



MOTOR VEHICLE POLLUTION IN AUSTRALIA

Report on the National In-Service Vehicle Emissions Study

prepared by the

Federal Office of Road Safety

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Tel: +61 6 274 7111

Fax: +61 6 274 6721

GPO Box 594

Canberra City

ACT 2601

Australia

A BRIEF NOTE FROM THE FORS PROJECT TEAM

This report is the culmination of two years' hard work by a great bunch of people.

We all hear a lot of talk about the need for cooperation between governments, industry and business. This project shows what good cooperation can achieve.

In 1991, FORS started to gauge what level of interest might exist for a project that would get to grips with car pollution in Australia. The initial response was most heartening.

When we came forward with concrete proposals, the reaction from all quarters was overwhelming. Virtually every organisation we approached offered support by way of people, services or products. Overall, our budget was boosted by several hundred thousand dollars through their generosity and enthusiasm.

As well as the visible contributions, everyone who became involved in the project - laboratory staff, mechanics, industry bodies, motoring clubs, contractors and the people from other State and Federal government bodies - all worked long and hard, often behind the scenes, to make this project happen.

To all of you, our heartfelt thanks.

Peter Anyon

Deborah Jones

Jon Real

Robert Jamieson

ACKNOWLEDGMENTS

The FORS Project Team wishes to acknowledge the considerable support given by a number of organisations over the duration of the NISE Study. Particular thanks are extended to the following contributors:

- the 600 householders who entrusted their private vehicles to the emissions laboratories for testing;
- DASFleet, for providing new-model 'replacement' vehicles at nominal rates for use by the private owners who agreed to let us test their cars;
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- General Motors-Holden's Automotive Ltd;
- Mitsubishi Motors Australia Ltd;
- Toyota Motor Corporation Australia Ltd
- all of whom donated late-model 'replacement' vehicles;
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- RACV Ltd, for providing motor vehicle mechanics to tune and repair, free-of-charge, all vehicles tested in Victoria; for the provision of roadside service coverage for all 'replacement' vehicles being driven in Victoria; and for the loan of child safety restraints for use in 'replacement' cars;
- the 6000 householders residing in Sydney and Melbourne who responded to the Study questionnaire;
- members of the Study Advisory Group who contributed their time, expertise and enthusiasm to the project.

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EXECUTIVE SUMMARY

INTRODUCTION

In recent years motor vehicle pollution levels in Australia have been reduced through the progressive introduction of increasingly stringent standards for exhaust emissions from both petrol and diesel engines.

But tighter standards for new vehicles address only one aspect of the problem. Once in service, vehicles can gradually deteriorate and, inevitably, some will be subject to abuse and tampering.

For these reasons, environmental planners have long suspected that the key to achieving acceptable air quality goals lies as much with ensuring that vehicles are well maintained as it does with introducing tighter new vehicle standards.

This issue has recently gained some prominence as regulators begin to understand that the current trend towards cleaner air may be reversed within the coming decade. Increases both in car usage and in the total vehicle population will start to outweigh the benefits of tighter standards unless more is done to control emissions.

One of the difficulties in establishing programs to manage pollution from cars, after they have entered service, has been an acute shortage of data on the emission characteristics of Australia's vehicle population, and on the extent to which pollution control systems deteriorate over time.

To address this shortcoming, the Federal Government allocated \$1.75 million to the Federal Office of Road Safety to undertake a comprehensive study on the emissions performance of Australia's current passenger car fleet.

The National In-Service Emissions (NISE) study commenced in May 1994 and was completed on time, on budget in April 1996.

OBJECTIVES OF THE STUDY

The principal objectives of the Study were to:

- estimate the total emissions of the current passenger car fleet, and of specified sub-sets of the fleet, before and after tuning
- assess the extent of emission control system deterioration and failure
- assess the emission performance of vehicles with reference to their original requirements
- identify the likely causes of vehicles' poor emissions performance
- assess the potential for reductions in emissions from the in-service fleet from regular maintenance/repair
- assess the need for inspection programs including the effectiveness and relative cost of a range of possible tests and inspections aimed at identifying high-polluting vehicles
- establish a statistical base for projecting future emission levels of passenger cars.

METHODOLOGY

The Study is based on a comprehensive program of standardised tests performed on a total of 640 privately owned passenger cars; conducted in specialist emission laboratories in Sydney and the Melbourne area.

Tests ranged from the most complex and time-consuming certification-level protocols down to the simplest checks which can be done with minimal equipment at the local repair shop.

The main test sample comprised some 540 cars from the 1980-91 age group and were sourced via a random survey of householders in the Sydney and Melbourne metropolitan areas, using a robust statistical sample design.

Each vehicle was tested both in its "as delivered" condition, and then again after tuning and minor repairs to the fuel and ignition systems.

Exhaust emissions of hydrocarbons (HC), carbon monoxide (CO) and oxides of nitrogen (NO_x) were measured for all vehicles. Evaporative hydrocarbon emissions were also measured for around 40% of the tested vehicles.

Additional smaller sets of vehicles were also subjected to the same testing regime as the main set. These groups included

old (1970-1979) models, newer (1992-1993) models and cars with modified engines.

All testing was done using test fuels with consistent specifications (one leaded, one unleaded) which were drawn from normal "summer grade" commercial production and drummed for use over the duration of the project.

Around 300 data items were collected on each vehicle tested. In addition, a considerable amount of information on travelling and maintenance patterns was collected from the 6000 households also surveyed as part of the project.

Overall, this study represents the most comprehensive vehicle emissions research ever undertaken in Australia.

Note: Cars tested in the NISE study fall into two distinct groups that are generally treated separately when analysing test data:

- (a) Vehicles manufactured after January 1986 were built to comply with Australian Design Rule ADR 37/00 and run only on unleaded petrol. They generally have computer-controlled engine management systems, fuel injection, and are fitted with catalytic converters.
- (b) Cars made between 1974 and 1986 were designed to meet the less stringent ADR 27 and run on leaded petrol, do not have catalytic converters and generally have carburettors rather than fuel injection systems.

KEY FINDINGS

DETERIORATION IN EMISSIONS PERFORMANCE

At first sight, overall emission levels from Australia's cars appear to be quite good in comparison with the standards to which they were originally designed (See Figures (i) and (ii)). These highly aggregated charts should be used with great caution, however, as they mask a lot of important factors. Closer inspection shows that there are many areas for potential improvements and some of great concern.

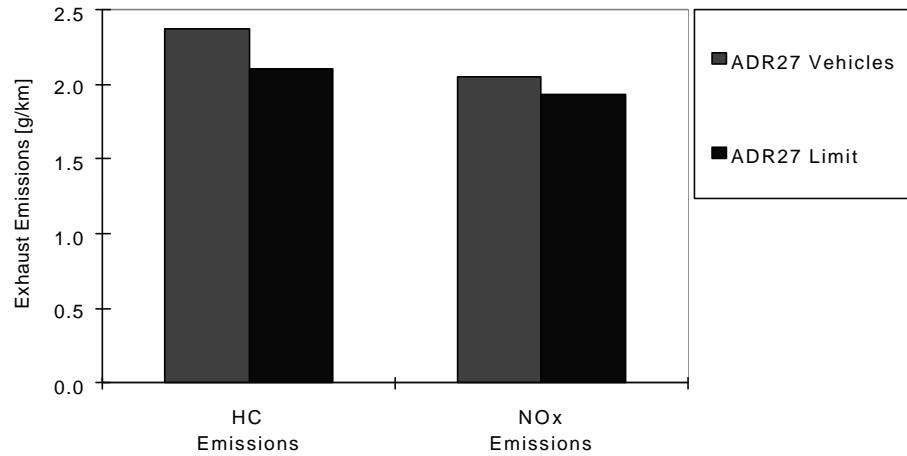


Figure (i) Average 1980-1985 Car Emissions (HC & NOx) vs ADR 27 Limits

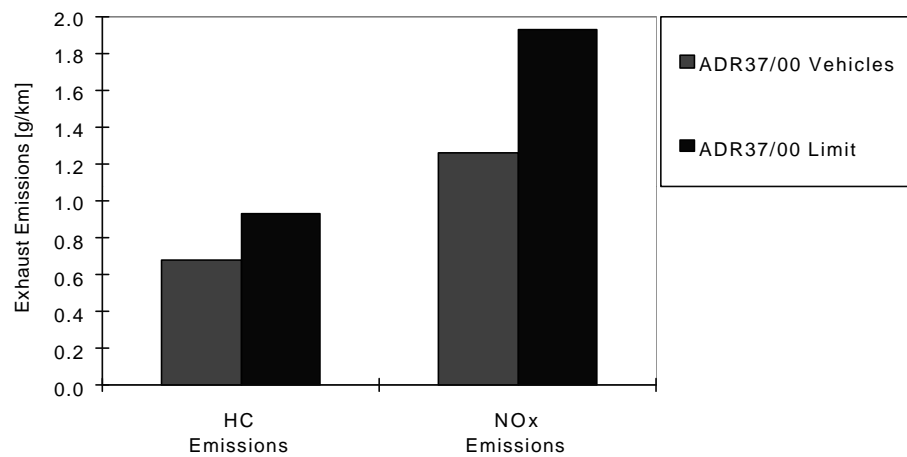


Figure (ii) Average 1986-91 Car Emissions (HC & NOx) vs ADR37/00 Limits

Not surprisingly, there is clear evidence that exhaust pollution levels from cars increase with age and kilometres travelled. This deterioration, however, varies widely among individual vehicles.

Embedded in the general picture are several interesting findings:

- all cars up to 10 years old are fitted with catalysts, yet very few (less than 4%) had catalysts which were identified as totally non-operational
- most ADR37/00 cars still complied with the exhaust emission limits after the 80,000km mark nominated in the ADRs (this is not the case with evaporative emissions)

- catalyst equipped vehicles can have emission levels just as high as non-catalyst vehicles, and the worst catalyst equipped vehicles exceed the ADR limits by a wide margin.

Modern cars rely heavily on “active” systems to control pollution levels (catalytic converters, on-board computers and sensors, etc). From data collected in the NISE project, it appears that these vehicles tend, on average, to deteriorate at a greater rate than older, pre-catalyst vehicles, whose emission levels were more dependent on intrinsic design features. Figures (iii) and (iv) illustrate this point for hydrocarbon emissions.

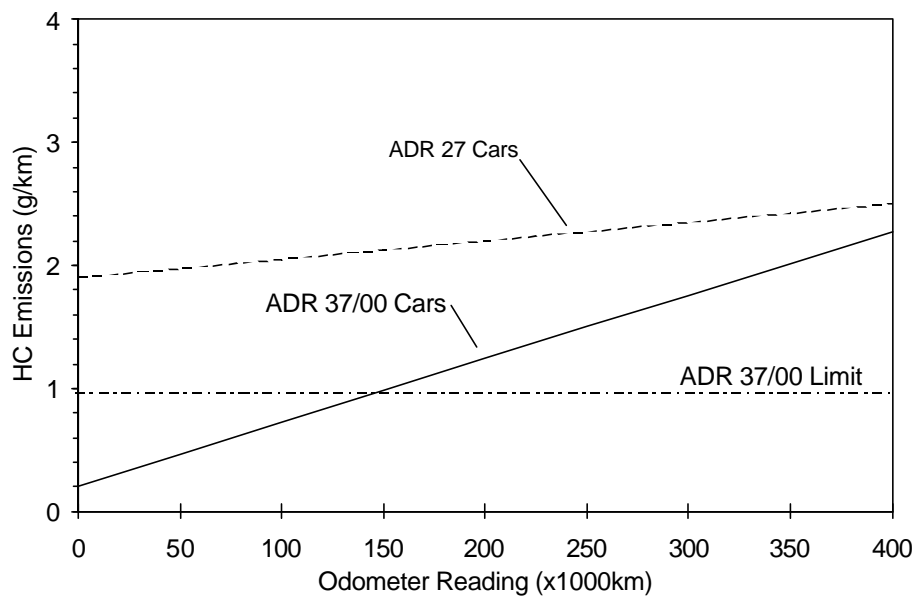


Figure (iii) Hydrocarbon Emissions by Odometer Reading (linear fit)

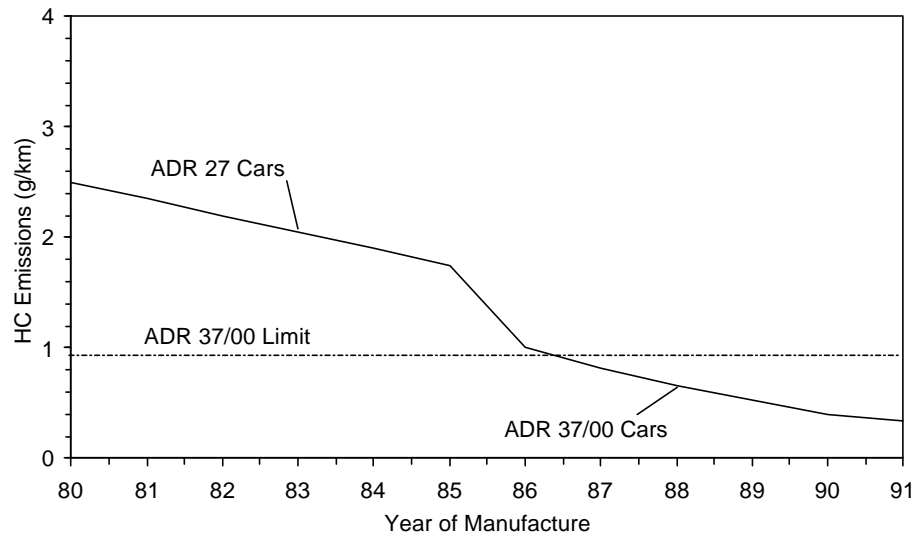


Figure (iv) Hydrocarbon Emissions by Year of Manufacture (smoothed data)

As a result, while new vehicles start from a much lower base, their higher deterioration rates could mean that the advantages of tighter new car standards may not be sustained in the longer term unless steps are taken to keep these cars in good condition.

Moreover, with even tighter standards and, possibly, extended durability requirements already on the horizon, manufacturers may be facing a considerable technological challenge to build vehicles that will continue to meet future standards for the duration of their service life.

DISTRIBUTION OF POLLUTION BY VEHICLE AGE

By combining, for each year of manufacture:

- (a) the average emissions of the group,
- (b) the number of cars in the group and
- (c) average annual kilometres travelled by cars in that group, then the relative (and absolute) contribution of each age group of cars to total pollution levels can be calculated.

Cars 10 to 16 years old currently dominate the pollution scene for hydrocarbon (HC) and carbon monoxide (CO) tailpipe emissions. This phenomenon was less evident for oxides of nitrogen (NO_x). Figure (v) illustrates the distribution of annual hydrocarbon tailpipe emissions for Australia.

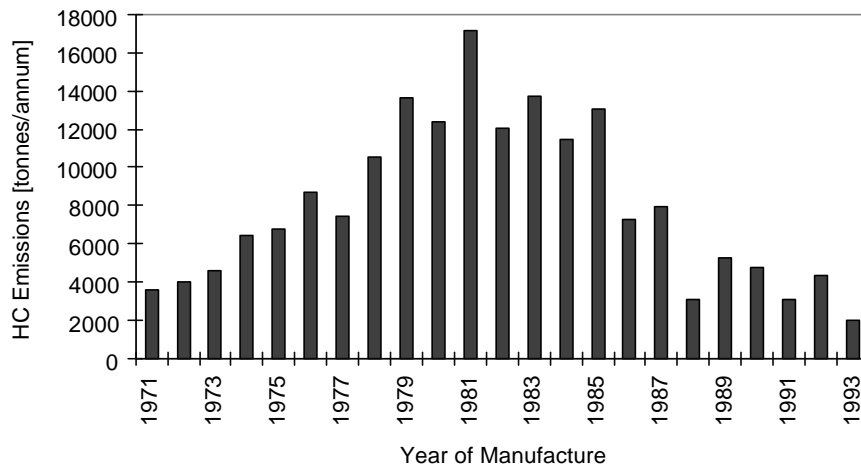


Figure (v) Example - Total Annual HC Exhaust Emissions by Model Year (All Australia)

Cars in the middle age group tend to stand out because they:

- (a) have fairly high average emissions;
- (b) are still driven fairly intensively; and
- (c) are still very numerous because of Australia's extremely low fleet turnover rate.

Newer cars, while accounting for higher average annual travel, have generally low average emissions provided they are well maintained.

However, given the elevated deterioration rates observed in catalyst equipped vehicles, it is possible that cars in this group may become a significant problem as they get older unless steps are taken to maintain the functionality of their emission control systems.

Older vehicles tend to have rather high individual emission levels, but contribute a diminishing amount to total pollution levels because of the generally low annual distances travelled by this group.

No group can be totally discounted, however, as individual vehicles in all groups were found to emit extremely high levels of pollution (up to 100 times typical new car levels) and these should be rectified regardless of age or usage.

EVAPORATIVE EMISSIONS

In the past, regulators and researchers have tended to focus on what comes out of the exhaust pipe. The NISE project has raised a number of serious concerns about “real world” levels of evaporative emissions.

These concerns relate both to the relevance of current test procedures (particularly the certification test fuel) and to the durability of evaporative emission control systems fitted to cars.

Using the NISE test fuel, which is typical of summer grade commercial gasoline, evaporative emission levels were found to be many times the maximum permitted ADR levels.

Even modern ADR 37/00 vehicles tested in the main sample had evaporative emissions that averaged four times the ADR limit. (See Figure (vi).)

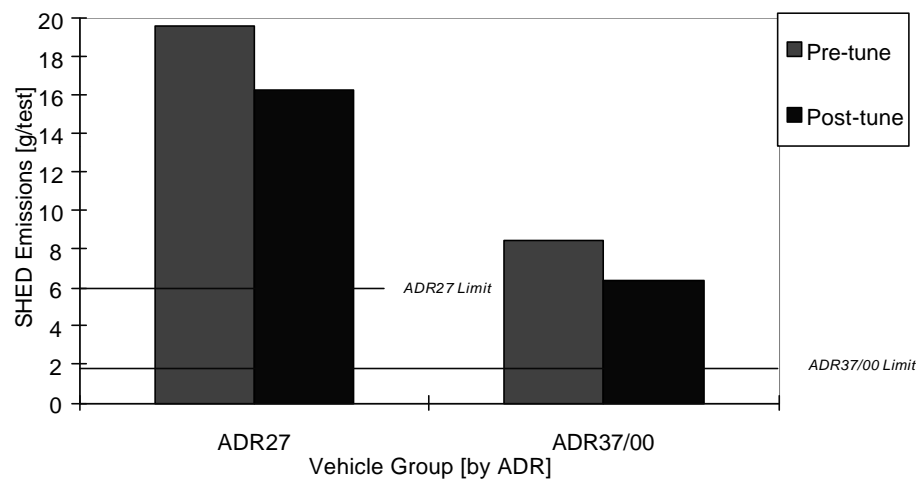


Figure (vi) 1980-91 Vehicles - Average Evaporative HC Emissions (pre & post tune)

The reasons for this are not entirely clear, but certainly the substantial difference in vapour pressure between certification test fuel and typical pump petrol (used in the NISE study) plays a major role.

In limited back-to-back tests using both certification test fuel and the NISE test fuel on a small group of cars, recorded emission levels were consistently much higher for the NISE fuel.

Some commentators have suggested that the activated charcoal in a car's vapour collection canister becomes contaminated by oil fumes or other residues in a relatively short time, greatly reducing the adsorption capacity of the charcoal canister.

The durability of fuel filler cap seals also appears to have a significant influence on the pressure integrity of cars' fuel systems. Replacement of the fuel filler cap on those cars with high evaporative emissions had a marked effect on test results.

In view of the above findings, some fundamental re-calibration may be required in some computer models used to predict airshed pollution.

The high levels of evaporative emissions found in the NISE study should be a cause of concern to regulators, the oil industry and the vehicle manufacturing industry alike.

Footnote: The Federal Government is already funding a complementary study into evaporative emissions, which may shed further light on the causes of high evaporative emissions, and may lead the way towards possible solutions.

POTENTIAL FOR EMISSION REDUCTIONS

EFFECT OF TUNING AND MAINTENANCE ON TAILPIPE EMISSIONS

The results of testing done in the NISE study clearly demonstrate that substantial reductions in pollution levels can be achieved through good maintenance practices.

The overall levels of improvement are tabulated below:

Average Reductions in Emissions from Tuning and Maintenance

	<i>All Cars in Study</i>	<i>ADR27 Cars</i>	<i>ADR37/00 Cars</i>
HC	16%	14%	21%
CO	25%	26%	24%
NOx	9%	8%	9%

However, the gains are not uniformly distributed, with most of the available improvements coming from a relatively small proportion of the total car population.

Typically, around 80% of the total emissions reductions available from tuning were delivered by only 20% of the cars in the NISE study sample (Figure (vii)).

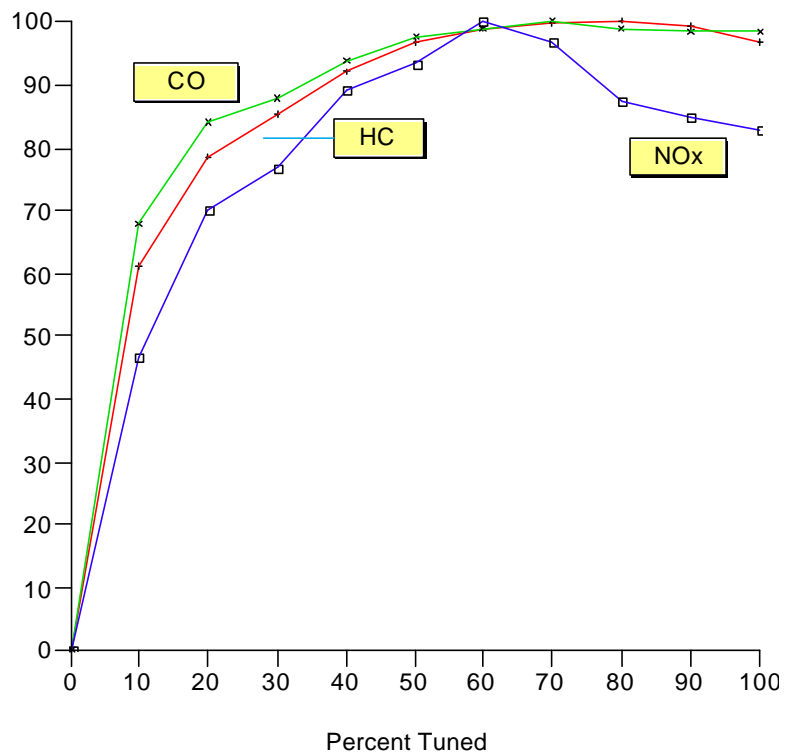


Fig (vii) Effect of Identifying and Rectifying the Worst Emitters - 1986-91 Cars.

Given this finding, one of the key policy issues to be faced by regulators in considering options for emission reduction programs will be whether to:

- (a) subject all vehicles to an inspection and maintenance regime;
- (b) only include pre-defined groups selected by age, kms travelled, etc; or
- (c) target vehicles to be included by some filtering mechanism such as remote sensing or a short test.

The choice of approach will effect the cost-effectiveness of any future programs.

EFFECT OF TUNING ON EVAPORATIVE EMISSIONS

The extremely high evaporative emission test results indicate that the current regime for controlling these emissions is not working in practice, particularly as it appears that emissions can often be substantially reduced by replacing key components.

Those cars with very high evaporative emissions tended to respond strongly to the fitment of a new, properly sealing fuel filler cap.

Because of cost constraints, only a small sub-set of six cars had a new charcoal canister fitted. All six showed a dramatic decrease in emissions with the new canister: some by a factor of seven or more. (Readers should note, however, that the statistical validity of this finding is limited by the small sample size).

The Study's findings suggest that the issue of testing and design for evaporative emissions should be reviewed. The complementary study already underway on this issue may assist in resolving some of the questions raised in the NISE study.

WHAT ABOUT STANDARDS FOR NEW VEHICLES?

Deterioration trends identified by the NISE research clearly show that tighter new standards are only of lasting value if vehicles are maintained in such a way as to retain, so far as possible, new car performance. The data also suggest that modern vehicles deteriorate at a faster rate than older cars.

One could argue, therefore, that tighter new car standards have actually increased rather than diminished the need for in-service maintenance programs.

It should also be appreciated that, because of Australia's extremely low vehicle turnover and scrappage rates, the effects of changes to new car standards take many years to significantly penetrate the fleet.

To illustrate this point, the project team calculates that, in one year, **tuning the existing car population would achieve a reduction in HC emissions ten times greater than would be achieved by requiring all new cars sold in 1997 to be zero emission vehicles!**

EFFECTIVENESS OF SHORT TESTS IN IDENTIFYING HIGH POLLUTERS

INTRODUCTION

To demonstrate compliance with the relevant ADRs, exhaust emissions are measured using a rolling road (*chassis*) dynamometer capable of simulating engine load / speed conditions similar to those typically found in city driving conditions.

By “driving” the car on the dynamometer to a pre-determined and tightly controlled cycle of acceleration, cruise and braking together with idle periods to simulate stationary traffic periods, an accurate and repeatable measurement of exhaust emissions can be made. Several such test cycles are used around the world.

The ADRs (in common with the US Federal Emission Standards) require that certification testing be done using the **FTP (Federal Test Procedure)** cycle, which simulates driving a distance of about 15km at speeds up to 94km/h. This is the **baseline test** cycle used in the FORS study as it allows a direct comparison of a vehicle’s current exhaust emissions performance with the levels it had to meet when new.

A long-standing goal for governments seeking to reduce vehicle pollution has been to develop a short test that reliably identifies high polluting vehicles.

Ideally, such a test would have the following characteristics:

- good correlation with certification test results
- ability to identify those cars whose emissions will be most reduced by tuning
- take only a few minutes to perform
- cost no more than, say, \$30 on a commercial basis
- preferably be capable of being done at distributed or roadside locations as well as in centralised facilities.

To address the above, a number of short tests of varying simplicity have been developed in recent years. All vehicles in the NISE study were tested using all the available short tests both prior to and after tuning. These tests were:

IM-240 - Modified IM240 (Inspection & Maintenance) Test Procedure

This test is based on the first four minutes of the FTP (ADR37/00) cycle but only covers about 2km total distance. Emission results are converted to grams per kilometre for HC, CO and NOx.

ASM - Acceleration Simulation Mode Test Procedure (ASM2525)

The vehicle is driven on a chassis dynamometer at a speed of 40km/h. Concentrations of raw exhaust emissions of HC, CO and NOx are measured.

SS60 - Steady State Loaded 60km/h

The vehicle is driven on a chassis dynamometer at a constant 60km/h. Emissions of HC, CO and NOx are measured.

HIGH IDLE - Steady State High Idle Test Procedure

With the engine running at a speed of 2500 rpm the concentrations of raw exhaust emissions are measured for HC and CO.

IDLE - Steady State Idle Test Procedure

With the engine running at idle speed (accelerator not depressed) the concentrations of raw exhaust emissions are measured for HC and CO.

For each vehicle tested, the results of all short tests have been compared with results obtained for the same vehicles using the FTP test. The results of these comparisons follow.

CORRELATION BETWEEN SHORT TESTS AND FTP TEST RESULTS

This issue has pre-occupied many researchers, particularly in the USA, over recent years. Not surprisingly, the NISE study found that, in general, loaded (dynamometer) tests provide better correlation than non-loaded (idle) tests, although there were a few exceptions. The correlations are summarised below.

Correlations Between Short Tests and ADR Test Results

	ADR 27			ADR 37/00		
	HC	CO	NOx	HC	CO	NOx
IM240	0.80	0.93	0.91	0.94	0.90	0.90
ASM	0.52	0.71	0.69	0.64	0.78	0.68
SS60	0.62	0.80	0.74	0.80	0.84	0.72
Hi Idle	0.49	0.71	N/A	0.70	0.62	N/A
Idle	0.44	0.55	N/A	0.72	0.67	N/A

The IM240 test achieved by far the highest correlation with the FTP test for all gases, and for both ADR27 and ADR37/00 cars. The consistent second best correlation was provided by the SS60 test, which performed better on ADR37/00 vehicles than on ADR27 cars.

The ASM test, which was expected to provide good correlation, came a fairly poor third and, in one case, had a lower correlation than the idle tests.

The two idle tests had the lowest correlation with FTP results, with neither showing a particular benefit over the other.

In summary, while the IM240 test showed the best correlation, it is only suited to a centralised approach, with high capital costs and specialist operator skills. The ASM and the two idle tests all had inferior correlation levels and some were incapable of measuring NO_x levels at all.

The SS60 test appears to provide the most practicable option for a short test, demonstrating good correlation with FTP results yet being suited to both centralised or distributed operation with relatively low capital costs.

EFFECTIVENESS OF SHORT TESTS

Correlation with the FTP cycle is only one part of the story. The bottom line for governments is the impact that an emissions reduction program will have on overall pollution levels and at what cost.

The relative effectiveness of each short test was assessed by analysing the actual emission reductions achieved through tuning vehicles picked out as the highest emitters by each of the five short tests.

The IM240 test was the clear winner in this area, with only a relatively small but varying difference between the effectiveness of the other tests.

However, all the tests were quite effective at selecting those cars that delivered the greatest tuning effect (noting that the idle tests are not suitable for measuring NO_x emissions).

Regardless of which test is used as an indicator of emission levels, it is clear that there is very little marginal gain in tuning more than the worst 40% of cars. Detailed cost-benefit studies may suggest an even lower proportion.

The question of which short test might provide the optimum solution will receive intensive further analysis by environmental and transport planners.

FUEL EFFICIENCY ISSUES

Although the main focus of the NISE study was to investigate pollution levels, the ADR 37/00 test cycle is identical to that used in Australian Standard AS2877 to measure fuel consumption.

The results of testing show that tuning cars can deliver fuel consumption benefits as well as reductions in emissions.

An overall improvement of around 1.5% was recorded on the main test sample. This would translate to annual fuel cost savings in the region of \$200 million if applied to the Australian car population.

Moreover, it was again the highest polluters that gave the greatest fuel consumption reductions from tuning and maintenance. The highest 10% of polluters gave a fuel consumption gain of over 5% after tuning.

COST OF REPAIRS AND MAINTENANCE

It should be stressed that the NISE study focused on the benefits to be gained from following the routine maintenance and tuning procedures recommended by vehicle manufacturers. The study was not an exercise in extracting every possible gain, regardless of cost.

In general, items replaced in the NISE study vehicles were restricted to normal service items such as spark plugs, filters, points and plug leads. Only in a very few cases were high cost items such as catalysis replaced.

Thus the tuning effects measured in the study reflect those that would be encountered by typical private owners maintaining their cars to normal service industry standards.

The average commercial cost of the materials and labour to repair, adjust and tune the test cars averaged around \$200 per vehicle. Little variation was encountered, on average, between older and more modern vehicles.

SUMMARY

The following points summarise Australia's car pollution situation and the potential for improvement:

- A well maintained passenger car fleet could reduce pollution to between 9% and 25% below existing levels
- These reductions would be accompanied by substantial greenhouse gas reductions and fuel savings of around \$200 million per annum
- The average cost of servicing, repairing and adjusting a car to achieve the above results is around \$200 at typical 1996 motor vehicle repair industry rates
- Evaporative emissions of hydrocarbons appear to create a major problem and there is some doubt as to whether the current certification test sets adequate "real world" design criteria for manufacturers to follow
- Relatively low cost, effective tests are available to identify high polluting cars

One simple dynamometer-based test (SS60 test) appears to offer the optimum combination of correlation with the ADRs and capability to select cars that will benefit most from tuning.

It is important to note that there are two key aspects of this study :

1. Do cars generally continue to meet the ADRs?
2. Can emission levels be reduced by maintenance?

While the first question is important in assessing the performance of vehicles (and manufacturers) against new car standards, the second is the relevant issue for planners - can simple tuning measures reduce the effect of vehicles on urban air quality?

This study shows that the answer to the second question is 'yes'. It also gives guidance on various other approaches.

Consideration of the study findings lead to the conclusion that managing urban air quality from the vehicle perspective requires a careful balance of new car standards and in-service management policies.

The NISE study report provides a solid foundation for developing these policies.