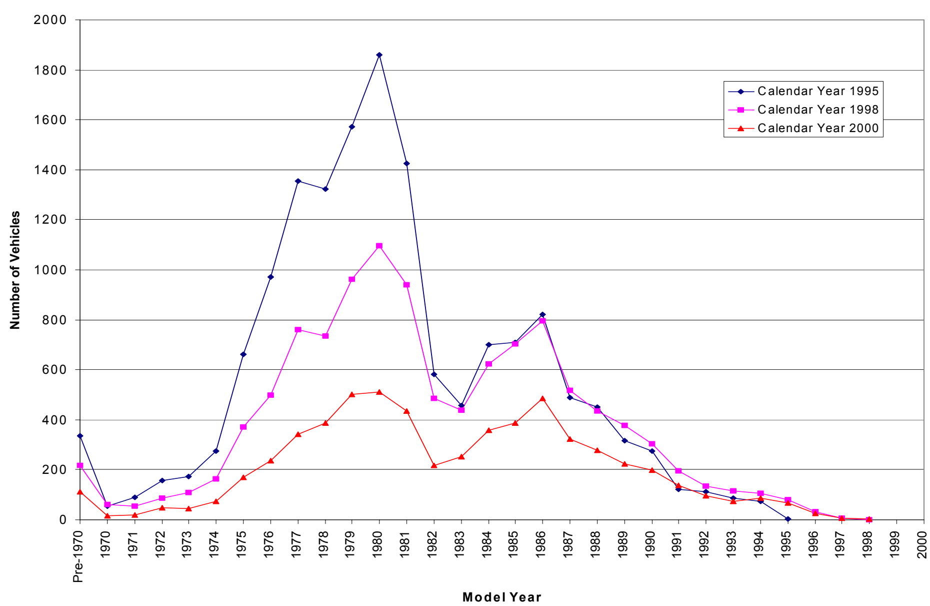


Figure 24. Number of Failed Vehicles vs. Model Year for Heavy Duty Trucks

7.3 FAILURE MODES

In order to achieve a final result of PASS for tailpipe emissions, the AirCare inspection requires that the readings for all measured gases be below their respective allowable maxima in both test modes – ASM and Idle. For the ASM test there are three gases measured and in the idle mode there are two, for a total of 5 pass/fail evaluations. Thus there are 31 combinations of modal emissions results which fail (Idle HC only, Idle CO only, ASM HC and Idle HC together, and so on), and only one combination which passes. Given that the overall failure rate of the program has tended to range from 10-15% over the first eight years, the most common outcome of the test is PASS. For the minority of vehicles that fail, some combinations are very rare, and some fairly common.

Table 10 below shows the ten most common failure modes for the overall failing vehicle population in calendar year 2000. The modal emissions results are combined into a character string as follows:

1st character HC at Idle

2nd character CO at Idle

3rd character HC on ASM test

4th character CO on ASM test

5th character NO_x on ASM test

For example, FPPFP would signify that the vehicle failed for hydrocarbons at Idle, and for carbon monoxide on the ASM test

Table 10. Top 10 Failure Modes for All Vehicles in Calendar Year 2000

Modal Emission Results	Number of Inspections	% of Total
PPPP**F**	25512	20.6%
FPPPP	21131	17.1%
PPP**F**P	17165	13.9%
P**F**PPP	9844	8.0%
FFPPP	7159	5.8%
PP**F**PP	7033	5.7%
PP**FF**P	5030	4.1%
FFFFP	4964	4.0%
FP**F**PP	4427	3.6%
P**F**P**F**P	3231	2.6%

The top ten modes of failure out of the 31 possible modes account for 85% of all the failed vehicles. Of the six most common mode of failure, five were for just one emission reading. Most common was for excess NO_x emissions, representing 20.6% of all the failures. Next was HC at Idle, accounting for a further 17.1%. CO on the ASM test was third at 13.9% and CO at Idle was fourth at 8.0%. HC on the ASM test was sixth at 5.7%, having been just ousted from fifth position by HC and CO at Idle with 5.8%.

The fact that the AirCare program spans such a wide range of vehicle types and ages makes it difficult to interpret the meaning of failure modes for the aggregated sample of failed vehicles. For one thing, the pass/fail criteria applied vary according to the type and model year of vehicle. Also, the pass/fail standards have been adjusted from time to time since the program began. Significant changes in the standards were made in September of 1995 and September of 2000.

Minor adjustments were made in January of 1996 and January of 1998. The standards are included in Appendix C.

7.4 FAILURE RATE BY PROGRAM YEAR

Table 11 illustrates the failure rate in the first 8 program years and the final 4 months of the year 2000.

Table 11. Failure Rates for the First 8 Program Years

Program Year	Overall Failure Rate (By Vehicle)
1 (1992-1993)	28.72% (excluding 1986+) 14.72% (including 1986+)
2 (1993-1994)	13.24%
3 (1994-1995)	10.41%
4 (1995-1996)	14.49%
5 (1996-1997)	13.53%
6 (1997-1998)	10.70%
7 (1998-1999)	9.64%
8 (1999-2000)	10.76%
Sept. 5, 2000-Dec. 31, 2000	12.34%

The data in Table 11 show a wide range of overall failure rates over the history of the program. The high failure rate evident in the first part of program year 1992-1993 is related to the exemption of 1986 and newer model year. The failure rate in the months where all eligible vehicles were included in the program was 14.72%.

According to Figure 25, The failure rate tended to change whenever the pass/fail standards were changed and also whenever each new model year was introduced to the program. Keeping in mind that the newest vehicles subject to testing have tended to have a failure rate of less than 1%, the effect of adding 75,000 passing vehicles to the overall fleet is to reduce the overall failure rate.

The failure rate for an inspection and maintenance program gives an overall impression of how many excess-emitting vehicles are identified each year. However, the importance of the failure rate as a performance indicator for the program is subject to interpretation. In its earliest years a highly effective program should have a high failure rate. This is true to the extent that a large number of excess-emitting vehicles would be identified. However, if a program operates for 8 years and has a consistent failure rate of, say 20%, it could be argued that the program must not be very effective. In order to reduce emissions, it is necessary to reduce the number of excess-emitting vehicles in operation. If excess-emitting vehicles are identified and effectively repaired so that they do not fail again, the failure rate will drop. This is the case with the AirCare program. In the periods where the pass/fail standards were consistent such as between 1996 and 1999, the failure rate decreased steadily from year to year.

Figure 25 shows the relationship between program month and failure rate beginning in September 1992 and concluding in December of 2000.

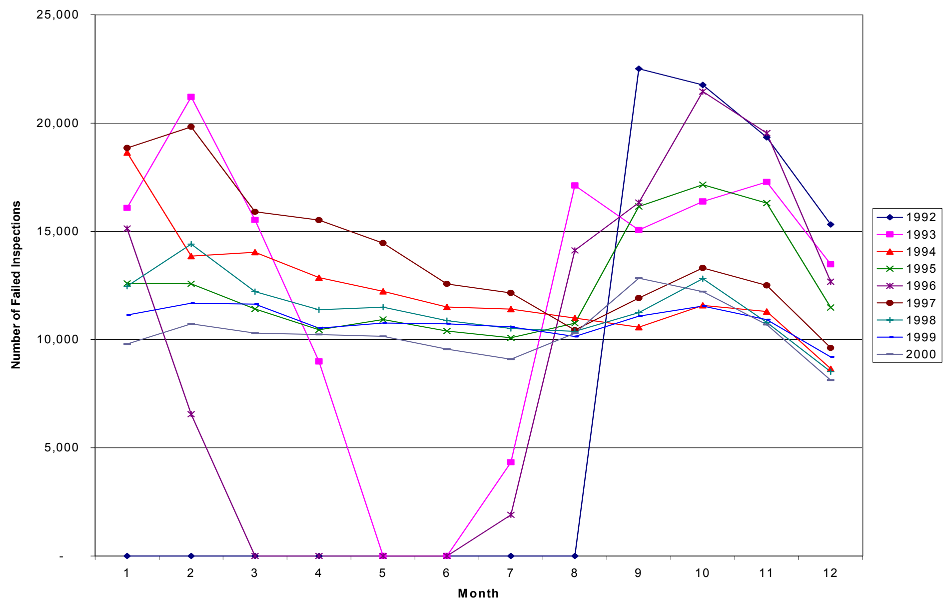


Figure 25. Failure Rate by Month

7.5 FAILURE RATE BY MANUFACTURER

Earlier in this report, a breakdown of the fleet according to vehicle manufacturer was presented for case years 1995 and 2000. In this section, the failure rate by manufacturer is discussed.

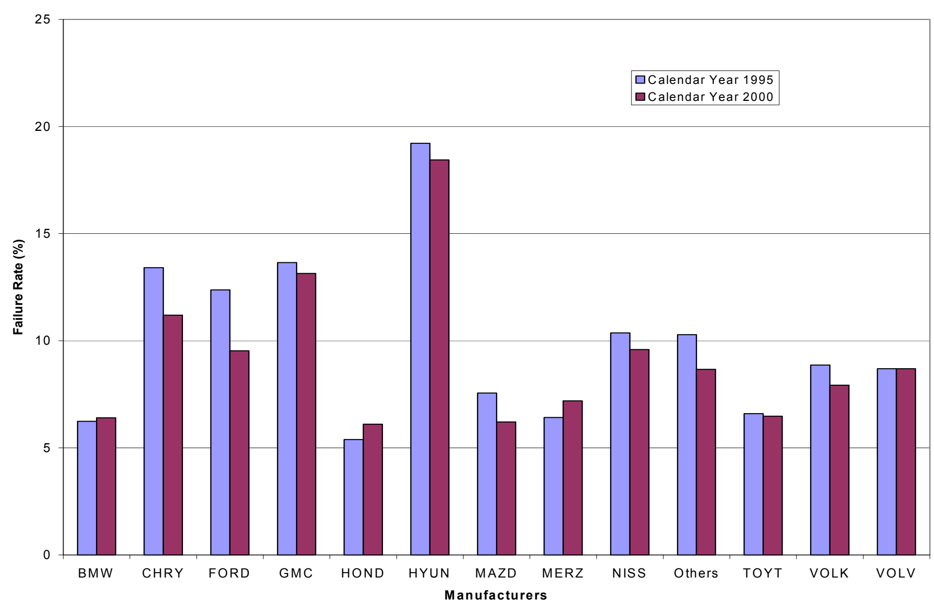


Figure 26. Failure Rate by Manufacturer for Passenger Vehicles

Figure 26 shows the failure rate in case years 1995 and 2000 for passenger cars from the ten most common manufacturers.

The highest failure rate among passenger cars from these manufacturers is for vehicles manufactured by Hyundai. Honda had the lowest failure rate. The "Big Three" exhibited failure rates that were close to the program year average. Given that these manufacturers dominate the fleet, it is not surprising that the overall program failure rate is heavily influenced by the individual rates of these three manufacturers. As a rule, the failure rates for all manufacturers were lower in 2000 than in 1995 with the exception of BMW, Honda and Mercedes Benz. It is not known why these manufacturers experienced increases in failure rate.

Figure 27 shows the results for light-duty trucks. The highest failure rate was observed for Volkswagen trucks, but it should be pointed out that this was a small sample consisting mostly of very old vehicles. General Motors had the next highest failure rate, followed by Suzuki. Honda had the lowest failure rate but it must be considered that Honda has only recently entered the truck segment of the market with a minivan and the small CR-V sport utility, which only received an idle test prior to September 2000.

As a rule, the failure rate of light-duty trucks is lower than that for passenger cars. This is partly attributable to more lenient standards being applied to these vehicles.

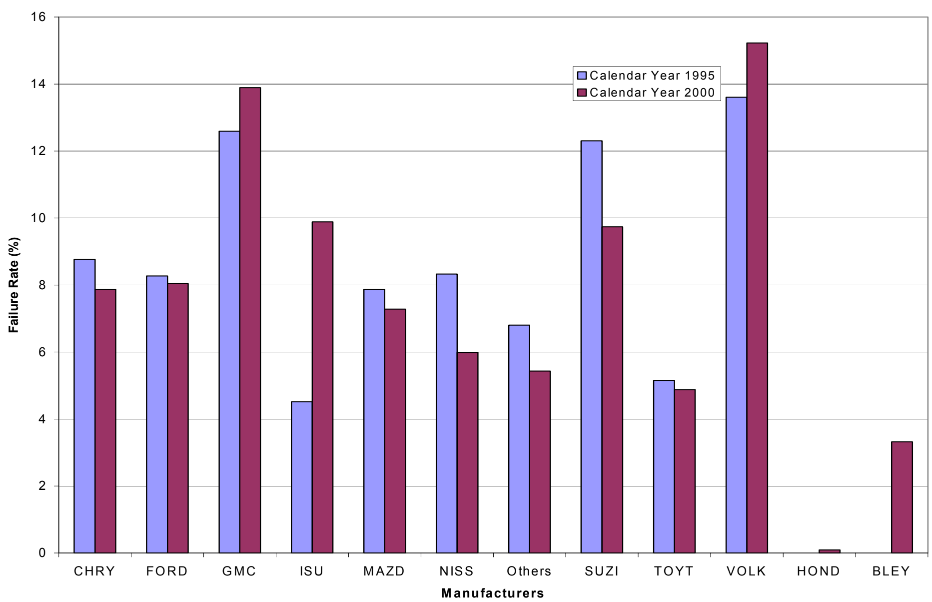


Figure 27. Failure Rate by Manufacturer for Light Duty Trucks

Figure 28 pertains to heavy-duty trucks. As mentioned earlier, this category consists of 99% GM, Ford and Chrysler trucks. The remaining 1% of vehicles in the sample had a much higher failure rate. The failure rates for GM, Ford and Chrysler vehicles were similar and a significant decrease was noted in 2000 compared to 1995.

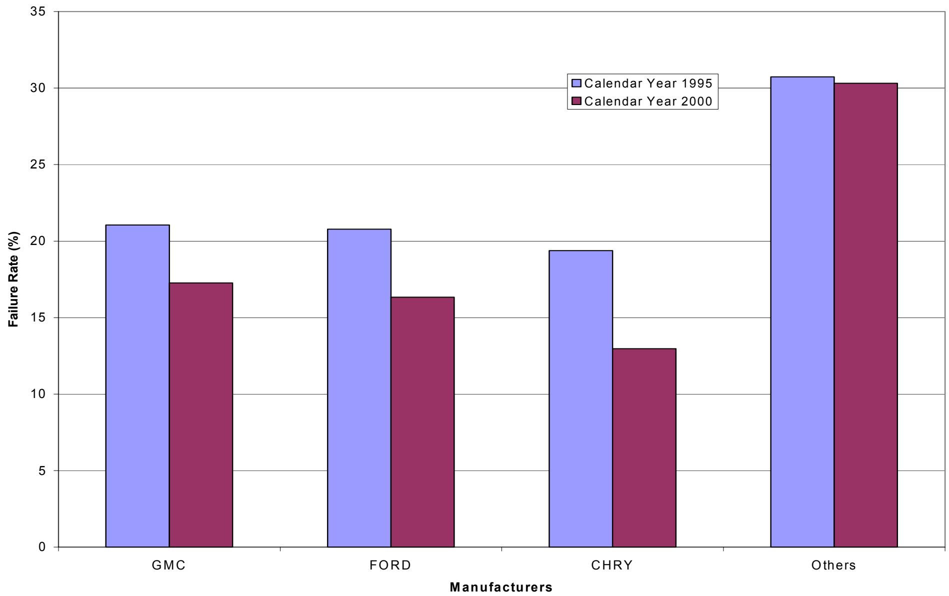


Figure 28. Failure Rate by Manufacturer for Heavy Duty Trucks

7.6 VEHICLES THAT HAVE EXPERIENCED FAILURE

The preceding discussion has been limited to the failure rate in each program year. However, this method of analysis does not give a complete picture of how vehicles subject to the AirCare program have performed.

From September 1992 through December 31, 2000, there were 8,924,358 inspections performed. Of these, 1,187,991 were failed inspections (13.3%). Due to that fact that most vehicles were tested multiple times, the number of vehicles tested during the review period was much less than the number of inspections - 1,876,123 vehicles. Of the vehicles that were tested at least once, 509,242 failed the inspection at some point. This represents 27% of the vehicles tested.

It has already been shown that the vehicle fleet subject to AirCare testing changes constantly. Within the overall fleet, there is a sub-population of vehicles that have failed the test at some point or another. It was of interest to determine the nature of this sub-population. Is it the same vehicles that fail the test year after year or do vehicles fail sporadically as faults develop in their engines and emission control systems? In order to check this, the database was queried to identify the number of vehicles with failures in one, two or more years. Presumably, a large number of vehicles with multiple failures would support the contention that an identifiable group of vehicles account for most of the excess emissions from the fleet. Conversely, a large number of vehicles with only one failure in 8 years would suggest that vehicles fail more randomly and, when repaired, do not tend to fail the test again.

Table 12 shows the number of vehicles that have experienced failure in 0, 1, 2, 3, or more years from 1992 to 2000.

The results shown in Table 12 suggest that most of the vehicles (286,186 out of 509,242 or 56.2%) that have failed an AirCare inspection at some point have done so only once. However, this means that 43.8% of failed vehicles have failed in two or more years. There are 16 vehicles that have failed 9 times, which means that they failed each year from 1992 to 2000.

Table 12. Vehicles with Multiple Failures

Number of Failed Years	Number of Vehicles
0	1,366,881
1	286,186
2	134,088
3	56,484
4	22,182
5	7,494
6	2,221
7	498
8	73
9	16

The results seem to support the theory that vehicles tend to fail as a result of some sort of correctable defect and then, after being repaired, continue to pass in subsequent years. Another possibility is that failing the AirCare inspection prompts the vehicle owner to sell the vehicle outside the program area or to retire the vehicle from use. An analysis of the data indicates that, for vehicles tested from 1992 through 1999, a result of "FAIL" was the last recorded result for 157,180 vehicles. Since vehicles can only be operated for 3 months in the AirCare region on the basis of a failed inspection, it must be assumed that these vehicles were removed from the area by some means.

Table 13. Number of Vehicles with Last Inspection as Failure

Year of Recorded Failure	Number of Vehicles Not Inspected in Following Year
1992	6,735
1993	11,305
1994	10,592
1995	12,212
1996	7,652
1997	10,789
1998	9,253
Total	**68,538**

Table 13 does not include results for vehicles that failed in calendar year 1999 because it is possible that some of those vehicles will re-appear in 2001. It would seem reasonable, given the trends indicated to assume that this number would be in the range of 10,000 vehicles, bringing the total up to approximately 79,000. This number represents vehicles that failed the AirCare inspection and did not receive a pass or conditional pass. This group accounts for approximately 15.5% of all the vehicles that have failed the inspection at some point in the first eight years.

The phenomenon of these “vehicles that never passed” has been observed in other I/M programs. A recent report issued by the US EPA [5], states that between 10% and 27% of vehicles that fail an I/M test never pass. On the basis of individual years, the percentage of “never-passed AirCare” vehicles appears as shown in Table 14 below. It is important to know that the numbers shown below included vehicles with conditional passes and therefore they are not the same as the numbers shown in Table 13.

Table 14. Number of Vehicles Never Achieved a Pass Inspection

Calendar Year	Number of Vehicles Failed	Number That Never Achieved a Pass (%)
1992	78,938	8,328 (10.6%)
1993	145,453	15,093 (10.4%)
1994	147,612	14,359 (9.7%)
1995	150,260	15,778 (10.5%)
1996	107,687	9,541 (8.9%)
1997	167,036	14,664 (8.8%)
1998	137,082	11,843 (8.6%)

7.7 TIME TO FIRST FAILURE

An analysis of all vehicles that had failed the inspection at least once was performed to determine when the first failure occurred. This was done by identifying the first failed test result and then counting the number of passing tests prior to the failure. The results are shown in Table 15.

Vehicles with a number of passed years before failure are those which have developed emission-related faults over time. Table 15 shows that 239,997 vehicles failed the very first time that they were tested. Analysis of these “first time failures" revealed that they were usually older vehicles, either already in use in the area when the program started up; or were new to the program area. It has been noted in earlier program analyses that there are not-seen-before vehicles of every model year appearing in the inspected fleet each year.

Table 15. Number of Years Passed Prior to Fail

Number of Years Passed Prior to Fail	Number of Vehicles
0	239,997
1	66,130
2	55,864
3	49,657
4	42,519
5	33,277
6	18,423
7	3,375

Figure 29 below shows the number of “first-time-seen” vehicles in calendar year 1995 and 1999 by model year.

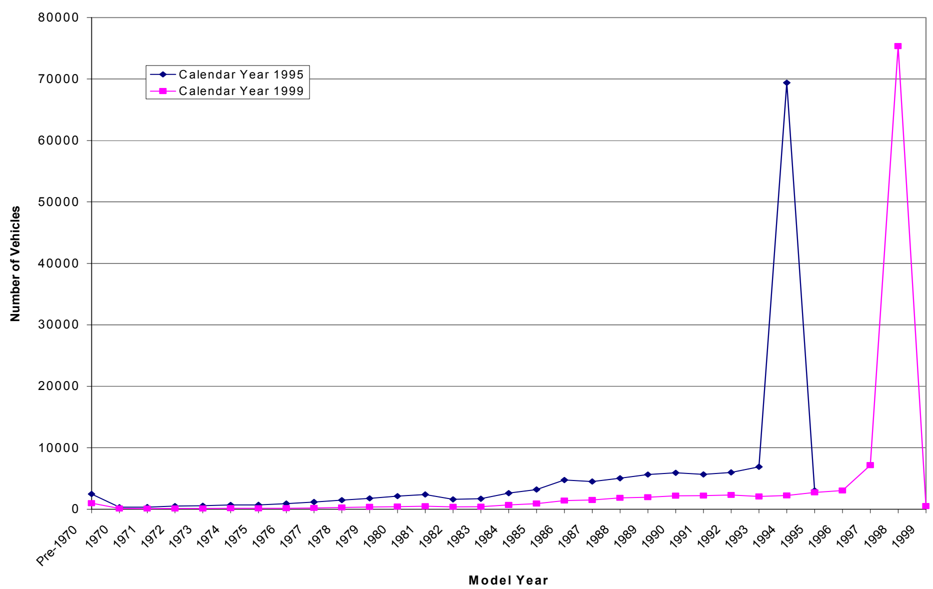


Figure 29. First-Time-Seen Vehicles by Model Years in 1995 and 1999

After program start up, already-in-use vehicles were inspected for the first time in 1992, 1993 or 1994. This spread was the result of the exemptions and labour disruptions in 1992 and 1993. After these initial effects, the number of “first-time-seen” vehicles ranged from 141,529 in 1995 to 112,623 in 1999. The intervening years of 1996, 1997 and 1998 saw 87,643, 132,011 and 121,946 “first-time-seen” vehicles, respectively. The low number for 1996 is the result of the labour disruption in that year.

Most of the "first-time-seen" vehicles in any given year are new vehicles that were previously exempted and have become eligible for testing in that year. The remainder consist of vehicles from all other model years which are new to the region.

7.8 MEAN TIME BETWEEN FAILURES

For vehicles that experienced more than one failed test result, an analysis was carried out to determine the time from the first failure and repair, to the next failure. This analysis gives an indication of repair effectiveness, something that will be discussed later in this report. Table 16 below shows vehicles that were successfully repaired in 1994 and how long they went before any subsequent failure.

Table 16. Life of Repairs Performed in 1994

	Non-Certified Repair in 1994		Certified Repair in 1994	
	Number	% of Initial	Number	% of Initial
Repaired to Pass in 1994	37954	100.0%	31783	100.0%
Never Failed Again and Still In Use in 1999	5105	13.5%	5916	18.6%
Failed Again at Some Time	18622	49.1%	14812	46.6%
Failed Next Year	7942	20.9%	5762	18.1%
Failed After 2 Years	3862	10.2%	2988	9.4%
Failed After 3 Years	3872	10.2%	3250	10.2%
Failed After 4 Years	1807	4.8%	1680	5.3%
Failed After 5 Years	1139	3.0%	1132	3.6%

The number of vehicles which passed in 1994 after a certified repair was a little lower than those which passed after a non-certified repair. However, after five years there were more of the certified repair vehicles which had continued to pass every year, and less of the certified repair vehicles which had failed again at some time. This suggests that certified repairs have a longer life than non-certified repairs. Overall, less than half of all the vehicles that were repaired to pass in 1994 ever failed again, and only about 20% failed again the very next year. This is higher than the overall failure rate in 1995, which indicates that if a vehicle has failed once, it seems more likely to fail again than a vehicle which has never failed. For those that did fail again, the average time to the next failure was 2.29 years for certified repairs, and 2.16 years for non-certified. Considering that less than half of all successful repairs ever failed again, the typical expected repair life must be at least 3 or 4 years.

7.9 PRE-AIRCARE FLEET VS. POST-AIRCARE FLEET

The vehicles tested over the first eight years of program operation can be classified into two groups. One includes vehicles that were already in service at the time that the program was introduced. These vehicles had already gone for a number of years without any checking of their emission levels. The second group consists of vehicles that entered the fleet after the

AirCare program started operation. These vehicles have been subject to periodic emissions inspections throughout their lives. As such, these groups were analyzed separately

The analysis considered two case years, 1995 and 2000. In 1995, there were 774,512 vehicles of model year 1991 and older that were tested. Of these 108,391 failed, or 14% of the vehicles. In the year 2000, there were 503,722 of these older vehicles tested and 81,547 failed, or 16% of the vehicles. Over the five-year period, the number of vehicles in the 1991-and-older group decreased due to vehicle retirement. A high proportion of the failing vehicles in both 1995 and 2000 belong to this older group.

The second group of 1992-and-newer vehicles has increased in size from 228,078 vehicles in 1995 to 464,411 vehicles in 2000. The number of failures in this group in 1995 was 4,115, while in 2000 it had increased to 11,486. The failure rate increased from 1.8% to 2.47%. The increase in the number of failing vehicles in this group over the five year span is the result of increasing age and accumulated mileage for the affected vehicles.

7.10 EMISSION COMPONENT TAMPERING CHECKS

Although tailpipe emission measurements have been afforded more prominence, the AirCare inspection process also included a visual underhood inspection for most of the review period. Due to difficulties in securing accurate information on the emission control hardware used on Canadian-specification vehicles prior to model year 1988, the visual inspection was carried out on an advisory basis only for older vehicles. This means that older vehicles with missing or tampered emission control devices were not automatically failed. If they were able to pass the emissions inspection regardless of the tampering, they received a passing result and an advisory indicating that certain emission control systems were not as originally installed.

From the beginning of the program, vehicles from model years 1988 and newer were failed if the catalytic converter was found to be missing. From January 1, 1996, the visual inspection became a pass/fail criterion for all 1988 and later model year vehicles. Thus, any defect identified with any of the emission control systems on these vehicles was grounds for failing the test, even if the tailpipe emission results met the standard.

Throughout the first 8 years of operation, the number of inspections with the visual inspection deficiencies totalled 296,547. This represents only 3.5% of inspections.

The most commonly observed component problem was a missing oxidation catalytic converter. The second most common reason was a faulty thermostatic air cleaner

Table 17 shows the problem identification rate attributed to each of the component inspections over the first 8 years of program operation. It can be misleading to show only the number of problems on each item because different vehicles can have different combination of items to be inspected. For example, there were more than 8 million inspections on the gas cap, but fewer than 1.5 million vehicles were inspected for the oxidation catalytic converter. Showing only the number of failures does not reflect the significance of each item. Therefore, the problem rates below were calculated by taking the number of deficiencies over the total number of inspections for each item.

Overall, there was a low rate of deliberate tampering evident in the vehicles presented for inspection.

Table 17. Failures for ECS Components

Item	Failures Rate
Fuel Filler Restrictor	1.18%
Positive Crankcase Ventilation	0.16%
Thermostatic Air Cleaner	2.01%
Evaporative Control System	0.16%
Exhaust Gas Recirculation	0.36%
Three Way Catalytic Converter	0.45%
Air Injection System	0.81%
Gas Cap	0.20%
Oxidation Catalytic Converter	11.39%

7.11 REJECTIONS FOR VISIBLE SMOKE

Vehicles that burn oil and emit blue smoke are considered to be gross polluters by the public. However, the consumption of lubricating oil is not automatically associated with high HC, CO or NO_x emissions. As a result, vehicles that the public would classify as gross emitters can pass a tailpipe test.

Aside from the public perception issue, vehicles with smoky exhausts pose a nuisance problem in the inspection centres. Workers in the inspection centres are concerned about exposure to harmful gases and toxic substances and were therefore concerned about breathing the smoke produced by vehicles that burn oil. In order to protect the work environment, inspection centre managers were given authority to reject vehicles that were obviously smoking. This policy was agreed in 1994. Any vehicles that were seen to be smoking continuously outside the inspection centre could be rejected from testing and be required to have repairs performed to reduce the smoke emissions. Because most of these rejections occurred in the queue prior to the test, they were not recorded in the database. Instead, managers logged the license plate number of vehicles that were sent away.

In 2000, PVTT staff undertook an evaluation of the smoking vehicle issue [6]. In order to perform the analysis, handwritten rejection logs were keypunched into an Excel spreadsheet. In some cases, the rejection for visible smoke occurred after the test process had been initiated, resulting in an aborted test. In these cases, existing test records were available. The major conclusions of the study were that, of 9786 incidences where a vehicle was turned away from the inspection centre, the number of individual vehicles involved was only 5238, suggesting that vehicles turned away from one inspection centre often appeared at another. Sometimes the vehicle was rejected again, but in many cases, it was tested, frequently passing.

The study concluded that certain inspection centres had higher rates of rejection for oil smoke than others, suggesting inconsistent application of rejection criteria across the testing network. The study found that many of the vehicles rejected received a test within a time period too short to permit meaningful repairs, suggesting that the reason for rejection may not have been compelling.

One problem is that vehicles that emit oil smoke do not necessarily do so on a consistent basis. There are two main avenues for an engine to burn oil. One involves the oil making its way past the piston rings and becoming involved in the combustion process. This problem is most prevalent in high-mileage engines where the rings and cylinder bores have experienced significant wear. The second avenue involves oil entering the combustion chamber by way of the valve guides. This can occur due to leakage past the seals at the top of the guide and/or excessive clearance between the valve stem and the guide. This latter mode tends to result in oil smoke being evident at idle or under deceleration. In these modes, the manifold vacuum is high and oil can be sucked down the valve guides and into the combustion process. In many cases, operating the engine in an off-idle mode causes the smoke to go away as there is insufficient infiltration of oil at lower manifold vacuum levels and higher engine speeds. Worn or broken piston rings tend to cause oil smoke under all engine operating modes, but the effect is usually more pronounced at higher engine speeds. Under these conditions, there is more pressure in the crankcase, oil splashing due to crankshaft revolution, and the rings are required to negotiate bore taper at a higher rate of speed.

In the case of valve guide/valve seal-related oil consumption, smoke may appear after a few minutes of idling. Driving the vehicle for a brief period will stop the smoking and there will likely be no smoke evident for the first minute or two of idling afterwards. Given this behaviour it is understandable how a vehicle could be rejected for smoke at one time and then accepted for testing at another. Repairs to eliminate oil-burning are costly, making it worthwhile to attempt other solutions. Anecdotal accounts from vehicle owners and repair facilities suggest that the use of higher viscosity oil, additives intended to reduce smoking and even partial drainage of the oil are sometimes tried in order to get a smoking vehicle to clear up long enough to get a test. It is likely that once the test has been completed and a pass or conditional pass obtained, the vehicle will continue to operate, emitting smoke from time to time.

The fact that vehicles are inconsistent in the way that they emit smoke and that it is necessary to rely on visual observation and subjective evaluation leads to concern about the consistency of the smoking vehicle rejection process.

Table 18 shows considerable variability in the rejection rate per centre. However, this is not entirely indicative of variations in judgement. Due to their location, the mix of vehicles presented for testing varies according to station. Centre 1, for example tests far more new vehicles most of the other centres, supporting a low rate of rejections. The greatest number of rejections occurred at Vancouver South, a station that sees a wide range of vehicle ages.

Table 18. Number of Vehicles Rejected by Centre

Centre	No. of Vehicles. Inspected	No. Rejected for Smoke	% Rejected
1	97,153	531	0.55%
2	102,132	1,006	0.98%
3	106,140	939	0.88%
4	71,299	541	0.76%
5	109,521	1,088	0.99%
6	114,896	970	0.84%
7	53,292	593	1.11%
8	47,973	614	1.28%
9	82,284	729	0.89%
10	75,730	566	0.75%
11	40,537	216	0.53%
12	146,726	1,853	1.26%
All	**1,047,683**	**9,646**	**0.92%**

Figure 30 shows the model year distribution for vehicles that were identified as smoking. Not surprisingly, there were almost none within the newest age group with the peak year being 1986. There were 1200 vehicles of this model year identified as smokers in 1999.

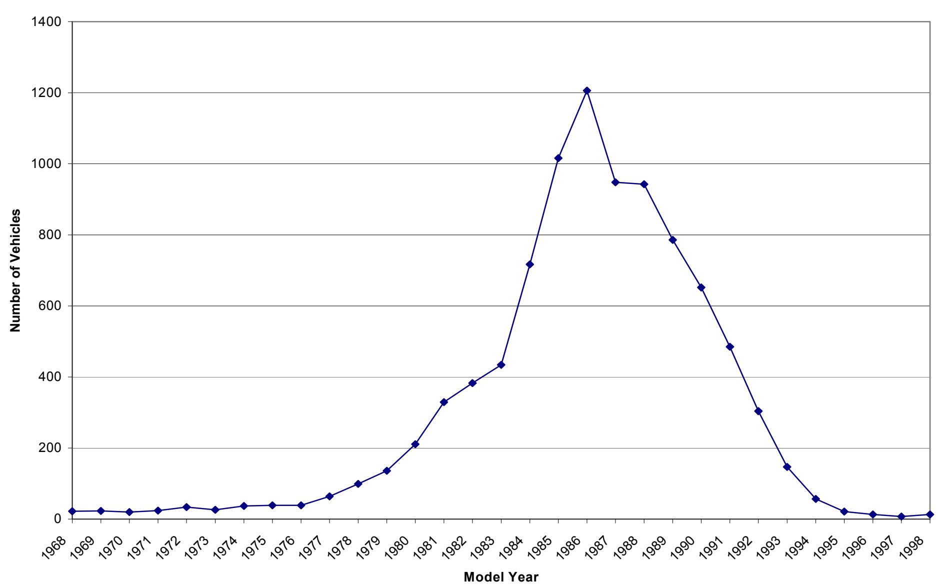


Figure 30. Number of Rejected Vehicles vs. Model Year

According to the experience of AirCare inspectors, certain vehicle types are prone to being smokers. An analysis of the 9646 records supports this contention. The table below shows the distribution by manufacturer of the vehicles rejected for smoking.

There is a very high rate of occurrence for Chrysler and Toyota in the sample. The Chrysler data is dominated by Caravan and Voyager vehicles equipped with the Mitsubishi-built 3.0L V-6 engine. This engine has a common defect with the valve guides, resulting in smoking after extended idling. Toyotas that smoke tend to be older Tercel and Camry models.

After this analysis was completed, the AirCare contractor's operations personnel were reminded of the importance of rejecting vehicles before they entered the building. After all, if the objective was to reduce exposure of the staff to noxious fumes, rejecting the vehicle once it was already inside the building and producing smoke would do little to alleviate the problem. Similarly, if rejection of borderline offenders simply resulted in multiple re-attempts, the exposure of employees to smoking vehicles was being increased, rather than reduced.

Table 19. Number and Percentage of Rejected Vehicles by Manufacturer

Manufacturer (with at least 20 vehicles in sample)	Number of Rejected vehicles	Percentage of Rejected Vehicle Sample
AUDI	25	0.27%
BMW	49	0.53%
CHRYSLER	2,578	27.68%
FORD	850	9.13%
GENERAL MOTORS	1,263	13.56%
HONDA	666	7.15%
HYUNDAI	577	6.19%
MAZDA	429	4.61%
MERCEDES BENZ	103	1.11%
NISSAN	300	3.22%
SUZUKI	58	0.62%
TOYOTA	2,043	21.93%
VOLKSWAGEN	234	2.51%
VOLVO	40	0.43%

7.12 DIESEL VEHICLE FAILURES

The influence of advanced engine technology in diesel engines resulted in most 1988 and newer diesel vehicles achieving a result of less than 2% on the AirCare opacity test. Beginning in September of 2000, a new diesel test was introduced. This new test measures opacity in the same way that the previous test did, but instead of operating the vehicle under steady state conditions, it is driven over a transient driving cycle. The chassis dynamometer is set to simulate the inertia and aerodynamic drag forces experienced by the vehicle in actual driving.

The end result is a more realistic assessment of whether a given vehicle would be seen to emit visible smoke in daily traffic. According to the first four month's of data, the new diesel test is far more effective than the previous one, with a failure rate of over 5%.

Table 20. Failure Rate of Diesel Vehicles by Calendar Year

Calendar Year	No. Vehicles Tested	Number Failed	% Failed
1992	5,126	32	0.62%
1993	12,682	50	0.39%
1994	16,583	61	0.37%
1995	17,175	59	0.34%
1996	11,114	44	0.40%
1997	17,734	35	0.20%
1998	18,238	25	0.14%
1999	18,245	30	0.16%
<Sep. 5, 2000	11,369	18	0.16%
=>Sep. 5, 2000	5,603	312	5.57%

As expected, the failure rate increases as vehicles age. Figure 31 shows the failure rate by model year for the diesel tests conducted from September to December 31, 2000.

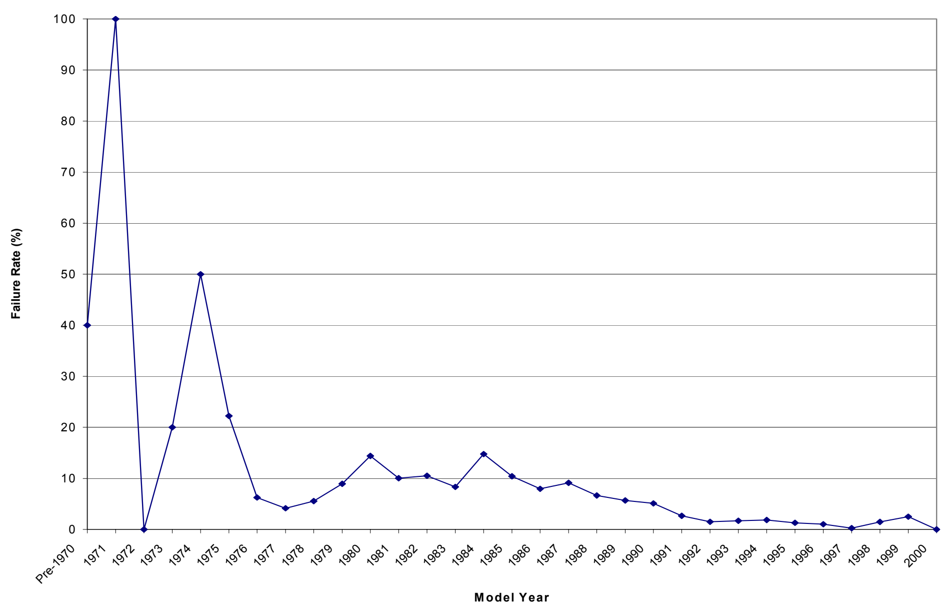


Figure 31. Failure Rate by Model Year for IM 147 Diesel Test (Sept-Dec, 2000)

8.0 REPAIRS TO EXCESS-EMITTING VEHICLES

When discussing I/M programs, the emphasis tends to be placed on the inspection, or "I" side, rather than the maintenance, or "M" side. However, the emission reductions directly attributable to I/M result from corrective maintenance performed on vehicles that fail the inspection. Therefore, the "M" side of I/M is, in fact, critical to the success of any I/M program.

The importance of the repair sector to the success of the AirCare program was not lost on its designers. From the outset, the program was designed to include a certified repair industry that would be better trained and equipped to deal with emission-related failures. Experience in U.S. programs had pointed out some weaknesses in the skills of automotive technicians when it came to repairing emissions problems. These weaknesses were further magnified when the inspection process included loaded dynamometer testing as opposed to simpler idle and two-speed-idle tests. From the beginning, AirCare was designed to incorporate loaded dynamometer testing with measurement of NO_x emissions, something that was quite innovative in 1992. Also, there had been no emissions testing program in place in the Vancouver region prior to 1992, meaning that the industry had not been able to develop any familiarity with emissions testing programs. The need to work with the repair industry and to monitor their performance were recognized as key elements of a successful program and resulted in the development of certification procedures for both repair facilities and repair technicians.

In order to ensure that the AirCare program would deliver its expected emission reductions, it was necessary to become involved with the repair sector. Program designers envisioned a well-trained and equipped industry that would understand the goals of the program and back up that understanding with solid technical skills. To encourage the public to seek out qualified repair facilities and therefore to provide a reason for shops to become certified, it was decided that vehicle owners who chose certified shops would not be subject to ping-ponging between the inspection centre and the repair facility. In other words, any vehicle owner who took their vehicle to a certified AirCare repair centre would be assured that they would make only one trip back to the inspection facility. This would be assured, even if the vehicle did not pass upon re-inspection. The logic was that, in taking their vehicle to a certified repair shop, the public had done what was recommended and should not be denied re-licensing of their vehicle if the actions of the repair facility were unsuccessful.

As a second incentive, a repair cost limit was established. This limited the expenditure for AirCare–related repairs to $200 in the first year of program operation for all vehicle types. Thus, vehicle owners would have limited liability by choosing a certified repair facility over a non-certified one. The repair cost limits were later increased as shown in Table 21 and Table 22.

The ability to limit the amount of dollars spent on repairing a failing vehicle is available only at certified repair facilities. All other repairs have to succeed in making a vehicle pass inspection if it is to be re-licensed. It was felt by program designers that the guarantee of only one re-inspection and the limit on the amount of money to be spent on repairs would be powerful incentives for the public to seek out certified repair facilities.

To make it even more attractive, it was decided that a list of certified repair facilities, broken down by geographical area, would be handed out to all motorists whose vehicle failed the inspection.

Table 21. Non-Tampering Repair Cost Limits

Model Year	Effective Date			
	Sep 1992	Sep 1993	Sep 1994	Jan 1996
Pre- 1975	$200	$200	$200	$250
1975 – 1987	$200	$225	$250	$350
1988 – 1992	$200	$250	$300	$400
Post 1992	$200	$300	$400	$500

Table 22. Tampering Repair Cost Limits

Model Year	Effective Date			
	Sep 1992	Sep 1993	Sep 1994	Jan 1996
Pre- 1975	$200	Advisory only	Advisory only	Advisory only
1975 – 1987	$200	Advisory only	Advisory only	Advisory only
1988 – 1992	$200	$600	$1000	$1000
Post 1992	No Limit	No Limit	No Limit	No Limit

* Tampering is defined as the removal, destruction, disconnection or modification of an emission control device or component.

The ability to exert some control over the quality of repairs performed and to collect data about the nature of repairs carried out was seen as a vital element of the program. In fact, program designers were so confident that the public would use only certified repair shops that no separate system of identifying re-inspections was developed. When a vehicle came for a re-inspection after visiting a certified repair shop, the submission of repair data would be the identifier of a re-inspection. All other tests were considered to be initial tests, even if the vehicle was being tested for the second, third or fourth time.

8.1 Repair Technicians

In British Columbia, it is necessary to earn a Trades Qualification (TQ) in order to work professionally in the vehicle repair business. The TQ qualification process is fairly rigorous and requires that technicians complete a combination of classroom training and 8000 hours of apprenticeship in order to obtain their TQ. In determining the requirements to be met for certification as an AirCare technician, it was decided that only technicians with a TQ would be eligible. However, in addition to the basic requirements for a TQ, a further requirement to pass an emissions knowledge exam was established.

The process of certifying technicians began in July of 1991, long before program start-up. A bank of exam questions was developed jointly by a sub-committee of automotive instructors and Sierra Research of Sacramento while Colorado State University developed the training curriculum to for the Emission Systems Theory and Operation course. This exam consisted of 4 sections. The first section consisted of twenty multiple-choice questions based on a written handout describing the AirCare program and its basic operating policies and procedures. The next section consisted of 80 questions pertaining to the formation of emissions in engines and the operation of emission control devices. The next two sections were optional, consisting of twenty questions each about alternative fuels (propane and natural gas) and diesel vehicles, respectively.

The certification process for technicians was designed so that certification would have to be renewed every three years. This was intended to provide flexibility in ensuring that new developments in technology were reflected in the examination questions, thereby confirming that technicians were keeping pace with new developments in the field. New examination questions have been developed over the course of the program and a second examination known as a re-certification exam has been developed. The re-certification exam is administered to those technicians that have already passed the theory exam and are looking to maintain their certification. The re-certification exam is geared more to the practical aspects of diagnosing and repairing emissions defects in vehicles. All new applicants for certification are only required to pass the theory exam.

Since the inception of the technician certification system, the program has maintained a fairly consistent group of active certified technicians numbering about 1200. The number of technicians that have applied for certification stands at 4430. 1900 technicians have ceased to be AirCare certified, either as a result of allowing their certification to expire or by failing to pass the re-certification exam. AirCare training and the theory exam are incorporated province-wide into the automotive technician training curriculum. Therefore, a large number of technicians have taken AirCare training but may never have been exposed to a vehicle that has failed an AirCare inspection.

To support the certified repair industry, training courses were developed to enhance the knowledge of technicians working in the AirCare program area. The first course was developed by Colorado State University and was made available through local community colleges and private training institutions. The course provided 40 hours of instruction at a cost of approximately $500. With the introduction of the re-certification examination in 1994, AirCare administration office staff developed a second course called the AirCare Practical Training Course. This was also a 40-hour course with an emphasis on hands-on diagnosis and analysis of emission results from actual testing. The cost for the practical training course ranges from $500-$600.

The success rate on the initial theory exam has ranged from 58 to 76%. Since 1991, 750 technicians have taken the AirCare theory course. The success rate on the examination after taking training is typically greater than 95%.

After 3 years, technicians must submit to a re-certification process. In 1995 a repair effectiveness monitoring system was implemented, tracking the effectiveness of each certified repair technician at resolving emissions problems. It was decided that technicians that maintained an average Repair Effectiveness Index, or REI, higher than the overall industry average would be automatically re-certified. Therefore, only those technicians who have performed below average or who have not performed sufficient repairs to establish reliable REI values are required to write the re-certification exam. Since its inception, 900 technicians have written the re-certification exam and the initial success rate has been 72%. After failing the re-certification exam, technicians must successfully complete the practical training course and pass the exam. Since the course was developed 200 technicians have gone through the training and the success rate on the examination after training has been in the area of 85%.

Technician training and monitoring with the Repair Effectiveness Index has not been popular with all technicians, particularly those who fail the re-certification examination. However, AirCare program administration staff feel that monitoring of the industry is necessary to ensure that the program is able to produce meaningful emissions reductions as well as to protect the public from unnecessary or ineffective repairs. The REI has been an important tool in this regard. The theories behind the REI and the calculation algorithm have been described in two SAE technical papers [7] [8]. Put simply, the REI provides a non-dimensional indicator of the quality of repairs. A successful repair is one that substantially reduces the emissions of a vehicle from its “before-repair” level. Secondly, the post-repair result should be indicative of a vehicle operating to its full potential for low emissions based on its age and level of emission control technology. The third variable is a direct correlation between the technician’s diagnostic information provided on the Repair Data Form and the vehicle’s post-repair actual results. Should a technician indicate no defects were found during the diagnostic check and the vehicle passed the post-repair inspection then the validation between the diagnostic information and the post-repair test is true. If a technician achieves excellent results in all of these areas and a validation between the diagnostic information and the post-repair test results is true, the REI will be close to 1. If the technician turns a marginally failing vehicle into a gross polluter as a result of his or her work, the REI would come out close to –1. If the work had no effect on emissions, the REI result would be zero. Positive REI’s suggest that the emissions are being reduced by the repair sector. Table 23 below shows the average REI for the repair industry as a whole since the REI system was implemented.

Table 23. Average REI by Calendar Year

Year	Average REI
1995	0.29
1996	0.32
1997	0.33
1998	0.36
1999	0.36
2000	0.37

According to Table 23, the average REI for the industry has been improving consistently over the years. In practice, the highest attainable REI for a single repair has tended not to exceed 0.80 and the highest average REI for a 3-month period maintained by a practising technician has been 0.65. The REI seems to provide a reliable means of assessing repair quality. Technicians that had a good reputation for successfully fixing vehicles prior to the introduction of the REI have tended to maintain high REI averages. Conversely, technicians with low average REI’s tend to show weaknesses in their understanding of how to diagnose and repair vehicles with high emissions. REI is also used to determine eligibility for Quality Repair Awards, which are warded every 3 months to technicians with high numbers of repairs and the highest average REIs for the quarter. 101 individual technicians have received Quality Repair Awards. Most (77) have only received one award, but many have received more, with one technician receiving ten.

8.2 REPAIR FACILITIES

In order for technicians to perform effective repairs, they must have the equipment and reference material to help them do the job. To this end, a repair shop certification process was developed. This process established minimum requirements for certifications as follows;

Technician Certification Requirements

Those persons applying for certification in the AirCare Program must meet the following pre-requisites:

British Columbia Trades Qualification (BCTQ) or Certificate of Qualification in:

- automotive mechanical repair
- heavy duty diesel, with three years automotive experience
- commercial vehicle mechanical repair

OR

B.C. Certificate of Apprenticeship in

- Auto electric and tune-up

Technicians possessing Inter-Provincial certificates or qualifications from other provinces are required to apply for a BCTQ at the local Provincial Apprenticeship Branch office.

Persons with Exemption Certificates issued by the Apprenticeship Branch are NOT eligible to write the AirCare certification examinations, as they do not meet the pre-requisites of the program.

Repair Centre Requirements

Each AirCare repair centre must have, as a minimum, all the equipment listed below on site, operational, and well-maintained. The meters, gauges, etc. listed may be furnished either as separate items or as components of a complete system such as an engine analyzer.

1. Oscilloscope or other ignition analyzer capable of displaying ignition patterns, cylinder power contributions, and square wave and injection patterns of vehicles inspected at AirCare inspection centres. The oscilloscope or ignition analyzer must also have the capability to test vehicles equipped with Distributorless Ignition System (DIS)
2. Ammeter
3. Ohmmeter
4. Voltmeter
5. Tachometer

6. Vacuum/pressure gauge
7. Cam-angle dwell meter
8. Ignition timing light, or timing light with timing advance adjustment to substitute for item #11
9. Compression test gauge
10. Vacuum pump for applying simulated manifold vacuum to emission control devices
11. Distributor advance tester
12. Exhaust emissions analyzer and calibration gases meeting the specifications established by the province. (AirCare centre owners should either confirm that an analyzer is certified by checking with the AirCare Program office, or require vendors to confirm the certification)
13. Scan tool(s), supplemental analyzer provisions, or detailed reference materials sufficient to allow the extraction and interpretation of computer fault codes from any vehicle being repaired that is equipped with an exhaust oxygen sensor and malfunction indicator light
14. Computer, modem, printer and an Internet Service Provider (ISP) for accessing vehicle inspection and repair information on-line**
15. Labscope that meet the requirements as outlined by PVTT**

** Enhanced program requirements since September 1, 2000.

There are approximately 1200 automotive repair businesses located in the AirCare-eligible area. At the point that the program began operating in September of 1992, less than 100 repair facilities had applied for certification. Once the program started testing vehicles, the demand to become certified increased significantly and within 6 months more than 500 repair facilities had been approved as AirCare-certified shops. The number of shops choosing to be AirCare certified has remained relatively stable around the 500 mark since that time. However, there have been 942 shops that have been certified at one time or another. 228 shops have maintained their certification continuously since 1992. Table 24 shows the Number of Certified AirCare Repair Facilities and Technicans since 1992. It is interesting to note that there were virtually zero repair shops that had gas analyzers prior to the start-up of the AirCare program.

Effective September 1, 2000, an additional requirement for certification was imposed. It became necessary to have a computer with Internet access in order to enter repair data electronically as opposed to the previous paper-based system. The introduction of this requirement caused a small number of repair shops to drop out of the program.

Of the repair shops that were AirCare certified in 2000, there were 105 that were new-car dealer service departments, 65 that were franchise-type chain stores and 280 that were independently owned.

Table 24. Number of Certified AirCare Repair Facilities and Technicans by Program Year

Number of Technicians at Repair Facility	Number of Active Repair Facilities with Specified Number of Active Technicians							
	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-00
1	227	202	220	218	201	227	229	211
2	159	184	183	160	174	157	164	161
3	73	91	84	82	88	92	86	91
4	44	46	53	48	36	41	35	35
5	18	27	21	16	20	17	20	18
6	8	14	13	10	11	10	10	10
7	5	11	6	4	6	3	5	4
8	0	2	1	2	2	3	1	0
9	0	0	1	0	0	0	0	0
10	1	0	1	0	1	1	0	1
11	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	1	0
Total Number of Active Repair Facilites	**535**	**577**	**583**	**540**	**539**	**551**	**551**	**531**
Total Number of Active Technicians	**1123**	**1339**	**1302**	**1160**	**1191**	**1181**	**1170**	**1134**

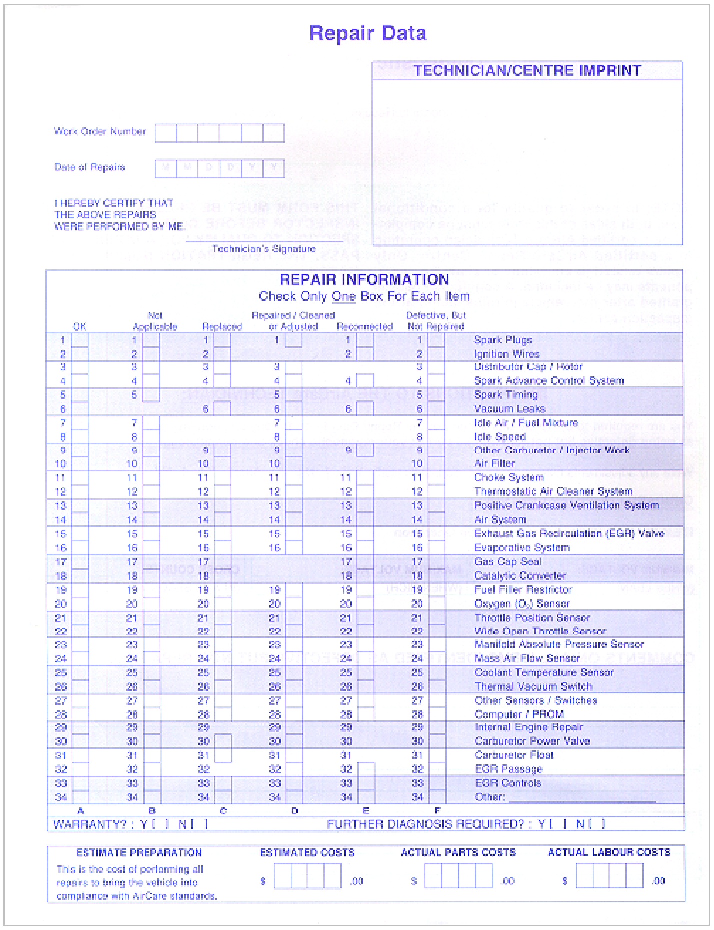
8.3 REPAIR DATA

Aside from the desire to provide the public with access to a trained and well-equipped repair industry, the establishment of a certified repair industry provided an opportunity to collect information about the types of repairs performed and on the results of emissions-based diagnoses.

The method for collecting this information was a Repair Data Form (RDF). An example of the form is shown as Figure 32.

The owners of vehicles that failed the AirCare inspection during the review period were provided with a blank RDF and a list of certified AirCare repair centres, along with their failed inspection report. The form was intended to be given to the repair shop when repairs were done and the shop would then fill in the necessary information. To ensure the integrity of the process, a system was devised using a technician card and a shop imprinter much like the old manual credit card processing systems. Certified technicians were issued a plastic card, with their technician ID and name embossed into the it at the time of certification.. Repair shops were required to lease an imprinter from a central supplier. To validate the repair data form and prove that the repairs were actually carried out by a certified repair facility, the area in the upper right-hand corner was imprinted with both the facility and technician ID numbers. To prevent fraudulent use of the RDF's, a security feature was incorporated both on the imprinter and the technician ID card.

The RDF used from September, 1992 to 1996 included 29 items or categories relating to emissions diagnosis and repair. This was expanded to 34 items in September 1996. In September of 2000, an electronic RDF was launched providing much greater flexibility in the reporting of repair actions. The new form allows for 91 possible items.


Repair Data

TECHNICIAN/CENTRE IMPRINT

Work Order Number

Date of Repairs

I HEREBY CERTIFY THAT THE ABOVE REPAIRS WERE PERFORMED BY ME.

Technician's Signature

REPAIR INFORMATION
Check Only One Box For Each Item

	OK	Not Applicable	Replaced	Repaired / Cleaned or Adjusted	Reconnected	Defective, But Not Repaired
1	Spark Plugs					
2	Ignition Wires					
3	Distributor Cap / Rotor					
4	Spark Advance Control System					
5	Spark Timing					
6	Vacuum Leaks					
7	Idle Air / Fuel Mixture					
8	Idle Speed					
9	Other Carburetor / Injector Work					
10	Air Filter					
11	Choke System					
12	Thermostatic Air Cleaner System					
13	Positive Crankcase Ventilation System					
14	Air System					
15	Exhaust Gas Recirculation (EGR) Valve					
16	Evaporative System					
17	Gas Cap Seal					
18	Catalytic Converter					
19	Fuel Filler Restrictor					
20	Oxygen (O_2) Sensor					
21	Throttle Position Sensor					
22	Wide Open Throttle Sensor					
23	Manifold Absolute Pressure Sensor					
24	Mass Air Flow Sensor					
25	Coolant Temperature Sensor					
26	Thermal Vacuum Switch					
27	Other Sensors / Switches					
28	Computer / PROM					
29	Internal Engine Repair					
30	Carburetor Power Valve					
31	Carburetor Float					
32	EGR Passage					
33	EGR Controls					
34	Other:					

A B C D E F

WARRANTY? : Y [ ] N [ ] FURTHER DIAGNOSIS REQUIRED? : Y [ ] N [ ]

ESTIMATE PREPARATION
This is the cost of performing all repairs to bring the vehicle into compliance with AirCare standards.

ESTIMATED COSTS $ .00 ACTUAL PARTS COSTS $ .00 ACTUAL LABOUR COSTS $ .00

Figure 32. Repair Data Form

For each item, there were 6 possible status definitions as follows:

OK	The item is functioning properly
Not Applicable	The item is not present on the vehicle or it is unrelated to the problem
Replaced	The item has been replaced
Repair/Cleaned/Adjusted	The item has been repaired, cleaned, or adjusted
Reconnected	The item has been reconnected
Defective, But Not Repaired	Item was too expensive to fit within the cost limit or parts were unavailable to perform the repair.

A fully completed RDF provides comprehensive information to the program administration office about the types and cost of repairs performed on vehicles that fail the AirCare inspection. This data will be discussed later in this section.

8.4 RDF STATISTICS

From September 2, 1992 through December 31, 2000, there were 368,160 RDF's turned in to AirCare inspection facilities. The number of RDF's submitted by program year is shown in the table below:

Table 25. Number of Repair Data Forms Submitted by Program Year

Program Year	Number of RDF's Returned	% of Vehicles Failed Submitting an RDF on Re-Inspection
1	59,580	45.8%
2	65,512	48.5%
3	43,125	41.2%
4	30,411	38.0%
5	56,720	39.7%
6	42,458	39.1%
7	36,064	36.2%
8	33,235	35.3%
Total	**367,105**	**41.0%**

To some degree, the number of RDF's submitted should be an indicator of the volume of repairs being performed by certified AirCare repair facilities. Even though every failing VIR issued by inspection centres was accompanied by a blank RDF, many were never turned in at the time of re-inspection. Only certified facilities have the capability of imprinting the form and only imprinted forms are accepted by the inspection centres as qualification for a Conditional Pass, therefore it must be assumed that all post-fail inspections in which a RDF was not submitted represent non-certified repairs.

The data in the above table suggest that certified repairs account for the minority of repairs in all program years. This has been a consistent finding since the program began. This was somewhat surprising to program administrators as it was expected that the public would prefer certified shops because of the assurance of receiving at least a Conditional Pass on re-inspection. While it cannot be ruled out that certified shops may perform repairs and then not complete the RDF, it would seem that the majority of motorists are content to have repairs performed at a non-certified shop. The reason why this is so is unknown. It has been speculated that the public may fear being charged more by a certified shop or may suspect some collusion between the inspection facilities and the certified repair industry.

The total number of vehicles that have failed inspection is 509,242. The 367,105 RDF's submitted during the review period (Sep. 92 to Aug. 2000) account for 272,219 individual registration numbers. The difference represents vehicles that have failed on more than one occasion and have submitted multiple RDF's.

A drop in the number of RDF's submitted is evident in more recent program years. Although it cannot be said for certain, it is possible that the introduction of Repair Effectiveness monitoring resulted in fewer RDF's being turned in at the time of re-inspection. Communication with the repair industry suggests that technicians are hesitant to submit an RDF if they are concerned that the vehicle will not do well on re-inspection. A poor result will negatively impact their REI average and may result in their not achieving automatic re-certification.

Another possibility is that the progressive increase in the repair cost limits has diluted the incentive for owners to seek out certified repair facilities. In the first two years of operation, choosing a certified shop allowed owners to limit their repair bill to $200. In later years, as the repair cost limit increased to as much as $500, owners may have become hesitant to choose certified repair facilities, hoping that they could achieve a passing result while spending a minimal amount on repairs.

It is unfortunate that such a large gap exists between the number of failing vehicles each year and the number of returned RDF's. Without the information included on the RDF, it is impossible to determine what was done to the vehicle between the initial failing test and the re-inspection or even to be certain that anything was done between the two tests.

The most common actions for any of the items listed on the RDF involve either "Replaced" or "Serviced".

The table indicates that for the first few years of operation, the components that tended to be replaced most often were basic tune-up items. In the third year, emission-specific components such as oxygen sensors appear for the first time. By year 7, oxygen sensors finally dislodge air filters and spark plugs from the number 1 position. Air Filter, Spark Plugs and Distributor Cap appear in the Top 5 every year. Table 26 below shows the Top 5 items that were shown as "Replaced" in program years 1 through 8.

Table 26. Top 5 "Replaced" Items by Program Year

Rank	Program Year							
	1	2	3	4	5	6	7	8
1	Air Filter	Air Filter	Air Filter	Air Filter	Spark Plugs	Spark Plugs	Oxygen Sensor	Oxygen Sensor
2	Spark Plugs	Spark Plugs	Spark Plugs	Spark Plugs	Air Filter	Air Filter	Spark Plugs	Spark Plugs
3	Distributor Cap	Distributor Cap	Distributor Cap	Oxygen Sensor	Oxygen Sensor	Oxygen Sensor	Air Filter	Air Filter
4	PCV Valve	PCV Valve	Oxygen Sensor	Distributor Cap	Distributor Cap	Catalytic Converter	Catalytic Converter	Catalytic Converter
5	EGR Valve	EGR Valve	PCV Valve	PCV Valve	PCV Valve	Distributor Cap	Distributor Cap	Distributor Cap

The most common "Serviced" items are the same year after year. The items are Idle Mixture, Idle Speed, Spark Timing, Vacuum Leaks, and Other Carb/Inj. It is interesting to note that adjusting idle mixture and idle speed remain the most common "non-parts-related" repair as the number of vehicles where either of these actions is even possible is diminishing year by year. Vehicles with electronic fuel injection have no adjustments for either of these parameters. By the end of this review period 82% of the overall AirCare-eligible fleet consisted of fuel-injected vehicles. Within the sub-population of failing vehicles, however, the proportion of carbureted vehicles increased from 18%to 45%.

The most common items remaining defective after certified repair are shown in Table 27. This data indicates which repairs were required, but not completed, usually because the cost would exceed the applicable repair cost limit. For the first four years, carburetors and fuel injection problems were the most common required-but-not-done repairs. As the standards became stricter, catalytic converter replacement has become more necessary, but the cost has made this the most common required-but-not-done repair from program year 5 onwards. Defective engines have been the most consistent reason for cost waivers throughout the entire review period, because the cost of an engine rebuild is higher than any reasonable repair cost limit.

Table 27. Top 5 "Remaining Defective" Items by Program Year

Rank	Program Year							
	1	2	3	4	5	6	7	8
1	Carb. Injector	Carb. Injector	Carb. Injector	Carb. Injector	Catalytic Converter	Catalytic Converter	Catalytic Converter	Catalytic Converter
2	EGR	Engine	Engine	Catalytic Converter	Engine	Engine	Engine	Engine
3	Engine	EGR	Catalytic Converter	Engine	Carb. Injector	Carb. Injector	Carb. Injector	Carb. Injector
4	Catalytic Converter	Catalytic Converter	EGR	EGR	EGR	EGR	Power Valve	Power Valve
5	Air Injection	Air Injection	Air Injection	Air Injection	Power Valve	Power Valve	EGR	EGR

The availability of a large amount of repair data makes the AirCare program somewhat unique among I/M programs. However, practical experience with this data has shown it be less amenable to analysis than one might think. One of the biggest problems is that it is very difficult to isolate the “true” repairs from incidental ones. For example, it has been shown that spark plug and air filter replacement is a very common occurrence as part of an AirCare repair. However, it cannot be concluded that faulty spark plugs and dirty air filters are the primary cause of failure. In some cases, this may be true, but in most, it is likely that the repair shop chose to replace these items as a matter of course because they are relatively inexpensive and easy to replace. Occasionally, some of the repair actions have nothing to do with the failure. For example, a vehicle that fails for high NO_x emissions will not benefit from replacement of the spark plugs or air filter, but the repair facility may include these actions in the repair. If the true cause of the high NO_x emissions was a faulty EGR valve, this will also be indicated on the RDF. However, the presence of other, non-related items makes it difficult to associate specific repair actions with emission reductions.

8.5 COST OF REPAIRS

When completing the RDF, repair facilities are required to enter the actual cost of the repairs performed as well as the estimated cost of performing all necessary emission-related repairs. If the re-inspection fails the tailpipe standards, but the estimated cost for complete repairs would have exceeded the applicable repair cost limit, the vehicle receives a Conditional Pass (designated a “C” or cost waiver).

Table 28 shows the average cost of repairs reported on RDF’s in each of the first 8 program years.

Table 28. Average Cost of Repairs by Program Year

Program Year	Average Cost ($)
1	207
2	177
3	188
4	217
5	244
6	254
7	265
8	261

The mean cost of repairs is not a complete indicator of the cost of repairs. Looking at the most recent data, it can be seen that many repairs involve a total cost of less than $150. A distribution of repair cost is shown Figure 33.

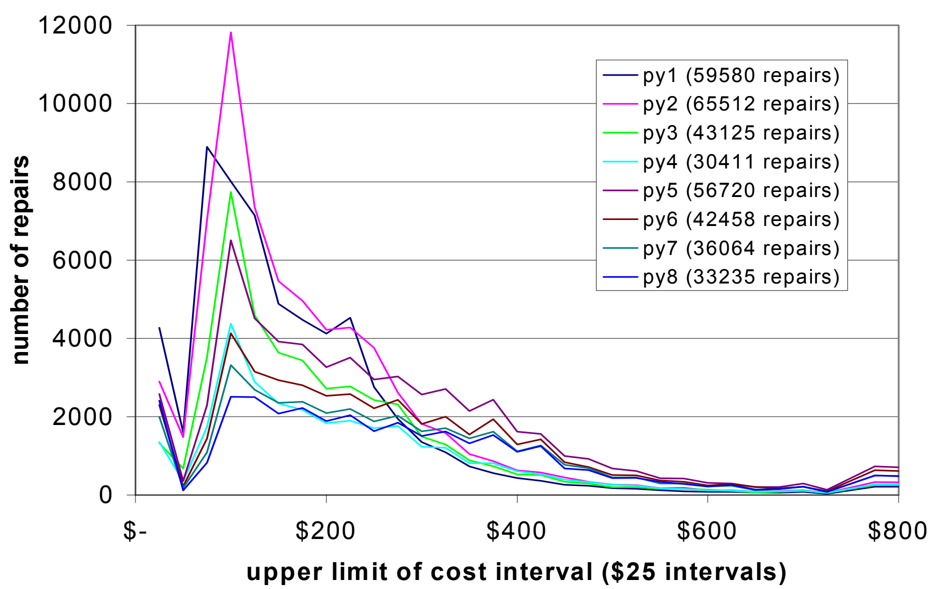


Figure 33. Repair Cost Distribution by Program Year

One possible conclusion from the above figure is that the cost of repairing vehicles to pass the AirCare inspection is not necessarily very high. This could be viewed as a positive factor, but repairs involving a total cost of less than $150 may include many which are not very effective, leaving the question of whether the vehicle was actually brought back to within its operating specifications.

8.6 CONDITIONAL PASSES

As described earlier, the notion of a Conditional Pass was created to provide some financial relief to owners of failing vehicles. The Conditional Pass would allow the vehicle to be re-licensed so repairs could be completed over a longer time period. The concept of waivers or hardship exemptions is applied in many other I/M programs. Usually, the issuance of a waiver requires that a minimum amount be spent attempting to bring the vehicle into compliance and that some kind of improvement in emissions be achieved. In some cases, a waiver may be granted in cases where the economic situation of the vehicle owner does not permit repairing the vehicle and denying the use of the vehicle would impose undue hardship. In the United States, the EPA requires that I/M programs maintain a waiver rate of less than 2%.

For the AirCare program, a different system was needed so that vehicle owners would be assured of at least a Conditional Pass provided that they took their vehicle to a certified AirCare facility for repairs. Therefore, there are two types of Conditional Passes – one where the vehicle cannot be repaired for less than the applicable repair cost limit, referred to as a "C" type of conditional pass and another where all the needed repairs were supposedly completed, but the vehicle was still not able to pass, referred to as a "Q" type of conditional pass. This second form of waiver does not exist in other I/M programs, but it was felt that there would be relatively few cases of the latter type.

Since the program began operating in 1992, there have been a total of 122,103 Conditional Passes issued out of 369,105 certified repairs. This means that 33.2% of certified repairs have been unsuccessful in making the vehicle pass re-inspection. Conversely, and more positively, 66.8% of the vehicles repaired by certified repair shops have passed on re-inspection. Figure 34 below shows the trend of numbers of Conditional Passes compared to total re-inspections.

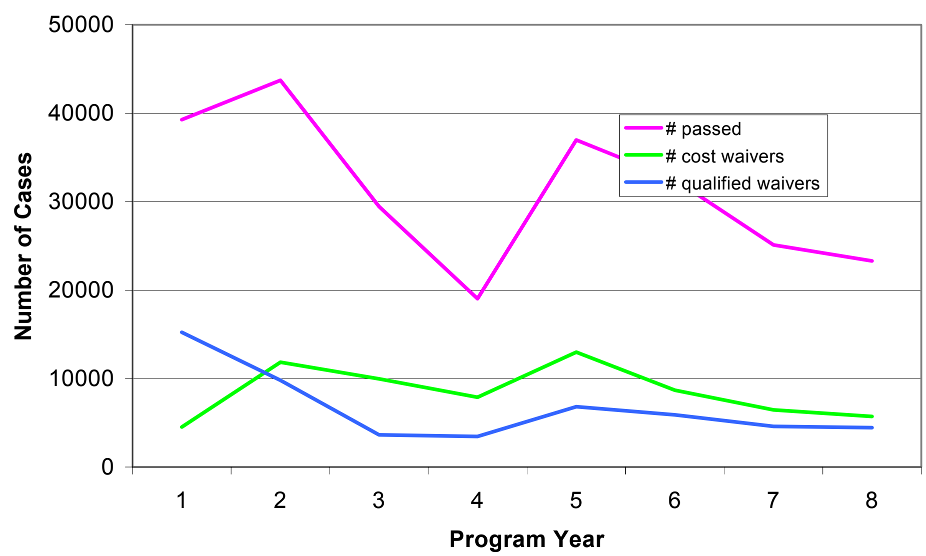


Figure 34. Results after Certified Repair by Program Year

There was a major change in the respective proportions of each type of waiver in December 1993. Up until this time there were many more Q waivers than C waivers. This appeared to indicate concerns respecting training of the repair industry, because Q waivers may indicate a lack of diagnostic ability of the repair technician. However, it was found that there was a lack of understanding regarding completion of the Repair Data Form. An article appeared in the Fall 1993 AirCare repair newsletter to clarify these procedures. The subsequent change in the relative proportions of C and Q waivers confirmed that the apparent high Q waiver rate problem was actually more of a clerical problem than a real diagnostic-ability problem.

The AirCare program does not impose a limit on the number of Conditional Passes that a vehicle can receive. This is in contrast to U.S. programs where a waiver is normally a one-time dispensation. From an environmental standpoint, the availability of multiple Conditional Passes provides the ability for dirty vehicles to avoid being fully repaired. The degree to which vehicles received multiple Conditional Passes was investigated and the results are shown in Table 29

It is clear from Table 29 that the vast majority of vehicles that receive a Conditional Pass do so only once. The number of vehicles with more than one Conditional Pass drops very quickly. Only one vehicle has received a Conditional Pass in every year that the AirCare program has been operating.

Table 29. Number of Conditional Passes vs. Number of Vehicles

Number of Conditional Passes	Number of Vehicles
1	79,353
2	13,732
3	3,151
4	722
5	205
6	37
7	12
8	1

The reasons for the high rate of waivers in the AirCare program relative to U.S. programs has never been clearly identified. One possibility is that the calculation of the waiver rate in U.S. programs is done differently than it is for the AirCare program. It is significant that in order to get a waiver in an U.S. program, it is necessary to show proof of repairs to a value exceeding the repair cost limit and to undergo a waiver application process that requires approval from the state government. This is a much more difficult process than the AirCare method. A Conditional Pass in the AirCare context is basically a default value that occurs when a vehicle is repaired at a certified repair facility and is unable to pass the re-inspection. It may be that the process in place for the AirCare program encourages vehicle owners to follow the process whereas in the United States, it may be easier to avoid the waiver process altogether. This gives the impression that the majority of vehicles that are failing the test are being repaired to pass, but is not an accurate reflection of the true situation.

Another concern that is often raised by the repair industry relates to the fact that many vehicle owners are keenly aware of the existence of the repair cost limit when they arrive at the repair shop and have already decided that they don't really want their vehicle fixed. The industry has maintained that the repair cost limits are too low to perform all of the necessary repairs and as a result, they are made to look bad unfairly. This would be a more valid position if there were a large number of "C" Conditional Passes relative to the number of "Q" Conditional Passes. However, the high proportion of "Q" Conditional Passes suggests that the problem is not always related to the repair cost limits being too low.

It is possible, however, that many of the "Q" results would have been "C" results had the diagnosis been more complete. To many repair shops, the difference between the two types of Conditional Passes makes no difference in their minds. The vehicle is allowed to be re-licensed either way. To the program administration, however, the difference is quite important.

8.7 REPAIR OBJECTIVES

The goal of an I/M program is to identify excess-emitting vehicles and to require that these vehicles receive corrective maintenance to return them to normal emission levels. This objective is not necessarily the goal of the vehicle owner or the repair shop. In order to ensure that repair shops would help to achieve the program's goals, a recommended procedure for diagnosing and repairing a vehicle to pass the AirCare inspection was developed. It is described as follows:

1. Examine vehicle to identify all out-of-specification parameters or defective components.

2. Prepare an estimate of the cost to fully correct all deficiencies related to excess emissions output.

3. Advise the vehicle owner and obtain authorisation to proceed. If the owner does not wish to spend more than the applicable repair cost limit, the repairs should be listed in the order of the greatest emissions benefit per dollar spent. Then, repairs should be performed in sequence until the point that the next repair would cause the total bill to exceed the repair cost limit (including taxes, shop supplies, etc.).

4. Any deficient items left unrepaired should be indicated as "Defective, but Not Repaired" on the RDF.

5. The owner should receive a complete explanation of all the deficient items found as a result of the diagnostic check and what should be corrected over the coming year. The owner should understand whether the vehicle is likely to pass or fail the re-inspection. He/she should also be made aware that the vehicle could pass the inspection and still require repairs to restore its full potential for low emissions.

The AirCare administration office provided all certified repair facilities with a poster outlining the procedures to be followed. However, the procedure is not always followed and vehicle owners do not necessarily understand their options when dealing with the fact that their vehicle has failed. Some vehicle owners are concerned about keeping their vehicle in top condition and will authorise any needed repairs. Others, however, wish to spend as little as possible on their vehicles and will only want the bare minimum. Repair shops may be tempted to satisfy this type of customer by attempting to “get the vehicle through”. This implies that minimal repairs or even out-of-specification parameter adjustments are used to enable the vehicle to pass. In other programs, this phenomenon has been referred to as “Clean for a Day”. Since the customer is only interested in obtaining a passed emission result, regardless of the method by which it is obtained, the shop perceives that they have done what is required of them and may even feel some satisfaction at being able to “trick” the test.

It is difficult to ascertain to what extent this type of behaviour occurs within the certified repair industry. Certainly, for most vehicles that return for re-inspection with a completed RDF, it is reasonable to assume that the procedure has been followed correctly. Certified shops may perform minimal repairs for some customers to save them money, but it is unlikely that they would complete the RDF in these cases. As said earlier, it is impossible to determine how many repairs are done by certified repair shops without completing a RDF.

The problem of insufficient repairs affects all I/M programs. Given that the pass/fail standards used for I/M are well above the range of normal performance, vehicles with defects are able to pass the test, even though their emissions greatly exceed design levels. AirCare program administrators have noted that the pubic tend to refer to any passed inspection as “passed with flying colours”, regardless of the margin between the vehicle’s measured emissions and the applicable standards. The administration office have attempted to combat this erroneous belief by supply a “Good Reading” on the inspection report. This value is statistically derived from actual program data and represents the best 25% of vehicles that have been inspected. The “Good Reading” alerts vehicle owners and repair technicians to the level of emissions performance that should be expected and serves to underscore the generous margin allowed between normal vehicle performance and the pass/fail limits. Discussion with some repair technicians has shown a level of scepticism concerning the “Good Readings” as to whether these levels are really achievable.

8.8 VARIABILITY

Another phenomenon that appears to affect all I/M programs is vehicle variability. Vehicles do not produce absolutely consistent levels of emissions at all times. Emission rates change according to engine operating mode. For this reason I/M tests are based on known operating regimes such as curb idle, 2500 rpm, or loaded steady state operation at a specified road speed. By controlling the mode of engine operation, it is possible to establish conditions under which a normal range of emissions output can be expected. Conversely, under the same conditions, it is possible to define threshold limits that should indicate the presence of defective components or improper parameter adjustments.

This is not always well understood by the public or even the repair industry. Although I/M program designers understand the principle of vehicle variability, the owners of vehicles that fail the test do not. For them, any means of obtaining a passing result is quite acceptable. In some cases, vehicle owners have discovered that repeated tests of their vehicle may result in obtaining a passing result, even with no repairs being performed. If this proves successful, the affected owner will often demand a refund for an improper test on the assumption that the measurement performed on the failing test was incorrect. This is usually attributed to incorrect readings from the exhaust gas analyzers or a procedural error in the performance of the test. As discussed earlier, the test is designed to minimise the effect of external variables. The greatest variable, unfortunately, is the vehicle itself.

Certified AirCare repair centres are required to have a gas analyzer that conforms to California Bureau of Automotive Repair (BAR) 1984 specifications. Essentially, this is a four gas (HC, CO, CO_2 and O_2) analyzer. Due to the fact that most repair shops do not have chassis dynamometers, the analyzer is typically used in two engine operating modes – idle and 2500 rpm. The specification has remained at BAR 84 because later designations such as BAR 97 require the use of a chassis dynamometer to measure NO_x emissions. The AirCare program administration has resisted imposing a requirement for repair shops to purchase dynamometers. Since the inspection centres already do the test and provide the needed information there is no reason to require that repair shops have the ability to duplicate the test. The AirCare inspection procedure has always incorporated an idle emissions measurement. On vehicles that fail the inspection, a 2500 rpm test would also be performed, providing a reference point for the repair industry. These two tests can be duplicated by the repair industry in their own environment. Unfortunately, some repair shops rely on emissions readings from their gas analyzer to second-guess the results of the AirCare inspection. Comments such as, “it passes on my machine” were not uncommon in the first few years of the program and are still heard occasionally even today. Fundamental disbelief in the accuracy of the inspection process is a major obstacle to program success. The fact that sometimes vehicles are able to pass re-inspection despite having no repairs performed tends to reinforce this false belief.

When the program first began, it was not uncommon to hear complaints about not being able to measure NO_x emissions at the repair shop. Although the administration office staff concedes that measurement of NO_x emissions is useful to confirm that repairs have been successful, it is not essential to the repair process. The existence of high NO_x emissions is indicative of a fault in the EGR system, excessive engine deposits or fuel management. A careful diagnosis of these systems will normally reveal the problem without the need to measure the NO_x emissions. Over time, the industry has become more comfortable with repairing NO_x problems but the complaint about not being able to measure NO_x is still heard occasionally.

8.9 Perceptions of Accuracy

One of the interesting discoveries resulting from the association of the program administration with the repair industry is that the separation of the inspection process from the repair industry can lead to the creation of an “us vs. them” attitude in some cases. The repair industry feel that having their work checked through the re-inspection process suggests that AirCare does not recognize their professional accreditation as automotive technicians. A poor attitude towards the program can translate into a negative experience for vehicle owners as well. Shops that are distrustful of the inspection centres and their staff have been known to advise that their vehicle should not have failed the test and that the test at the inspection centre was done wrong or the gas analyzers were inaccurate. Some repair shops have also expressed concern about the qualifications of the staff that perform the inspections. The contractor provides basic training to its staff in the performance of tests. It is not necessary or required that these staff be qualified automotive technicians, but some technicians discount the validity of AirCare tests because the staff are “not qualified”.

In a centralized test program, the repair industry is held accountable for the quality of work performed by requiring that vehicles be re-tested at an AirCare testing facility after being repaired. This is not popular with all repair shops, particularly those with low success rates at fixing emissions problems.

8.10 CONSUMER PROTECTION AND DISPUTE RESOLUTION

One of the associated responsibilities of providing a certified repair industry is that the public expects to be protected from unscrupulous repair shops and to have their complaints dealt with on their behalf by program administrators.

Given the thousands of repairs performed in response to failed AirCare inspections, there have been relatively few complaints received. When a customer calls with a complaint, the first action is to ask whether they have advised the repair facility of the problem. Business owners have a vested interest in ensuring that their customers are satisfied and will normally take the necessary action to resolve their concerns. In most cases, getting the two parties to talk to one another about the problem results in a solution and nothing further is heard about the matter.

If, however, the vehicle owner and the repair facility fail to resolve the issue, the AirCare program administration may become involved. Disputes typically reach this level when the customer's vehicle has received a Conditional Pass and there is a belief on the part of the owner that the repairs for which he/she paid were either incorrect or unnecessary. The two parties will often be at loggerheads – one insisting that the work done was ineffectual and therefore not worth the dollars spent and the other maintaining that the work performed was needed, even though the vehicle was not able to pass the re-inspection. In order to break the deadlock, it is necessary to examine the vehicle to determine why it is unable to pass the test and what would be needed to bring the vehicle into compliance. To initiate this process, the vehicle owner must agree to supply their vehicle to the administration office for a detailed examination by staff technicians.

The investigation usually begins with a full FTP test of the vehicle in question. This is an important step, because it establishes the vehicle's emissions output relative to the standards it was designed to meet. If the vehicle fails the FTP test by exhibiting emissions above the standards to which it was designed, it can be concluded that some sort of emission related defect persists in the vehicle, despite the repair efforts already undertaken.

Once the FTP test has been completed, an AirCare staff member who is a qualified automotive technician will perform a thorough diagnosis of the engine and emission control system. This diagnostic procedure is identical to the one that should be used by any certified shop when diagnosing an emissions problem. Any deficiencies identified during the diagnostic check are recorded on a worksheet. Printouts of readings from diagnostic equipment are also produced as evidence. After completing the diagnosis, a verbal explanation is given to the vehicle owner, supplemented by a complete written description sent by mail to both the repair shop and the vehicle owner within 5 working days of the examination.

If the analysis by AirCare staff indicates problems that were overlooked by the certified repair shop, it is expected that these repairs will be completed. Similarly, if there was work performed by the certified repair shop that did not appear to be justified, it will be recommended that some sort of restitution be made. Usually, the cost of the needed work is reduced by the amount of any compensatory amount. In most cases, the vehicle ends up passing the test and the situation is resolved. At the very least, the customer is made aware of the reason that their vehicle did not pass the test and what work needs to be done.

Since the program began operating in 1992, more than 200 investigations have been carried out in the above manner. Most end happily. Occasionally, however, the discoveries made during the examination of the vehicle by AirCare staff lead to concerns over the competency of the technician that did the diagnosis and work that led to the complaint.

In these cases, a Technician Competency Hearing may be held. The technician will be summoned to appear before a panel at the AirCare administration office. The technician will be advised by mail and provided with the particulars of the complaint and the highlights of the findings of the investigation. During the interview, the evidence will be presented to the technician and he/she will be able to ask questions for clarification. The panel members will ask the technician questions about the case in order to assess the interviewee's knowledge of emissions diagnostic procedures. Discussion usually centres on why the technician chose the course of action that they did and what tests they carried out in order to confirm their diagnosis. After the interview, the panel deliberates in a separate room. The panel must determine if the technician has acted in such a way that would justify recommending that their certification be suspended. In most cases, the panel concludes that the problem is attributable to a lack of knowledge and experience that should be correctable through training. Therefore, the panel's typical recommendation to the technician is that they take available training as a condition of remaining certified. Technicians tend to accept the panel's advice and enroll voluntarily in training courses. In one case, a technician went from being the subject of a competency interview to receiving a Quality Repair Award as an exemplary performer.

9.0 CALCULATION OF EMISSION BENEFITS

There is no standard methodology for evaluating the effectiveness of inspection and maintenance programs, but there is basic agreement as to how program benefits should be defined. The benefits of an I/M program are equal to the difference in total emissions from the in-use vehicle fleet with an I/M program in place vs. what the total would be if there were no I/M program. The most difficult part of this exercise is determining what the non-I/M scenario would be. In order to do this, it is necessary to have a control group, something that is not usually available.

The United States Environmental Protection Agency has recently released two draft guideline reports on the use of remote sensing, and on the use of in-program data, for the evaluation of I/M programs [9] [10]. Remote sensing allows for the collection of a large sample of emission data on vehicles operating in a region, whether there is an I/M program in place or not. In an area where an I/M program is in place, measurements taken by a remote sensing device provide a secondary source of information about vehicles that have passed through the inspection process. Also, the remote sensing measurements tend to capture results for vehicles that may be from outside the I/M program area and are therefore analogous to a control group. Evaluation of AirCare program benefits has been based on in-program data, and includes many approaches discussed in the EPA guideline.

9.1 PROGRAM EVALUATION METHODOLOGIES FOR AIRCARE

Program analyses performed by AirCare staff prior to this review have utilised a methodology that concentrates on the direct benefits of the program. By comparing pre-repair and post-repair emissions for vehicles that fail the test, the emission reduction attributable to the program can be evaluated for each vehicle. This method also assumed some carry-over benefits from previous years for vehicles that continued to pass after being repaired. Although there are many factors governing the emissions characteristics of the in-use vehicle fleet, it is reasonable to assume that the impact of an I/M program is most directly related to the process of identifying vehicles with excess exhaust emissions and requiring that they be repaired. Repair or replacement of systems or components that reduce emissions produces an emissions benefit that can last for many years.

Not unexpectedly, the calculation of emission benefits corresponding to the identification and repair of an excess-emitting vehicle is a complex process. One of the complicating factors is that the emissions capabilities of the vehicles going through the program depend on the vehicle type and year of manufacture. Due to the fact that new vehicles are required to meet federal emission standards at the end of the assembly line, changes in federal standards have resulted in advances in vehicle technology. The effect of new vehicle technology can be seen in the results obtained from AirCare testing.

9.2 COMPARISON OF MEDIAN ASM EMISSION READINGS

A simple indication of program effectiveness and the progress made as a result of new vehicle emission standards can be obtained by plotting median values for tailpipe emissions of HC, CO and NO_x from successive program years. Figure 35, Figure 36 and Figure 37 show these data for passenger cars for HC, CO and NO_x emissions.

The data show that there are effectively two fleets in the AirCare program area, one consisting of 1988 and later model year vehicles and one consisting of 1987 and older model year vehicles. The change in 1988 was related to Canada adopting U.S. EPA emission standards for new light-duty vehicles. All three figures show a step change in median emission results for all three pollutants in that year. Median ASM HC readings tend to be below 20 ppm for the 1988 and later group while the older group ranges from 60 ppm to 100 ppm.

For CO emissions, the step change occurs in 1988, but not to the same degree as for HC emissions. There is another step evident between the 1974 and 1975 model years. This can be attributed to the introduction of oxidation catalytic converters on most vehicles effective with the 1975 model year.

NO_x emissions exhibit a dramatic change between 1987 and 1988 model years. This is due to the switch to three-way catalytic converters from oxidation catalytic converters. Oxidation converters have little effect on NO_x emissions. Vehicles of the 1995 model year and later have the lowest NO_x due to a change in federal emission standards that required a phased-in reduction of 60% in the new-vehicle standard. The newest passenger cars have median NO_x emissions of less than 100 ppm while the oldest three-way catalyst vehicles tend to perform at about 300 ppm. The median NO_x performance for oxidation catalyst vehicles ranges from 800 to 1000 ppm.

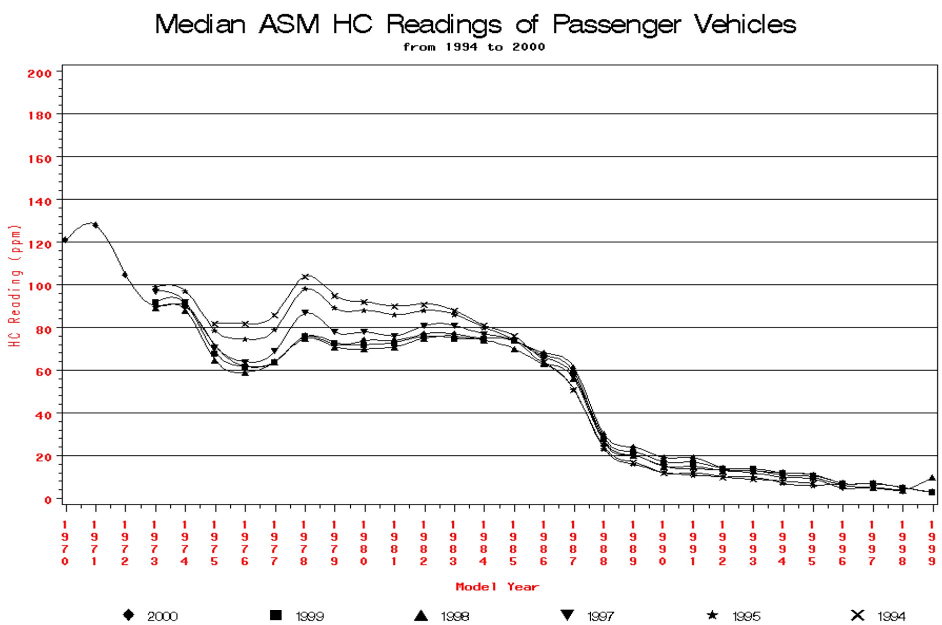


Figure 35. Median ASM HC for Passenger Vehicles by Calendar Year

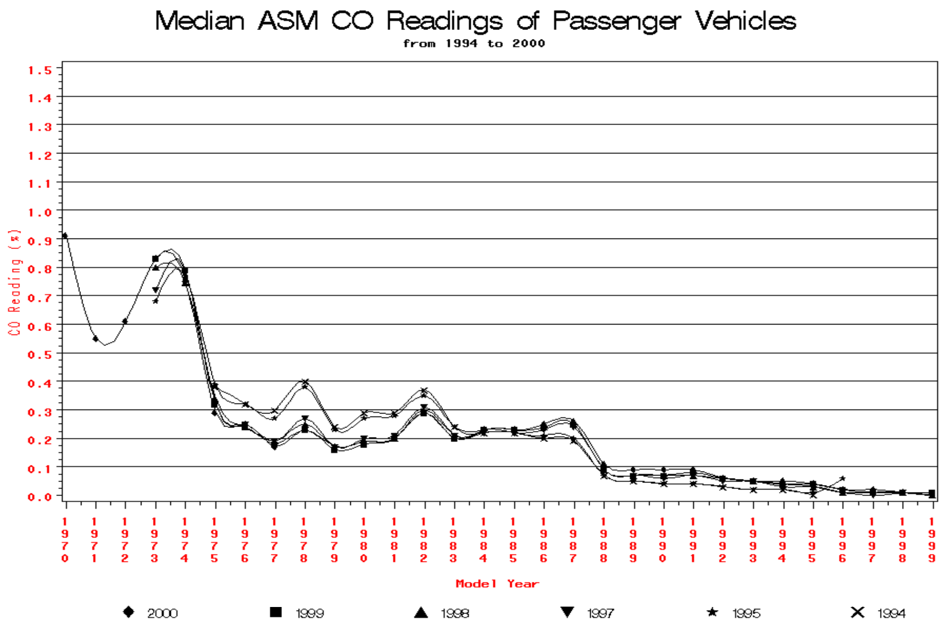


Figure 36. Median ASM CO for Passenger Vehicles by Calendar Year

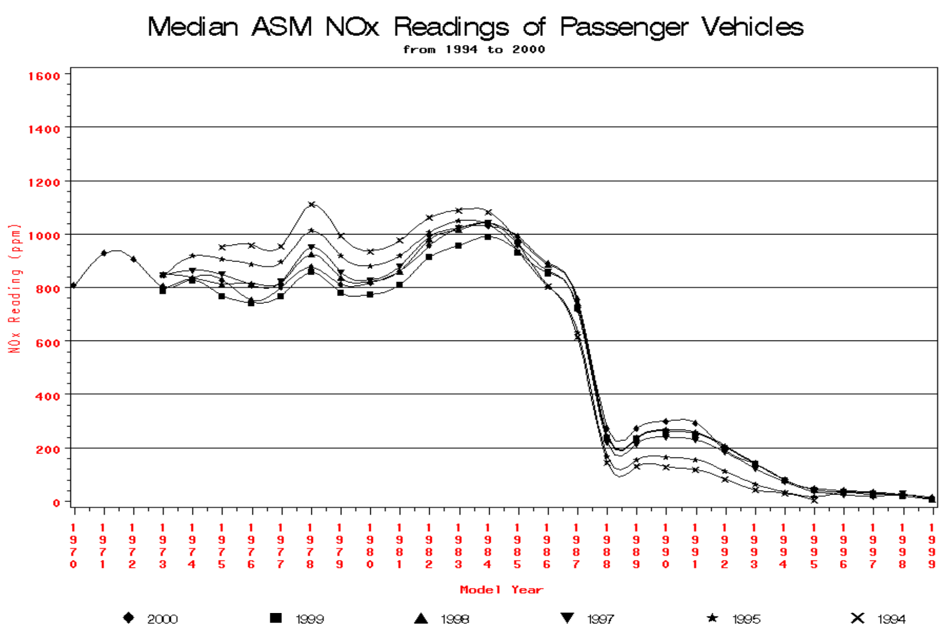


Figure 37. Median ASM NO_x for Passenger Vehicles by Calendar Year

Figure 38, Figure 39 and Figure 40 show similar data for light-duty trucks. The indicated trends and median emission levels are comparable to passenger cars.

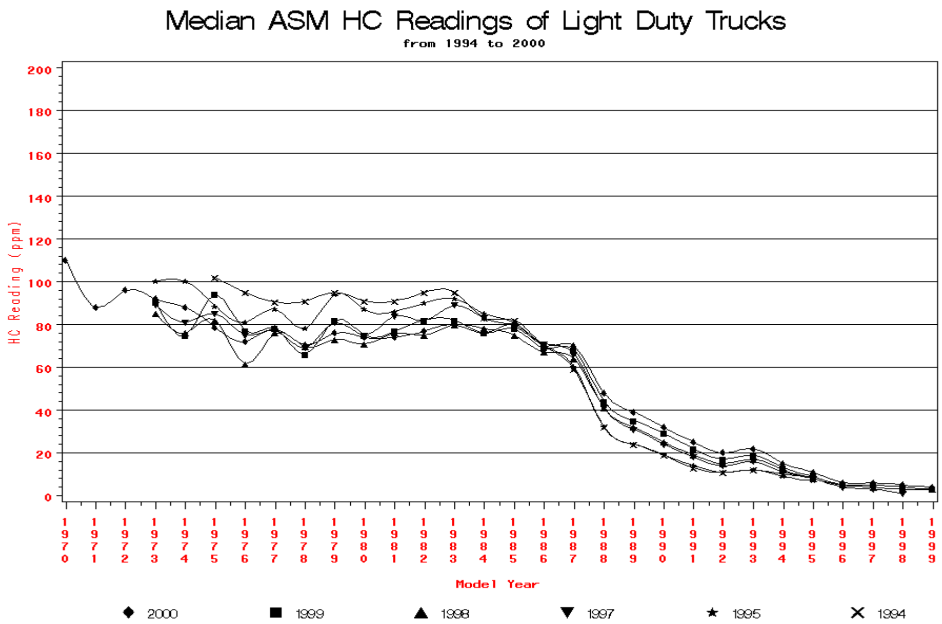


Figure 38. Median ASM HC for Light Duty Trucks by Calendar Year

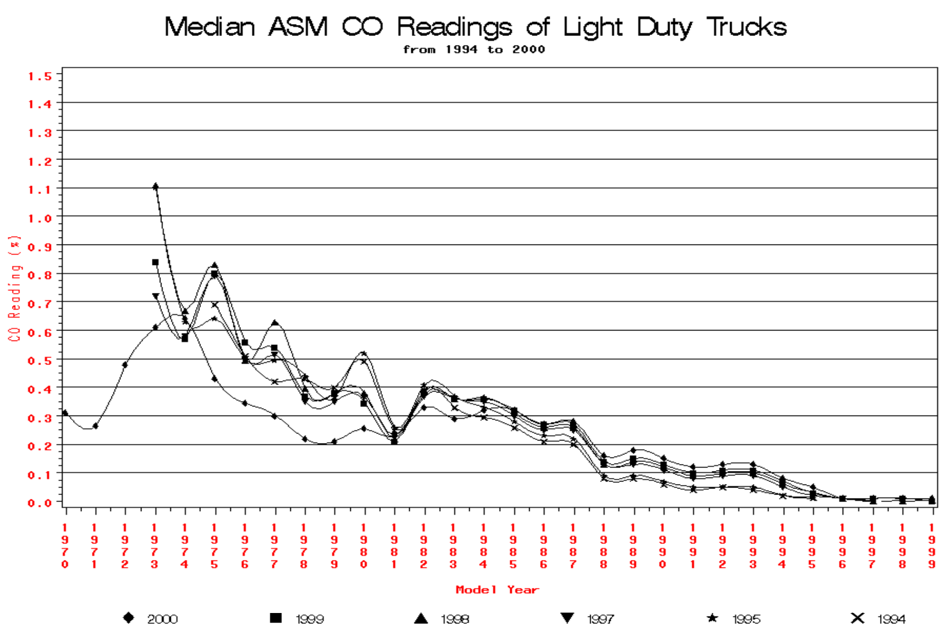


Figure 39. Median ASM CO for Light Duty Trucks by Calendar Year

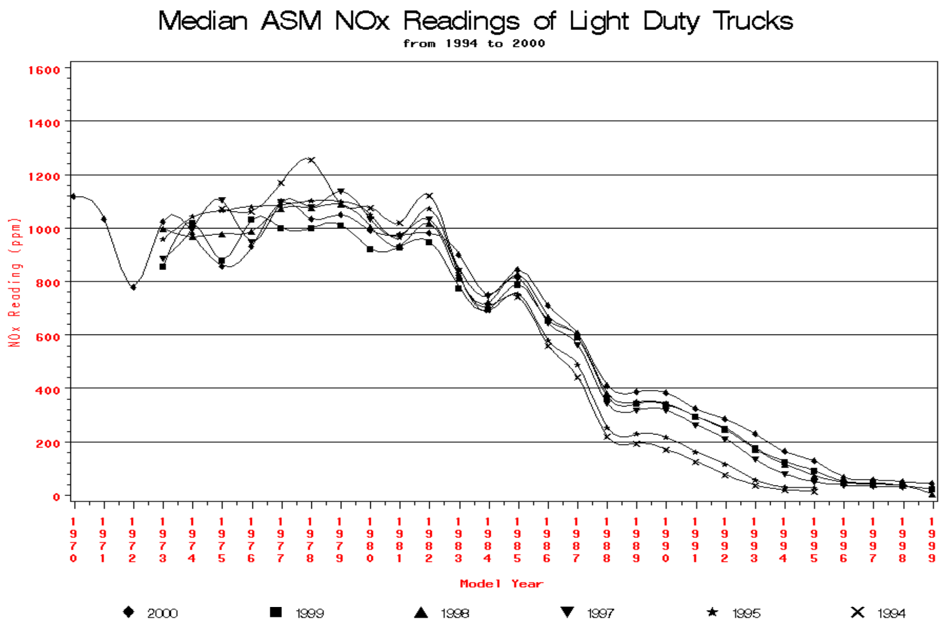


Figure 40. Median ASM NO_x for Light Duty Trucks by Calendar Year

Figure 41, Figure 42 and Figure 43 show the data for heavy-duty trucks. This vehicle type did not follow the same schedule of changes in new vehicle standards, resulting in a different-shaped curve. Substantial reductions are evident between 1995 and 1996 for HC, CO and NO_x. It is interesting to note that NO_x emissions increased between the 1987 and 1995 model years. Heavy-duty vehicles are typically subject to an emissions test that involves testing only the engine on a dynamometer. The correlation between the ASM test and this test procedure is not well understood. Presumably, engineering changes to engines in the early 1990's produced increased NO_x emissions on an ASM test. A technology change appears to have taken place in the 1996 model year that dramatically reduced ASM NO_x.

The median emission results for Idle tests were plotted as well for both HC and CO and for all three vehicle types, but are not included in this report. Technology shifts are not as apparent in the idle results but it is obvious that newer technology vehicles tend to exhibit much lower tailpipe HC and CO values than older vehicles. The main reason for this is the change from carburetors to fuel injection. Fuel injection systems removed the ability to adjust the idle mixture and idle speed, two factors that greatly influence the idle mode emission results.

Another interesting feature of these graphs is that there is a change in the median values from year-to-year. Although it is difficult to read from the charts themselves, there are opposite trends evident in the newer vehicle group as opposed to the older vehicles. On the newer vehicle end, the median emission results are increasing each year, while among the older vehicles they are decreasing. The reasons for this are not obvious, however, it could be postulated that the moderate increase evident for the newest vehicles in the fleet is an indicator of normal vehicle degradation. After all, this fleet segment has a very low incidence of failure in AirCare testing and would not be expected to have experienced much impact from the I/M program. For the older vehicles, the failure rate is much higher, suggesting that the program may be responsible for the downward trend in median emissions.

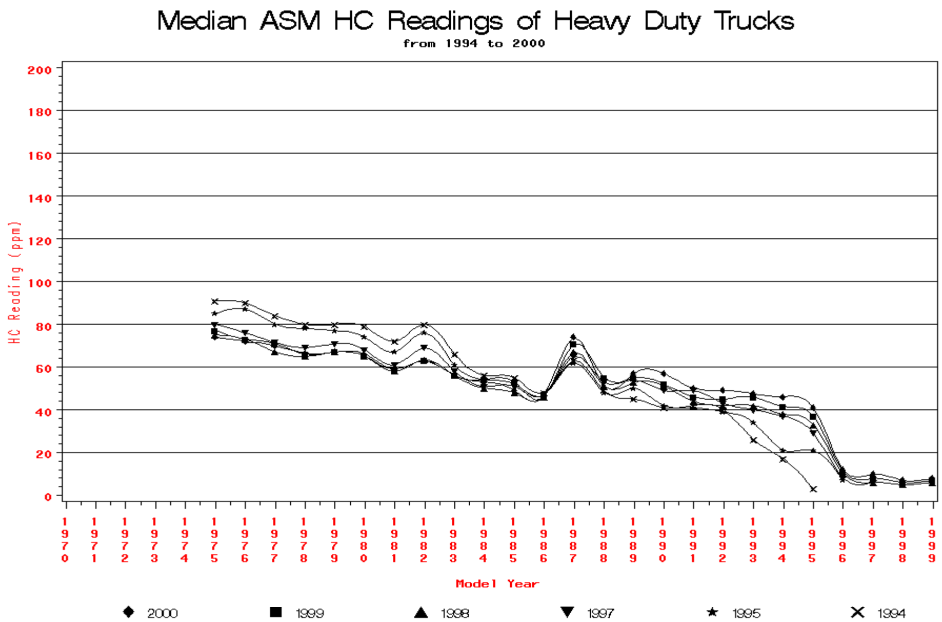


Figure 41. Median ASM HC for Heavy Duty Trucks by Calendar Year

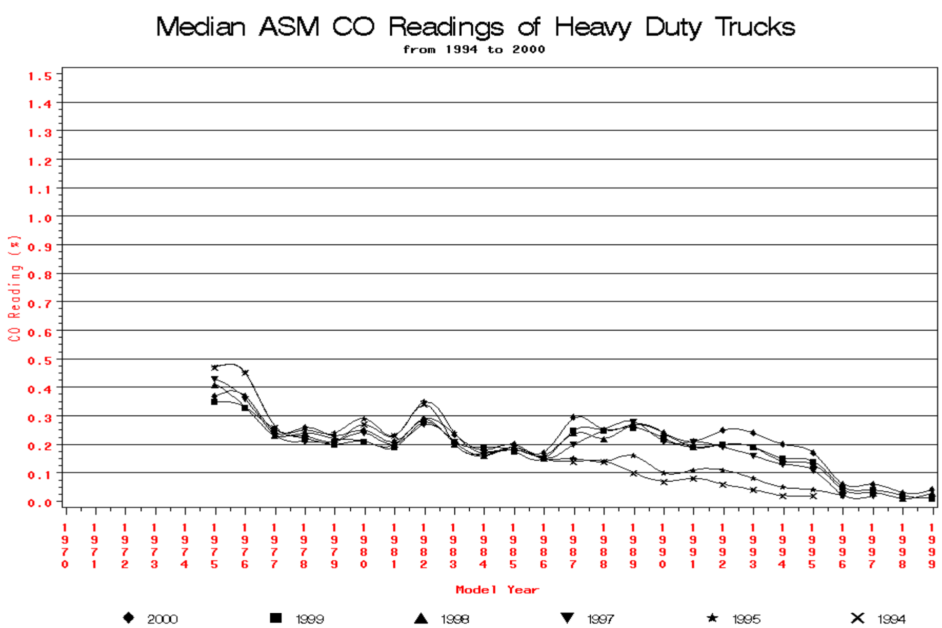


Figure 42. Median CO for Heavy Duty Trucks by Calendar Year

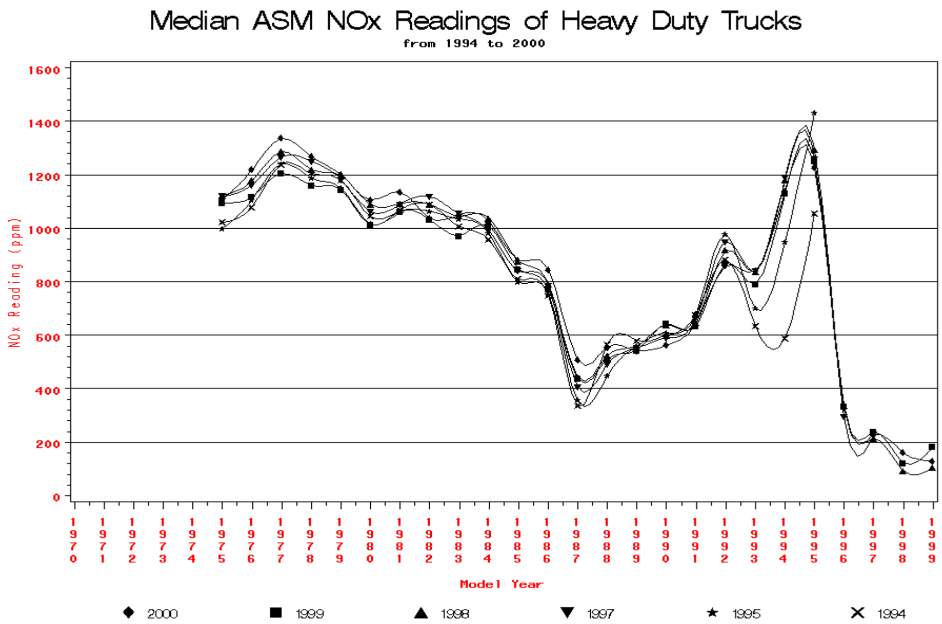


Figure 43. Median ASM NO_x for Heavy Duty Trucks by Calendar Year

9.3 EMISSIONS AND REDUCTIONS IN ASM SPACE AND IDLE SPACE

Where no mass-emission data is available, one alternative way of evaluating an IM programs effectiveness is to examine the inspection readings for vehicles which pass, those that fail, and those that have been repaired. This approach has not been used for AirCare evaluations previously, for two reasons:

1. It has not been necessary because mass-emission data has been available.

2. ASM and idle readings have not been well correlated to mass-emissions and therefore can not give any direct indication of program effectiveness in terms of inventory reductions.

This report does include an analysis based on ASM and idle readings to illustrate how they have changed, and to derive a measure of the comparative effectiveness of certified repairs and of non-certified repairs. The inclusion of this form of data allows comparison of this program with other programs that assess their effectiveness based on ASM and/or idle readings.

9.3.1 Mean ASM and idle readings for vehicles as received

Table 30 shows the mean readings each program year for all initial inspections; the mean readings for vehicles which passed at their first attempt in the year; and the mean readings of the first failed inspections for vehicles which failed. Three patterns stand out from this table. The overall trend for all readings is downward. This trend is not as marked for vehicles which fail as for those which pass. The passing vehicles have always comprised between 83% and 90% of the fleet, and therefore their strong downwards trend contributes heavily to the trend for all initial inspections.

Table 30. ASM and Idle Space Mean Emissions - As Received

	All Initial Inspections					Vehicles Passed First Time					Vehicle's First Fail				
	Idle		ASM			Idle		ASM			Idle		ASM		
Program Year	HC ppm	CO %	HC ppm	CO %	NOx ppm	HC ppm	CO %	HC ppm	CO %	NOx ppm	HC ppm	CO %	HC ppm	CO %	NOx ppm
1	180	1.64	92	0.68	1011	94	0.90	62	0.34	834	443	4.09	184	1.73	1560
2	125	0.96	70	0.48	719	67	0.52	49	0.22	603	444	3.50	186	1.88	1324
3	109	0.78	63	0.41	631	60	0.44	44	0.19	538	449	3.26	192	1.91	1211
4	99	0.63	58	0.34	588	46	0.27	36	0.11	482	361	2.60	163	1.47	1067
5	98	0.55	56	0.33	575	44	0.23	34	0.11	467	380	2.38	164	1.46	1080
6	82	0.45	48	0.28	536	39	0.20	31	0.09	439	354	2.26	153	1.48	1087
7	73	0.38	44	0.23	478	36	0.17	29	0.07	396	356	2.19	157	1.49	1042
8	69	0.35	42	0.22	468	35	0.16	28	0.07	388	340	2.04	151	1.45	1038

The decrease in the mean readings for passing vehicles is mostly a reflection of the changing fleet, which in year 8 (1999-2000) contained almost all Tier 0 and Tier 1 vehicles, whereas in year 1 (1992-1993) the inspected fleet was predominantly pre-Tier 0. The decrease in mean readings for failing vehicles shows that although newer control technology does fail, the resulting emission readings are not as high as when older technology fails.

9.3.2 ASM and Idle space reductions as a result of certified repairs

Table 31 shows the mean readings before repair; the mean readings after repair; the mean of the non-dimensionalised reductions; and a factor defined as V1 which is an indicator of the overall non-dimensionalised reductions in ASM and idle space.

The mean readings of failed vehicles before and after repair show the same downwards trend with time as observed in the previous table. However, comparison of Table 31 results with Table 30 shows that the initial failing HC and CO readings for vehicles which receive certified repairs are typically slightly lower than the average first fail. The before-certified repair mean NO_x readings were slightly higher up to year 4, and then very slightly lower from year 5 onwards. This indicates that the vehicles receiving certified repairs are not a complete cross section of all the failing vehicles, and suggests that some of the worst HC and CO failures are not being taken in to certified repair centres.

The mean after-repair readings are consistently lower than the mean before-repair readings. It is important to realize that about one third of all vehicles receiving certified repairs go on to receive a conditional pass, or waiver. This means that at least one of their readings is higher than the standard allowed, and thus the existence of the conditional pass route raises the average emission readings after certified repair. The route has been provided for vehicles which would be ‘too expensive’ to repair, and so certified repairs may include a higher proportion of the worst vehicles than non-certified repairs. This will be discussed further in the next section.

The difference of the means could be used as a direct indicator of reductions achieved, but we have considered it more valid to use a measure based on the mean of the non-dimensionalised differences. For example, one vehicle's idle HC could be reduced from 400 to 300 ppm, and a second vehicle's readings reduced from 200 to 100 ppm. In both cases, the change is 100 ppm, but for the first vehicle, this is 25% of the initial reading, whereas for the second, it is 50% of the initial reading. We would take the mean reduction as 37.5%. If the difference in means was calculated, it would be based on an initial mean reading of 300 ppm, and final mean reading of 200 ppm, to give a difference of 100 ppm, or 33.3% of the initial mean.

Table 31. ASM and Idle Space Mean Emissions Reduction by Certified Repairs

	Mean Readings before Repair					Mean Reading after Repair					Mean non-dim. Reductions					
	Idle		ASM			Idle		ASM			Idle		ASM			
Program Year	HC ppm	CO %	HC ppm	CO %	NOx ppm	HC ppm	CO %	HC ppm	CO %	NOx ppm	HC	CO	HC	CO	NOx	V1
1	421	4.10	173	1.70	162	215	1.73	126	1.20	129	0.42	0.50	0.20	0.25	0.26	0.34
2	420	3.45	178	1.93	136	205	1.51	124	1.22	108	0.44	0.48	0.24	0.29	0.22	0.35
3	426	3.18	185	1.99	122	199	1.37	121	1.21	998	0.46	0.48	0.27	0.31	0.19	0.36
4	341	2.48	160	1.50	105	164	0.97	106	0.89	884	0.45	0.48	0.27	0.33	0.17	0.35
5	361	2.28	160	1.50	106	156	0.86	98	0.82	847	0.49	0.47	0.31	0.35	0.19	0.37
6	335	2.18	151	1.53	106	136	0.77	86	0.76	811	0.51	0.48	0.34	0.38	0.20	0.39
7	336	2.09	154	1.55	102	134	0.71	85	0.71	760	0.51	0.48	0.35	0.40	0.21	0.40
8	319	1.97	148	1.47	103	124	0.65	79	0.64	741	0.53	0.47	0.38	0.41	0.22	0.41

The approach we have taken is the same as used to derive one of the factors, V1, which comprise the Repair Effectiveness Index, REI, which is explained in another section of this report. For every individual repair, the amount that the readings are reduced after repair is compared to the initial readings; for instance a non-dimensionalised reduction = 0.5 would indicate that the final reading was half of the initial, and a value = 0 would indicate no change. The means of these reductions for all vehicles are shown at the right side of Table 31. The rightmost column, V1, is the average across all five combinations of pollutant/test mode. These six non-dimensionalised columns show how much the readings have been improved by certified repairs. The degree of improvement has generally increased over the eight years shown. Reductions in idle readings have been typically greater than those in ASM readings, and also have not changed as much over time. ASM reductions have improved substantially for HC and CO, but have remained about level for NO_x. It must be emphasized that these comments apply to the non-dimensionalised reductions, which are applied to before-repair readings which have themselves been reduced, so, as has already been observed, the after repair readings are lower in later years than early in the program.

9.3.3 ASM and Idle space reductions as a result of non-certified repairs

These repairs were identified by finding vehicles which initially failed inspection, but within 6 months returned to pass, without there being any record of a certified repair. Thus there is no data on what was done to these vehicles to transform their initial failing inspection result to a passing result. It is usually assumed that they received some sort of repair, either at a non-certified repair shop or by the owner. However, at one extreme, they also include vehicles which simply tried the test again, and managed to pass; and at the other extreme they include a number of repairs which were done at certified repair shops but for various reasons did not have repair information submitted. Table 33 shows ASM and Idle space data for these non-certified repairs in an exactly similar manner as previously described for the certified repairs in Table 31.

By definition, all of the vehicles considered in this group eventually passed inspection, because there is no possibility of conditional pass, or waiver. Those which continued to fail would either be removed from use, or move over to the certified repair route. This can explain the following three observations:

Mean readings before repair are lower than for certified repairs. The unsuccessful, and presumably more difficult repairs, with higher initial readings, do not form part of the non-certified repair group, whereas they are included in the certified repair group.

Table 32. ASM and Idle Space Mean Emission Reduction by Non-Certified Repairs

	Mean Readings before Repair					Mean Reading after Repair					Mean non-dim. Reductions					
	Idle		ASM			Idle		ASM			Idle		ASM			
Program Year	HC ppm	CO %	HC ppm	CO %	NOx ppm	HC ppm	CO %	HC ppm	CO %	NOx ppm	HC ppm	CO %	HC	CO	NOx	V1
1	392	3.93	157	1.43	1605	151	1.51	94	0.65	1176	0.49	0.53	0.31	0.35	0.32	0.42
2	395	3.33	162	1.62	1342	138	1.27	87	0.60	1013	0.53	0.52	0.36	0.40	0.25	0.44
3	401	3.13	165	1.65	1230	131	1.13	82	0.57	964	0.56	0.53	0.39	0.41	0.22	0.44
4	315	2.41	140	1.25	1051	99	0.71	67	0.36	849	0.56	0.53	0.40	0.46	0.19	0.44
5	327	2.20	141	1.26	1062	96	0.67	64	0.36	826	0.58	0.51	0.44	0.46	0.21	0.45
6	307	2.10	133	1.31	1072	90	0.62	60	0.35	792	0.57	0.50	0.43	0.47	0.23	0.46
7	310	2.02	137	1.31	1026	86	0.57	58	0.34	748	0.59	0.51	0.45	0.48	0.24	0.47
8	299	1.91	134	1.29	1026	80	0.50	54	0.30	707	0.60	0.51	0.47	0.49	0.25	0.48

Mean readings after repair are significantly lower than for certified repairs. Only successful repairs, which finally pass inspection are included, and so they naturally have lower readings than vehicles going the conditional pass route via certified repair. Non-dimensionalised reductions are greater than for certified repairs. Again, this is because only vehicles which eventually pass are included.

9.3.4 Change in ASM and Idle Readings

The previous section presented average values for ASM and idle readings and the amount of reduction achieved in these readings. Of course, these are only averages; an individual vehicle readings may show different amounts of decrease, or some increase. In this section we consider the range of values for how much change has been observed, and how many vehicles have each amount of change.

Figure 44 to Figure 51 show the distribution of change-in-readings for each program year. Each plot considers all the vehicles which finally satisfied program requirements, after having initially failed in that year. Thus, they include vehicles with non-certified repairs as well as certified, and vehicles which received conditional passes as well as those which were repaired to pass. The changes in each of the five readings are shown separately. The vertical scales are plotted from –100% to +100%. At the lower end, -100% would represent a zero reading after repair, and is therefore an absolute limit. There is no theoretical upper limit to the scale, because it is possible for the final reading to be many times the initial, but for the plots the scale has only been taken to +100% which indicates an after-repair reading of double the initial reading. A simple approach to these plots is first to consider how many repaired vehicles show decreased readings, compared to how many show increased readings. There are also many which show appreciable no change. For the purposes of these plots, this included cases where both initial and final readings were well below the allowable maxima are included.

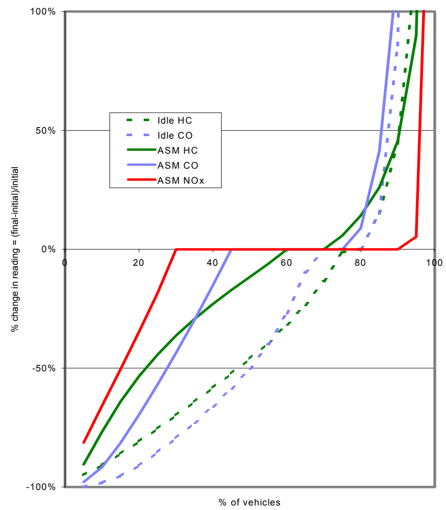


Figure 44. Change in readings from failed inspection to final inspection for vehicles satisfying program requirements in Program Year 1

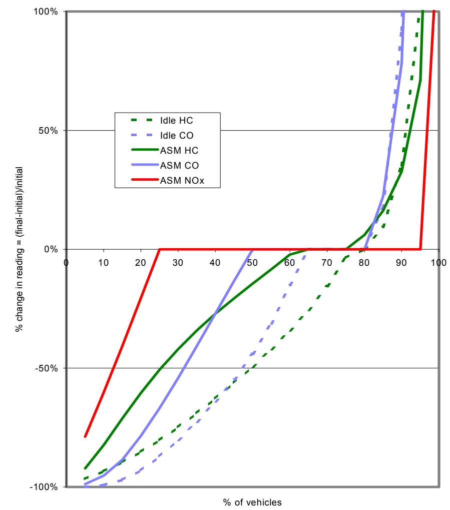


Figure 45. Change in readings from failed inspection to final inspection for vehicles satisfying program requirements in Program Year 2

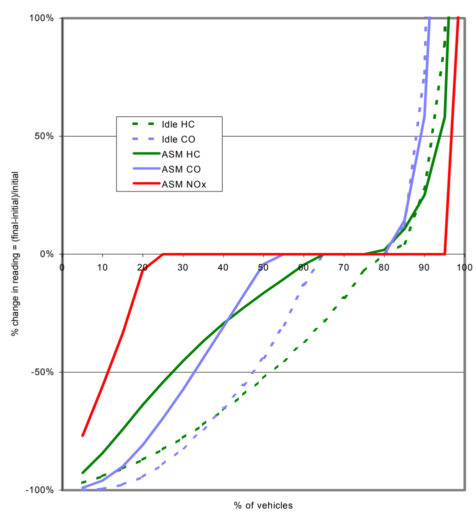


Figure 46. Change in readings from failed inspection to final inspection for vehicles satisfying program requirements in Program Year 3

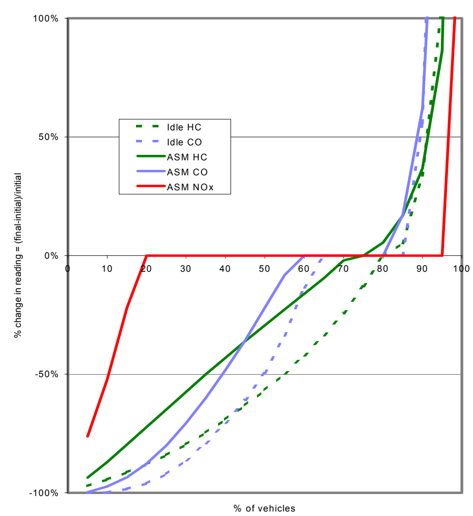


Figure 47. Change in readings from failed inspection to final inspection for vehicles satisfying program requirements in Program Year 4

In program year 1 (Figure 44) the idle HC and idle CO lines show that 65% and 70% respectively of repairs achieved a reduced reading, with 20% showing an increased reading after repair. For ASM HC 60% were reduced, and 30% increased; ASM CO; 45% reduced and

25% increased; and ASM NO_x; 30% reduced and 10% increased. For other years, (Figure 45 to Figure 51) the corresponding percentages vary somewhat, but the overall picture is similar, and the number of vehicles showing reduced readings is consistently much greater than the number showing increased readings.

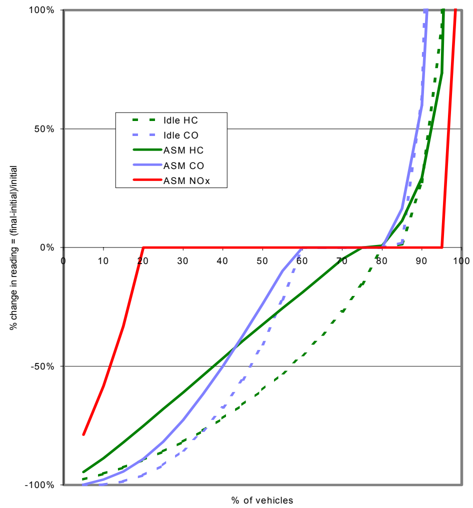


Figure 48. Change in readings from failed inspection to final inspection for vehicles satisfying program requirements in Program Year 5

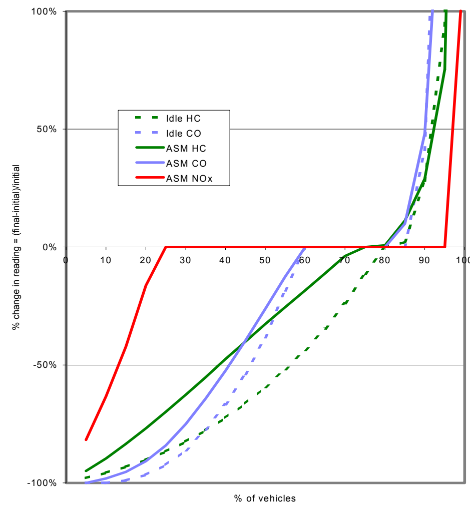


Figure 49. Change in readings from failed inspection to final inspection for vehicles satisfying program requirements in Program Year 6

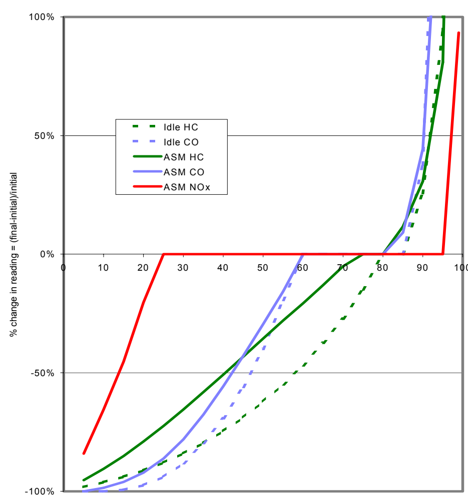


Figure 50. Change in readings from failed inspection to final inspection for vehicles satisfying program requirements in Program Year 7

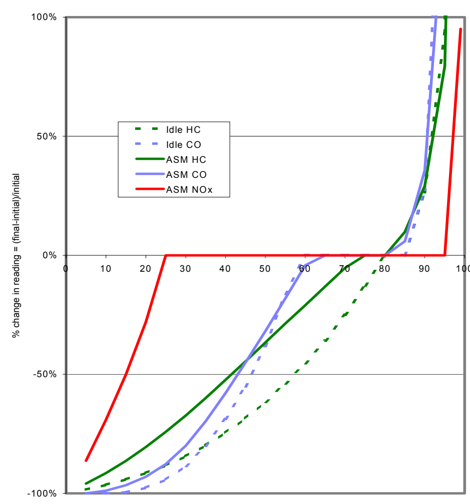


Figure 51. Change in readings from failed inspection to final inspection for vehicles satisfying program requirements in Program Year 8

Readings which increase after repair are clearly a cause for concern. In most cases the increase is completely accommodated within the allowable maximum. For example, both readings are good enough to pass inspection, but the after-repair reading is higher than the initial reading. The associated repair would have been aimed at reducing the reading which caused inspection failure, and any change in one of the other readings would normally be acceptable so long as it stayed with reasonable limits. This analysis could be taken further, to examine the changes as a function of which readings initially failed, or to isolate particular groups of vehicles with identifiable patterns of increase or decrease caused by different types of repair. This exercise could result in an understanding of repair effectiveness which could be fed back into improving subsequent repairs, by way of advising which repairs have already proven effective. It is not included in this report.

The most evident conclusions to be drawn from the graphs presented, include the following:

Most repairs show a reduction in HC and in CO readings, which is consistent with HC and CO failure modes being most common overall.

Only about 25% to 30% of repairs show NO_x reductions, and this is consistent with the overall incidence of failure for NO_x.

There is a definite percentage of repairs which show one or more increased readings.

Between program years 1 and 8, there has been a change in the relative effectiveness of ASM and idle HC and CO repairs. For year 1 (Figure 44) idle HC and CO lines are very close, and much lower than the lines for ASM HC and CO, which are also very close. This suggests that repairs were most successful at reducing idle emissions, whether the failure was for HC or for CO. For year 8 (Figure 51) the idle HC and ASM HC lines are very close, and the idle CO and ASM CO lines are very close. It appears that the pollutant type (HC or CO) is now becoming more important in determining the amount of possible reduction, than whether the failure was in idle mode or ASM.

9.3.5 Program effectiveness evaluation using ASM and Idle space data

If no mass emission testing had been performed on vehicles in the program area, and if there were no other similar data available from other sources, it would be necessary to attempt program evaluation entirely from ASM and idle inspection readings. A simple approach would be to compare the fleet mean readings in each year with the mean readings at the start of the program. For the AirCare program, year 2 was the first full year, because most of the newer vehicles were exempted during year 1. Comparing year 2 to year 8 (from Table 30) gives the following:

Mean idle HC reduced by 44.8%

Mean idle CO reduced by 63.5%

Mean ASM HC reduced by 40.0%

Mean ASM CO reduced by 54.2%

Mean ASM NO_x reduced by 34.9%

The next step would require some known correlation to enable a conversion from these readings to the projected change in inventory. AirCare technical staff have periodically investigated possible correlations between ASM and idle readings and the mass emission data for the mass emission sample vehicles described elsewhere in this report. We have included various weighted combinations of ASM and idle readings, in attempts to more properly reflect transient driving. The degree of correlation has always been low. This is not surprising because idle conditions only apply for a very small portion of a transient test, and ASM2525 conditions are completely synthetic and may only be equivalent to a few seconds from a transient test. The conditions prevailing throughout the remaining parts of a transient test can produce emission rates which have no relation to ASM and idle readings. However, this does not invalidate the ASM and idle tests for inspection purposes. They have been proven to be good filters for finding vehicles which need to be repaired. The only required correlation with transient mass-emission tests is the need to minimize errors of omission and of commission. However, this has not precluded the use of ASM and idle readings for other evaluation oriented purposes, especially when mass data is not available. Even in the AirCare program we have used these readings to derive our repair effectiveness index. We believe that this type of index is valid, because it merely compares repairs to each other, rather than seeking to achieve a conversion to mass and an absolute measure of emission reductions.

Patterns of failure were of interest for this analysis. There are two extreme scenarios that could apply to an inspection and maintenance program. In one extreme, all of the vehicles that failed would be repaired or retired such that they never failed again. In this case, all failing tests would be uniquely associated with one vehicle. In the other extreme, there would be a sub-population of vehicles that failed the test each and every year. This group would effectively be the “bad actors” in the fleet that could be targetted for repair or retirement. In this case, there would be far more failed inspections than failed vehicles.

Not surprisingly, the observed result is somewhere between these two extremes. Also, as expected, the patterns of failure are complex, especially when looking at a broad time period. The analysis requires looking at the entire database for each failed vehicle to determine if it failed the inspection again at some point. This could happen in one year, two years or even more. The worst case scenario over 8 years would be represented by a pattern “FFFFFFFF” in which the vehicle failed 8 years in succession. There would be 255 possible combinations such as “FPPPPPPP” or “FPFPFPFP” for vehicles with 8 tests and less for vehicles with fewer than that amount. In every case, it is necessary to identify tests that are initial tests. This was difficult because tests in the database were not clearly identified as initial tests or re-tests. Thus, it was necessary to check backwards and forwards from each test to determine if there was a matching test in a timeframe consistent with a fail-repair-retest cycle.

The rationale for performing such an analysis was to determine if there was a “hard-core” group of vehicles in the fleet that failed consistently and resisted efforts to repair them. Experience with customer complaints from vehicle owners whose car or truck had failed the test suggested that this might be a plausible scenario. In many cases, an investigation of the history of the vehicle would reveal a number of previous failures. Given that less than one in three vehicles tested had ever experienced a failure, it seemed likely that there was some truth to the theory that the excess emissions from the fleet could be largely attributed to a small group of vehicles.

An analysis of the 19,967 vehicles that have been tested in each of the 8 calendar years was performed and the results are shown in Table 33.

As with the previous analysis, the bulk of failures occur only once. This suggests that there is no identifiable group of high emitters that cause all of the excess emissions. The probability of failing the test increases with age and any vehicle is susceptible to failure at any point.

Table 33. Number of Passes for Vehicles with Inspections in all 8 years

Number of Passes at First Attempt in Inspection Cycle	Number of Vehicles
8	9,706
7	4,296
6	2,690
5	1,605
4	886
3	457
2	215
1	89
0	23

9.4 MASS EMISSION SURVEYS

A major part of the work of the AirCare Research Centre is to perform testing from which emissions factors can be derived. This has been a continuous activity since 1993, but for the purposes of emission factor development, two survey periods have been defined. The first ran to the end of 1996, and provided the information for previous program-effectiveness evaluations in 1998, 1999 and 2000. The second period ran from January 1997 to December 2000.

9.4.1 Vehicle solicitation

Drivers of vehicles that failed the tailpipe emissions inspection are invited to participate in the survey. Initially it was hoped to select participant vehicles in a way which would make the samples reflect the overall fleet profile, but this was not possible because so few of those invited to participate actually respond. So no attempt has been made to target particular groups of vehicles, and the samples have become biased towards those drivers more likely to participate. However, stratification of the samples and the fleet, with adequate sample sizes within each stratification does allow valid mapping of sample data onto the overall fleet. In return for allowing their vehicles to be tested in the failed condition, and then again after they has been repaired, the owner is given a coupon for a free re-inspection and a $10 gasoline coupon. It is made clear that the purpose of participation is for us to collect information about the vehicles emissions, before and after it is repaired. There is no expectation of receiving a diagnosis of the problem which caused the failure.

9.4.2 Test procedure

Mass emissions are measured over the third phase of the FTP, after pre-conditioning at a steady 50km/h for four minutes. This is commonly referred to as a HOT 505 test. It does not provide any information regarding cold start emissions. However, the entire process is short enough that customers can wait while their vehicles are being tested. Exactly the same procedures are used for the before-repair and after-repair tests. During the second test the owner is asked to provide any available information about the repairs which have been performed. Reinspection and gasoline coupons are issued at the end of the second test.

9.4.3 Sample sizes

From 1993 to the end of 2000 there were 1831 before-repair tests, and 1189 after-repair tests completed. Although some vehicles are still expected to return for after-repair tests into 2001, it is nevertheless clear that many owners do not complete the cycle of participation. However there were 256 vehicles that went through the cycle twice, which suggests that some owners consider participation well worthwhile. For the purposes of emission factor development, duplicate occurrences of the same vehicle have been removed from the dataset. Although repeated participation is not discouraged, the repeated occurrence of the same vehicles in the data may cause some distortion. These vehicles will be studied separately towards understanding why some vehicles fail inspection again even though they were repaired in an earlier inspection year. After eliminating repeat participants, the number of vehicles with matched pairs of before-repair and after-repair tests was 1062. For each vehicle, the inspection database was queried to find the failed inspection immediately before the before-repair test, and the next inspection immediately after the after-repair test. Only 1005 vehicles proved to have failed inspections at the start of the cycle, and 957 had reinspections after the after-repair test. There are a number of factors which can make these numbers less than the value of 1062. Some people may participate just to get the inspection and gasoline coupons; some may want to see test results to confirm the value of a repair that was going to happen anyway; some may have simply taken the cycle out of order somewhat and therefore frustrated our procedure for matching tests with inspections; and some may have not bothered with the final reinspection. Whatever these reasons, the final number of complete cases identified was 957. The first sample, MES1, to the end of 1996, consisted of 304 cases, and the second sample, MES2, to the end of 2000, includes 653 cases.

A much smaller sample group of passing vehicles which pass inspection has also been collected. Some of these vehicles have been solicited in the same way as failing vehicles, but others have been tested during the course of the other activities undertaken at the AirCare Research Centre. This group comprises 37 vehicles which have a HOT 505 test and a passed ASM/Idle inspection.

9.4.4 Comparison of HOT 505 sample and ASM Failing Vehicle profiles

Figure 52 and Figure 53 show comparisons of the samples to the overall fleet inspection failures in terms of vehicle model year. MES1 has been compared to failed inspections performed in 1995, and MES2 to those in 1999. In both cases, the match of sample to fleet inspection failures is remarkably good.

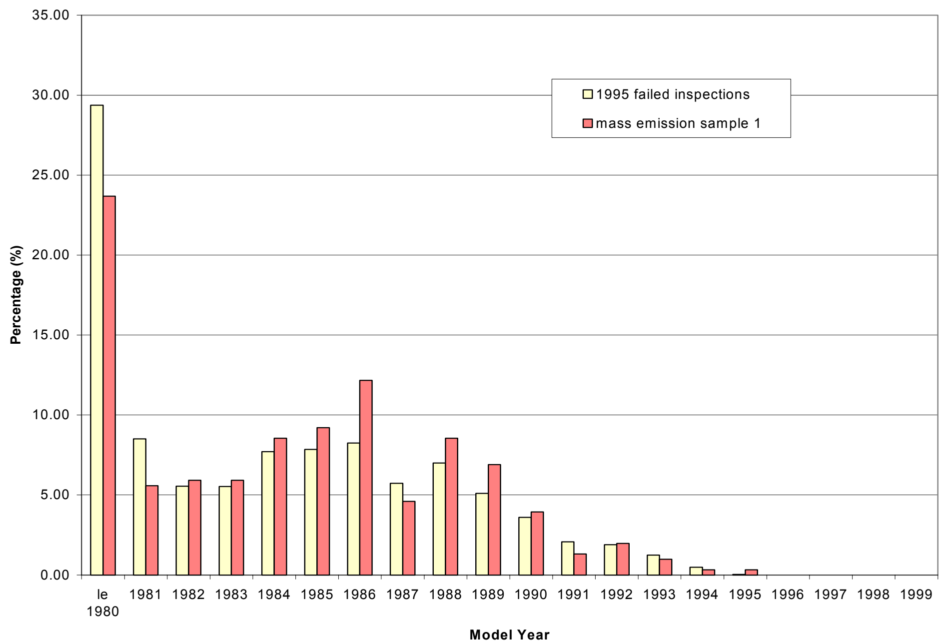


Figure 52. Comparison of Mass Emissions Sample 1 to Fleetwide Failures in 1995 by Model Year

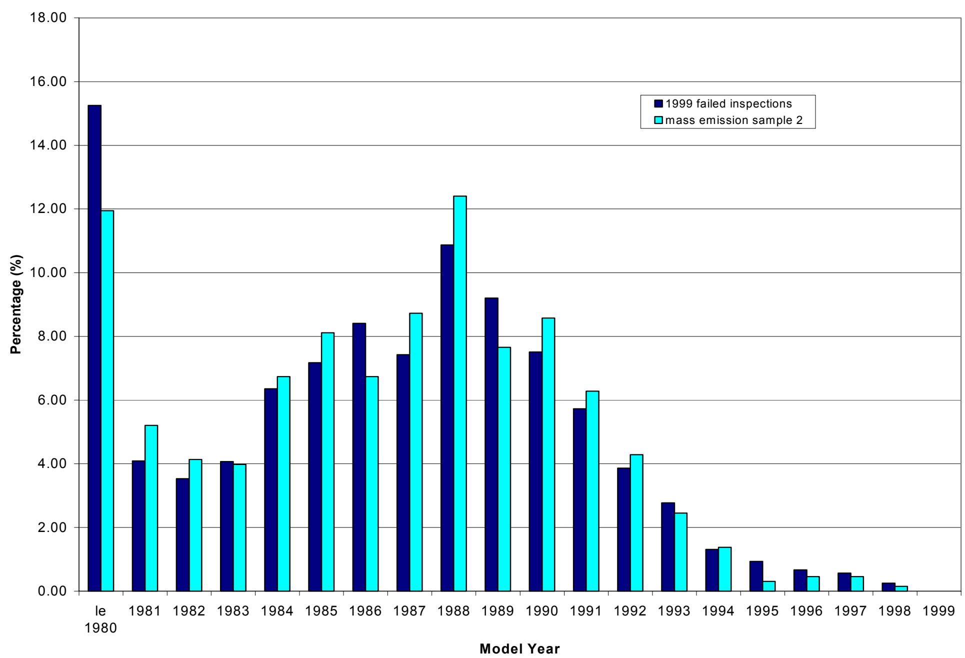


Figure 53. Comparison of Mass Emissions Sample 2 to Fleetwide Failures in 1999 by Model Year

Table 34, Table 35, Figure 54, and Figure 55 group the samples and the fleet inspection failures according to vehicle type, emission control technology and model year, in the way that will be used to define emission factors from the Mass Emission Samples.

Table 34. Comparison of Mass Emissions Sample 1 to Fleetwide Failures by Vehicle type, Emissions Technology and Age Groupings in 1995

		1995 Failed Inspections		Mass Emission Sample 1	
		Number	% of Total	Number	% of Total
All Pre-1971 Vehicles	1 A	3868	3.28	8	2.63
All Basic-Mixture-Control Vehicles	2 A	26933	22.84	37	12.17
All Vehicles with Oxidation Technology	3 A	40347	34.22	126	41.45
All Pre-1988 Vehicles with 3-way Catalyst	4 A	23146	19.63	62	20.39
1988-1993 Passenger Vehicles with 3-way Catalyst	4 P1	14092	11.95	55	18.09
Post-1993 Passenger Vehicles with 3-way Catalyst	4 P2	366	0.31	2	0.66
1988-1993 Trucks with 3-way Catalyst	4 T1	8964	7.60	14	4.61
Post-1993 Trucks with 3-way Catalyst	4 T2	200	0.17	0	0.00
Total		**117916**		**304**	

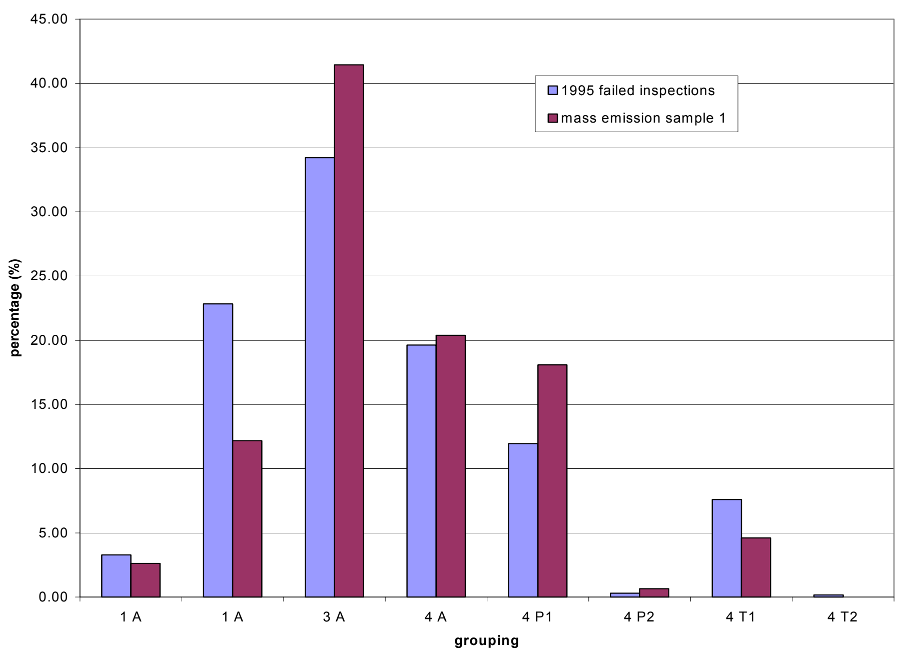


Figure 54. Comparison of Mass Emissions Sample 1 to Fleetwide Failures by Vehicle type, Emissions Technology and Age Groupings in 1995

Table 35. Comparison of Mass Emissions Sample 2 to Fleetwide Failures by Vehicle type, Emissions Technology and Age Groupings in 1999

		1999 Failed Inspections		Mass Emission Sample 2	
		Number	% of Total	Number	% of Total
All Pre-1971 Vehicles	1 A	2534	2.56	13	1.99
All Basic-Mixture-Control Vehicles	2 A	13964	14.13	50	7.66
All Vehicles with Oxidation Technology	3 A	18659	18.88	147	22.51
All Pre-1988 Vehicles with 3-way Catalyst	4 A	21641	21.89	153	23.43
1988-1993 Passenger Vehicles with 3-way Catalyst	4 P1	25604	25.90	218	33.38
Post-1993 Passenger Vehicles with 3-way Catalyst	4 P2	2646	2.68	15	2.30
1988-1993 Trucks with 3-way Catalyst	4 T1	13800	13.96	54	8.27
Post-1993 Trucks with 3-way Catalyst	4 T2	0	0.00	3	0.46
Total		**98848**		**653**	

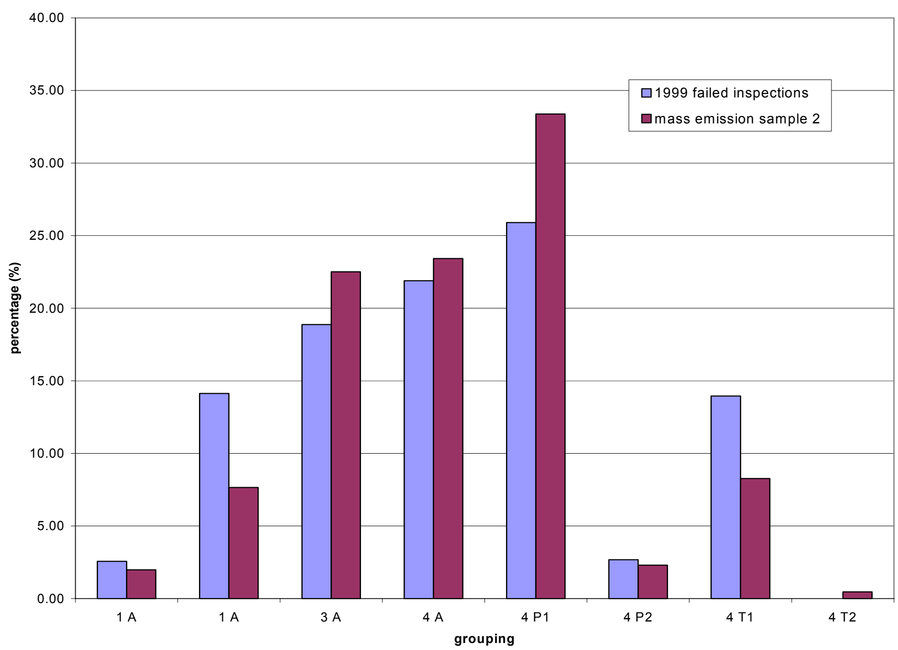


Figure 55. Comparison of Mass Emissions Sample 2 to Fleetwide Failures by Vehicle type, Emissions Technology and Age Groupings in 1999

For MES1 and failed inspections in 1995, grouping 3A (vehicles with oxidation technology) was predominant. In 1999, and for MES2, the 4P1 grouping (1988-1993 passenger vehicles with 3-way catalyst technology) had taken over as the largest group of failures. Both MES1 and MES2 show an under-representation in groupings 2A and 4T1. Grouping 2A is ‘all basic mixture-control vehicles', and 4T1 is '1988-1993 trucks with 3-way catalyst technology'. However, the sub-samples for each grouping may still be adequate for developing emission factors. This illustrates why stratification is so important when applying sample data to an entire fleet. For developing emission factors, the stratification has been taken one step further, to the level of emission inspection failure mode. As previously explained, within each grouping, only the six most common failure modes have been individually considered. All the other modes within the grouping have been taken as 'other'. There is insufficient HOT 505 data to create emission factors for each individual failure mode for each grouping. Within each grouping, only the six most common failure modes were considered. All the other modes within the grouping were simply taken as 'other'. Thus 74.55% of all failures are modelled with respect to their actual failure mode, and the remaining 25.45% of failures only with respect to their vehicle type, technology level and age grouping, and the fact that they failed in some less common mode. These 25.45% of failures represent 3.24% of all inspections.

9.5 IDENTIFICATION OF MOST COMMON FAILURE MODES

The emissions reduction calculation requires emission factors to be assigned to all vehicles affected by the program, both for their initial condition (whether that be a first-time-pass or a fail), and for their final condition after any necessary repairs. The appropriate factors have to be derived from mass emission test data and are dependent on the vehicle type, its age, its level of emission control technology, whether it passed, and its failure mode if it failed.

For the purpose of conducting the evaluation, there are eight technology groupings considered. These sub-groups and the description of the dominant failure modes for each are shown in the following tables: Table 36 to Table 43 are derived from 1999 ASM/Idle inspection data. Each table is for a specific grouping of vehicles, defined by their vehicle type, emission control technology and model year. They show how many vehicles passed the emissions inspection, and how many achieved each different failure mode combination.

Table 36. Failure Modes of All Pre-1971 Vehicles

all pre-1971 vehicles		
modal emission results	number of inspections	% of total
other	346	3.25
PPFPP	130	1.22
FPFPP	147	1.38
PFPFP	397	3.73
FPPPP	435	4.09
PPPFP	657	6.17
PFPPP	1272	11.95
PPPPP	7263	68.22
total	10647	

Table 37. Failure Modes of All Basic-Mixture-Control Vehicles

all basic-mixture-control vehicles		
modal emission results	number of inspections	% of total
other	2627	3.82
FFPPP	1044	1.52
PFPFP	1068	1.55
PPPPF	1138	1.65
PPPFP	3460	5.03
PFPPP	4290	6.23
FPPPP	5314	7.72
PPPPP	49903	72.49
total	68844	

Each table is in order of least likely mode to most likely mode. In general, single mode failures are far more likely than multiple-mode failures. Of the multiple-failure modes on 1988 and newer model year vehicles, the FFFFP four-mode failure is very much more common than many of the two or three-mode failures. This is intuitively consistent with the expected performance of a vehicle whose oxygen sensor has failed and caused a general over-fueling situation. This four-mode failure is much less common on pre-1988 model year vehicles, even when they are three-way catalyst vehicles. None of the pre-1971 vehicles were subject to a NO_x standard, so this component of the result is always a pass for these vehicles.

Table 38. Failure Modes of All Vehicles with Oxidation Technology

all vehicles with oxidation technology		
modal emission results	number of inspections	% of total
other	6179	6.55
PFPFP	1065	1.13
FFPPP	1854	1.97
PPPPF	3155	3.34
PFPPP	3234	3.43
PPPFP	5166	5.48
FPPPP	5289	5.61
PPPPP	68403	72.50
total	94345	

Table 39. Failure Modes of All Pre-1988 Vehicles with 3-way Catalyst

all pre-1988 vehicles with 3 way catalyst technology		
modal emission results	number of inspections	% of total
other	8071	5.37
FFPPP	1681	1.12
PPFPP	1947	1.30
PFPPP	2793	1.86
PPPPF	2854	1.90
FPPPP	5545	3.69
PPPFP	7541	5.02
PPPPP	119869	79.75
total	150301	

Table 40. Failure Modes of 1988-1993 Passenger Vehicles with 3-way Catalyst

1988-1993 passenger vehicles with 3 way catalyst technology		
modal emission results	number of inspections	% of total
other	11955	3.78
FFPPP	2373	0.75
PPFPF	2403	0.76
FFFFP	3301	1.04
PPFPP	4395	1.39
FPPPP	5135	1.62
PPPPF	6775	2.14
PPPPP	279881	88.51
total	316218	

Table 41. Failure Modes of Post-1993 Passenger Vehicles with 3-way Catalyst

post-1993 passenger vehicles with 3 way catalyst technology		
modal emission results	number of inspections	% of total
other	762	0.38
FFFFP	177	0.09
FPFPP	184	0.09
PPFPP	336	0.17
PPPPF	434	0.22
FPPPP	568	0.29
PPPFP	765	0.38
PPPPP	195553	98.38
total	198779	

Table 42. Failure Modes of 1988-1993 Trucks with 3-way Catalyst

1988-1993 trucks with 3 way catalyst technology		
modal emission results	number of inspections	% of total
other	5395	3.85
PPFPP	1153	0.82
PPPFP	1223	0.87
FFPPP	1239	0.88
FFFFP	1461	1.04
FPPPP	3368	2.40
PPPPF	3796	2.71
PPPPP	122547	87.42
total	140182	

Table 43. Failure Modes of Post-1993 Trucks with 3-way Catalyst

post-1993 trucks with 3 way catalyst technology		
modal emission results	number of inspections	% of total
other	321	0.28
PPPFP	81	0.07
PPFPP	87	0.08
FFFFP	93	0.08
FFPPP	126	0.11
FPPPP	231	0.20
PPPPF	273	0.24
PPPPP	113144	98.94
total	114356	

9.6 DEVELOPING MASS EMISSION FACTORS

For each sample the before-repair HOT 505 results were used to derive before-repair emission factors, by averaging the results having the same initial ASM/Idle failure mode, within each of the eight groupings. After-repair factors were further sub-divided into those whose final reinspection results were marginal (referred to as 'bad'), and those significant emission reductions (referred to as 'good'). These two designations were to address the fact that not all repairs are equal. The designation depends on the value of V2 for the final result, where V2 is defined in the same way as used for REI, and indicates how far the final reinspection readings were below the allowable maxima. The cut between 'good' and 'bad' was chosen at V2=0.25. For both sample groups, this placed the majority of cases in the 'good' category.

Table 44. Emissions Factors used for Emission Reduction Calculation

technology group	failure mode	emission rates gram/km: initial condition			emission rates gram/km: after 'bad' repair			emission rates gram/km : after 'good' repair		
		HC	CO	NOx	HC	CO	NOx	HC	CO	NOx
1 A	FPFPP	5.0	39.0	1.8	4.3	39.0	2.0	2.8	39.1	2.2
1 A	FPPPP	5.0	38.9	1.5	4.5	34.8	1.6	3.5	26.5	1.8
1 A	PFPFP	3.9	93.9	1.0	3.1	99.1	0.6	2.2	30.5	2.4
1 A	PFPPP	3.6	40.6	2.4	3.3	37.0	2.5	2.8	29.9	2.8
1 A	PPFPP	10.0	39.0	2.9	7.6	39.1	2.5	2.7	39.2	1.6
1 A	PPPFP	3.8	82.1	1.2	3.6	74.0	1.3	3.0	57.8	1.5
1 A	other	3.7	39.0	1.8	3.4	39.0	2.0	2.8	39.1	2.2
1 A	PPPPP	3.7	39.0	1.8						
2 A	FFPPP	5.6	37.0	1.4	4.7	34.8	1.3	2.7	30.3	1.3
2 A	FPPPP	2.5	14.3	2.5	2.4	16.1	2.2	2.1	19.9	1.7
2 A	PFPFP	1.9	24.5	1.9	1.9	22.9	1.9	1.8	19.8	2.1
2 A	PFPPP	1.4	14.6	1.9	1.4	12.8	1.9	1.4	9.3	2.0
2 A	PPPFP	2.3	37.0	1.6	2.2	33.2	1.7	2.0	25.6	2.0
2 A	PPPPF	1.4	7.9	3.2	1.2	7.5	2.9	1.0	6.7	2.2
2 A	other	3.9	22.3	2.6	2.2	23.9	2.8	1.1	10.8	1.8
2 A	PPPPP	1.5	18.8	1.9						
3 A	FFPPP	1.6	21.8	1.6	1.5	23.2	1.4	1.0	13.9	1.4
3 A	FPPPP	1.9	12.7	1.8	1.6	18.3	1.9	1.4	15.2	1.5
3 A	PFPFP	1.9	40.1	1.1	2.1	36.5	0.9	1.0	13.7	1.8
3 A	PFPPP	1.6	23.3	1.8	1.9	24.4	2.0	1.2	13.4	1.9
3 A	PPPFP	2.0	39.3	1.2	1.3	30.8	1.3	1.3	20.2	1.5
3 A	PPPPF	1.0	8.8	3.2	0.9	6.2	3.3	1.3	9.6	2.1
3 A	other	2.5	25.1	2.0	1.6	18.3	1.3	1.4	15.1	1.6
3 A	PPPPP	1.6	11.4	1.0						
4 A	FFPPP	1.9	26.5	1.4	1.7	23.2	1.5	1.4	16.5	1.6
4 A	FPPPP	1.6	11.0	1.5	1.4	10.9	1.5	1.0	10.7	1.3
4 A	PFPFP	1.3	17.9	1.6	2.2	22.2	1.1	0.8	17.1	1.6
4 A	PFPPP	1.9	9.9	1.2	1.6	11.4	1.3	0.9	14.3	1.4
4 A	PPPFP	1.1	31.4	0.9	1.3	26.0	0.7	0.8	15.7	1.0
4 A	PPPPF	0.8	8.6	3.1	0.8	20.9	1.1	1.0	12.9	1.8
4 A	other	2.2	37.4	1.2	1.8	29.2	0.5	0.9	14.8	1.2
4 A	PPPPP	0.5	9.4	1.2						
4 P1	FFFFP	1.3	34.7	0.5	1.1	19.7	0.5	0.2	5.0	0.5
4 P1	FFPPP	0.4	6.6	0.5	0.3	13.0	0.2	0.2	4.4	0.6
4 P1	FPPPP	0.4	4.9	0.7	0.3	1.8	0.7	0.3	4.0	0.6
4 P1	PPFPF	0.6	6.5	1.4	0.6	6.8	1.4	0.5	5.9	1.3
4 P1	PPFPP	0.5	6.4	0.7	0.7	9.1	0.6	0.3	3.7	0.6
4 P1	PPPPF	0.4	5.4	1.5	0.4	5.1	1.3	0.3	4.4	0.9
4 P1	other	1.0	14.4	0.8	0.6	9.6	0.7	0.2	3.7	0.5
4 P1	PPPPP	0.1	2.7	0.6						
4 P2	FFFFP	0.2	15.0	0.2	0.2	10.5	0.2	0.1	1.4	0.2
4 P2	FFPPP	0.2	2.7	0.2	0.2	2.3	0.2	0.1	1.4	0.2
4 P2	FPPPP	0.1	1.4	0.6	0.1	1.0	0.5	0.1	0.4	0.3
4 P2	PPFPP	0.2	2.7	0.1	0.1	2.5	0.2	0.1	2.0	0.2
4 P2	PPPFP	0.1	15.0	0.3	0.1	5.2	0.2	0.1	0.5	0.0
4 P2	PPPPF	0.1	2.7	1.0	1.0	5.3	1.9	0.1	1.9	0.3
4 P2	other	0.5	6.9	0.2	0.4	5.7	0.3	0.2	3.2	0.3
4 P2	PPPPP	0.1	2.1	0.2						
4 T1	FFFFP	1.9	39.4	0.6	1.4	28.2	0.8	0.4	5.7	1.1
4 T1	FFPPP	1.2	17.0	0.9	1.1	13.3	1.0	0.8	5.9	1.1
4 T1	FPPPP	1.0	12.8	0.9	1.3	39.3	0.5	0.6	8.4	0.8
4 T1	PPFPP	1.9	11.0	1.1	1.6	10.1	1.1	0.9	8.3	1.1
4 T1	PPPFP	0.8	21.5	0.7	1.3	46.4	0.5	0.6	12.6	0.8
4 T1	PPPPF	0.6	10.9	1.8	0.6	10.7	1.5	0.5	7.5	1.1
4 T1	other	2.0	23.1	0.8	1.7	26.4	0.3	0.9	9.3	0.9
4 T1	PPPPP	0.5	6.1	1.0						
4 T2	FFFFP	0.2	15.0	0.2	0.2	10.5	0.2	0.1	1.4	0.2
4 T2	FFPPP	0.1	5.0	0.2	0.1	3.8	0.2	0.1	1.4	0.2
4 T2	FPPPP	0.1	2.7	0.2	0.1	2.3	0.2	0.2	1.6	0.2
4 T2	PPFPP	0.2	2.7	0.2	0.2	2.3	0.2	0.1	1.4	0.2
4 T2	PPPFP	0.1	15.0	0.2	0.1	10.5	0.2	0.1	1.4	0.2
4 T2	PPPPF	0.1	2.7	1.0	0.1	2.3	0.7	0.1	1.4	0.2
4 T2	other	0.1	2.7	0.2	0.1	2.2	0.2	0.1	1.1	0.2
4 T2	PPPPP	0.1	2.7	0.2						
Pnew	PPPPP	0.1	2.1	0.2						
Tnew	PPPPP	0.1	2.7	0.2						

Having stratified and sub-divided the data to this extent, a number of gaps became apparent. The sparsest data was for the oldest and newest vehicles having the final reinspection designation of 'bad', and some of the failure mode stratifications for the oldest and newest vehicles were very underrepresented in both samples. This sparsity and underrepresentation would be addressed by interpolating across the most reliable, well represented strata. However, at this point it was recognised that for the well represented strata, the emission factors were very much the same in MES1 and MES2. The intent of separating MES1 and MES2 was to recognise that emission factors derived during the earlier sample period may no longer be valid late in the second sample period.

For example, the mass emission rate appropriate to a 1988 car which was tested in 1993 may be lower than when that car was tested again in 1998. Thus MES1 factors would be used to model program effectiveness up to 1996, and MES2 factors for program effectiveness from 1997 to 2000. But comparison of MES1 factors with MES2 factors showed much less difference than the variation present within each sample. A decision was made to combine the samples. This minimised the amount of interpolation required.

Two types of interpolation were applied. With reference to Table 44, these were 'vertical' and 'horizontal'. Vertical interpolation was used to improve confidence in factors for failure mode stratifications which still had comparitively little data. This was possible because the failure modes are not completely unique, but are combinations of five individual failure modes. For example, the CO factor for a mode that includes ASM CO failure will be similar to the CO factor for all other modes (for the same vehicle grouping) which include ASM CO failure. Horizontal interpolation was used to derive many of the 'bad' after-repair factors, because these were still relatively uncommon compared to 'good'. For strata having insufficient 'bad' after-repair data, the factors were taken as giving one third of the improvement which would be given by the 'good' after-repair factors [bad = fail - (fail - good) / 3]. The value of one third was decided after examining the ratios of fail, 'good' and 'bad' factors for strata with more plentiful data.

9.7 ESTIMATING MASS EMISSION REDUCTIONS

The total annual emissions from an individual vehicle can be estimated by multiplying its annual mileage by appropriate emission factors. The appropriate factors are chosen from the emission factor table with reference to the vehicle type, its emission control technology, and the failure (or pass) mode achieved in inspection. For vehicles which pass their first inspection, the result will be an assessment of their actual annual emissions. For vehicles which fail, the result is an assessment of what the emissions would be if the vehicle remained in that condition without being repaired. To assess the amount of improvement that is achieved by repairing such a vehicle requires an additional calculation using emission factors appropriate to either 'good' or 'bad' repair. This is the entire basis of the following explanation. (It must be emphasised that the emission factors used in these calculations are based on HOT 505 tests, and therefore can not result in an actual assessment of the emissions inventory directly. However, the assumption will be that the percentage changes, due to repair or fleet turnover, indicated by these calculations, can be applied to the actual inventory.)

For each program year the entire inspected fleet was divided into the following sets:

- **Vehicles which passed inspection at their first attempt.**

  This is where the first inspection in the year was a pass, and there were no failed inspections in the six months prior to the passed inspection.

- **Vehicles which failed their first attempt at inspection**

  This is where the first inspection in the year was a fail, and there were no other failed inspections in the six months prior to this inspection.

- **Vehicles which failed their first attempt at inspection but subsequently returned for reinspection after certified repair.**

  This is a subset of the previous set, where a reinspection-after-certified-repair took place within six months after the failed inspection

- **Vehicles which failed their first attempt at inspection but subsequently returned to achieve a pass, and were not recipients of certified repairs.**

  This is also a subset of the 'failed first attempt' set, and is where a later inspection, within six months, achieved a pass, but there is no record of the vehicle having received a certified repair.

- **Vehicles which failed their first inspection and did not subsequently return to achieve a result which would enable continued licensing and insurance.**

  This is also a subset of the 'failed first attempt' set, and is where the vehicle did not subsequently return, within six months, to achieve a result which would enable continued licensing and insurance.

Within each of these sets, for each program year, the number of vehicles was counted, with reference to their vehicle type, emission control technology, and failure (or pass) mode. The proportions of vehicles achieving 'good' or 'bad' final emissions performance was estimated using an assessment of V2, which is defined in the section of this report describing Repair Effectiveness Indices, REI. V2 is an indication of how close the final emission readings are to ideal (best 24%). Again using the same 56 subgroups of vehicle type, emission control technology, and initial failure mode, and assessing certified and non-certified repairs separately for each year, a V2 value was calculated for each repair. Those where V2 => 0.25 were labelled 'good' and those where V2 < 0.25 were labelled 'bad'. This is exactly the same criteria as was used to characterise the mass-emission sample data after-repair results. The labels 'good' and 'bad' are value judgements, but they are only relative judgements, rather than absolute. The proportions of 'good' and 'bad' were applied to each subgroup in each the two data sets containing certified and non-certified repairs.

Special consideration was given to assessing the numbers of vehicles in each data set and each subgroup in program years 1 and 4. Both these years were affected by inspector strikes, and in year 1 many newer vehicles were exempted from inspection. The effect was to allow a large number of vehicles to continue in use without any inspection requirement. This reduced the number of emission repairs, and their emission reduction benefits. However, the emission reduction benefits still depend on the actual number of repairs which were performed and this was indicated from the actual inspection records in just the same way as for other years. The baseline counts of how many vehicles actually passed and failed in the various modes had to be scaled up from the actual numbers to the total fleet size, to give the numbers that would have passed or would have failed, if all had been inspected. Of course, those that would have failed, but were not, remained that way, and could not deliver any emission reduction benefit.

In all other years the only exempt vehicles were those too new to require inspection. Their numbers were estimated from the total fleet growth rate, and their emission factors taken as equal to the pass-first-time factors for the newest of the vehicles that actually were subject to inspection.

The total 'no-more-AirCare' fleet emissions for each year were calculated by multiplying the number of vehicles in each of the 64 subgroups by their annual mileage and their initial emission factors. This is an assessment of what the total would be if there were no subsequent repairs in that year. The change relative to the previous year represents the effect occurred because of maintenance, repairs, and fleet turnover combined.

The reduction achieved in a year as a direct result of emission repairs was calculated by subtracting the total emissions of repaired vehicles from their total emissions in their initial failed condition. Vehicles in the final dataset, which did not finally achieve a result enabling licensing, were not included in this calculation. Many of these vehicles would be removed from use, and the emission reductions attributable to their removal contribute to the lower initial total assessed for the subsequent year. It is not possible to assess how many would have been removed from use in the absence of the AirCare program. So although the reductions attributable to those which were removed as a direct consequence of being unable to pass inspection, is a direct benefit of the AirCare program, it has not been possible to assess these reductions separately from the overall fleet turnover reductions.

Table 45. Percentage Reductions as Direct Result of Emission Repair in the Year

Program Year	HC	CO	NO_x
1	3.85	3.88	1.43
2	5.52	6.09	1.58
3	3.33	2.65	1.16
4	4.19	4.00	0.91
5	9.72	8.98	2.20
6	8.53	8.10	1.93
7	8.59	8.06	1.86
8	8.33	7.71	1.83

Table 46. Fleet Turnover (etc) Percentage Reduction from the Previous Year

Program Year	HC	CO	NO_x
2	12.72	11.70	10.83
3	7.44	3.35	6.24
4	3.22	1.04	5.60
5	2.98	0.51	3.81
6	9.80	6.29	11.20
7	2.77	-0.42	5.78
8	3.00	-0.25	6.32

Table 45 to Table 51 summarise the results of these emission reduction estimates. Table 45 shows the annual percentage reductions of HC, CO and NO_x which can be directly attributed to emission repairs performed after failing an inspection in that year. Table 46 shows the reductions, compared to the previous year from all other causes, such as regular maintenance, non-AirCare repairs, and fleet turnover. Table 47 shows the combined percentage reductions from the previous year from all causes, including maintenance, emission repairs, fleet turnover, and continuing benefits from repairs in previous years.

Table 47. Total Percentage Reduction from the Previous Year

Program Year	HC	CO	NOx
2	16.57	15.58	12.26
3	12.96	9.44	7.82
4	6.56	3.69	6.75
5	7.17	4.51	4.73
6	19.52	15.27	13.39
7	11.30	7.69	7.71
8	11.59	7.81	8.18

Table 48 shows the remaining inventory in each year as a percentage of the original inventory. Table 49 shows the cumulative reductions to the inventory over the eight years. In line with the previously mentioned intention of assessing changes to the inventory rather than the absolute inventory, everything is referred to a pre-AirCare inventory of 100%.

Table 48. Remaining Inventory at End of Each Year

Program Year	HC	CO	NOx
1	96.15	96.12	98.57
2	78.82	79.28	86.35
3	70.20	74.42	79.94
4	65.01	70.69	74.73
5	56.87	63.99	70.27
6	46.37	54.74	61.02
7	41.10	50.56	56.36
8	36.45	46.79	51.77

Table 49. Cumulative Inventory Reductions since Start of Inspection Program

End of Program Year	HC	CO	NOx
1	3.85	3.88	1.43
2	21.18	20.72	13.65
3	29.80	25.58	20.06
4	34.99	29.31	25.27
5	43.13	36.01	29.73
6	53.63	45.26	38.98
7	58.90	49.44	43.64
8	63.55	53.21	48.23

Table 50 shows what fraction of the reduction in each year was due to emission repairs. Benefits from emission repairs performed in previous years are included in the overall benefits from all causes, because they are reflected in the basic inventory assessment for each year. These benefits are attributable to the inspection program, but this model does not require a separate estimate of the continued benefit of repairs in years subsequent to the year of repair.

Table 50. Fraction of Annual Benefit due to Emission Repair in Previous Year

Program Year	HC	CO	NOx
2	0.23	0.25	0.12
3	0.43	0.65	0.20
4	0.51	0.72	0.17
5	0.58	0.89	0.19
6	0.50	0.59	0.16
7	0.75	1.05	0.25
8	0.74	1.03	0.23

The total inventory reductions which have been achieved over eight years were 63.6% HC, 53.2% CO, and 48.2% NO_x. Table 51 shows an estimate of what proportions of these benefits were due to emission repairs. Some of the other reductions were indubitably caused by earlier retirement of vehicles which were having trouble complying with inspection requirements, so the actual rate of inventory reduction which would have taken place in the absence of the inspection program would therefore have been less than shown.

Table 51. Estimated Benefits over Last 8 Years

	HC	CO	NO_x
Overall 8 Years	**63.6%**	**53.2%**	**48.2%**
Due to Emission Repair	34.3%	38.4%	10.2%
Other	29.3%	14.8%	38.0%

The reductions achieved in each year were not constant. Reductions due to emission repairs depend on factors which include: inspection failure rates; types of failure; types of vehicle; effectiveness of diagnosis and repair; waiver policies and cost limits; and vehicle exemptions, whether by policy for new vehicles, or *de facto* because of strikes. Fleet turnover reductions depend on many factors ranging from macro-factors like the economic climate and the price of fuel, down to individual decisions about when a car is finally due for retirement. Some of the factors affecting other reductions such as improved regular maintenance to increase assurance of passing inspection, can be considered as benefits of the inspection program; whereas some such as better public awareness of the problems caused by vehicle emissions could presumably have been achieved in other ways.

9.7.1 Comparison of Estimated Emission Inventory Reductions with Previous Evaluations

The first evaluation of program effectiveness was performed towards the end of 1994, and estimated the inventory reductions achieved in the first two program years. The amount of available mass emission data was very small, because the mass emission testing facility at the AirCare Research Centre did not become operational until the end of 1993. This only enabled a fairly simple stratification of the sample data, and the inspection data was not yet amenable to analysis of any temporal patterns.

Further evaluations were performed in 1996, 1998, 1999, and 2000. Each time, the amount of mass emission data, and the amount of sample stratification, was increased; although the 1999 and 2000 evaluations continued to use the mass emission factors and stratifications, which had been developed in 1996.

All these evaluations used a method which can be described as forward interpolation.

- From a fixed starting point in 1992, the reductions due to repairs in the first year were estimated using inspection data and mass emission factors, a further reduction due to fleet turnover was estimated from accepted perceptions of fleet growth rate and new vehicle sales figures. This resulted in assessment of the inventory in year two.
- The same approach was applied to each subsequent year, but each time including some estimate of the continuing benefits of emission repairs which had been performed in earlier years.
- This type of forward interpolation allows evaluation right up to the time of the evaluation but it can not include an assessment of what actually was achieved, because the data which would allow such assessment will not exist until the following year.

The present evaluation has been performed in retrospect, and has not needed forward interpolation. Each year the actual achievements of the previous year have been assessed without any need to speculate about what the fleet turnover benefits were, or how much benefit there was from emission repairs. Eliminating the need to model ongoing benefits from repairs in previous years, and from fleet turnover, precludes the possibility of accumulated drift which would result from any mis-approximation of their effects. The emission reductions due to repairs in each year have been modelled as described earlier, but they have not been used to project what the next years inventory would be. Again, this precludes another source of accumulated drift.

The assessment of each years base inventory now depends entirely on the counts of how many vehicles there were in that year; their annual mileage; and on the emission factors allocated to each combination. It does not depend in any way on modelling what has happened since the previous year. This means that the model responds to actual fleet dynamics. It has shown that the NO_x reductions due to fleet turnover have actually been higher than previously estimated. The end-of-year-eight NO_x inventory from Table 48 shows 51.8% of the 1992 inventory, which is a reduction of 48.2%. The reduction is 10.2% dues to emission repairs, and 38.0% to other causes. The previous model only showed a total 24.9% reduction in NO_x to the same point in time. The AirCare-attributable reduction is a little different, but the fleet turnover and other reductions were previously only estimated as 16.1%, because they were based on a necessarily oversimplified model of fleet turnover. However, the HC and CO benefits due to fleet turnover etc, were previously overestimated. Appendix D presents a mathematical comparison of the present evaluation method to the previous method.

The biggest change to the mass emission factors and their stratification used in this evaluation, as compared to all previous, is the identification of individual failure modes. Previously no distinction was made between ASM and idle failure modes in allocating mass emission factors. This was true in apportioning the numbers of vehicles in the fleet, and also in assessing mass emission factors from the mass emission samples, so the overall effect of this simplification was mitigated somewhat. The present analysis uses different factors for different failure modes. The most marked effect of this model enhancement is seen in the assessment of CO and NO_x reductions. The present estimate of CO reductions is less than previously, and for NO_x the present estimate shows greater reductions than the previous estimates. This is because of vehicles which fail idle CO, but not ASM CO are being allocated CO factors which are lower than previously, so the amount of benefits modelled for their repair is less. Conversely, these idle CO repairs can be achieved without the NO_x penalty commonly associated with ASM CO repairs.

9.8 APPLICATION OF PERCENTAGE REDUCTIONS TO THE LDV MASS EMISSIONS INVENTORY

The GVRD emissions inventory is usually completed at intervals of five years. Inventories were completed for 1990, 1995 and 1998. The 2000 inventory is still being compiled. The AirCare program started in September 1992, and therefore requires an assessment of the 1992 inventory to use as a baseline for the reductions which have been described above. In the previous section, Table 51 indicates that the reductions in HC, CO and NO_x over eight years, due to causes other than direct AirCare repairs were 29.3%, 14.8% and 38.0% respectively. These would be achieved by steady annual reductions of 4.24%, 1.99% and 5.79%. If we assume that these steady rates can be extrapolated back to the 1990 to 1992 period, the 1992 inventory can be assessed from the 1990 values. The complete period from 1990 to 2000 is shown in Table 52. The tonnage numbers are all derived from the GVRD 1990 inventory, with the no-AirCare imaginary situation assessed by applying steady decay rates as just described, and the actual with-AirCare situation derived from the percentage reductions which have been calculated.

Table 52. GVRD Light Duty Vehicle Emission Inventory (tonnes)

Year	HC		CO		NO_x	
	no IM	with IM	no IM	with IM	no IM	with IM
1990	40,109		376,211		20,099	
1991	38,408		368,724		18,935	
1992	36,780		361,387		17,839	
1993	35,220	33,864	354,195	340,469	16,806	16,565
1994	33,727	27,762	347,147	280,809	15,833	14,512
1995	32,297	24,724	340,238	263,603	14,916	13,435
1996	30,928	22,898	333,468	250,364	14,053	12,558
1997	29,616	20,029	326,832	226,648	13,239	11,810
1998	28,361	16,332	320,328	193,899	12,472	10,256
1999	27,158	14,477	313,953	179,081	11,750	9,472
2000	26,007	12,836	307,706	165,721	11,070	8,700

Table 53 shows the inventory, and how, it has changed since 1990 for the complete Lower Fraser Valley (LFV). The LFV light-duty vehicle emissions inventory has been taken as equal to the GVRD inventory multiplied by 1.085.

Table 53. LFV Light Duty Vehicle Emission Inventory (tonnes)

Year	HC		CO		NO_x	
	no IM	with IM	no IM	with IM	no IM	with IM
1990	43,518		408,189		21,807	
1991	41,673		400,066		20,545	
1992	39,906		392,105		19,355	
1993	38,214	36,742	384,302	369,409	18,235	17,973
1994	36,594	30,122	376,654	304,677	17,179	15,745
1995	35,042	26,825	369,159	286,009	16,184	14,577
1996	33,556	24,844	361,812	271,645	15,247	13,626
1997	32,134	21,731	354,612	245,913	14,364	12,814
1998	30,771	17,721	347,556	210,381	13,533	11,127
1999	29,467	15,708	340,639	194,303	12,749	10,277
2000	28,217	13,927	333,861	179,807	12,011	9,439

The Lower Fraser Valley data, from Table 53, is shown graphically in Figure 56, Figure 57, and Figure 58.

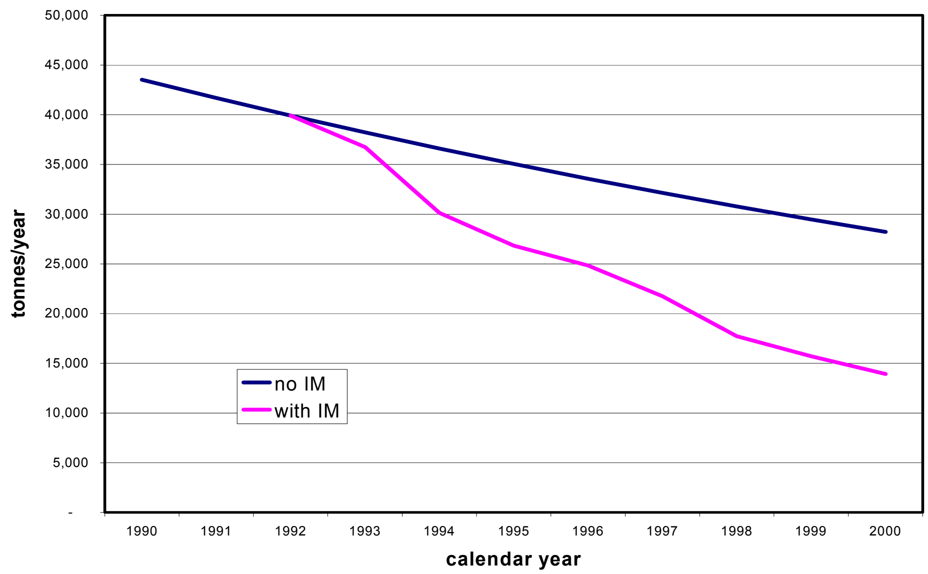


Figure 56. LFV Light Duty Vehicle HC Emission Inventory (tonnes)

In each of these tables and graphs, the ordinate is shown as calendar year, for the sake of clarity. However, the analysis has actually been performed with reference to program years, which have a four-month phase shift from calendar years. Thus, for example where the ordinate shows a calendar year of 1993, this actually refers to program year one, which ran from September 1992 to August 1993.

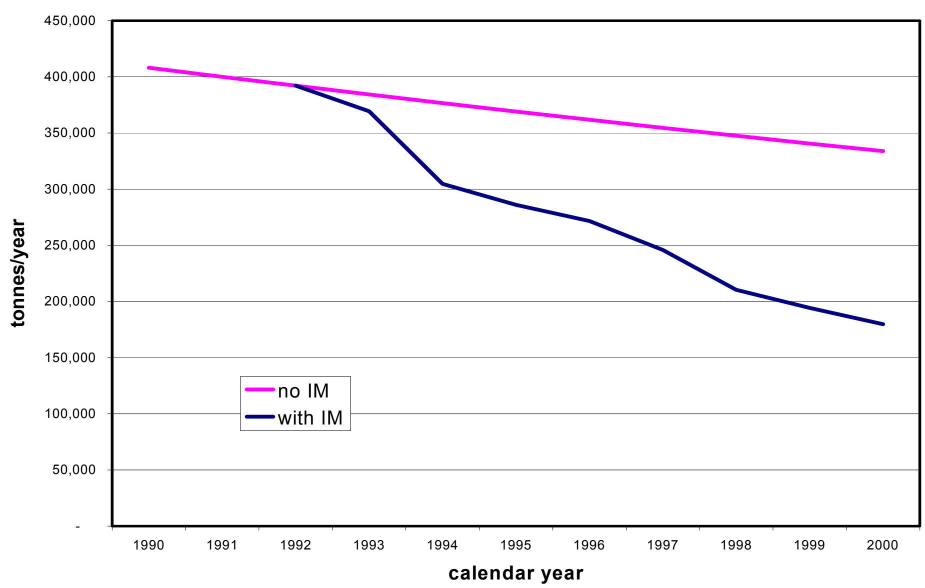


Figure 57. LFV Light Duty Vehicle CO Emission Inventory (tonnes)

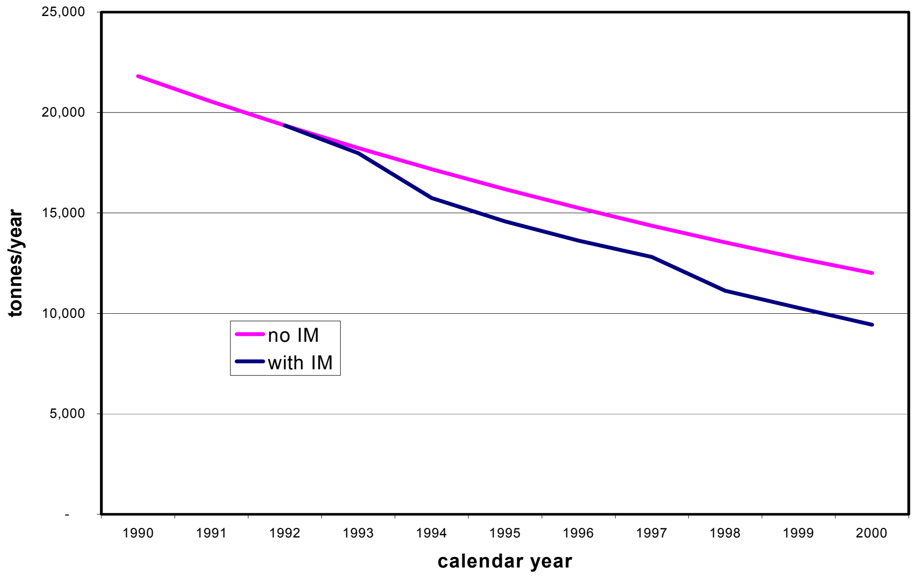


Figure 58. LFV Light Duty Vehicle NO_x Emission Inventory (tonnes)

The sum inventory of all three emissions is shown in Table 54 and Figure 59.

Table 54. LFV Light Duty Vehicle Total Emission Inventory (tonnes)

Year	$HC+CO+NO_x$		$HC+CO/7+NO_x$	
	no IM	with IM	no IM	with IM
1990	473,515		123,638	
1991	462,284		119,370	
1992	451,366		115,276	
1993	440,750	424,124	111,349	107,488
1994	430,427	350,545	107,580	89,392
1995	420,385	327,411	103,963	82,261
1996	410,616	310,115	100,491	77,276
1997	401,110	280,458	97,157	69,676
1998	391,859	239,229	93,955	58,902
1999	382,855	220,288	90,878	53,742
2000	374,089	203,174	87,922	49,053

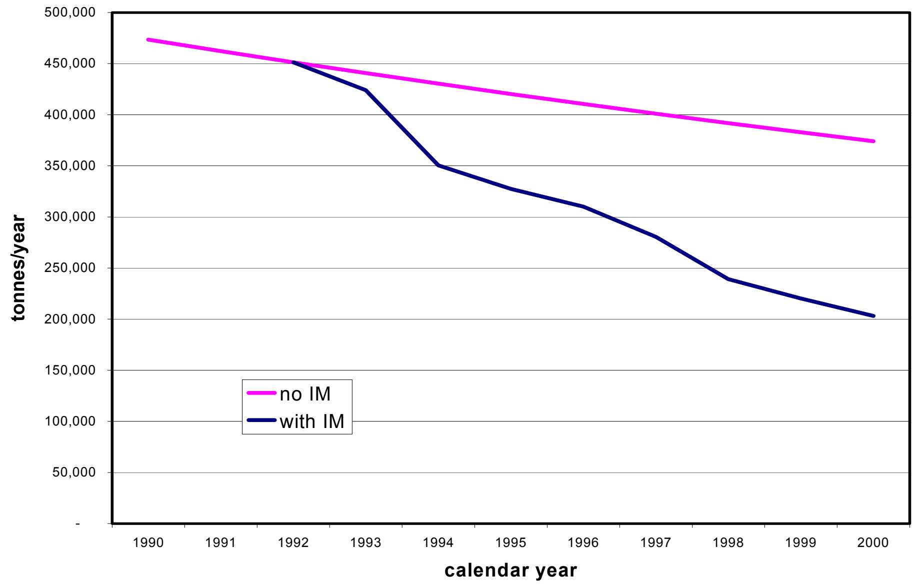


Figure 59. LFV Light Duty Vehicle Total (HC + CO + NO_x) Emission Inventory (tonnes)

9.9 FUEL CONSUMPTION BENEFITS AND GREENHOUSE GAS REDUCTIONS

The belief that fuel consumption improvements are always a natural consequence of good emission repairs still appears to be common. The Five-Year AirCare Review, published in 1998, dedicated some effort to describing cases where emission repairs typically do reduce fuel consumption; and also, in contrast, to types of repair that usually make fuel consumption worse. From the available data at the time, an average improvement for the vehicles in the Mass Emission Samples was 2.26%. For the sake of estimating potential fuel consumption benefits, this was applied to the entire number of failed vehicles to calculate the amount of fuel saved in a year, and the equivalent reduction in carbon dioxide emissions. However, the main intention was to demonstrate that there is only weak correlation between good emission repairs and improved fuel economy.

The Mass Emission Samples are now much larger. A new analysis has been undertaken using 880 vehicles for which both before-repair and after-repair fuel consumption data was available. This report will not present detail of how fuel economy was affected by which types of repair. Figure 60 shows the distribution of percentage reduction in fuel consumption as a result of repair. The mean improvement was 1.102%, but the standard deviation is 9.613%, and the distribution is very close to normal (random) . Each vertical bar includes vehicles from each of the technology groups which were defined with respect to emission control. There is no apparent difference in the distributions for the groups. This chart clearly demonstrates the weak correlation between emission repair and fuel consumption benefits.

If the mean fuel consumption improvements by technology groups from MES 1&2 are applied across all emission repairs, and are combined with annual mileages as used in the mass emission reduction calculations, and typical nominal fuel consumption figures, a figure for potential annual fuel savings can be calculated. This would amount to almost 1.7 million litres of gasoline saved in program year eight, which would have produced almost four million kg of carbon dioxide.

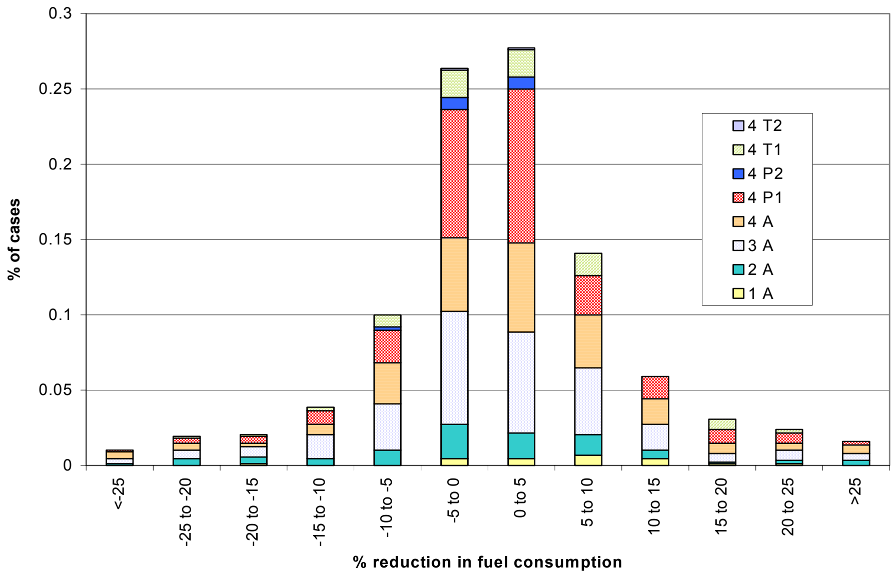


Figure 60. Reduction in Fuel Consumption as a Result of Repairs (880 Cases from MES 1&2)

It must be emphasised that the AirCare program is aimed at regulated emissions. Any fuel consumption benefits, or carbon dioxide emissions reductions, are entirely incidental. The data we have available so far indicates that average fuel consumption benefits are small and that for individual repairs the actual change in fuel consumption can range from significantly worse to significantly better. Much more data, and a more detailed analysis, would be required to characterise the actual fuel consumption of the in-use fleet, to compare its degradation to manufacturers original specifications, and to examine how it is affected by the AirCare inspection and maintenance program. One particular focus of this analysis would be on repairs that appear to increase fuel consumption. Most emission-related defects would not normally be expected to improve fuel economy, so repairs should not normally cause a disbenefit. It seems likely that those repairs which did increase fuel consumption may also have been ineffective in terms of reducing regulated emissions. Measurement errors must also be considered. The mass emission tests from which the present analysis has been derived, only report fuel consumption to a precision of 0.1 litres/100km. This figure happens to be about 1% of a average vehicle's fuel consumption, and therefore casts some doubt on the precision with which benefits, of the same magnitude, can be reported.

APPENDICES

A. References

B. Test Procedure for AirCare ASM 2525/Idle/2500 rpm Test

C. AirCare Emission Standards

D. Mathematical Comparison of Evaluation Methods

A. References

1 “The Used Vehicle Market in Canada” DesRosiers Automotive Consultants Inc., December 2000

2 “Playing with Fire. Science and Politics of air Pollution from Cars” D.H. Stedman, University Lecture, University of Denver, March 29, 1995. http://www.du.edu/news/Univ_Lecture/ULECTscience.html

see also Smog Check Program, Bureau of Automotive Repair, California. http://smogcheck.ca.gov/000001.htm

3 “Canadian Vehicle Survey” Transport Canada, Canadian Council of Motor Transport Administrators, Statistics Canada, Quarter 2, 2000,

4 “A Study of Mileage Accumulation rates of Light-Duty Vehicles in the Lower Fraser Valley” S.J. Stewart, SAE 961702

5 “Evaluating vehicle Emissions Inspection and Maintenance Programs” National Academy Press, 2001

6 "Rejection of Smoking Vehicles at AirCare Inspection Centres" S.J.Stewart July 2000, available on request

7 “British Columbia Vehicle Emissions Inspection and maintenance Program: Effectiveness of Repairs” Sam Loo, Stephen Stewart, David Gourley, SAE 950482

8 “Repair Effectiveness Indices for the British Columbia Vehicle Emissions Inspection and Maintenance Program” Stephen Stewart, Sam Loo, SAE 961700

9 “Guidance on Use of Remote Sensing for Evaluation of I/M Program Performance” Jim Lindner, EPA, draft July 2001

10 “Guidance on Use of In-Program Data for Evaluation of I/M Program Performance” Jim Lindner, EPA, draft August 2001

B. Test Procedure for AirCare ASM 2525/Idle/2500 RPM Test

1. The vehicle registration number is entered by the inspector. The vehicle's fuel type is determined from the registration. The vehicle type is identified and emissions control system (ECS) inspection, if applicable, is performed. If the vehicle fuel type is "D"(diesel), the system will automatically select the diesel opacity test.

2. Is the vehicle a 2 wheel drive or selectable 4 wheel drive (i.e. capable of operating in 2WD mode?) Y or N? If N, test vehicle according to 2 speed idle test procedure - do not operate on the dynamometer or driveline damage will occur. If system is a selectable type, ensure it is in 2WD mode.

3. If Y, have customer drive vehicle forward, placing vehicle drive wheels between the rollers on the dynamometer. Instruct the driver/customer to exit the vehicle and step into the booth containing the exhaust analysis equipment. (If Handicapped, can be overridden for 2 speed idle test)

4. Place wheel chocks in front of the non-drive wheels. Permit ample room for dyno wind up.

5. Place stone guards behind the vehicle to protect against stones or other objects flying out from the tire tread during dynamometer operation. Strategic placement of the stoneguards also creates a deflector to direct exhaust gases into the floor exhaust grates.

6. The dynamometer horsepower setting is automatically calculated using the formula: (Net Weight (lbs.) + 300)/300. Net weight is taken from the vehicle registration document and should approximate the weight of the vehicle with no passengers or payload but with a full fuel tank (i.e. curb weight). Example: a vehicle with a net weight of 2700 lbs. would be tested at (2700+300)/300 or 10.0 hp.

   The horsepower calculation is performed by the lane computer and is transmitted to a second PC which controls the Mustang dynamometer. The horsepower setting is to be applied at the test speed of 40 km/hr (25 mph)

7. Insert sample probe(s) in tailpipe(s). If vehicle has dual exhaust, use two probes with a "Y" fitting such that the sample represents a combination of both exhaust pipes. The system will automatically check for the presence of a combined $CO + CO_2$ level of 6% for gasoline vehicles and 4% for natural gas vehicles. Lower values indicate an exhaust leak or major misfire and the vehicle is rejected. A satisfactory sample may be obtained by using a boot or repositioning the probe to an accessible upstream hole in the tailpipe provided it is safe to do so. If there is adequate sample, the analyzers will undergo an auto zero calibration that resets the zero reading based on the room air in the analyzer enclosure. If the system detects more than 21 ppm HC after the completion of the previous test, a "hangup Check in Progress" message appears and the system pumps fresh air out of the tailpipe probe (i.e. reverse direction to sampling) to purge any HC accumulation in the sample line. Testing cannot proceed unless the sample dilution and auto zero conditions are complied with.

8. Vehicle speed is set to 40 km/hr (±3 km/hr). After speed reaches target range, system allows 10 seconds for vehicle to stabilize before collecting sample from the tailpipe. The

readings for HC, CO and NO_x are monitored once per 1.2 second during sample collection.

In order for the test mode to terminate prior to the maximum mode time, the following conditions must be satisfied:

i) three successive readings for HC are within 20 ppm of one another, 3 successive readings for CO are within 0.20% of one another and three successive NOx readings are within 150 ppm;

ii) on 1988 and later vehicles, the stable HC readings are less than 40% of the maximum allowable, the stable CO readings are less than 25% of the maximum allowable and the stable NOx readings are less than 85% of the maximum allowable, or;

iii) on 1987 and older vehicles, the stable HC readings are less than 50% of the maximum allowable, the stable CO readings are less than 50% of the maximum allowable and the stable NO_x readings are less than 85% of the maximum allowable, or;

iv) the vehicle has operated in the target speed range for 90 seconds for 1988 and later vehicles or 60 seconds for 1987 and older vehicles

NOTE: 1988 is the model year in which Canadian emissions standards were harmonized with US 49 States levels and three way catalyst technology with feedback fuel control become the norm. 1987 and older vehicles are primarily open loop, oxidation catalyst type and are tested to quite lenient cut points.

9. Conditions 8(i) AND 8(ii) or 8(iii) must be satisfied to "Fast Pass" a vehicle. The values printed on the inspection report for a "fast-passed" vehicle are the average of the last recorded 10 HC and CO readings before test termination along with the average of the last 50 NO_x readings.

10. A vehicle which never achieves stable readings or that has emissions above the allowable maxima will continue to operate on the loaded mode test until the maximum mode time of 60 (1987 and older) or 90 seconds (1988 and newer) is reached. At this point, the average of the last recorded 10 HC and CO readings along with the average of the last 50 readings for NO_x will be printed on the inspection report.

11. Following termination of the driving portion of the test, the idle measurement is performed. The idle mode requires that the dynamometer speed be 0 km/hr and, for 1987 and older vehicles, that the engine rpm be less than 1150 rpm. The inspector is instructed to place the gear selector in PARK or Neutral. Although vehicles with automatic transmissions tend to idle in DRIVE most of the time, the test procedure requires that idle emission samples be taken in PARK or NEUTRAL (This has the minimal effect on emissions). On 1988 and later technology vehicles, idle speed is often not adjustable. Due to the difficulty in accurately measuring rpm on some new engines with distributorless ignition systems, it was felt that the likelihood of someone being able to "cheat" on the test by increasing the idle speed would be minimal and did not justify the time lost attempting to capture an accurate rpm reading on these newer vehicles.

12. Once the computer has established the conditions described above have been met, the system will wait ten seconds in order to allow the vehicle's idle emissions to stabilize. When the system is ready, sample is drawn from the tailpipe. The maximum mode time for the idle test is 30 seconds. A vehicle may "fast pass" at some time between ten seconds and thirty seconds provided that the sample readings meet the same stability criteria described for the loaded test and the readings are less than 40% of the applicable maximum allowable. NO_x emissions are not sampled during the idle mode.

13. If the vehicle passed the driving portion of the test, the exhaust measurement process is stopped after the vehicle fast passes on the idle test or at the termination of the 30 second maximum mode time. The HC and CO readings printed on the inspection report are the average of the last 10 readings taken prior to termination of the test mode.

14. If the vehicle has failed the loaded mode portion of the test for either HC or CO, the inspector is prompted to remain in the vehicle during the idle measurement so that a 2500 rpm, no load measurement can be taken after the idle test. This test mode does not carry any pass/fail standards. The information is collected to inform the repair industry of the vehicle's operating condition at the time of the test, using a test mode that they can duplicate in the repair bay. Due to the fact that most repair shops do not have dynamometers to replicate the AirCare inspection, it is important to let them know if a high HC or CO condition noted under dynamometer operation is also present at 2500 rpm with no load on the engine. If readings appear normal at 2500 rpm but are abnormally high under load, the technician will know that the problem is induced by loading the vehicle and can concentrate diagnostic checks at those systems which are load sensitive (i.e. power valve operation, MAP sensor, etc.) For 1987 and older vehicles, a tachometer is used to set engine rpm to 2500 rpm. The computer monitor prompts the inspector to depress the accelerator and increase the engine rpm until it enters the target zone which is 2200 - 2800 rpm. The mode time is 30 seconds and the readings for HC and CO printed on the inspection report are the last ones noted prior to the termination of the test. It is possible to set cut points for the high idle test, in which case there could also be a stability and fast pass routine added to the software. However, the loaded mode test is a superior method of identifying excess emitters.

Two Speed Idle Test Method Description

1. The test procedure follows the basic requirements described in 40 CFR 85.

2. The two speed idle test is used in cases where the vehicle to be tested cannot be driven on the dynamometer (i.e. the vehicle is a full-time 4WD or is physically too large to drive on the dynamometer. The emissions at 2500 rpm are measured and recorded only to confirm that adequate preconditioning took place.

3. The system instructs the inspector to connect the non-contact rpm pickup or the clamp-on inductive probe (for 1987 and older vehicles) to sense engine rpm. If the rpm signal cannot be determined, the inspector will judge the rpm "by ear" (requires manager override). The engine speed will be increased into the target zone 2200-2800 rpm or to the level deemed appropriate by the inspector in order to precondition the vehicle for the subsequent idle emissions measurement. The vehicle is held at high rpm for 30 seconds. For 1988 and newer vehicles, the 2500 rpm engine speed is provided by the vehicle's tachometer or "by ear" with no manager override.

4. After completion of the 2500 rpm preconditioning, the engine rpm is allowed to return to a free idle. Provided that the idle rpm is below 1150 rpm (1987 and older vehicles), the system will begin sampling idle emissions from the tailpipe after ten seconds. If the emission readings are stable and below the applicable cut points, the idle test is terminated and the last recorded average stable reading is printed on the inspection report. Because of the uncertainty of obtaining adequate preconditioning of the vehicle in an unloaded, high idle mode, the system has been designed to allow a second preconditioning mode if the vehicle fails the idle test. If the vehicle passes the second measurement, the old value is discarded and the passing result is printed on the inspection report. This feature was added because it would ensure that the idle failure is consistent and is observable to the repair industry. Although the failure may be a valid one caused by reduced O_2 sensor activity or other bona fide defect, the repair sector may find that extended preconditioning of the engine/catalyst will produce a passing reading and suggest to the customer that the vehicle was tested incorrectly rather than trying to fix the problem. By ensuring that the idle emissions remain high after extended preconditioning, the likelihood of getting the vehicle fixed properly is much greater.

Diesel Opacity Test (Sep 1992 to Aug 2000

1. The diesel test procedure used in British Columbia is the same as the test employed in Arizona in 1992. It requires the use of a Wager opacity meter or equivalent with a output range of 0-100% opacity.

2. All diesels must be driven to provide enough engine load to produce any smoke emissions. Diesel vehicles with all-wheel-drive cannot be tested in the AirCare network at present, however, such vehicles are very rare. All diesel vehicles eligible for AirCare comprise only about 2% of the total fleet and the all-wheel-drive fraction of this total would be less than 10%.

3. The smoke meter is also calibrated daily and manually zeroed prior to use by depressing a zero key on the display unit. The AirCare administration has purchased certified optical filters representing 8% and 20% opacity so that the units can be audited for accuracy. They have demonstrated consistent accuracy so far. Smoke emissions are somewhat possible to evaluate with the human eye. Failing vehicles can easily be identified as such because they are visibly smoky.

4. The dynamometer horsepower setting is 10.0 hp for all diesel vehicles regardless of size or weight. A ten-foot long flexible rubber hose is fitted over the tailpipe which ducts the exhaust to a small cart where the opacity meter is mounted. Each inspection station has one opacity meter cart which can be moved from lane to lane and connected to the host computer using a quick connector on a jiffy pole near the shelter where the customer waits while their vehicle is being tested. The flexible rubber hose terminates in a 3.0" diameter pipe with the opacity meter mounted over the open end. The exhaust gases from the vehicle travel through the flexible hose and past the opacity meter where the measurement is made. The vehicle is driven to a target speed of 50 plus or minus 3 km/hr. The maximum mode time is 30 seconds at which the last 5 seconds of opacity observations are averaged and recorded. A maximum allowable opacity of 20% is applied to vehicles of model year 1987 and older; 10% for model years 1988 through 1994 and 5% for model years 1995 and newer; to determine if the vehicle passes or fails.

C. AIRCARE EMISSION STANDARDS

During the summer of 1992 eleven thousand voluntary inspections were performed. The original AirCare standards were derived from the data provided by these inspections, and knowledge of the standards used in existing U.S. programs, with appropriate adjustments for Canadian specification vehicles. Fourteen cut-point categories were defined, in terms of Vehicle Type; Model Year; Engine Size, and Catalyst Type. The original standards were defined in BC MVAR 321/92 as shown in the table below.

Category	IW[a]	Model Year	Catalyst[b]	Engine Size (litres)	Idle HC (ppm)	Idle CO (%)	2500 rpm HC (ppm)	2500 rpm CO (%)	ASM2525[c,d] HC (ppm)	ASM2525[c,d] CO (%)	ASM2525[c,d] Column (A) NO_x (ppm)	ASM2525[c,d] Column (B) NO_x (ppm)
1	All	pre-1975	N	<=2.5	1500	8.0	900	7.0	500	6.50	N/A	N/A
2	All	pre-1975	N	>2.5	1500	6.5	850	4.5	500	4.50	N/A	N/A
3.1	<5250	1975-1981	N or O	<=2.5	600	6.0	400	4.0	500	3.50	7000 x 10^3 / IW[f]	2500
3.2	<5250	1982-1987	N or O	<=2.5	500	5.0	350	3.0	500	3.00	7000 x 10^3 / IW[f]	2500
5.1	<5250	1975-1981	N or O	>2.5	500	6.0	400	2.5	500	3.00	9000 x 10^3 / IW[f]	2500
5.2	<5250	1982-1987	N or O	>2.5	400	5.0	300	2.5	500	2.50	9500 x 10^3 / IW[f]	2500
7	<5250	post-1987	N or O	<=2.5	220	1.2	220	1.2	500	1.20	4000 x 10^3 / IW[f]	1500
8	<5250	post-1987	T	<=2.5	220	1.2	220	1.2	500	1.20	4000 x 10^3 / IW[f]	1500
9	<5250	post-1987	N or T	>2.5	220	1.2	220	1.2	500	1.20	6500 x 10^3 / IW[f]	1500
10	<5250	post-1987	T	>2.5	220	1.2	220	1.2	500	1.20	5000 x 10^3 / IW[f]	1500
11	>=5250	post-1974	N	All	400	5.0	380	3.0	N/A	N/A	N/A	N/A
12	>=5250	post-1974	O or T	All	300	4.0	220	2.5	N/A	N/A	N/A	N/A

a IW = Curb Weight + 300 (in pounds)
b N = None
O = Oxidation Catalyst
T = Three-way Catalyst

c ASM2525: speed = 25mph; dyno horsepower = IW + 300
d The applicable NO_x standard shall be the greater of Colunm (A) or (B)
N/A Not Applicable

In September 1995 the standards were made tighter and more closely matched to particular groups of vehicles. This required an increase to 46 cut-point categories. All the cut-point categories were defined in terms of Model Year; Engine Size; and Vehicle Type. All the new category definitions and cut-points are shown in the next table.

Minor adjustments were made in January 1996, 1997 and 1998, to keep only the newest vehicles in the strictest cut-point categories.

CATEGORY DEFINITIONS				ASM2525				IDLE		2500rpm	
Category 1(a)	Model Year 1(b)	Engine Size 1(c)	Vehicle Type 1(d)	HC (ppm)	CO (%)	NOx (A) (ppm)	NOx (B) (ppm)	HC (ppm)	CO (%)	HC (ppm)	CO (%)
1	pre 73	=<2.5	P	500	6.0	N/A	N/A	1500	7.5	500	4.0
2	pre 73	>2.5	P	500	4.5	N/A	N/A	1500	5.5	500	3.0
3	73-74	=<2.5	P	500	4.0	(8000/IW)*1000	2500	750	6.0	500	4.0
4	73-74	>2.5	P	500	3.0	(8000/IW)*1000	2500	650	5.0	500	3.0
5	75-79	=<2.5	P	400	3.0	(7000/IW)*1000	2500	450	5.0	400	3.0
6	75-79	>2.5	P	350	2.5	(7000/IW)*1000	2500	400	4.5	350	3.0
7	80-87	=<1.8	P	300	3.0	(8000/IW)*1000	2500	350	4.0	300	2.0
8	80-87	>1.8 =<2.6	P	300	2.0	(9000/IW)*1000	2500	350	4.0	300	2.0
9	80-87	>2.6 =<4.0	P	200	1.5	(7000/IW)*1000	2500	300	3.5	200	1.5
10	80-87	>4.0 =<6.0	P	150	1.0	(7000/IW)*1000	2000	300	3.5	150	1.5
11	80-87	>6.0	P	150	1.0	(7000/IW)*1000	2000	300	3.5	150	1.5

12	88-91	=<1.8	P	100	1.0	(4000/IW)*1000	1500	130	1.1	100	1.0
13	88-91	>1.8 =<2.6	P	90	0.9	(3500/IW)*1000	1200	120	1.0	90	0.9
14	88-91	>2.6 =<4.0	P	85	0.7	(3500/IW)*1000	1000	105	0.8	75	0.7
15	88-91	>4.0 =<6.0	P	85	0.5	(3500/IW)*1000	850	90	0.6	60	0.5
16	88-91	>6.0	P	85	0.5	(3500/IW)*1000	850	90	0.6	60	0.5
17	92 +	=<1.8	P	85	0.5	(3500/IW)*1000	1500	90	0.6	60	0.5
18	92 +	>1.8 =<2.6	P	75	0.4	(3500/IW)*1000	1000	80	0.5	50	0.4
19	92 +	>2.6 =<4.0	P	75	0.3	(3500/IW)*1000	850	80	0.4	50	0.3
20	92 +	>4.0 =<6.0	P	75	0.3	(3500/IW)*1000	850	80	0.4	50	0.3
21	92 +	>6.0	P	75	0.3	(3500/IW)*1000	850	80	0.4	50	0.3
22	pre 73	=<2.5	LDT	500	6.0	N/A	N/A	1500	7.5	500	4.0
23	pre 73	>2.5	LDT	500	4.5	N/A	N/A	1500	5.5	500	3.0
24	73-74	=<2.5	LDT	500	4.0	(8000/IW)*1000	2500	750	6.0	500	4.0
25	73-74	>2.5	LDT	500	3.0	(8000/IW)*1000	2500	650	5.0	500	3.0
26	75-79	=<2.5	LDT	400	3.0	(7000/IW)*1000	2500	450	5.0	400	3.0
27	75-79	>2.5	LDT	350	2.5	(7000/IW)*1000	2500	400	4.5	350	3.0
28	80-87	=<1.8	LDT	300	3.0	(8000/IW)*1000	2500	350	4.0	300	2.0
29	80-87	>1.8 =<2.6	LDT	300	2.0	(9000/IW)*1000	2500	350	4.0	300	2.0
30	80-87	>2.6 =<4.0	LDT	200	1.5	(7000/IW)*1000	2500	300	3.5	200	1.5
31	80-87	>4.0 =<6.0	LDT	150	1.0	(7000/IW)*1000	2000	300	3.5	150	1.5
32	80-87	>6.0	LDT	150	1.0	(7000/IW)*1000	2000	300	3.5	150	1.5
33	88-91	=<1.8	LDT	200	1.5	(4000/IW)*1000	1500	260	2.2	200	2.0
34	88-91	>1.8 =<2.6	LDT	200	1.5	(4000/IW)*1000	1500	240	2.0	200	2.0
35	88-91	>2.6 =<4.0	LDT	200	1.0	(4000/IW)*1000	1400	210	1.6	200	1.0
36	88-91	>4.0 =<6.0	LDT	150	1.0	(4000/IW)*1000	1200	180	1.2	150	0.8
37	88-91	>6.0	LDT	150	1.0	(4000/IW)*1000	1000	180	1.2	150	0.7
38	92 +	=<1.8	LDT	200	1.5	(4000/IW)*1000	1500	180	1.2	200	2.0
39	92 +	>1.8 =<2.6	LDT	120	0.8	(4000/IW)*1000	1200	160	1.0	120	1.0
40	92 +	>2.6 =<4.0	LDT	100	0.6	(4000/IW)*1000	1000	160	0.8	100	0.5
41	92 +	>4.0 =<6.0	LDT	100	0.6	(5000/IW)*1000	1000	160	0.8	100	0.5
42	92 +	>6.0	LDT	100	0.6	(5000/IW)*1000	1000	160	0.8	100	0.5
43	pre 75	All	HDT	500	3.0	N/A	N/A	1500	6.0	500	3.0
44	75-79	All	HDT	400	2.5	N/A	3600	500	4.5	400	3.5
45	80-87	All	HDT	300	2.0	N/A	3600	400	3.0	300	2.0
46	88 +	All	HDT	150	1.0	N/A	3000	250	2.5	150	1.5

ASM 2525: Speed = 25 mph; dyno horsepower = IW/300

The applicable NOx standard shall be the greater of Column (A) or (B)

HC = Hydrocarbons

CO = Carbon monoxide

NOx = Oxides of nitrogen

IW = Curb weight + 300 (in pounds)

P = Passenger car

LDT = Light duty truck (pre-88, =<6000 lbs GVWR)
(88+, =<8500 lbs GVWR)

HDT = Heavy duty truck (pre-88, >6000 lbs GVWR)
(88+, >8500 lbs GVWR)

(%) = Percentage by volume

(ppm) = Parts per million by volume

GVWR = Gross Vehicle Weight Rating

N/A = Not Applicable

The intent of the changes made in September 2000 was not primarily to make the cut-points tighter. The intention was to make them very specific by Vehicle Type; Model Year; Engine Size and Vehicle Weight. Each combination of these factors now has a specific set of cut-points. For ASM 2525 cut-points a change was made from Engine Size as a determining factor, to Vehicle Weight. Vehicle Weight more validly reflects how tailpipe concentrations are affected by driving operation. The new standards are defined in BC MVAR 274/2000, and can be accessed on the www.aircare.ca website, but are not reproduced here.

D. MATHEMATICAL COMPARISON OF EVALUATION METHODS

Calculation of Percentage Reduction in Year, as a Result of Repairs

Each vehicle is assigned gram/km emission factors for HC, CO and NOx, which depend on the vehicle type; its model year; and its initial inspection readings.

Vehicles which are repaired are also assigned final gram/km emission factors which depend on final inspection readings.

All emission factors are derived from mass emission testing data.

Each vehicle is also assigned km/year annual mileage factors which depend on the vehicle type, and its model year.

Then:

% Reduction as a Result of Repairs = 100 x (S - F) / S

where

S = fleet emission rate at start of year

F = fleet emission rate at end of year

The units of **S** and **F** are tonnes/year. They are rates, not annual totals.

$$\mathbf{S} = \sum_{\text{passing vehicles}} \text{g/km} \times \text{km/year} + \sum_{\text{failing vehicles}} \text{g/km} \times \text{km/year} + \sum_{\text{exempt vehicles}} \text{g/km} \times \text{km/year}$$

and

$$\mathbf{F} = \sum_{\text{passing vehicles}} \text{g/km} \times \text{km/year} + \sum_{\text{repaired vehicles}} \text{g/km} \times \text{km/year} + \sum_{\text{exempt vehicles}} \text{g/km} \times \text{km/year}$$

Cumulative emission reductions

The present method of evaluating the overall cumulative emission reductions over eight years, consists simply of re-evaluating **S** each year. Thus the total reduction, from all causes, from year zero to any chosen year, **y**, is equal to $\mathbf{S_0}$-$\mathbf{S_y}$. The result is not the same as would be obtained by adding all the annual reductions due to repairs, because there are many other factors which need to be taken into account. These include inventory reductions due to retirement of older vehicles, increases by addition of new vehicles, residual benefits from repairs performed in previous years.

This approach requires that each years inventory not be assessed until the end of the year. The previous approach sought to predict the next years inventory from the reduction model of the present years repairs, and by making appropriate assumptions about the residual benefits of previous repairs, and inventory reductions due to fleet turnover. The following is a simplified mathematical statement of this previous approach, and is presented to illustrate how any inaccuracy these assumptions will cause the evaluation to drift a little more each year.

Previous Cumulative Model

$\mathbf{I_0}$ = initial inventory at start of IM program
$\mathbf{I_y}$ = inventory in year y
$\mathbf{R_y}$ = reduction in year y, due to IM program
$\mathbf{T_y}$ = reduction in year y, due to fleet turnover
t = % reduction due to fleet turnover
r = % reduction due to IM program
d = % of repair benefit still present in next year

With an IM program

$$I_y = I_0 - T_{y-1} - R_{y-1} - T_{y-2} - d^2 . R_{y-2} - T_{y-3} - d^3 . R_{y-3} \ \ldots\ldots$$

where $T_y = I_y . t$

$R_y = I_y . r$

and for illustration **t**, **r** and **d** remain constant

Thus:

$$I_1 = I_0 - T_0 - R_0$$

$$I_2 = I_0 - T_1 - R_1 - T_0 - d.R_0$$

$$I_3 = I_0 - T_2 - R_2 - T_1 - d.R_1 - T_0 - d^2.R_0$$

$$I_4 = I_0 - T_3 - R_3 - T_2 - d.R_2 - T_1 - d^2.R_1 - T_0 - d^3.R_0$$

……..

Without IM program

$$I_y = I_0 - T_{y-1} - T_{y-2} - T_{y-3} \ \ldots..$$

where $T_y = I_y . t$

thus, if **t** remains constant: $I_1 = I_0 (1-t)$

$I_2 = I_0 (1-t)^2$

….

$I_y = I_0 (1-t)^y$