NISE2 –Contract 1 Sample Design and Data Analysis

Prepared for:

Department of the Environment and Heritage

Transport Systems Centre

TSC

Transport
Systems
Centre

By:
Mr Chris Dyson
Statistician
Transport Systems Centre

and

Dr Rocco Zito
Senior Research Fellow
Deputy Director Transport Systems Centre

Date of issue December 2005

Important Notice

Table of Contents

List of Figures

List of Tables

Table of Abbreviations

ADR	Australian Design Rule
CUEDC	Composite Urban Emissions Drive Cycle
DCDB	Digital Cadastral Database
GIS	Geographical Information Systems
GPS	Global Positioning System
IM240	US Inspection and Maintenance Cycle 240 seconds duration
ITS	Intelligent Transport Systems
NEPM	National Environmental Protection Measure
NISE2	The Second National In-Service Emissions Study
Petrol CUEDC	Petrol Composite Urban Emissions Drive Cycle
SPC 240	Short Petrol Composite Urban Emissions Drive Cycle 240 Seconds
VKT	Vehicle Kilometres Travelled

EXECUTIVE SUMMARY

The primary objective of the Preliminary Phase of NISE 2 was to establish an Australian composite urban emissions drive cycle (CUEDC) for light duty petrol vehicles, a short drive cycle for light duty petrol vehicles and to subsequently test vehicles to determine the degree of correlation between vehicle emissions measured using the CUEDC drive cycle (both hot and cold start), the short drive cycle, the ADR37 drive cycle and the IM240 drive cycle.

Two contracts were awarded for the Preliminary Phase of NISE 2, being *Contract 1: Sample Design and Data Analysis* (to the Transport Systems Centre) and *Contract 2: Drive Cycle and Short Test Development* (to Orbital Engine Company).

This report refers to *Contract 1: Sample Design and Data Analysis* and covers the sample design (based on fleet profile) for the vehicle testing associated with the drive cycle and short test development in the Preliminary Phase of NISE 2 and the analysis of the data generated from *Contract 2: Drive Cycle and Short Test Development*. Data were analysed to establish the degree of correlation between vehicle emissions measured using the derived Petrol CUEDC drive cycle, the ADR37 drive cycle, a short four minute drive cycle based on the Petrol CUEDC cycle and the IM240 drive cycle emissions data collected under Contract 2.

Contract 2: Drive Cycle and Short Test Development during the Preliminary Phase of NISE 2 covered development of a light duty petrol CUEDC, a short drive cycle (SPC240) and all vehicle emission testing. Outcomes from Contract 2 are reported separately elsewhere.

The first milestone to be achieved as a part of Contract 1 was to develop the vehicle sample design for the preliminary phase of NISE 2. It was calculated that the sample size of 36 passenger cars, 12 light commercial vehicles, and 12 four wheel drives (a total of 60 vehicles) would sufficiently indicate the extent of variation encountered in the national fleet with regard to variations in emission control. The most popular vehicles, in proportion to the Australian vehicle fleet, were selected and these three categories were further stratified by age and vehicle size. This enabled comparisons among emissions generated under various test cycles as well as the objective planning of a much larger sample to be tested to represent the national fleet. This larger sample, to be tested in the Main Phase of NISE 2, should give definitive data on the emissions of traffic on Australian roads, both in current conditions and projected some distance into the future as the national fleet continues to evolve.

This 60-vehicle sample provided a quite adequate sample for planning an emissions testing program to meet the two study objectives, namely to calibrate the most promising stationary testing cycles to identify outstandingly gross emitters and to estimate, to an adequate degree of precision, total petrol emissions from passenger vehicles, four wheel drives and LCVs in metropolitan Australia. The presumption is that vehicles readily accessed can adequately represent a cross section of the nation-wide vehicle condition for their model and age cohort. All the emissions testing was performed by the Orbital Engine Company in Perth, so all vehicles tested were also sourced in Perth. It was thought that the State the vehicles were sourced from was not a primary issue as far as emissions performance is concerned.

Orbital Engine Company conducted drive cycle testing on the nominated sample of vehicles under Contract 2: Drive Cycle and Short Test Development . Some models were substituted due to sourcing difficulties. Each of the 60 vehicles was tested on the four cycles specified above, with 15 of the vehicles having repeat tests performed in order to obtain an understanding of how significant testing variation was. The results showed that the within test variation was quite low for the longer cycles and higher for the shorter cycles, suggesting that repeat tests should be performed for the shorter cycles if they are to provide reliable results.

The degree of correlation between each of the five cycles for the emissions of carbon dioxide, carbon monoxide, total hydrocarbons, oxides of nitrogen and fuel consumption was determined. Overall the correlations were quite strong when the results for the 60 vehicles were analysed. It was noted that the distribution of the data was skewed and not normally distributed. This is to be expected since when emission testing occurs vehicles that are well maintained perform well and vehicles that are not, usually have emissions results that are significantly larger. This positive skewness has the effect of biasing the correlation analysis to indicate better correlations than are warranted. It was found that if the emission data was transformed by cube rooting the data, a more normal distribution of the data resulted, and hence providing better estimates of the correlation between the cycles, and permitting valid statistical inferences.

After transformation the overall correlation using the entire 60 vehicle sample for all emissions between all the cycles was still quite strong. As expected when the data was disaggregated by year of manufacture and vehicle type generally the correlations were weaker. This was the result of reducing the range of value encountered. However the analysis did show that the emission characteristics of different vehicle types and year of manufacture were different and would require further clarification as a part of the main phase analysis, given that sample sizes were adequately large enough to provide reliable results.

The Petrol CUEDC proved to be well correlated to the ADR37 cycle, though the real power of the Petrol CUEDC cycle comes from the individual emissions results of the four constituent road flow categories, namely, Residential, Arterial, Freeway, and Congested. The regression analysis for these two cycles produced linear transformation equations that were sufficiently sound to be used predictively for all emissions, though NOx had the weakest correlation. It is recommended that the final transformation equations be derived after main phase testing, using larger samples and hence better estimating the variability in the makes and models of vehicles tested. This increase in sample size and variability will increase the robustness of the final equations produced.

The Petrol CUEDC is a composite cycle, and hence the overall result is not of real use in an emission modelling context. The real power of the Petrol CUEDC is that it allows modellers to weight each road flow category in a way that is commensurate with the situation they are modelling. In this way providing a more accurate and reliable estimate of in-service emissions performance. While the Petrol CUEDC has good correlation with ADR 37 it is the weighting of the individual components that is most useful. Hence it would be essential to perform the Petrol CUEDC cycle as part of the main phase testing. The ADR37 cycle would also have its uses for comparison with the previous in-service vehicle emissions study conducted by the Federal Office of Road Safety in 1997. These comparisons will allow deterioration rates to be estimated, which is another important factor when considering emissions modelling.

The newly developed short cycle, SPC240, derived as a part of Contract 2 was analysed for its ability to identify gross polluters. It was found that it performed adequately in this respect, though the analysis also showed that all cycles tested also performed adequately in detecting gross polluters. Since the IM240 is already being used internationally as an inspection and maintenance cycle, it is recommended that it be retained in preference to the SPC240 for this specific purpose.

The testing and analysis work that has been carried out in the Preliminary Phase of NISE2 has provided a good basis to proceed with the main phase testing. The Preliminary Phase outcomes ensure that the Main Phase vehicle sample design, and following analysis will produce results that are accurate and reliable. These results will provide an invaluable body of knowledge of the in-service emissions performance of the Australian light duty petrol fleet.

INTRODUCTION

The principal focus for the Preliminary Phase of the Second National In-Service Emissions Study (NISE 2) is to develop and validate reliable and cost-efficient emission tests for light duty petrol vehicles, derived from "real world" driving patterns. These tests will be subsequently used to identify vehicles in need of retuning or refurbishment to enable them to meet appropriate emissions standards. These tests will be used also, along with the standard certification tests, in the subsequent Main Phase of NISE to estimate the metropolitan emissions performance of the current in-service light duty petrol vehicle fleet. The Preliminary Phase will hence provide the basic tools for use in the Main Phase to generate a more accurate and representative measure of the actual amount of pollutants emitted from the Australian light duty petrol vehicle fleet by testing vehicles over a vehicle driving cycle based on actual Australian on-road conditions and driving patterns.

STUDY OBJECTIVES

The objectives of the preliminary phase are to establish:

1. an Australian composite urban emissions drive cycle (CUEDC) for light duty petrol vehicles;

2. a short test, of no longer than 4 minutes, which can provide a reliable measure of emissions performance; and

3. the degree of correlation between vehicle emissions measured using the derived CUEDC drive cycle, a short drive cycle derivative of this, and the standard certification tests based on the ADR37 drive cycle and the IM240 drive cycle.

This report meets the following specific tasks as outlined for Contract 1:

- provide advice on the sample design (based on fleet profile) for the vehicle testing associated with the drive cycle and short test development in the Preliminary Phase of NISE 2;

- analyse data collected under Contract 2: Drive Cycle and Short Test Development during the Preliminary Phase of NISE 2;

SELECTION OF SAMPLE OF VEHICLES TESTED

The particular models chosen to represent their cohort were of the manufacture most prolific on Australian metropolitan roads, as recorded in the Australian Bureau of Statistics (ABS) Motor Vehicle Census 2003. See Appendix 1 for an example of the basic data and Appendix 2 for the vehicle types grouped, by frequency, into the age categories used in this study. The composition of the sample is shown in Table 1, there having been three of the initial 4WD choices substituted because of non-testability on a 2WD chassis dynamometer.

Table 1 Vehicle models selected for testing

	PVS	**PVM**	**PVL**	**4WDS**	**4WDL**	**LCV**
Category	**1**	**2**	**3**	**4**	**5**	**6**
YOM	Corolla	Camry/Vienta	Commodore high km	Vitara	Landcruiser	Hilux
1986-93	Laser	Magna	Commodore low km	Liberty	4Runner	Hiace
	Pulsar	Telstar	Falcon high km			Econovan
	Colt	Pintara	Falcon low km			Triton
YOM	Corolla	Camry	Commodore high km	Kia Sportage	Jeep	Hilux
1994-98	Excel	Magna	Commodore low km	Liberty	Landcruiser	Rodeo*
	Laser	Pulsar	Falcon high km			Holden ute
	Festiva	Lancer*	Tarago			Hiace
YOM	Corolla	Camry/Vienta	Commodore high km	Landrover Freelander	X-trail	Holden ute
1999-02	Laser	Magna	Tarago	Honda CRV	Prado	Rodeo
	Mazda 323	Astra	Falcon high km			Falcon ute
	Accent	Pulsar	Falcon low km			Hilux*

In the event, there were also slight changes through the choice being not readily available (*) but not more than one in any group in Table 1. The actual sample therefore 'fitted the bill' quite adequately, although the contrasts between high and low km selections in the third category were not very great, of the order of 30-40% only. The consequent duplication of such vehicles, common as they are, merely makes results from the overall sample more representative of the national petrol vehicle fleet.

The individual vehicles were selected from vehicles for sale (9), privately owned (37), company cars (5) or rentals (9), all in Western Australia, the site of the testing facility. There is no reason to suppose that they were, as a group, materially different from the classes they represented when viewed nationally. Most vehicles would presumably have had routine maintenance (and no doubt the scheduled maintenance for newer vehicles still in warranty).

The purpose of having high and low km vehicles in the large passenger vehicle group was to cover high km drivers, who might be expected to need a larger vehicle on that account, and those choosing a larger vehicle for comfort, safety, etc. Further, because emission standards apply regardless of engine size (though a weight of over 2.7 t puts a vehicle in a different category for acceptable emissions levels, applicable to some larger LCVs and 4WDLs, see Table 2) the task of the catalytic converter on a larger engine has a correspondingly larger task to keep emissions within acceptable/legal limits. Of course, smaller cars can also be high km vehicles for their age and if they have been worked particularly hard performance might suffer.

It was assumed that the sample size of 48 cars and LCVs, and 12 4WDs, should cover sufficient of the variation encountered in the national fleet with regard to deficiencies in emission control to enable reliable comparisons among emissions generated under various test cycles as well as the objective planning of a much larger sample to be tested to represent the national fleet. This larger sample should give definitive data on the emissions of traffic on Australian metropolitan roads, both in current conditions and projected some distance into the future as the national fleet continues to evolve.

METHODS AND PRELIMINARY RESULTS

Both ADR37 and Petrol CUEDC are drive cycles of around 30 minutes duration; ADR37 was derived in the United States in the 1980s and therefore to some degree does not represent current Australian in-service vehicle emission levels. It is questionable whether one should try necessarily to match its emissions outcomes with those generated in a cycle representing Australian conditions such as Petrol CUEDC. With this in mind, one raises the issue of the emissions status of vehicles which are near the ADR37/01 emissions limits, particularly CO at 2.1 g/km, NOx at 0.63 g/km and total HCs at 0.26 g/km (Table 2). Having a third category of 'marginal' for, for example, CO values between, say, 1.5 and 2.5 g/km, would identify vehicles that are not requiring the urgent attention needed for a vehicle with a value of 10 or 20 g/km. Vehicles in this last group are described as 'really gross emitters' and it is to these we pay particular attention.

The sixty vehicles built between 1986 and 2002, representing a cross-section of the more typical vehicle types on Australian metropolitan roads, were put through five simulated drive cycles to compare their engine emissions under the various cycles and against each other. The emissions collected were total hydrocarbons (THC, or HC, indicating improperly burned fuel), Carbon Monoxide, CO, nitrogen oxides (NOx) and carbon Dioxide, CO_2, all as g/km. Fuel consumption was measured (L/100km). For the two short cycles IM240 and Short Petrol CUEDC 240 seconds (SPC240) integrated measures of emissions are preferred as the practical alternative to the post-catalyst bag results.

The five cycles used were the ADR37, a long cycle from a cold start, IM240, a short 240-second derivative from a hot start; and a long cycle based on Australian metro traffic data, Petrol CUEDC, using both hot and cold start, and a short 240-second derivative, SPC240 from a hot start. Unlike other cycles, Petrol CUEDC includes freeway driving simulation, matching part of Australian metro conditions, though SPC240 does not contain this component.

The preliminary phase vehicle sample represented three time periods of manufacture (1986 - 1993; 1994 - 1998; and 1999 – 2002) and different styles of vehicle: small, medium and large passenger vehicles, PVS, PVM and PVL, with 2-wheel drive; light commercial vehicles, LCV; and smaller and larger 4WDs, 4WDS and 4WDL.

Legislated emission standards for petrol-driven vehicles as new, from the first two time periods, were ADR37/00. For newer vehicles, the legislated standards are ADR37/01, applicable from 1.1.1999. This implies that older vehicles should not be expected to conform to the current standards, much stricter than when they were new, whereas the vehicles built since 1999 should currently conform and are expected to, unless their emissions performance has deteriorated. The emissions limits for these standards are presented in Table 2, along with the cube roots of these values (see discussion following Figure 1). For reference, the latest ADR's are included, ADR79/00 and /01, applicable from 2003 and 2005 respectively for new model vehicles.

Table 2 Regulated Emission Limits by year of introduction, g/km (cube root in brackets)

Criterion	ADR37/00	ADR37/01	ADR79/00	ADR79/01		ADR36/00*
Introduced	**1986**	**1999**	**2003/04**	**2005/06**		**1988**
Exhaust gas						
CO	**9.3** (2.10)	**2.1** (1.28)	**2.2** (1.30)	**2.3** (1.32)		
HCs	**0.93** (0.98)	**0.26** (0.64)		**0.20** (0.58)		
HCs+NOx			**0.50** (0.79)			
NOx	**1.93** (1.25)	**0.63** (0.86)		**0.15** (0.53)		

* Vehicles over 2.7 t only; acceptability not based on drive cycle test, but a 13-mode steady state test

The difficulty of applying two sets of standards to the full set of vehicles is bypassed by applying ADR37/01 standards to all vehicles, fully recognising that the older two groups of vehicles would not be expected to comply. The principal objective is to identify really gross emitters in the fleet. Naturally, it is expected that older vehicles will dominate the set of such vehicles, whatever criteria are used to define gross emissions levels.

The emissions data produced by the 60 vehicles undergoing the five cycles were provided by Orbital Australia Pty see (Orbital Engine Company, 2005).

Table 3 to Table 6 show the pairwise correlation coefficients (r, not R^2) among the cycles for various emissions, using the per vehicle raw data for 1) full cycles and 2) where the freeway phase of PCUEDC has been omitted (correlation coefficients in brackets). In Table 3 to Table 6, all emissions are those measured in the bag after the catalytic converter. Correlation coefficients less than 0.975 (R^2 less than 0.95) are shown in italics; correlation coefficients less than 0.9 (R^2 less than 0.81) in bold italics. The latter outcomes only arose in fuel consumption analyses. Non italicised correlations are thus very strong (and not giving rise to any possible concern). The correlations using the raw data (Table 3 to Table 11) agree with those presented by Orbital in their September 2005 Final Report, though analyses based on transformed data for CO, NOX and THC levels have been preferred in this report on statistical grounds.

Number of vehicles = 60 or very close to it (minimum 57).

Table 3 THC correlations

	Petrol CUEDC Hot	Petrol CUEDC Cold	SPC240	IM240	ADR37
Petrol CUEDC Hot		.990 (.984)	.990 (.980)	.991 (.984)	.992 (.992)
Petrol CUEDC Cold	.990 (.984)		.987 (.982)	.989 (.984)	.986 (.988)
SPC240	.990 (.980)	.987 (.982)		.988	.982
IM240	.991 (.984)	.989 (.984)	.988		.988
ADR37	.992 (.992)	.986 (.988)	.982	.988	

Table 4 CO correlations

	Petrol CUEDC Hot	Petrol CUEDC Cold	SPC240	IM240	ADR37
Petrol CUEDC Hot		.995(.988)	.984 (.975)	.991 (.986)	.989 (.995)
Petrol CUEDC Cold	.995 (.988)		.986 (.982)	.992 (.981)	.993 (.989)
SPC240	.984 (.975)	.986 (.982)		.975	.977
IM240	.991 (.986)	.992 (.981)	.975		.991
ADR37	.989 (.995)	.993 (.989)	.978	.991	

Table 5 NOx correlations

	Petrol CUEDC Hot	Petrol CUEDC Cold	SPC240	IM240	ADR37
Petrol CUEDC Hot		.990(.983)	*.958* (.981)	*.966* (.988)	*.960* (.991)
Petrol CUEDC Cold	.990 (.983)		*.954 (.970)*	*.963 (.967)*	*.967* (.989)
SPC240	*.958* (.981)	*.954 (.970)*		.978	.980
IM240	*.966* (.988)	*.963 (.967)*	.978		.984
ADR37	*.960* (.991)	*.967* (.989)	.980	.984	

Table 6 CO2 correlations

	Petrol CUEDC Hot	Petrol CUEDC Cold	SPC240	IM240	ADR37
Petrol CUEDC Hot		.986(.984)	.985 (.976)	.990 *(.973)*	.987 (.989)
Petrol CUEDC Cold	.986 (.984)		.983 *(.974)*	.978 *(.957)*	.985 (.979)
SPC240	.985 (.976)	.983 *(.974)*		.979	.975
IM240	.990 *(.973)*	.978 *(.957)*	.979		.982
ADR37	.987 (.989)	.985 (.979)	.975	.982	

In Table 7 to Table 10 the short cycles’ data (SPC240 and IM240) were the integrated after-catalyst values (“int”). Correlations differ from those in Table 3 to Table 6 only with regard to those involving either SPC240 or IM240, or both. Table 12 shows correlations between the integrated and non-integrated data.

Table 7 THC correlations

	Petrol CUEDC Hot	Petrol CUEDC Cold	SPC240(Int)	IM240(Int)	ADR37
Petrol CUEDC Hot		.990(.984)	.990(.982)	.990(.984)	.992(.992)
Petrol CUEDC Cold	.990(.984)		.988(.984)	.984(.980)	.986(.988)
SPC240(Int)	.990(.982)	.988(.984)		.989	.982
IM240(Int)	.990(.984)	.984(.980)	.989		.987
ADR37	.992(.992)	.986(.988)	.982	.987	

Table 8 CO correlations

	Petrol CUEDC Hot	Petrol CUEDC Cold	SPC240(Int)	IM240(Int)	ADR37
Petrol CUEDC Hot		.995(.988)	.980(.977)	.991(.988)	.989(.995)
Petrol CUEDC Cold	.995(.988)		.983(.982)	.991(.982)	.993(.989)
SPC240(Int)	.980(.977)	.983(.982)		*.973*	.978
IM240(Int)	.991(.988)	.991(.982)	*.973*		.992
ADR37	.989(.995)	.993(.989)	.978	.992	

Table 9 NOx correlations

	Petrol CUEDC Hot	Petrol CUEDC Cold	SPC240(Int)	IM240(Int)	ADR37
Petrol CUEDC Hot		.990(.983)	*.923(.950)*	*.923(.953)*	*.960*(.991)
Petrol CUEDC Cold	.990(.983)		*.919(.936)*	*.922(.933)*	*.967*(.989)
SPC240(Int)	*.923(.950)*	*.919(.936)*		.979	*.949*
IM240(Int)	*.923(.953)*	*.922(.933)*	.979		*.949*
ADR37	*.960*(.991)	*.967*(.989)	*.949*	*.949*	

Table 10 CO2 correlations

	Petrol CUEDC Hot	Petrol CUEDC Cold	SPC240(Int)	IM240(Int)	ADR37
Petrol CUEDC Hot		.986(.984)	.978*(.968)*	*.972(.958)*	.987(.989)
Petrol CUEDC Cold	.986(.984)		*.967(.955)*	*.957(.936)*	.985(.979)
SPC240(Int)	.978*(.968)*	*.967(.955)*		.978	*.969*
IM240(Int)	*.972(.958)*	*.957(.936)*	.978		*.967*
ADR37	.987(.989)	.985(.979)	*.969*	*.967*	

Table 11 shows fuel use correlations using the same format.

Table 11 Fuel consumption correlations

	Petrol CUEDC Hot	Petrol CUEDC Cold	SPC240(Int)	IM240(Int)	ADR37
Petrol CUEDC Hot		*.967* (.976)	***.883*** (.986)	***.877*** (.984)	***.883*** (.991)
Petrol CUEDC Cold	*.967* (.976)		*.914 (.912)*	*.900* ***(.894)***	*.909 (.908)*
SPC240(Int)	***.883*** (.986)	*.914 (.912)*		.992	.987
IM240(Int)	***.877*** (.984)	*.900* ***(.894)***	.992		.988
ADR37	***.883*** (.991)	*.909 (.908)*	.987	.988	

Table 12 Effect of integrating short cycle on within-test correlation coefficients between integrated and non-integrated value

Emission / Cycle	**SPC240**	**IM240**
THC	**.998**	**.997**
CO	**.997**	**.999**
NOx	**.955**	**.956**
CO_2	**.978**	**.988**

The correlations in all cases are quite strong with the minimum value being 0.877 for a fuel consumption correlation between IM240 and the Petrol CUEDC Hot. For the four emissions of NOx, CO, THC and CO_2 all the inter-test correlations are over 0.91 (minimum $R^2 = 0.845$). This result can be related to the correlation criterion stated in Contract 2 which states that the average correlation between the four gases should be greater than 0.85, though this criteria is applied to the most polluting 30% of vehicles. This comparison is presented later in the report. The correlations in Table 12 are extremely strong for THC and CO but less so for, NOx. The Orbital 2005 report refers to clipping of modal / integrated emission values during testing ie if emissions values are greater than that of the range of the emission analyser then the value of the analyser maximum is adopted and not the actual maximum. This effect could possibly be a reason for the poorer NOx correlations experienced.

However the distributions of the variables summarised in Table 3 to Table 5 and Table 7 to Table 9 are very strongly positively skewed. Those in Table 6, Table 10 and Table 11 are less so because they represent fuel usage, with much more consistent sets of values than for THC, CO and NOx. This observation is somewhat independent on the level of correlations among drive cycles. The effect of the extreme skewness is to bias statistics that rely on normal distributions and most significance tests. Generally this skewness tends to bias correlation coefficients upwards and, correspondingly, standard errors of regression coefficients downwards. The skewness can be reduced to levels close to zero through transformation of the data values. Examples of such transformations are power or logarithmic transformations. For these data, the powers that appear to be most effective are raising values to the power of one third or one quarter. Logarithmic transformation of the values encountered among the 60 vehicles tested tends to create slight negative skewness, ie log transformation ‘overdoes’ the adjusting.

For example in Figure 1, the raw data for all 60 vehicles are plotted for the NOx values obtained in the Petrol CUEDC Hot test, including all four phases, against the SPC240 test (r = 0.958, Table 5). In Figure 2, the same data have been cube root transformed on both axes. The ADR37/01 reference line appears in the appropriate places on both scatters (0.63 for raw data, 0.857 for cube rooted data).

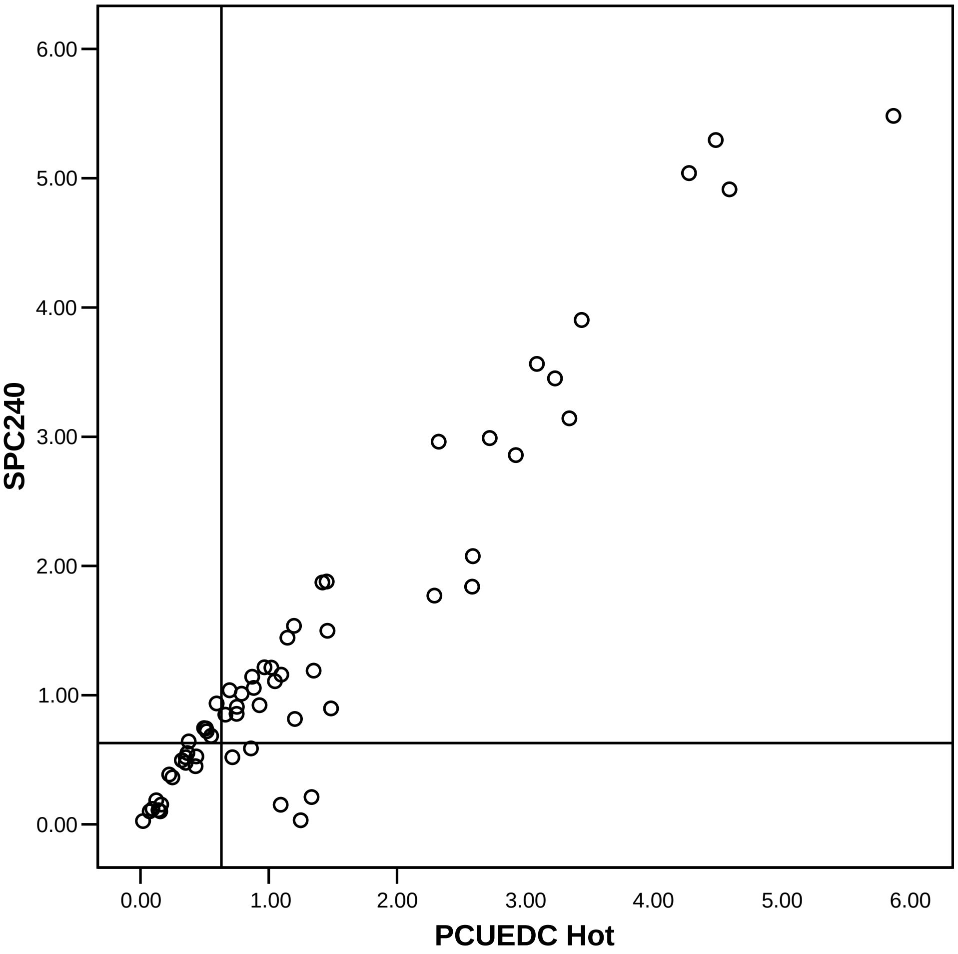

Figure 1 NOx values (g/km) for the SPC240 cycle and the PCUEDC Hot cycle

In Figure 1, the skewed distribution places considerable weighting (leverage) on the high NOx values and the four highest points would tend to dominate the estimated value of a linear regression coefficient. It should be noted that some emission scatters noted in the literature are much more skewed, thanks to outstandingly gross emitters, than that in Figure 1. Nevertheless, the scales in Figure 1 are such that the cut-off values for conventionally designated gross emitters are relatively near the origin, with poor separation of data points around the indicated ADR37/01 cut-off value in this sample of vehicles.

Consideration should be given to the NOx status of the various indicated clusters. There are at least 10 vehicles whose Petrol CUEDC Hot values exceed the ADR37 cut-off value by a factor of around two; another nine by a factor of at least three and a further four exceeding it by a factor of at least six. Which of these groups represent(s) the core of the 'national emissions problem' ? If these numbers are at all illustrative, the two higher groups emit, in total, about the same total amount of NOx, but the cost-benefit ratio of remediation is greatest with the highest group. On the SPC240 axis, the clustering is slightly different for moderate values but the same for the (4) outstandingly gross emitters.

The mal-distribution of values, particularly from a statistical viewpoint, is resolved by taking the cube root of the quantified emission. This tends to give adequately normally distributed data with the statistical benefits that flow from that. This transformation also clarifies the position around the ADR37/01 cut-off value.

Figure 2 contains the same data as Figure 1, but with both scales cube root transformed.

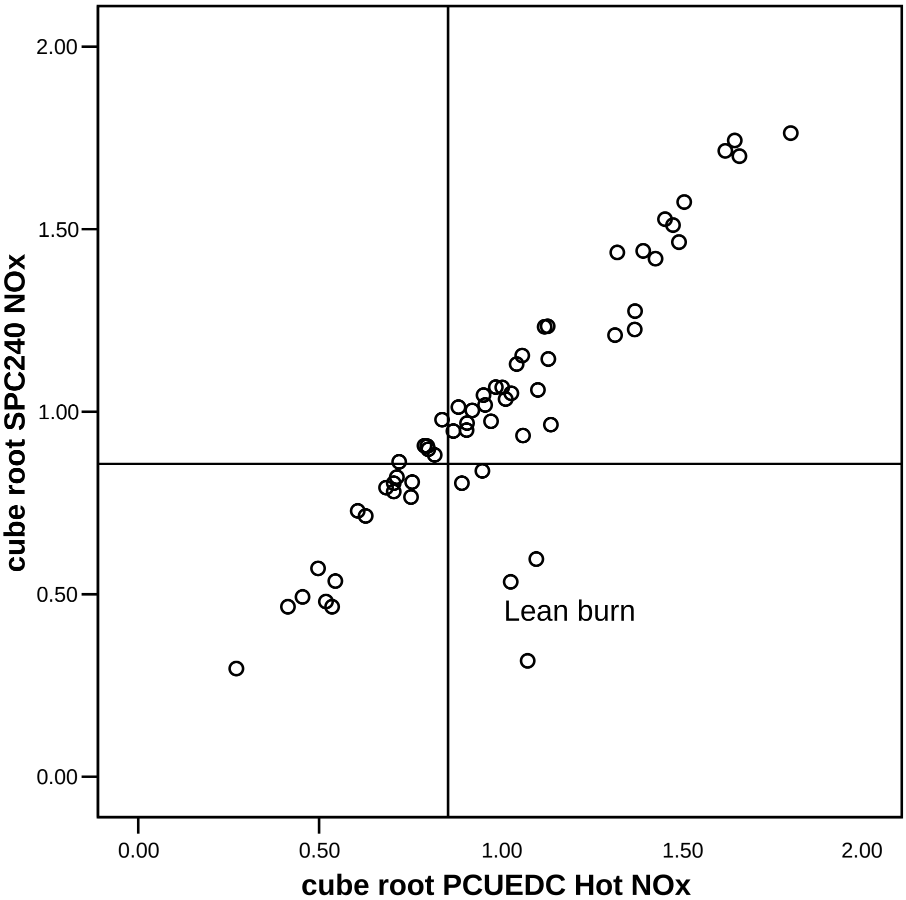

Figure 2 Cube rooted NOx values for the SPV240 cycle and the PCUEDC Hot cycle

In Figure 2, the transformed NOx values are much more normally distributed with much clearer delineation around the revised cut-off value. The cube root-transformed values of the ADR37/01 cut-off value of 0.63 g/km are shown (0.857; refer Table 2)

The correlation coefficient in Figure 1 is 0.958, as in Table 5. In Figure 2, it is 0.898. It is apparent that the main reason for this drop is the **three quite clear ‘outliers’ from the general correlation relationship**, which are from three large passenger vehicles going into ‘lean burn’ mode in the freeway phase (Phase 3) of the Petrol CUEDC Hot cycle. Thus they are, indeed, genuine outliers since those engines are performing differently from the remainder in the Petrol CUEDC cycle but not differently in the SPC240 cycle. These three points are **fairly apparent in Figure 1, but not strongly so**, since their indicated variation is not dissimilar to the group in the centre of Figure 1. In Figure 2, the group that is in the centre of Figure 1 now has variation comparable with that in the lower values, and the three outliers are very obvious. If these three outliers are removed, the correlation coefficient in the raw data (Figure 1) is 0.976 and in the transformed data 0.975. The latter version is preferred on account of the homogeneous variance as values go from small to large, clearly not so in Figure 1, without the three outliers. Thus the correlation coefficient itself does not necessarily indicate a statistically undesirable situation but skewness does. When confidence limits are placed on estimated cut-off values, the normally distributed data gives appropriate values. This is not so where they are derived directly from the skewly-distributed raw data.

It should be commented that the fourth root transformation generally has given very low skewness values for these two NOx variables. However, because of the anticipated presence of extreme gross emitters in the national fleet, one would expect a limited amount of positive skewness to be appropriate after transformation. By ‘over-transforming’, essentially to ‘tame’ very high values, the small raw values do become too widely separated under transformation compared with the central group.

CORRELATION AMONG GROSS POLLUTERS

One of the specifications from Contract 2 was to determine what the correlations between cycles were for the 30th percentile group of highest emitters. Contract 2 stated it required:

“As a guide, it is anticipated that for the 30 percentile group of highest polluters measured on the CUEDC, the short test will deliver a minimum R^2 correlation value of 0.80 for each gas of interest (NO or NOx, THC, CO and CO2), with an average R2 correlation, across all four gases of not less than 0.85.”

On this issue of sufficiently high correlations among the *upper 30% of emitting vehicles**, the following Tables show the NOx correlations.

NOx correlations, raw data

		PCUEDCH	PCUEDCC	SPC240int	ADR37	IM240int
PCUEDCH	Pearson Correlation	1	.912(**)	.957(**)	.917(**)	.994(**)
	Sig. (2-tailed)		.000	.000	.000	.000
	N	18	18	18	18	18
PCUEDCC	Pearson Correlation	.912(**)	1	.886(**)	.989(**)	.893(**)
	Sig. (2-tailed)	.000		.000	.000	.000
	N	18	18	18	18	18
SPC240int	Pearson Correlation	.957(**)	.886(**)	1	.901(**)	.966(**)
	Sig. (2-tailed)	.000	.000		.000	.000
	N	18	18	18	18	18
ADR37	Pearson Correlation	.917(**)	.989(**)	.901(**)	1	.908(**)
	Sig. (2-tailed)	.000	.000	.000		.000
	N	18	18	18	18	18
IM240int	Pearson Correlation	.994(**)	.893(**)	.966(**)	.908(**)	1
	Sig. (2-tailed)	.000	.000	.000	.000	
	N	18	18	18	18	18

NOx correlations, cube root transformed data

		PCUEDCH	PCUEDCC	SPC240int	ADR37	IM240int
PCUEDCH	Pearson Correlation	1	.987(**)	.933(**)	.956(**)	.919(**)
	Sig. (2-tailed)		.000	.000	.000	.000
	N	18	18	18	18	18
PCUEDCC	Pearson Correlation	.987(**)	1	.931(**)	.963(**)	.924(**)
	Sig. (2-tailed)	.000		.000	.000	.000
	N	18	18	18	18	18
SPC240int	Pearson Correlation	.933(**)	.931(**)	1	.905(**)	.982(**)
	Sig. (2-tailed)	.000	.000		.000	.000
	N	18	18	18	18	18
ADR37	Pearson Correlation	.956(**)	.963(**)	.905(**)	1	.899(**)
	Sig. (2-tailed)	.000	.000	.000		.000
	N	18	18	18	18	18
IM240int	Pearson Correlation	.919(**)	.924(**)	.982(**)	.899(**)	1
	Sig. (2-tailed)	.000	.000	.000	.000	
	N	18	18	18	18	18

* The highest 30% of emitting vehicles was obtained by summing the quotients of (the cube root value of each emission in each test divided by the mean over all vehicles of the cube root values for that emission for that test) and ranking this sum, giving an overall emissions index not favouring any test or any emission. The high emitting vehicle with missing data from the ADR37 cycle was not included. It was not thought useful to subdivide the vehicles by age group, giving only 6 or 7 vehicles per group.

The weakest NOx correlation among the raw data = 0.886, whose square is 78.5%. The average R^2 for the raw data was 85.3%. The cube root transformed data gave similar, though more appropriate, r and R^2 values, the minimum R^2 being 80.8% and the average 88.4%. hence the results of the testing met the criteria given above.

For CO, the lowest r for the raw data was 0.986 (R^2 = 97.2%) and in the transformed data 0.952 (R^2 = 90.6%).

For THC, the lowest r for the raw data was 0.978 (R^2 = 95.6%) and in the transformed data 0.949 (R^2 = 90.1%).

For CO_2, the lowest r for the raw data was 0.950 (R^2 = 90.2%) and in the transformed data 0.958 (R^2 = 91.8%).

For fuel consumption, the lowest r was 0.981 (R^2 = 96.2%).

It should be noted that there is no issue of over-transforming when the low end of the range of emissions values is omitted. It might be noted that the transformed values gave much more consistent minimum R^2 values (ranging from 88% to 92%) than did the raw values (ranging from 78 to 97%).

PRECISION OF TEST REPEATS

Repeating tests gives improved emissions estimates, as well as indicating whether results obtained are significantly effected by the inter-vehicle / test variability. Repeats were investigated on the long cycle tests ADR37 and PCUEDC Cold and the short test SPC240. Table 13 shows the extent of the summarised disagreement between the test repeat values for the four emissions. The percentages quoted here apply both to the average of the proportional standard error of the mean value, and to the average of the proportion, of the difference between one reading and the mean of the two, as calculated by Orbital[1].

Table 13 Mean percentage standard errors of per vehicle emissions values used in analyses

Emission Cycle	**ADR37**	**PCUEDC Cold**	**SPC240**	Crude mean
THC	**4.2**	**2.8**	**9.8**	5.6
CO	**6.5**	**4.8**	**12.4**	7.9
NOx	**3.7**	**2.0**	**7.7**	4.5
CO_2	**1.0**	**0.7**	**1.3**	1.0
Crude mean	3.8	2.1	7.8	

The outcome in Table 13 shows that PCUEDC gave consistently stronger between-repeat agreement than ADR37, though there was no significant difference for any of the four emissions; and that the short test was comparatively very variable. If it were a matter of cycle length alone, ie the repeat was done with exactly the same engine conditions, the standard error for the short test might be about 2.7 times as high as for the long test. However, it has been stated in Orbital's Contract 1 report that sometimes there was difficulty setting up the vehicle in identical conditions, so there is a 'retest' effect as well as a not-quite replicated cycle effect.

The data on CO_2 is much more consistent, being produced steadily in all phases of the cycle. Other emissions were noticeably higher in the warm-up phases, and differences between repeats were dominated by differences in the first, cold start, phase. By inference, one might expect that PCUEDC Hot data may show smaller differences among repeats.

---

[1] Orbital have summarised discrepancies between two test values in terms of the ratio (percentage) of the mean that is represented by half the difference between the two readings = the difference between one of the readings and their mean. Since to convert this half-difference to the estimated standard deviation of a single reading requires it to be multiplied by the square root of 2, and to derive the standard error of the mean of two readings from the standard deviation of one requires division by the square root of two, this half-difference is in fact the standard error of the mean of the two readings. This standard error of mean is directly comparable with the residual standard error from a regression analysis of such an emission variable.

When the level of relative variation indicated by Table 13 is compared with that demonstrated by simple linear regressions on cube-root transformed data, there is no comparison. For example, the ‘repeat’ variation for NOx under the two long cycles is around 3%. The residual standard error of the regression is around 24% of the mean using the untransformed versions. This translates into a 1 in 65 (about 2%) contribution to variation. So repeat testing all the vehicles would have been expected to reduce residual variance by about 2%. It can seriously be considered whether this is worth the effort, when testing only 4% more vehicles, each vehicle being tested only once, would achieve a very similar outcome. The same cannot be claimed for the short tests if the performance of SPC240 represents that of IM240 also – see below.

Table 14 shows the maximum values encountered and the number of vehicles on which repeats were carried out.

Table 14 Maximum percentage standard errors of per vehicle emissions values used in analyses

Emission Cycle	**ADR37**	**PCUEDC Cold**	**SPC240**
THC	9.4	8.7	48.6
CO	16.6	17.1	75.6
NOx	12.7	6.3	46.0
CO_2	3.4	1.6	5.2
No. of vehicles retested	**17**	**18**	**50**

Table 14 contains some alarmingly high values for the short test, ie likely to have given a misleading individual vehicle figure were retesting not carried out, and possibly even with it. Again, the CO_2 picture is well in hand, and THC looks acceptable on the long tests. SPC240 looks very questionable comparatively. Were this test to be seriously considered in future, repeats appear almost mandatory – indeed Orbital took it upon themselves to carry out 50 (SPC240) and 52 (IM240) repeats[2] on the short tests compared with less than 20 on long tests, note there were only 18 repeat tests required to be performed under Contract 2. Thus the short test data overall was slightly more precise that it would have been had only between 15 and 20 repeats been carried out.

In the between-test correlation tables for the four emissions (Table 7 to Table 10), it is noted that the short tests were not inferior, in their various correlations, to the long tests for THC and for CO. But they were for CO_2 and, particularly, NOx. This perhaps suggests that consideration be given to carrying out more than two repeats of the short tests to ensure an adequately precise value for the mean is obtained. The main phase testing could provide some further insights into this.

---

[2] With data capable of showing high variability serious discrepancies among ‘repeats’, it points to the need for further repeats. If there is delay in accessing the results of analysis, ie a discrepancy is not revealed straight away, it can be advantageous to test each vehicle three times and take the two results that agree most closely if one value looks like an outlier.

DETAILED RESULTS AND DISCUSSION

Further to earlier comments about the need for a third category of emission level, ie one around or a little above the legislated cut-off, it is apparent that a rather large group of vehicles appears to fall into this category. See Figure 1. This does assist in discriminating among tests to identify numbers of vehicles falling at opposite sides of the simple formal ADR37/01 cut-off under different cycles.

If we discount the three outliers mentioned above, for which there is a quite clear explanation, there were two vehicles above the 0.63 g/km NOx cut-off on Petrol CUEDC Hot but under on SPC240 and six the other way about. Thus SPC240 has proved a little more stringent on NOx tolerance, overall, than PCUEDC Hot.

If, however, one does consider the possibility of an ambiguous group straddling the formal cut-off, this would appear, as described by the full 60 vehicles in this sample, to lie between scale values of 0.7 and 1.1 in Figure 2, ie between actual NOx values of 0.34 and 1.33 g/km in Figure 1. This comprises half the 60 vehicles (about 31 of them). There is, therefore, surely a case to take this suggestion seriously in the context of there not having been a totally appropriate cycle for Australian conditions prior to the assembling of Petrol CUEDC and its attempted short-form derivative SPC240, if the focus remains on emissions relative to the formal ADR37/01 cut-off. In other words, if the level of emissions typified by ADR37/01 is to continue to be applied to identify gross emitters, the group of vehicles thus identified is very sensitive to which cycle is used. However it will be shown later that in order to identify the worst say 10 per cent of polluters the cycle used is irrelevant.

DETAILED INSIGHT INTO NOX EMISSIONS

Comparison of the proposed SPC240 compared with the existing standard of the ADR37 cycle for NOx values is shown in Figure 3, together with the ADR37/01 cut-off, all under cube root transformation.

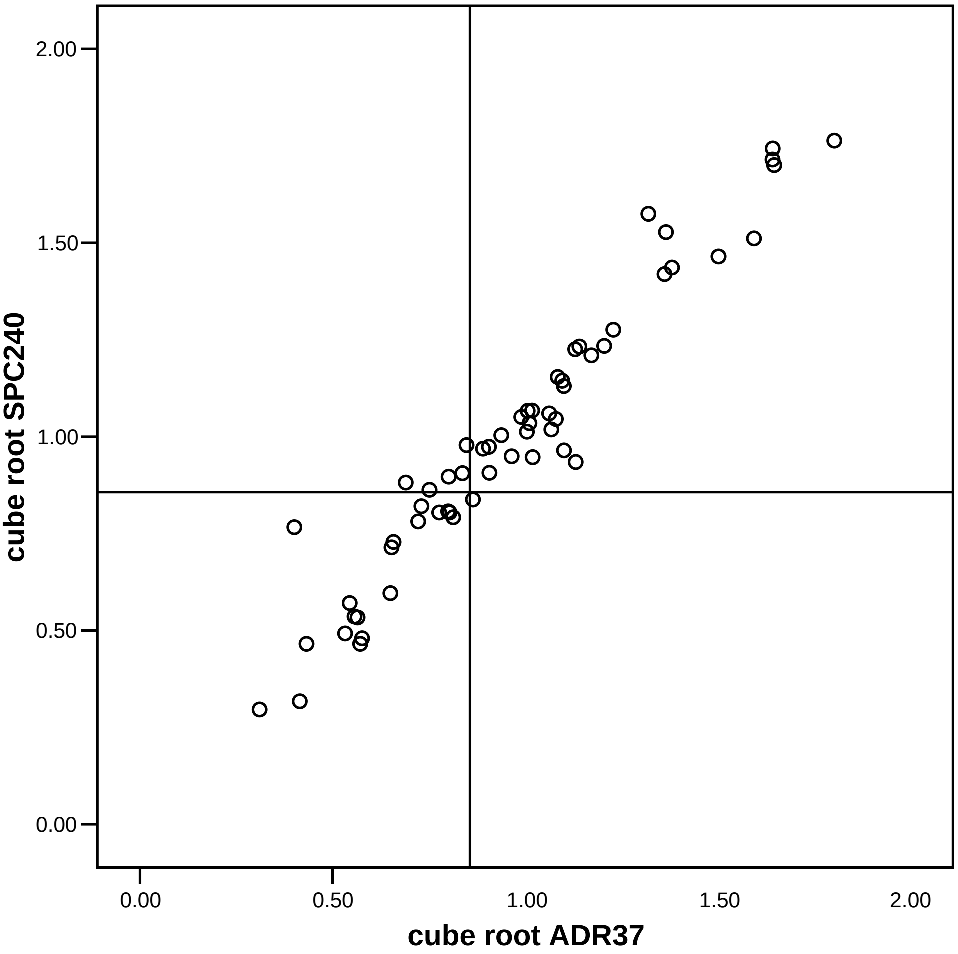

Figure 3 Cube rooted NOx values for the SPC240 cycle and the ADR37 cycle

The correlation coefficient in Figure 3 is 0.968, compared with 0.970 in Table 6. The extent of disagreement relative to the formal cut-off is limited to counts of 1 omission cf 5 commission 'errors', again, therefore, SPC240 being the more stringent. It is apparent that the scatter lies largely above the 1-1 line (corner to corner in Figure 3) and it is obligatory to use normally distributed data to check whether this is a chance effect or not, ie whether the SPC240 cycle tends to generate higher NOx values than does the ADR37 cycle

The naïve regression of cube root SPC240 NOx (y) on cube root ADR37 NOx (x) is:

$$y = (0.026 \pm 0.035) + (1.004 \pm 0.035)x \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

ie non-significant intercept and a slope not significantly different from 1, in fact extremely close to 1. The two standard errors in equation 1 are the same (0.035) by coincidence. The non-significant intercept does not justify forcing the line of best fit through the origin, as will be emphasised later. Indeed, to conclude from equation (1) that 'y = x' is a sufficient summary is a quite mistaken interpretation.

Since the slope is so close to unity in equation (1) it makes sense to test the difference between the mean values for each of the cube root transformed NOx variables. The difference is 0.030, in favour of SPC240, significant @ $p< 0.02$. However, when the integrated SPC240 values are used, the difference is only 0.012, quite non-significant. Indeed, the mean difference between the integrated SPC240 values and the SPC240 after Cat bag values, each under cube root transformation, of 0.018, is significant, $p<0.05$. Thus SPC240 after Cat Bag, overall, registered NOx values a significant 0.086 g/km higher than ADR37 on an appropriate statistical basis ($p < .05$), but the integrated values by only a non-significant 0.035 g/km (the significance tests being carried out on the transformed data and the quoted means being back-transformed). See Table 15 below.

Table 15 Comparative NOx levels of ADR37 and SPC240 cycles for all[*] vehicles

NOx Test	Raw mean (g/km)	Transformed mean	Back-transformed mean (g/km)
ADR37after Cat bag	1.265[a]	0.963[a]	0.894[a]
SPC240 integrated	1.281[a]	0.975[a]	0.929[a]
SPC240 after Cat bag	1.364[b]	0.993[b]	0.980 [b]

* One vehicle omitted, incomplete data; a = means not significantly different from each other @ $p < .05$; b = mean significantly different from means marked a. Figure 1 typified the situation where the variance (the level of disagreement among tests) is uneven along the NOx scale, ie is systematically larger with the NOx value, *in general*. Sufficiently homogenous variance has been achieved in Figure 2, when the three outliers are discounted; as it has in Figure 3.

However, it has been noted that the variance does not increase proportionally, or even regularly, with NOx or the other emissions levels. It certainly does for low values, but it seems not to do so for very high values, illustrated by the upper four points in Figure 2 and Figure 3, and true in all other inter-cycle comparisons in this study.

- In other words, **outstandingly gross emitters perform relatively more consistently under different cycles than do moderate or slight emitters. This strongly suggests that the task of detecting outstandingly gross emitters is not very sensitive to the cycle used.** But certainly there are differences for moderate emitters. Presumably, even relatively moderate differences for only slight emitters are not important practically.

- **If it is true, as indicated by the results from this sample, that a good proportion of vehicles on the road do not conform to ADR37/01, as far as NOx is concerned, then, apart from outstandingly gross emitters, exactly which vehicles constitute the set which emit NOx over the relatively low reference threshold is rather sensitive to the cycle used to identify them.**

DETAILED INSIGHT INTO CO EMISSIONS

CO emissions cube rooted: SPC240 cycle integrated cf ADR37 cycle. Figure 4 shows the relationship ($r = 0.945$ for all vehicles) and the ADR37/01 cut-offs (corresponding to 2.1 g/km) as a solid line. The other cut-offs correspond, somewhat arbitrarily, to CO = 25 and 50 g/km. Vehicle age is disregarded here.

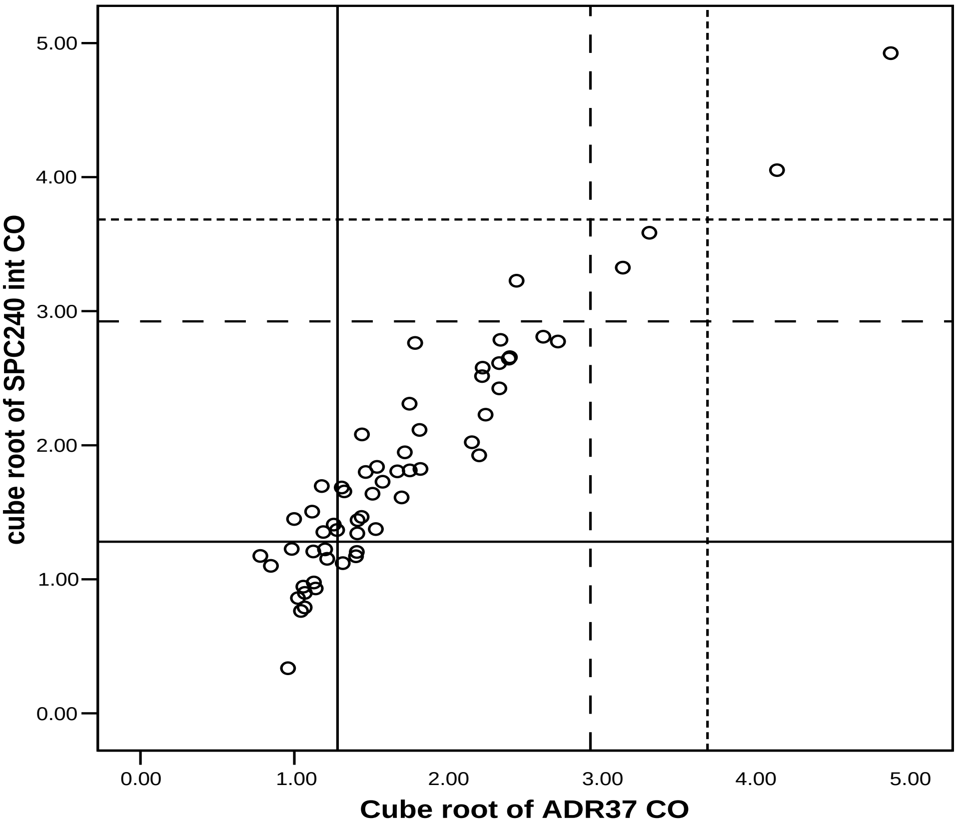

Figure 4 CO levels from ADR37 and SPC240 cycles, with various reference levels

The dashed lines in Figure 4 show cut-offs suggested by the scatter, to identify really gross emitters (fine dash, > 50 g/km) and moderately gross emitters (coarse dash, >25 g/km). We find that SPC240 and ADR37 agree on the two really gross emitters but SPC240 identifies one more moderately gross emitter.

More clarification is achieved when vehicles are separated by age group (ie grouped year of manufacture) as shown in Figure 5 to Figure 7(SPC240 vs ADR37).

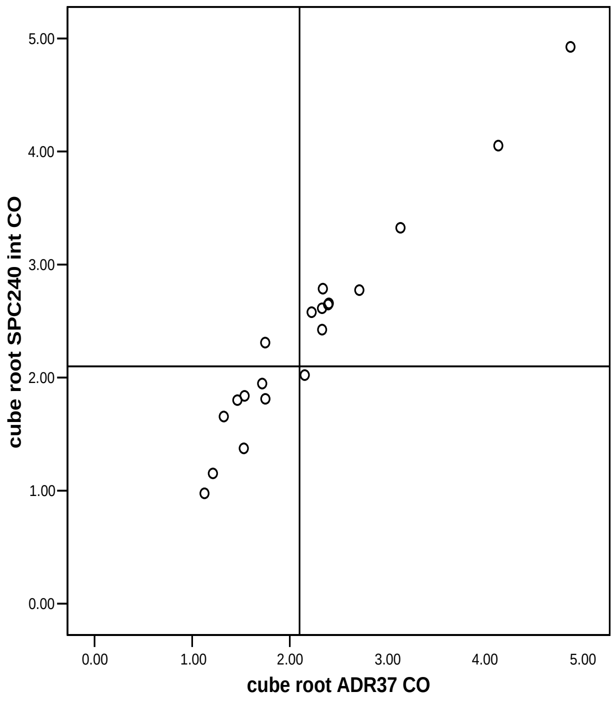

Figure 5 Pre-1994 YOM vehicles, with the contemporary ADR37 CO standards shown

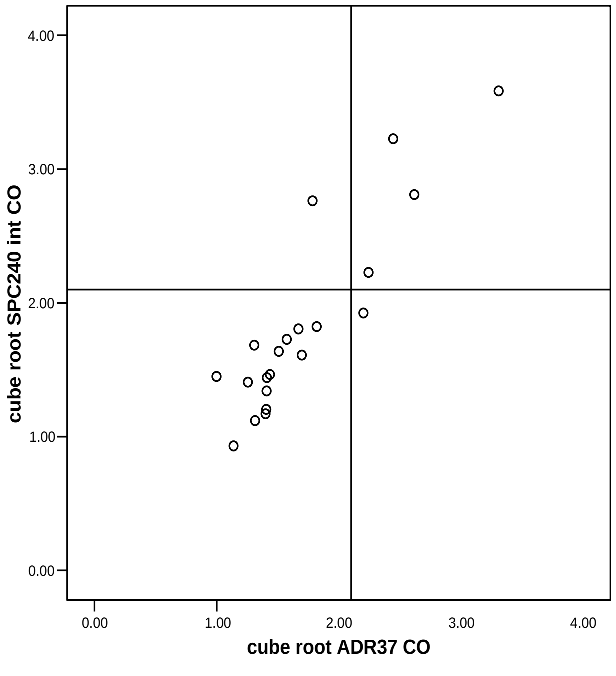

Figure 6 1994-8 YOM vehicles with the contemporary ADR37 CO standards shown

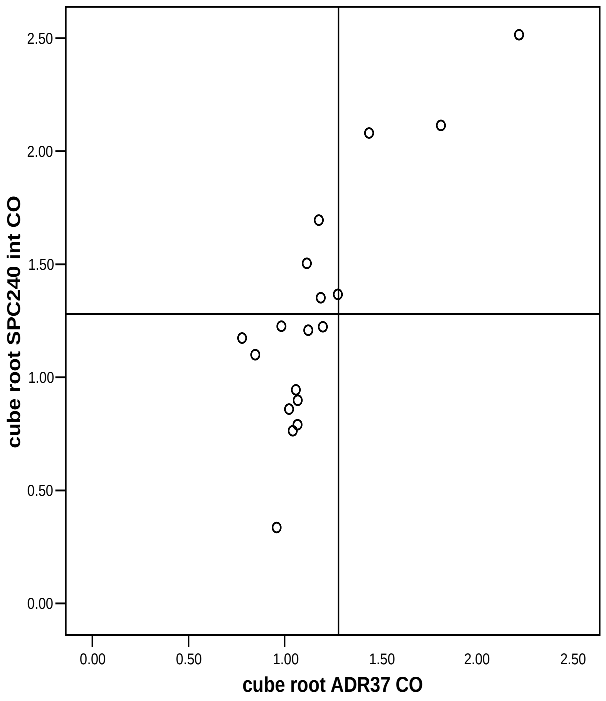

Figure 7 Post-1998 vehicles, with the contemporary ADR37 CO standards shown

The older vehicles have the ADR37/00 cut offs; the newer vehicles have ADR37/01 cut offs. It is illustrative of the relative consistency of older higher emitters (>25 g/km, >2.9 scale value) that the correlation coefficient for the newer vehicles only is a low 0.826 whereas for the older vehicles alone it is 0.976. Not surprisingly, for the medium age vehicles Figure 6 it is intermediate (r = 0.896; ADR37/00 cut off). See below.

DETAILED INSIGHT INTO TOTAL HYDRO CARBONS

Figure 8 and Figure 9 show the overall relationships for THC emissions for the short (y) vs long (x) cycle for the Petrol CUEDC and ADR37 cycles respectively, using cube root transformed data. The integrated values for the short tests are shown.

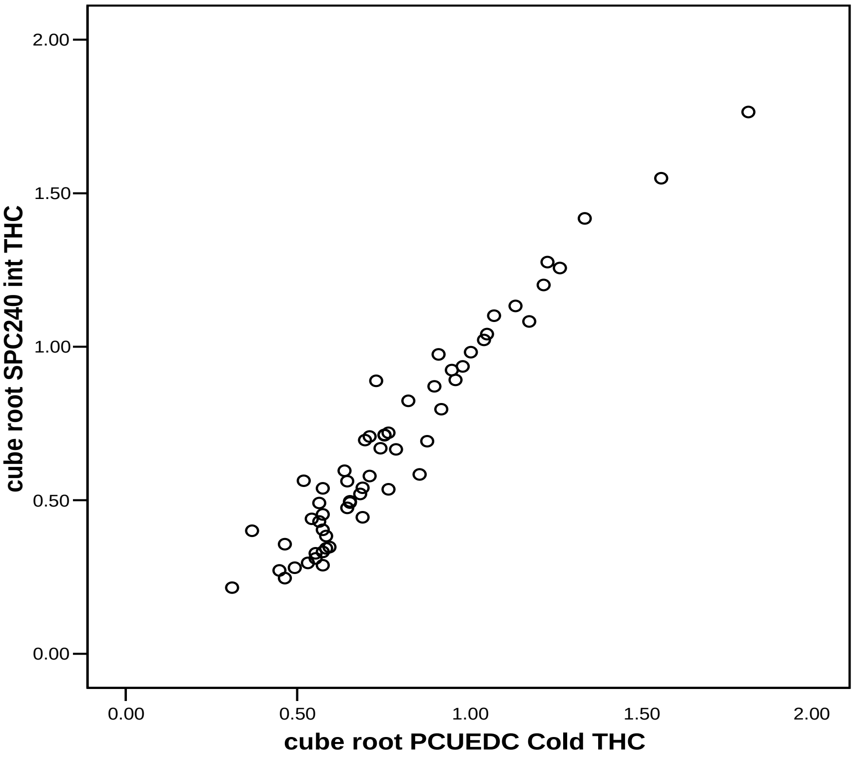

Figure 8 Cube root THC SPC240 V Petrol CUEDC

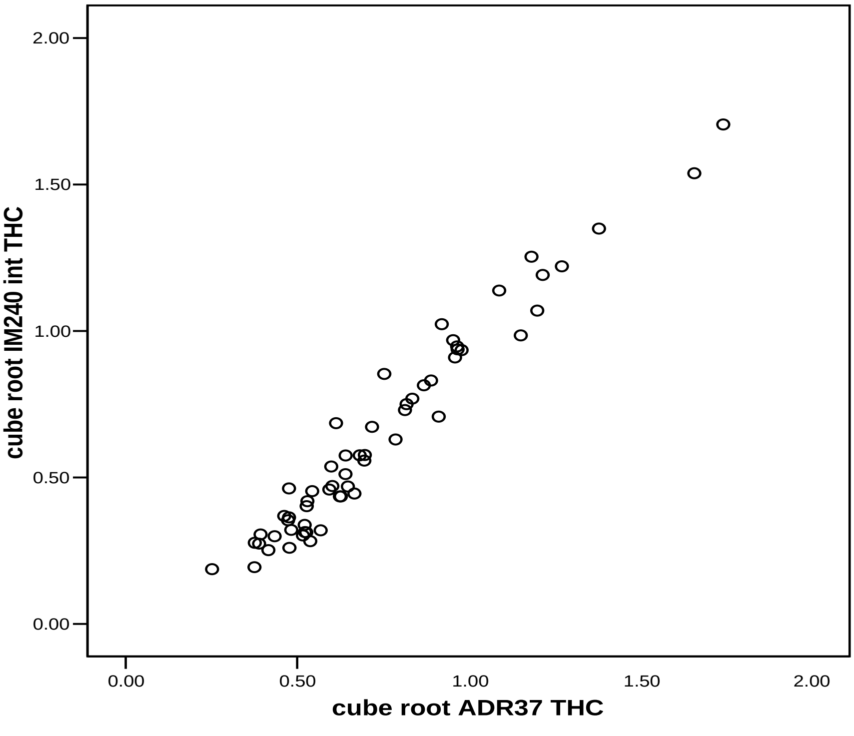

Figure 9 Cube root THC IM240 V ADR37

In Figure 10 to Figure 13, the short cycles are compared, firstly for all vehicles, then for the three age groups. The appropriate ADR37 cut offs at manufacture are 0.98 for Figure 11 and Figure 12and 0.64 for Figure 13.

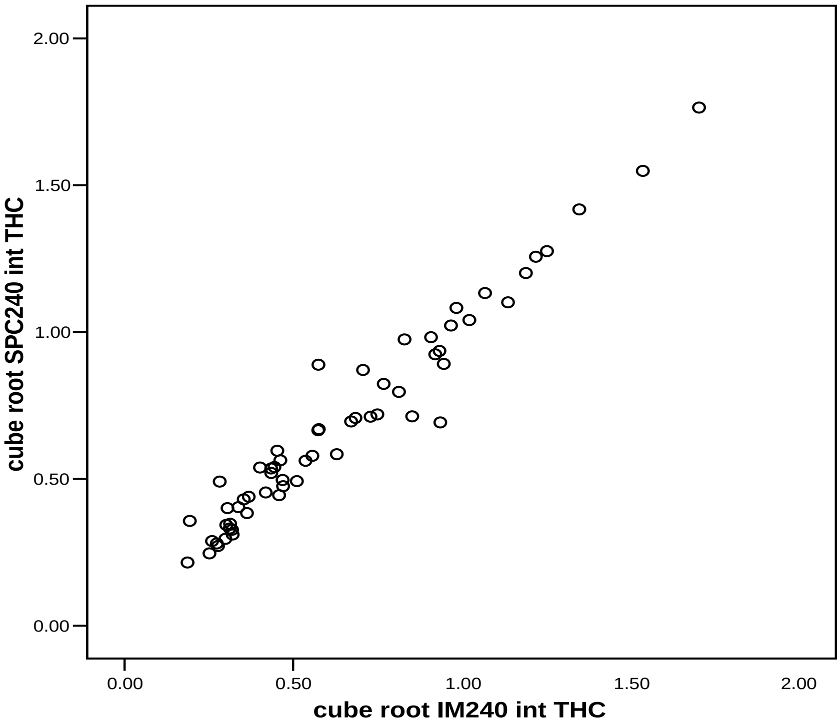

Figure 10 Cube root THC SPC240 V IM240 all vehicles

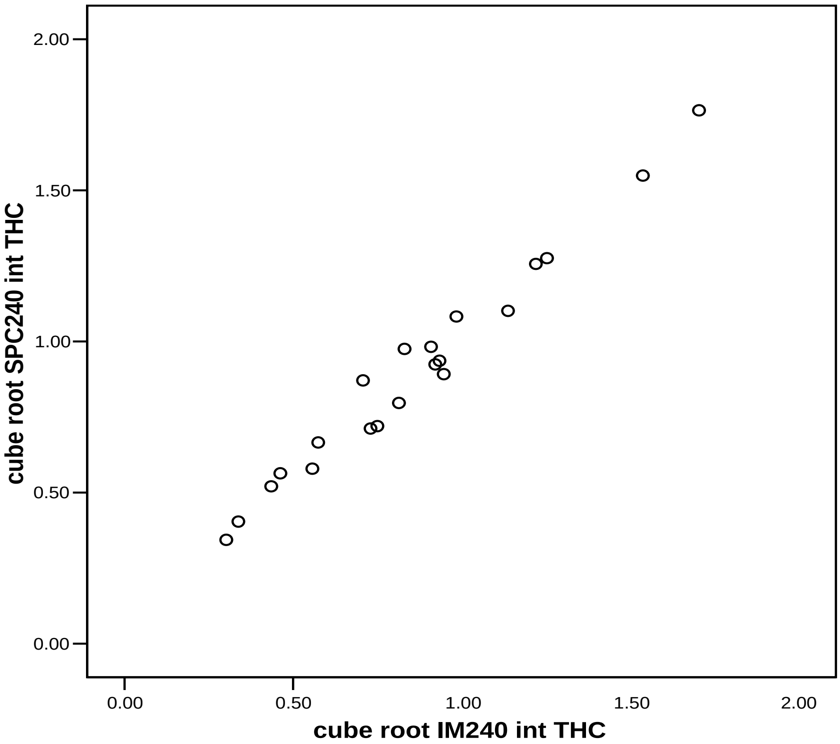

Figure 11 Cube root THC SPC240 V IM240 older vehicles

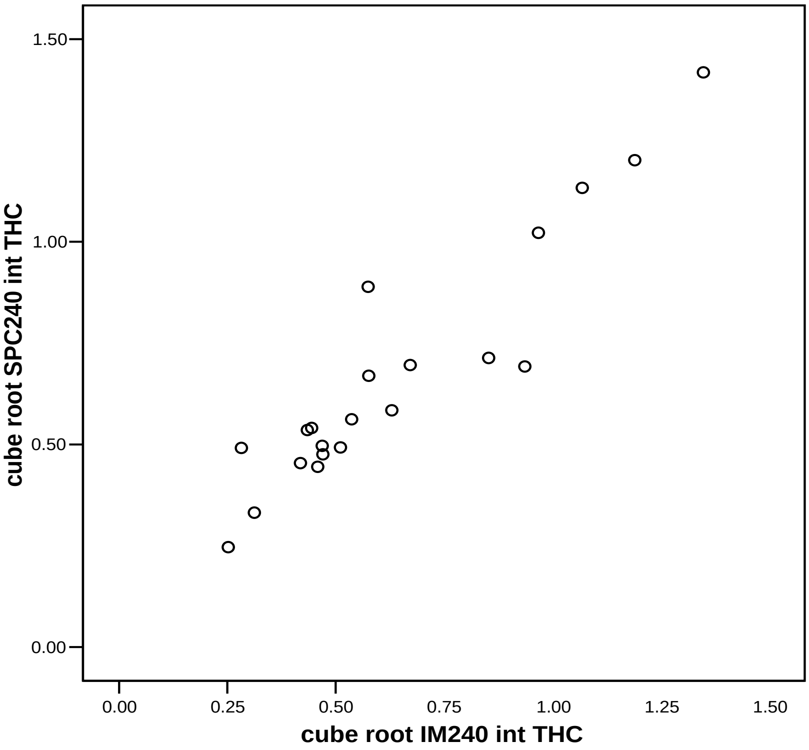

Figure 12 Cube root THC SPC240 V IM240 medium aged vehicles

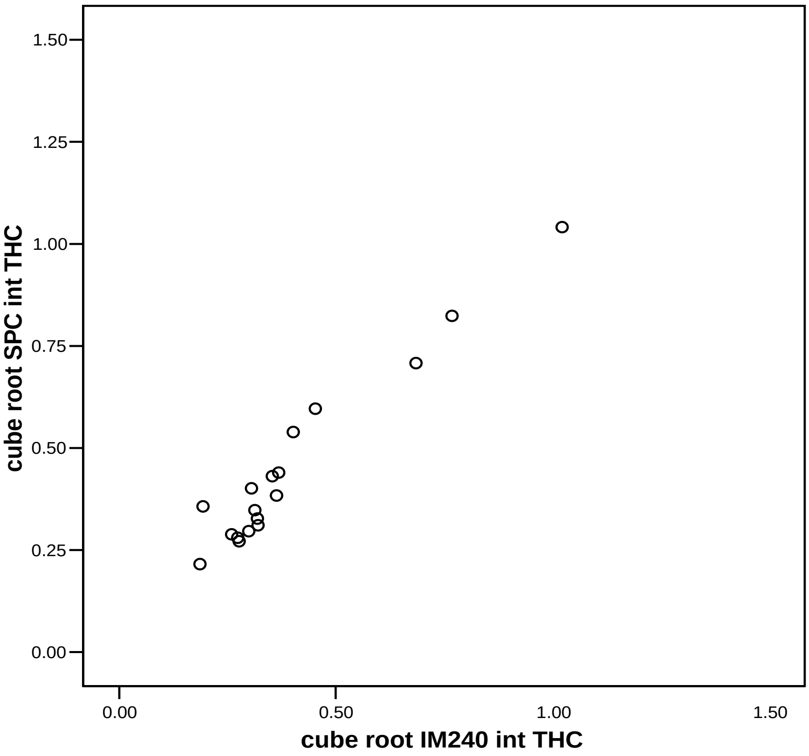

Figure 13 Cube root THC SPC240 V IM240 newer vehicles

There is fairly good agreement between the short tests on technical gross emitters, though SPC240 shows slightly greater numbers (7 vs 6, in Figure 11 and 4 vs 3 in Figure 12, both on ADR37/00; and equally 3 in

Figure 13, on ADR37/01). It would be marginal to describe any of the 60 vehicles as really gross emitters on account of the level of THC emissions.

THC AND NOX RELATIONSHIP

There is interest in the relationships between NOx and THC levels for the different groups (ages) of vehicles. These are shown in Figure 14, all with the same scales. ADR37/01 cut-offs are shown. The data are from the ADR37 test. Cube root transformations are applied throughout.

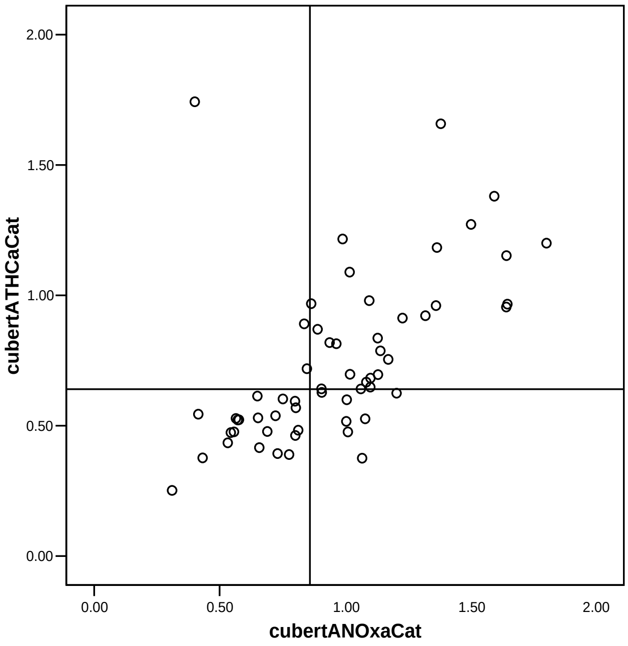

Figure 14 ADR 37 THC v NOx all vehicles

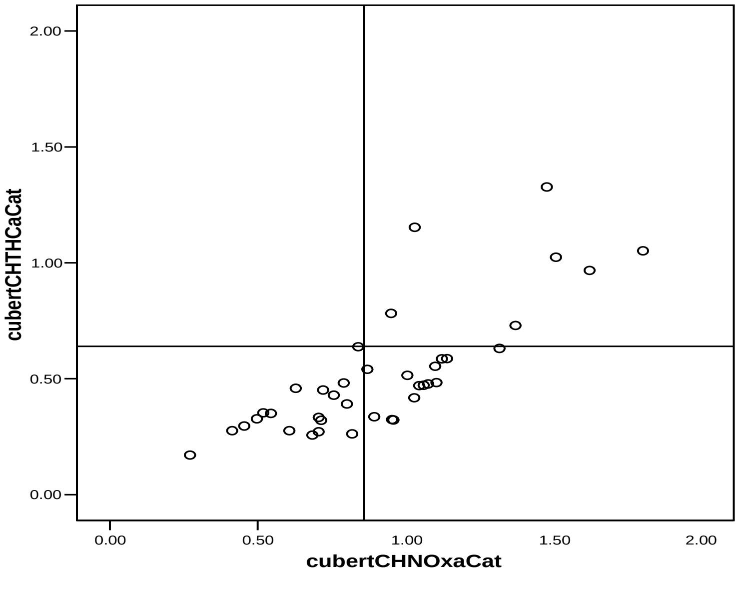

Figure 15 ADR 37 THC v NOx post-1993 vehicles only

Figure 16 to Figure 18 show the groups separately.

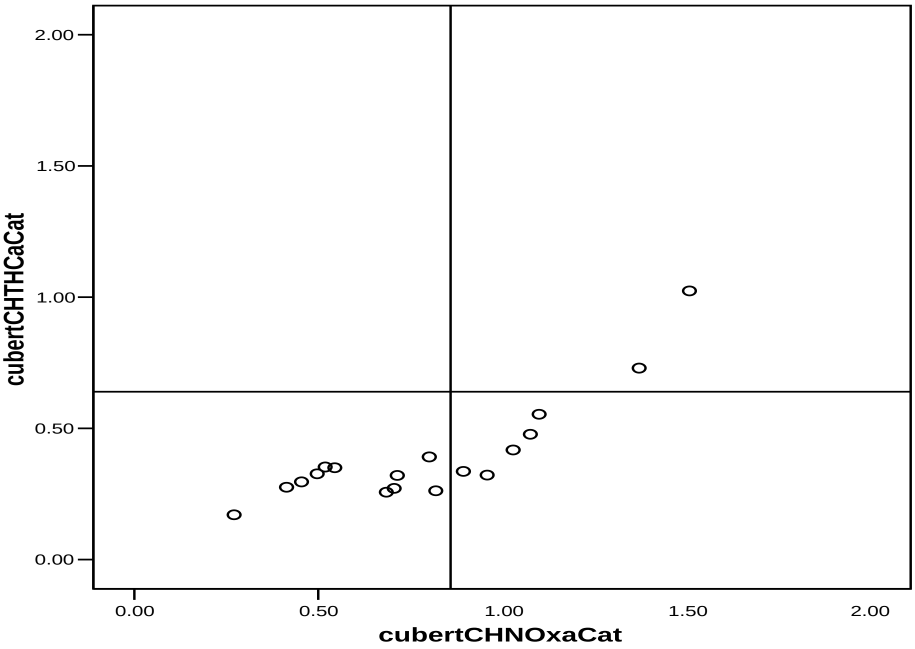

Figure 16 ADR 37 THC v NOx post-1998 vehicles only

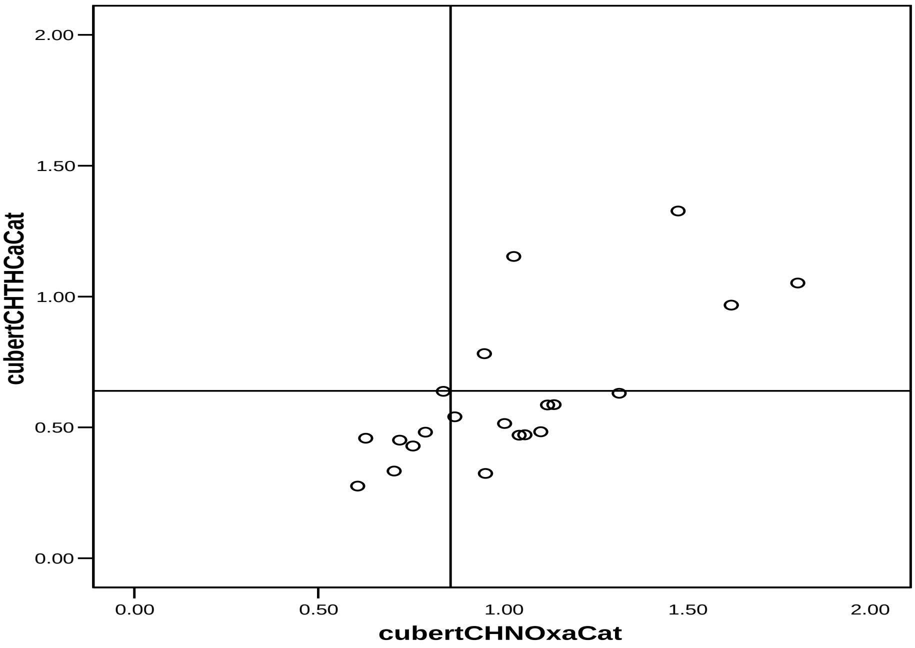

Figure 17 ADR 37 THC v NOx vehicles 1994-1998 only

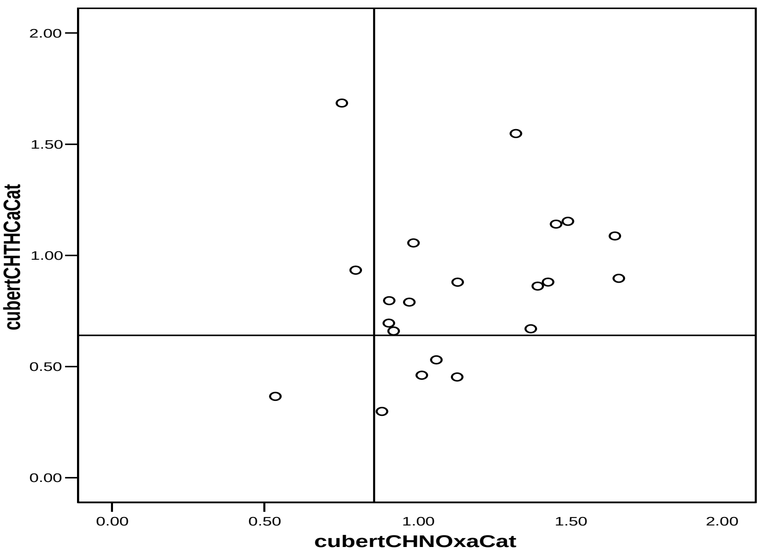

Figure 18 ADR 37 THC v NOx pre-1994 vehicles only

The newer the vehicle, the less of a problem with THC there is compared with NOx, based on ADR37/01 criteria applying the cut-offs shown in the progression from Figure 16 to Figure 18.

The relationship with the newer vehicles (Figure 16) is nearly linear, but with a bit of upward curvature. The data might suggest that 'fixing' NOx would also fix THC for this group, if there is direct or indirect causation as well as a mutual association.

For the moderately aged vehicles (Figure 17), the relationship is rather ragged, with two vehicles having a higher THC level than might be expected from their NOx level (the upper two points in the scatter). This clearly suggests some degree of independence between levels of these two emissions.

The older vehicles (Figure 18) confirm this independence quite strongly, one vehicle having an acceptable NOx level, rare for the older vehicles, but with quite excessive THC.

Whether one needs to consider some type of trade-off in attempting to repair older vehicles is a possibility to consider.

SHORT CYCLE COMPARISON FOR REALLY GROSS EMITTERS

The two short tests, SPC240 integrated and IM240 integrated, are compared directly, for all vehicles in Figure 19. Conventional standards fall centrally within the data scatter: this is not a 'gross' criterion. Using a CO cut off of 25 g/km identifies four gross emitters unambiguously and one further candidate in SPC240.

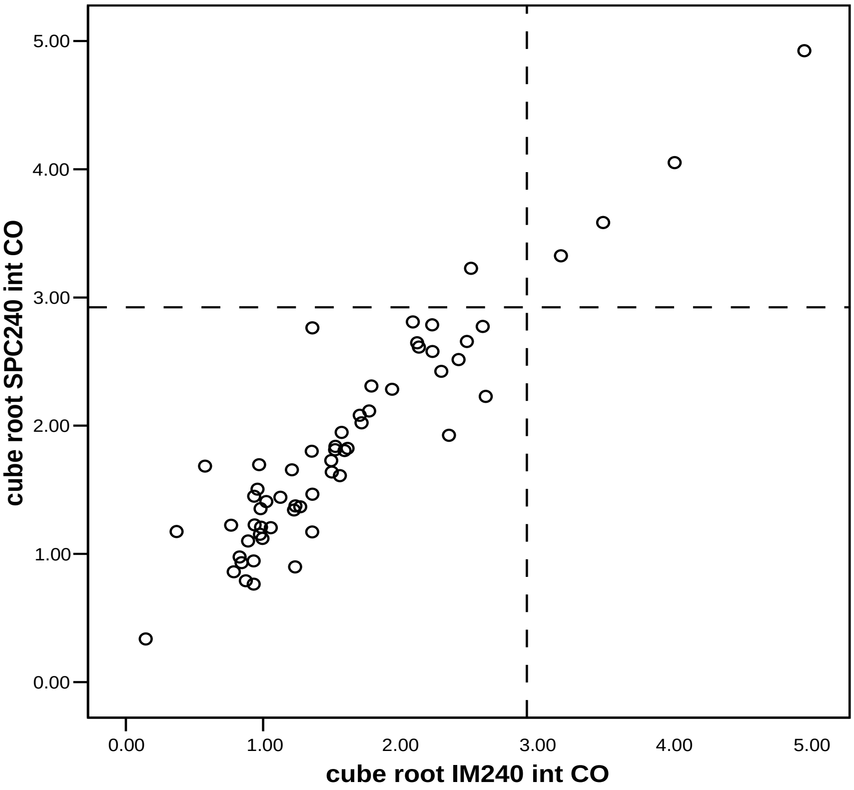

Figure 19 Short Cycle Comparisons for CO

IDENTIFYING VEHICLES EXCEEDING ADR37 STANDARDS AS GROSS EMITTERS

There were 21 older vehicles tested that have ADR37/00 as their standard. Their ADR37/00 standard when new for CO was 9.3 g/km, cube rooted to 2.1.

Figure 20 shows the scatter for ADR37 and its 240-second derivative IM240. Figure 21 compares SPC240 with the Petrol CUEDC cold

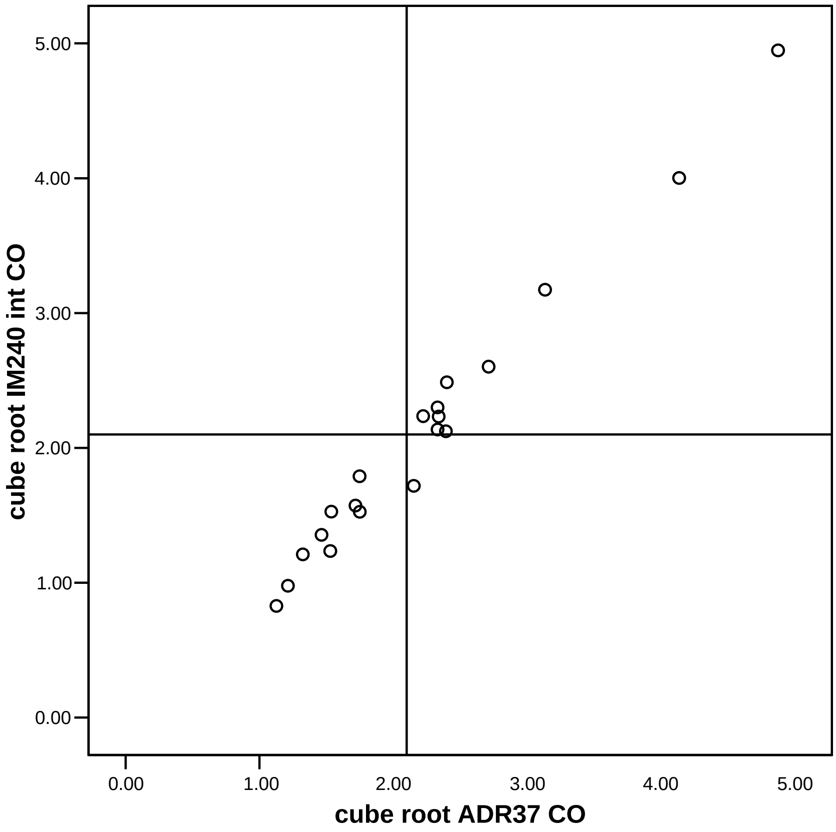

Figure 20 Cube rooted CO values for the IM240 cycle and the ADR37 cycle, ADR37/00 level indicated

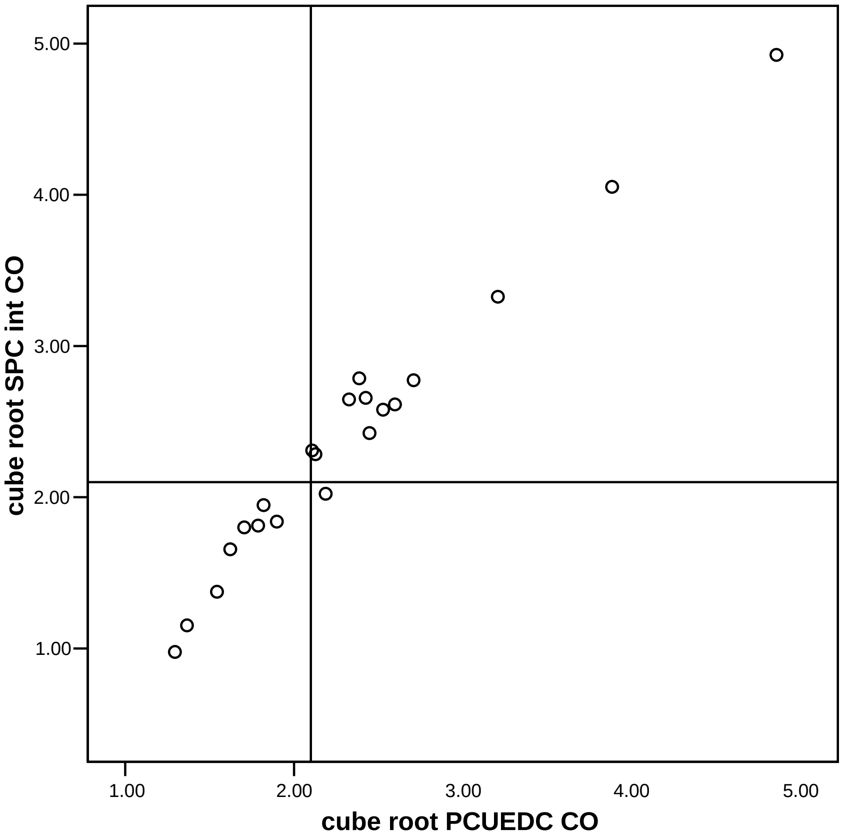

Figure 21 Cube rooted CO values for the SPC240 cycle and the PCC cycle, ADR37/00 level indicated

It can be seen from Figure 20 that IM240 'misses' one gross emitter of the 11 + 1* identified by ADR37. (*Note that one ADR37 CO value is missing, but other cycles indicate that the vehicle in question was clearly a gross emitter.). In Figure 21, SPC240 identifies 12 gross emitters and Petrol CUEDC Cold 13. Thus, on CO, SPC240 matched ADR37 but did not quite match Petrol CUEDC Cold.

Correspondingly, numbers of gross emitters of NOx, arbitrated on by the critical ADR37/00 NOx value of 1.93, were: IM240 7, ADR37 7; SPC240 6, Petrol CUEDC Cold 9 (just!)

On the older vehicles twice as many gross emitters of CO were noted than of NOx, based on the ADR37/00 standard (Figure 22). There was little difference among the pairs of corresponding cycles considered (ADR37-based, Petrol CUEDC Cold-based, as in Figure 20 or Figure 21) but Petrol CUEDC Cold was slightly ahead of ADR37, by around 15% of vehicles. SPC240 was, on this small sample, identifying the same number of vehicles as IM240 exceeding the NOx limit (7/21) but two more over the CO limit (12/21 cf 10/21). However, it is emphasised that the critical values of 9.3 for CO and 1.93 for NOx pass through the data fairly close to the medians of these older vehicles, as is apparent by the numbers of defaulters identified, where hair-splitting is consequently most likely.

The very weak connection between NOX gross emitters and CO gross emitters is shown in Figure 22, ADR37/00 standards shown). Only one third of these older vehicles did not exceed one or both the ADR37/00 limits.

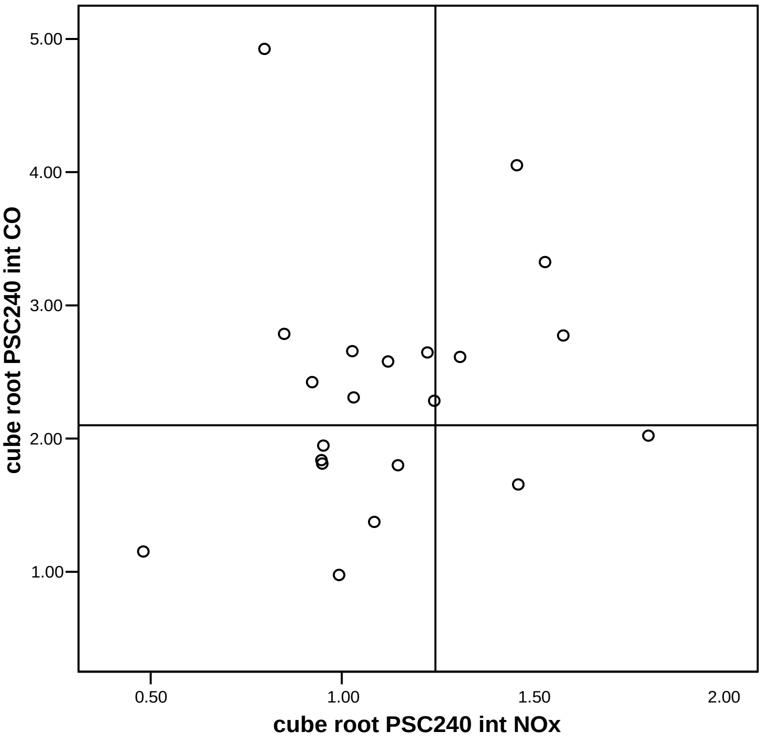

Figure 22 Comparing CO and NOx gross emitters for the older vehicles

Two vehicles that were outstandingly gross emitters of CO were easily picked by all cycles. Even a third, emitting at a somewhat lower level, was easily discriminated all round by a scale cut-off value of around 3, ie CO g/km > 25, say. However, Figure 22 shows that the highest emitter of CO conformed for NOx (the upper left point), whereas the next two worst for CO were also rather poor for NOx (upper right)..

There were 18 newer vehicles tested that had ADR37/01 as their emission standard. The CO limit for this ADR is 2.1 g/km, cube rooted to 1.28.

Figure 23shows the scatter for ADR37 and IM240 after Cat bag, and Figure 24 shows the scatter for SPC240 after Cat bag and Petrol CUEDC Cold.

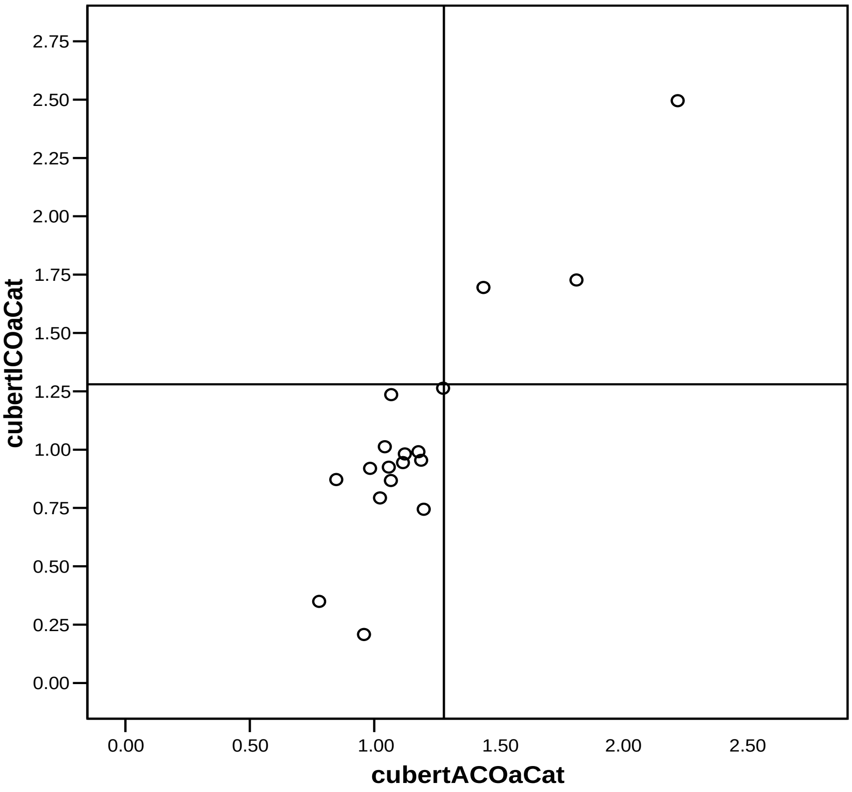

Figure 23 Cube rooted CO values for the IM240 after Cat bag cycle and the ADR37 cycle

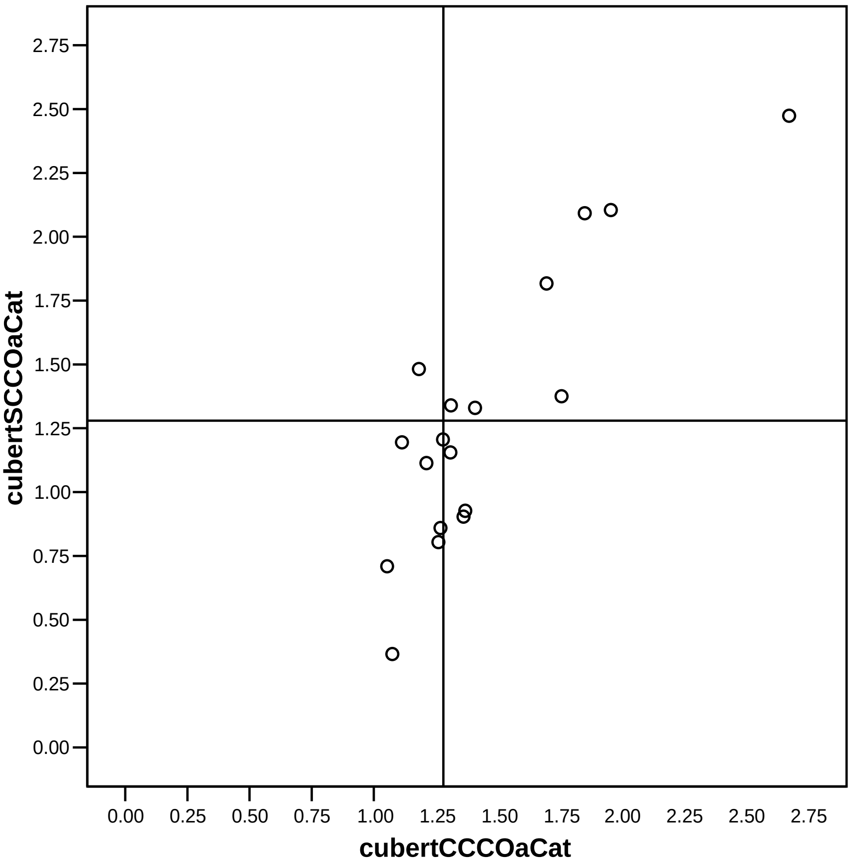

Figure 24 Cube rooted CO values for the SPC240 after Cat bag cycle and the PCC cycle

In Figure 23 and Figure 24 we see a quite different picture emerging for these newer vehicles. The scales on the two graphs are the same. The ADR37-based cycles in Figure 23 each show 3 gross emitters, and almost a fourth, whilst Figure 24 shows 10 gross emitters for Petrol CUEDC Cold and 8 for SPC240 after Cat bag.

- If anything can be suggested by the limited scope of the Figure 24 scatter, it is that the critical value for CO in a Petrol CUEDC Cold-based cycle should be lifted to around $(1.6)^3$ = about 4 g/km. This would give 5 gross outliers for Petrol CUEDC Cold and 4 for SPC240 after Cat bag. There was only one outstandingly gross emitter relative to others in this group of vehicles, separated by CO > 10 g/km.

Quite clearly, the much larger main sample will provide much stronger data for better defining an appropriate level for discrimination.

The comparison of the integrated values for CO in the two short cycles is shown in Figure 25

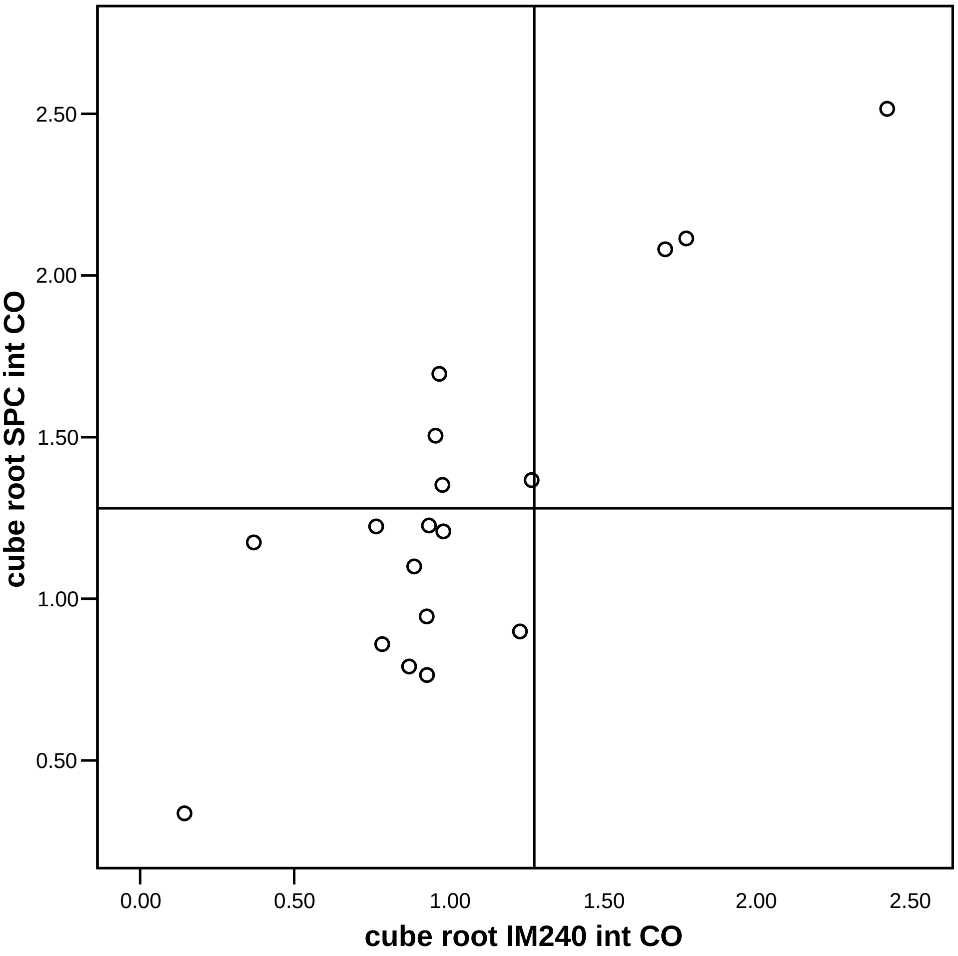

Figure 25 CO comparison for integrated values of IM240 and SPC240, against ADR37/01 limits

Figure 26 shows SPC240 giving a much higher number of gross emitters (7/18) than IM240 (nearly 4/18)

The NOx comparison gives a similar mismatch in terms of numbers, but it was a close thing. The three newer vehicles exhibiting 'lean burn' NOx excesses in PCC (Figure 2) do not affect this comparison since there was no freeway phase in the short cycles.

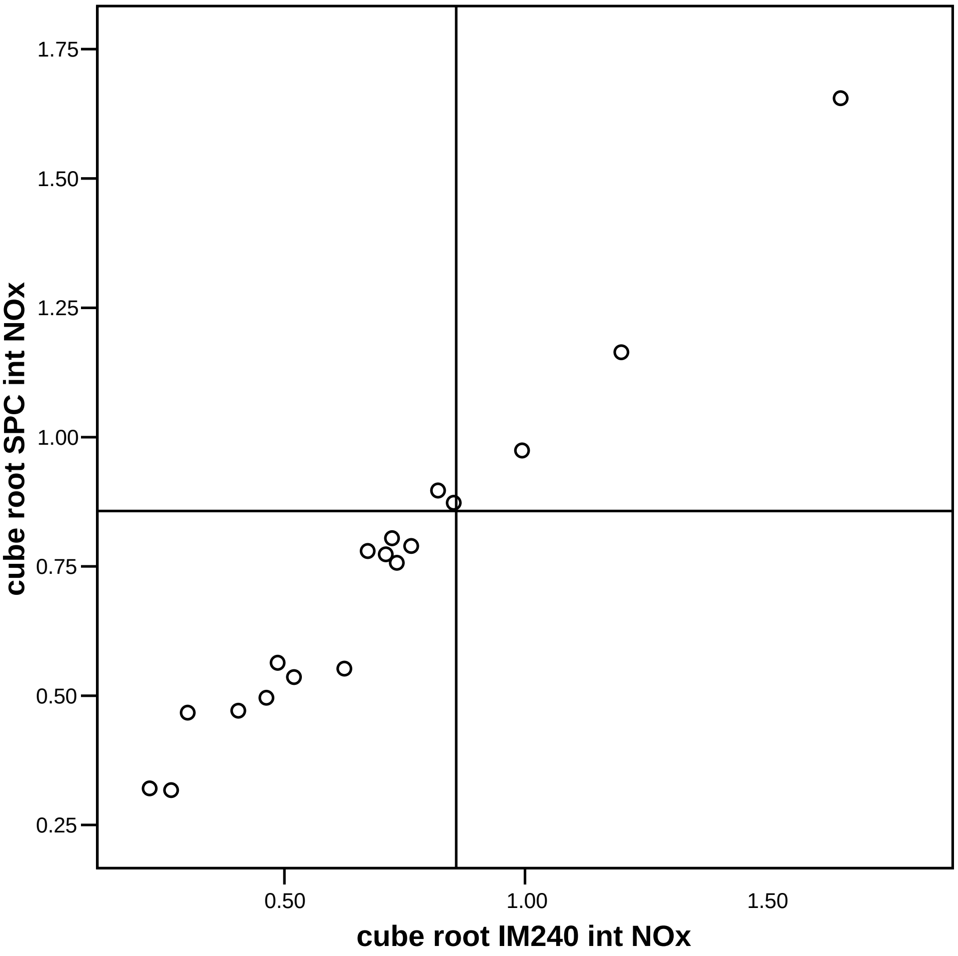

Figure 26 NOx comparison between the two short tests with integrated values, newer vehicles ref ADR37/01

The ADR37/01 critical value of NOx is 0.63, cube rooted to 0.86. There were three gross emitters (3/18) for IM240, but nearly a fourth, and a marginal 5/18 for SPC240. The indications are that the critical ADR37/01 NOx value of 0.63 works adequately for newer vehicles. A value of 2 g/km might be realistic for really gross emitters (scale value 1.26 in Figure 18).

There were 21 moderately aged vehicles tested, whose models originally complied with the ADR37/00 standard.

For CO, against ADR37/01, which is tougher than as new, gross emitter numbers were: IM240, after Cat bag: 13, ADR37: 18; SPC240 after Cat bag: 17, Petrol CUEDC Cold: 20. Thus the great majority qualify as gross emitters of CO against the more stringent ADR37/01 standards. A cut off that reflects the really gross emitters lies at around 2^3 = 8 g/km which identifies 5 vehicles for all cycles except Petrol CUEDC Cold with 6.

See Figure 27 and Figure 28 for, in this case, NOx scatter plots.

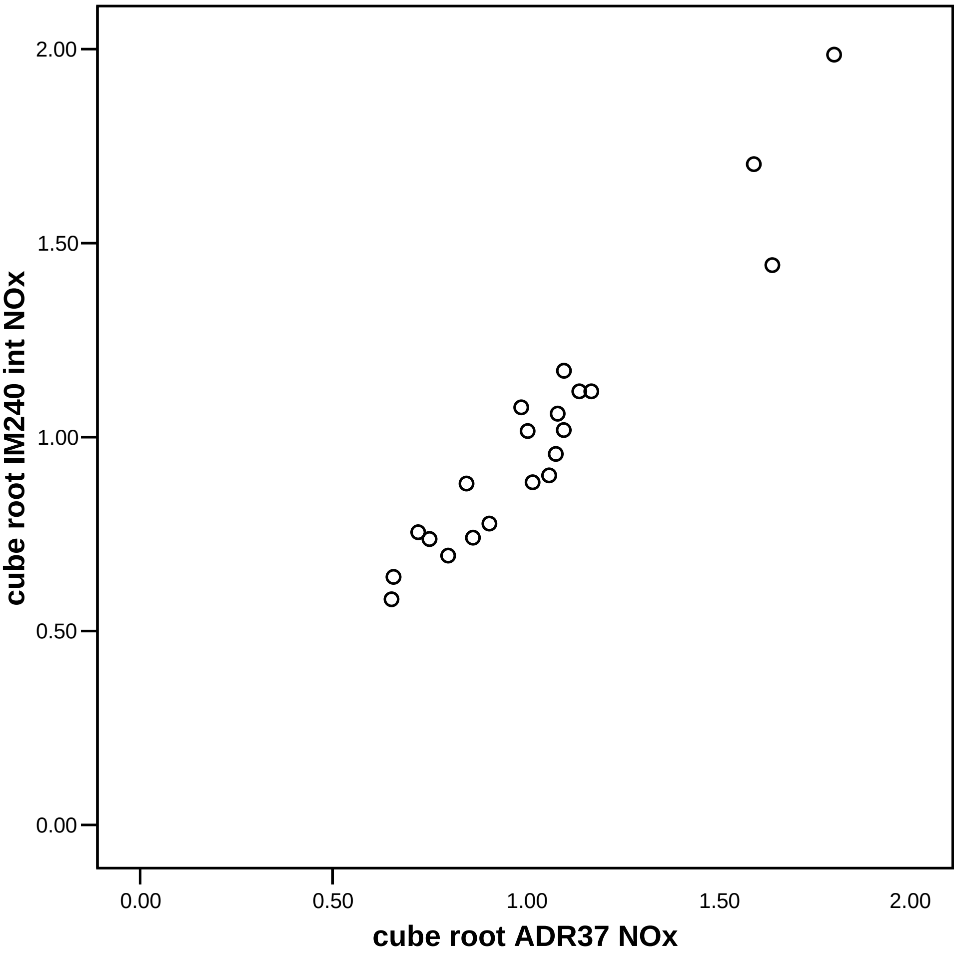

Figure 27 Cube rooted NOx values for the IM240 cycle and the ADR37 cycle

The ADR37/00 standard appears in Figure 27 and Figure 28 as $1.93^{(1/3)} = 1.245$. Against this, there are three outstandingly gross emitters successfully identified in Figure 27, but one or two more ‘dragged in’ in Figure 28. A scale value of 1.4 serves well all four cycles, ie > 2.75 g/km, separating out the ‘big three’.

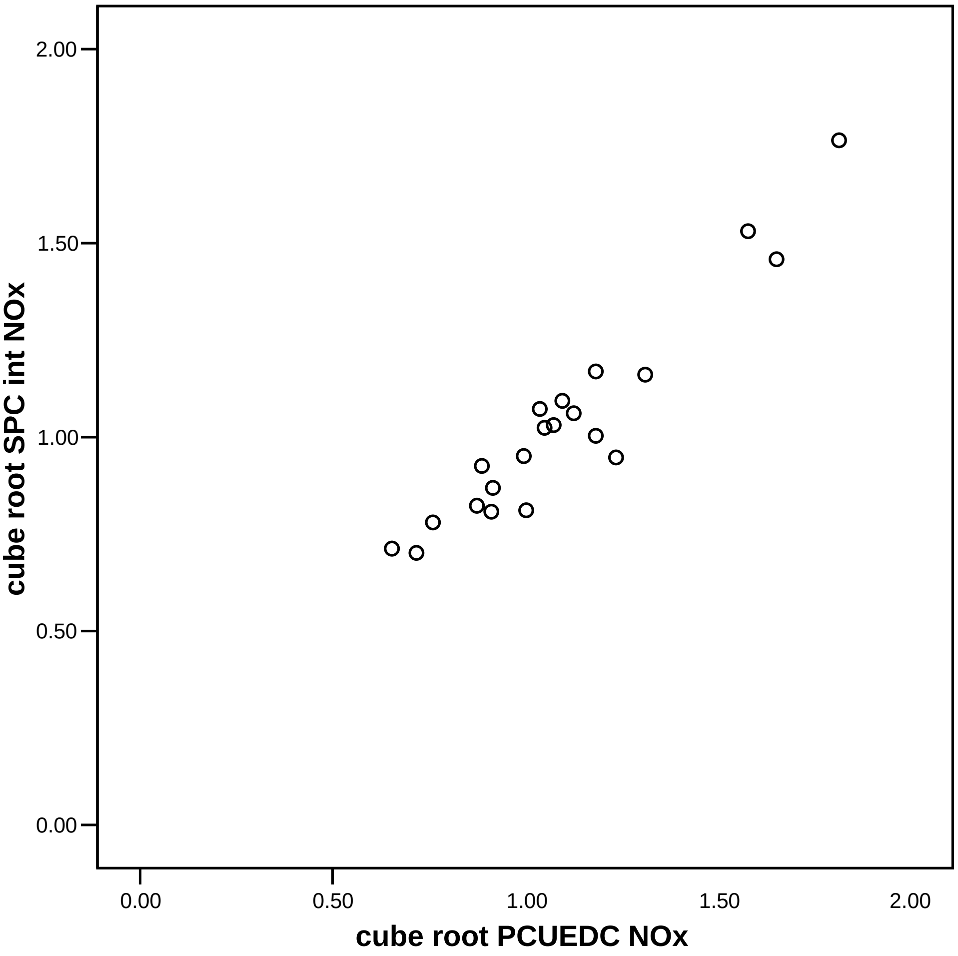

Figure 28 Cube rooted NOx values for the SPV240 cycle and the PCC cycle

For NOx, on ADR37/01, Figure 27 and Figure 28 show gross emitter numbers were: IM240: 14, ADR37: 15; SPC240: 16, Petrol CUEDC Cold: 18. Again, therefore, Petrol CUEDC Cold has been more sensitive.

Figure 29 compares the two short tests with integrated values, and both ADR37/00 (greater) and ADR37/01 (lesser) reference lines.

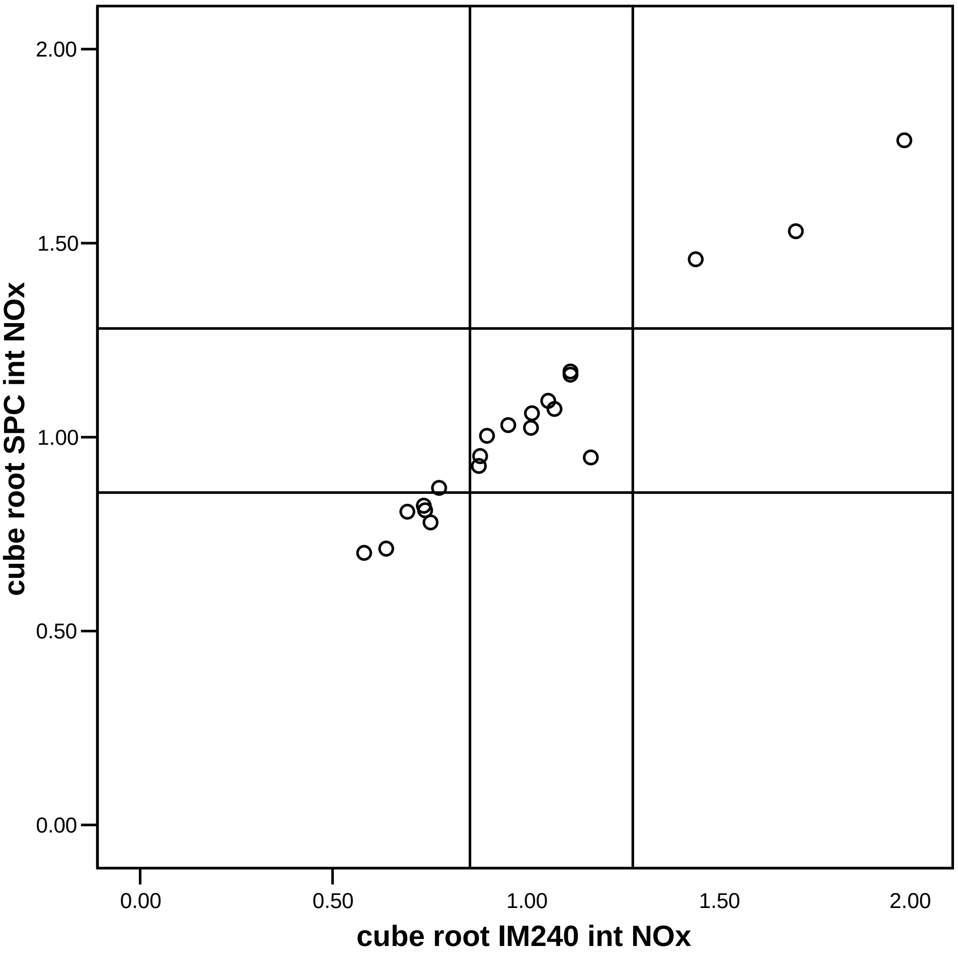

Figure 29 NOx comparison for integrated short tests, medium age vehicles, with ADR37/00 and/01 shown

The corresponding scatter for CO shows much lower agreement (Figure 30).

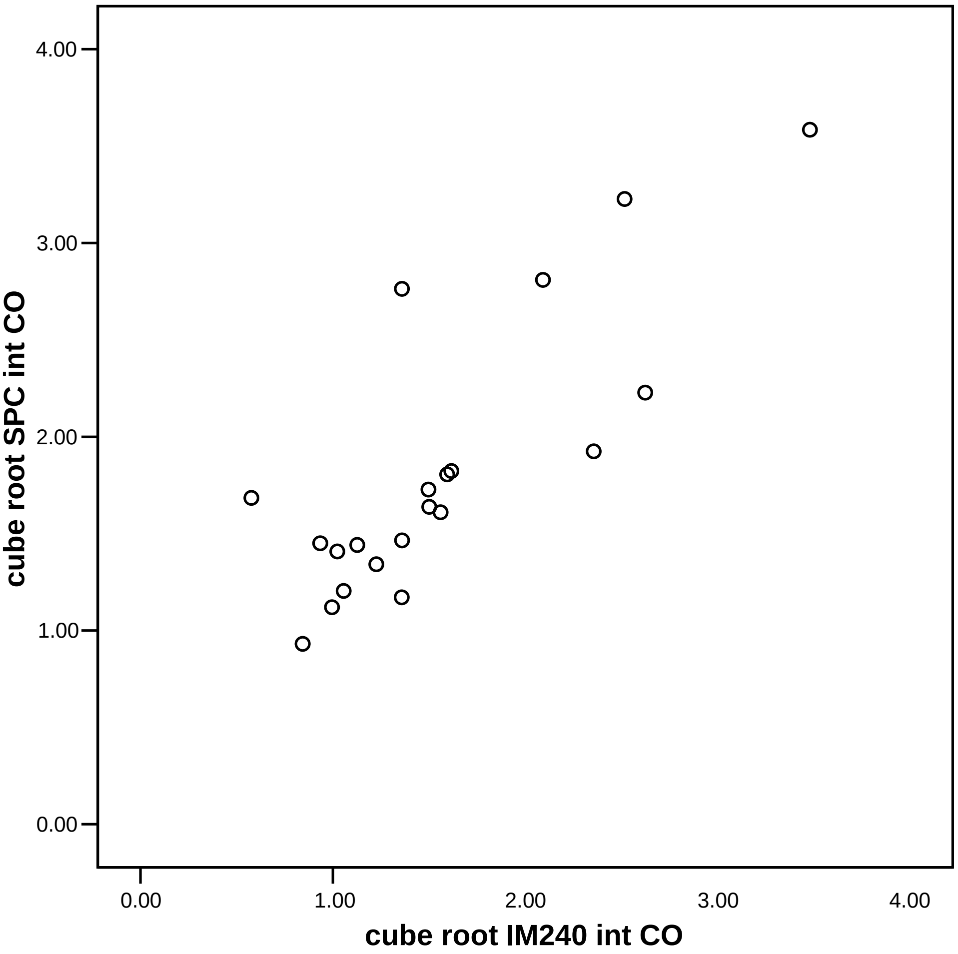

Figure 30 CO comparison for integrated short tests, medium age vehicles

Summarising over the full 60-vehicle sample, SPC240 matched ADR37 and outperformed it for CO on the newer vehicles. Petrol CUEDC Cold was most sensitive in the context of this sample.

The nomenclature of ‘gross emitters’ seems singularly inappropriate to the general emissions levels of this set of vehicles. Only the newer vehicles showed a clear majority of vehicles, around 80%, adhering to current ADR37/01 standards, though not for CO on the Petrol CUEDC-based cycle. Vehicles between 6 and 11 years of age failed abysmally, but adequately against the more lenient ADR37/00.

Again, the scatters in Figure 20 to Figure 28 suggest a two-stage problem: really gross outliers and ‘technical’ outliers. The emphasis must be to fix the really gross examples first, bearing in mind that these values are cube roots. The really gross outliers are around 4 times as bad (g/km) as those exceeding the standard by a moderate amount.

Overall, for moderate age vehicles, SPC240 matched ADR37 on ADR37/01 but was inferior to PCC.

STATISTICAL CLUSTER ANALYSIS AS A MEANS OF DECIDING 'BEST' CUT-OFF VALUES

Statistical clustering picks out significantly different groupings among the individual values of a variable. There is no reference to (existing) standards and the cut-off values are defined solely by the sample to hand. It is of some interest to enquire whether the identification of really gross emitters matches the outcome from statistical clustering.

Formal statistical Cluster Analysis applied to the emissions from the sample of 60 vehicles tends to confirm that there are high level outliers and, indeed, some level of discrimination among the rest. As an example, The SPC240 integrated CO values gave three clusters, whether the data were cube-root transformed or not, though the clusters were different in the two analyses. It would be taken that the cube-root version Table 17) were the more correct, being more normally distributed and therefore more amenable to the clustering process. Apart from really gross emitters, there is no self-evident cut-off point defined by the preliminary sample of 60 vehicles. Therefore any lower cut-off must be determined on pragmatic grounds rather being based on scatter or clustering.

Table 16 Statistical clusters for CO untransformed, Cluster Distribution for SPC240 integrated CO

		N	Std dev	Mean CO g/km	Upper cut-off g/km
Cluster	1	46	3.5	4.2	15
	2	12	9.4	24.2	Between 46 and 66
	3	2	37.4	93.0	n.a.
	Combined	60		11.2	

Table 17 Statistical clusters for CO cube-root transformed, Cluster Distribution for cube root of SPC240 integrated CO

		N	Mean	Back-transformed mean CO g/km	Upper cut-off g/km
Cluster	1	28	1.18	1.64	4.5
	2	27	2.20	10.65	Between 22 and 34
	3	5	3.83	56.18	
	Combined	60	1.86	6.44	

The untransformed data (Table 16) provided a CO cut-off for two really gross emitters of around 53 g/km and for moderate emitters of 15 g/km. Under cube root transformation (Table 17) the generated cut-offs were 2.30 and 1.65. These back-transform to five really gross emitters above around 28 g/km and a lower discrimination at around 4.5 g/km, a rather different outcome. The latter, although being preferred on theoretical grounds, ties in well with the lower of the informal, arbitrary cut-offs of 50 and 25 g/km. It is emphasised that these cluster boundaries are very much dependent on the constituent vehicles in the sample, and that a much larger sample of vehicles could define cut-offs more precisely, should such exist statistically, with some assurance eg after main phase testing. The second separation at a lower level in this sample of 60 vehicles would not be expected to match the formal cut-off, either at the ADR37/00 (9.3) or ADR37/01 (2.1) levels, though the two values of 15 g/km (from untransformed) and 4.5 g/km (from back-transformed) are very broadly within the ball park of ADR37/00's 9.3 g/km.

PREDICTING PETROL CUEDC HOT EMISSIONS FROM ADR37 EMISSIONS

The close overall relationships between emissions measured on the various cycles would lead us to suppose that the emissions level from any one cycle can be satisfactorily predicted from those from any other. In particular, the overall correlation coefficients between ADR37 and Petrol CUEDC Hot (full cycle) were, from Table 2 to Table 5: THC, 0.992; CO, 0.989; NOx, 0.960; and CO2, 0.987. The relatively poor value for NOx, in context, results in part from three vehicles going into lean burn in the freeway phase. When these three are excluded, the NOx correlation coefficient is 0.976 ($R^2 = 0.95$), as already stated. Thus the NOx relationship is not quite as strong as for the other three emissions. Again, as already indicated, the fuel consumption correlation is much poorer, r = 0.883, though it is a high 0.991 when the freeway phase is omitted.

OLDER VEHICLES, NOX

In order to obtain accurate regression equations for predictive purposes the appropriate 'independent' variables must be included. As has already been noted, vehicle age group has a great bearing on emissions levels, as a result of differing standards at the time of manufacturer and extent of engine wear. Since ADR37/00 applied equally to the vehicles in the sample manufactured before 1999, y ear of manufacture is used as a principle covariate for the 42 vehicles in this larger group. Perhaps surprisingly, it does not emerge as a significant contributor to the regression of Petrol CUEDC Hot, either as the sole regressor or accompanying ADR37 NOx. It has the anticipated sign (older vehicles slightly worse) but has little effect on the relationship between Petrol CUEDC Hot NOx and ADR37 NOx for the older vehicles. Casewise diagnostics indicate the vehicles DEH0042 is an outlier in the relationship between Petrol CUEDC Hot and ADR37 under cube root transformation. When it is omitted, the regression equation is presented in:

Regression of NOx values for Petrol CUEDC Hot on ADR37 (cube root transformations) and YOM

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
Coefficients	B	Std. Error	Beta		
(Constant)	-.036	.042		-.872	.389
cube root ADR37	1.024	.037	.974	27.871	.000
yom minus 1993	-.003	.003	-.031	-.884	.382

The adjusted R^2 value is 0.953 and the residual standard deviation 0.068.

When YOM is omitted, the equation is:

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
Coefficient	B	Std. Error	Beta		
(Constant)	-.041	.041		-.993	.327
cube root ADR37	1.027	.037	.977	28.126	.000

Again, the adjusted R^2 value is 0.953 and the residual standard deviation 0.068.

An adequate representation of the equation is:

Petrol CUEDC Hot NOx (g/km) = $\{1.027 * \text{cube root of } [\text{ADR37 NOx (g/km)}] - 0.041\}^3$……………………….(2)

Fitted values for Petrol CUEDC Hot g/km are shown in the following Table 18:

Table 18 Petrol CUEDC Hot NOx values predicted from ADR37 NOx values for pre-1999 YOM

ADR37 g/km	Petrol CUEDC Hot g/km	Ratio	Corresponding ratio using naïve linear regression on raw values (not shown)
0.2	0.175	0.876	1.057
0.6	0.562	0.937	1.010
1.0	0.959	0.959	1.001
1.4	1.360	0.971	0.997
1.8	1.764	0.980	0.995
1.93	**1.896**	**0.982**	**0.994**
2.2	2.170	0.986	0.993
2.6	2.578	0.992	0.992
3.0	2.987	0.996	0.992
3.4	3.397	0.999	0.991
3.8	3.808	1.002	0.991
4.2	4.220	1.005	0.990
4.6	4.632	1.007	0.990
5.0	5.045	1.009	0.990
5.4	5.459	1.011	0.990
5.8	5.873	1.013	0.989

If, instead of using equation (2) one took a constant ratio of 0.982, being the ratio around the ADR37/00 cut-off for NOx of 1.93 g/km, as shown in the above Table, it would invoke errors of up to 5% in the range of interest (above 0.6 g/km, as in ADR37/01). This appears to be unacceptable.

The untransformed data would indicate the best constant ratio as 0.994, being more strongly influenced by the higher values than the transformation version, since they have more weight in the naïve regression, but this would generate values 1% too high around the ADR37/00 critical value and 8% too high around the ADR37/01 critical value. Since this is a conservative error it would generate errors of commission, the preferred option. But the transformation equation(3) appears necessary.

OLDER VEHICLES, CO

The relationship for CO likewise does not reflect YOM for this group of vehicles:

Petrol CUEDC Hot CO (g/km) = $\{0.953*\text{cube root of }[\text{ADR37 CO (g/km)}] + 0.009\}^3$……………………………(3)

Adjusted R^2 value is 0.948 and the residual standard deviation 0.18.

Table 19 Petrol CUEDC Hot CO values predicted from ADR37 CO values for pre-1999 YOM vehicles using transformed data

ADR37 g/km	Petrol CUEDC Hot g/km	Ratio	Corresponding ratio using naïve linear regression on raw values
1	0.9	0.901	0.766
2	1.8	0.896	0.834
3	2.7	0.894	0.856
6	5.3	0.890	0.879
9.3	**8.3**	**0.888**	**0.887**
10	8.9	0.888	0.888
15	13.3	0.887	0.892
20	17.7	0.886	0.894
30	26.5	0.884	0.897
40	35.3	0.884	0.898
50	44.2	0.883	0.898
60	53.0	0.883	0.899
70	61.8	0.882	0.899
80	70.6	0.882	0.899
90	79.4	0.882	0.900
100	88.2	0.882	0.900
120	105.8	0.881	0.900

It seems that a simple ratio of 0.888 might suffice, the value at the ADR37/00 CO cut-off of 9.3 g/km, to within 1% error across most of the range of values encountered. The naïve regression on raw values is again up to 7% astray, so that, again, the transformation equation appears necessary.

NEWER VEHICLES, NOX

After the removal of the three 'lean burn' vehicles, whose Petrol CUEDC NOx performances were problematical, the transformed data (Figure 31) performed much more consistently ($R^2 = 0.920$) and reliably (not skew) than the raw data ($R^2 = 0.876$, very skew, Figure 32):

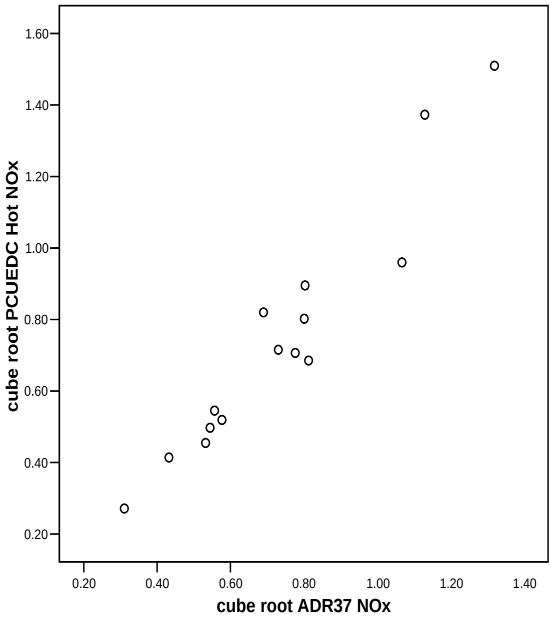

Figure 31 Cube root transformed NOx new vehicles PCUEDC v ADR37

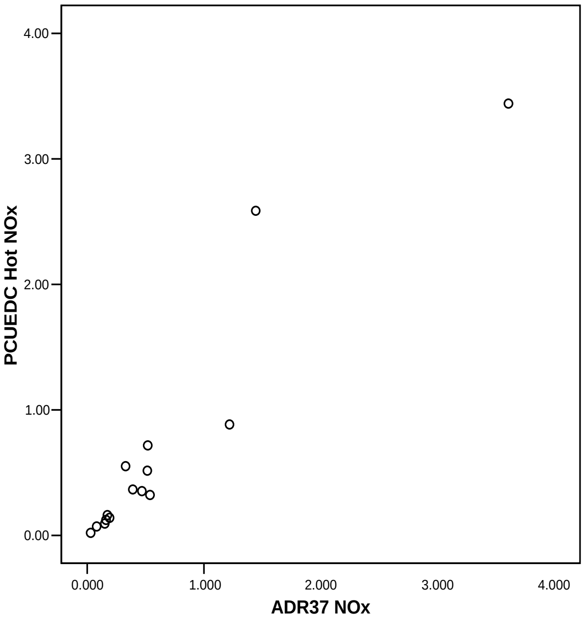

Figure 32 Raw NOx new vehicles PCUEDC v ADR37

The regression equation, via transformation, is:
Petrol CUEDC Hot NOx (g/km) = {1.209*cube root of [ADR37 NOx (g/km)] – 0.149}^{3}……………………….(4)

The regression coefficient in equation (4), 1.209 is close to being significantly different from that from the older vehicles in equation (2), 1.027, $t = 1.78$, $p < 0.1$, two-tailed. This suggests that separate regression equations might be needed for different age groups of vehicles for NOx. When age group is ignored, the outcome is somewhat inferior to the two separate regressions. But more data are needed to clarify the need for separate age group-related regressions for NOx.

NEWER VEHICLES, CO

There is much less reason to transform the data when attention is restricted to the post-1999 vehicles with their lower and more absolutely consistent CO emission levels. The equation, based on the raw data, is:

Petrol CUEDC Hot CO (g/km) = 0.948 * [ADR37 CO (g/km)] – 0.179……………………………………..(5)

Adjusted R^2 value is 0.989 and the residual standard deviation 0.38. The adjusted R^2 value using the cube root transformation is 0.840, a much inferior outcome resulting from over transforming. Again, more data would be required to compare formally the compatibility of equations (3), older vehicles CO levels, with equation (5), CO from newer vehicles.

Table 20 Petrol CUEDC Hot CO values predicted from ADR37 CO values for post-1999 YOM vehicles

ADR37 g/km	Petrol CUEDC Hot g/km	Ratio using linear regression on raw values
1	0.77	0.769
2	1.72	0.859
2.1	**1.81**	**0.863**
3	2.67	0.888
4	3.61	0.903
5	4.56	0.912
6	5.51	0.918
7	6.46	0.922
8	7.41	0.926
9	8.35	0.928
10	9.30	0.930
11	10.25	0.932
12	11.20	0.933

The variation in the ratio is quite unacceptable as a constant multiplier so equation (5) should be used.

The analysis performed above provide a robust frame work in which to extend the analysis on completion of the main phase testing. While results of the linear transformation given above using preliminary data are generally sound, it would be recommended that final regression equation be derived using main phase and preliminary phase data. This would add robustness to the transformations since a greater variety of makes and models of vehicle will be tested, and hence incorporated into the final regression equations. The greater sample size of the main phase will also allow further disaggregation of the data into consistent groupings without having to consider the effects of small sample sizes.

The disaggregation of the data does raise an issue of the use of the transformation process. While statistically we have shown the process to be satisfactory it must be remembered that drive cycles historically have a dual purpose. ADR/37 for instance is a regulatory cycle that essentials imposes an emissions limit on a vehicle, and whether this cycle actually reflects real world driving is of little consequence. The main issue is that the vehicle is under the emissions limit that is set. Petrol CUEDC on the other hand is a reflection of real world driving under four different road flow categories. Hence the overall result of the Petrol CUEDC is of little consequence, but the individual results for each road flow category are. Since they allow the emission modeller to weight each road flow category according to the study area they are considering and then end up with a final weighted averaged emission factor representing emissions performance of the vehicles in question. While this weighted averaged value mathematically turns out to be a simple linear transformation of the overall result, which has little effect of the validity of the correlation with cycles such as ADR37. However there is a large effect on the appropriateness of the weighted emissions factor for modelling purposes.

The benefit of the transformation process is that it allows historical emissions results from ADR37 cycles to be used in modelling scenarios to obtain a greater coverage of the vehicle fleet. However this benefit must be balanced against the new data the will be derived from the main phase testing of NISE2 that is likely to give a good coverage of the light duty petrol vehicle fleet and hence provide current disaggregated results for the Petrol CUEDC cycle. A much richer and reliable data source than the transforming of historical data.

CONCLUSIONS

The 60-vehicle sample has served its purpose well. It has shown that the various cycles tested can give very similar or rather distinctive outcomes depending on the emission gas under study and the broad year of manufacture of the vehicle. Results confirm that somewhat different outcomes are obtained from the ADR37-based cycles and the Petrol CUEDC-based cycles particularly in the vicinity of the legislated standards. To the extent that it might be important to clarify an individual vehicle's acceptability, or not, in relation to ADR37/01 levels the choice of test is relevant, the Australian traffic-based cycles discerning more 'gross emitters' than the ADR37 cycle. Clearly, levels specific to Petrol CUEDC cycles can later be defined using results from the main sample, necessarily in association with tolerable pressure on tuning facilities nationwide.

It is pointed out that 'gross emitter' is a misnomer for the vehicles that marginally contravene ADR37/01 standards. Those with much higher emissions levels than the standards require a better description. These are the vehicles that are the 'really gross emitters'; but this is a rather emotive term. It is suggested that vehicles with emission levels up to, say, twice the acceptable standard are termed excessive emitters; and that it is those that are beyond this level that are the gross emitters. In effect, however, the 60-vehicle sample suggests the cut-offs between these two categories for the different emissions should be rather higher than by a factor of two. The main point is that priority be given to cleaning up gross emitters, as defined here, before attention in paid to the (merely) excessive emitters.

Gross emitters, as defined above, seem to be readily identified by any of the cycles tested. Different tests give slightly different thresholds between gross and excessive emitters. It is recommended that if the identification of gross emitters is a priority for short tests, then the main phase testing be used to set the emission limits for gross emitters. As this cycle is already an International in-service vehicle emission standard, the addition of another cycle ie SPC240, to perform the same function for very little benefit in identifying gross emitters seems superfluous.

The main study will later provide the opportunity to determine how rapidly older vehicles deteriorate. This is important in assessing future demand for amelioration of the ageing end of the fleet. Since the ADR37 test was performed as a part of the first National In-Service Vehicle Emissions Study, in 1996, this cycle should be repeated in the main phase testing of NISE2 to enable these deterioration rates to be calculated for the various vehicle categories tested.

When analysing the emissions data from the 60 vehicle sample it was found that the data could be grouped into three categories. Namely

1. Within specifications vehicles, ie that meet the required emission limits
2. Excessive emitters, ie vehicles that have emissions up to two times the emissions limit
3. Gross emitters, ie vehicles with emissions greater than twice the emissions limit

The emissions limits applied to these categories are subject to change once the main phase testing has been completed, since the greater sample size of vehicles tested will give a greater degree of confidence as to where the emission limits should separate these categories.

It was clear from the testing performed that the first two categories had the largest number of vehicles with the third having the least. Statistically this phenomenon leads to a distribution of the data that is positively skewed, and hence not suitable to simple correlation analysis. Correlation analysis assumes a regular distribution of the data along the x axis. It was found that if the data was cube root transformed the distribution of the data became more regular and hence correlation analysis could now be performed on the transformed data with confidence.

One of the criteria in Contract 2 of the preliminary phase was that the highest 30% of (overall) emitters showed a correlation ie an average R^2 of greater than 85%, over all inter-cycle comparisons, and over all test emissions. This criterion was met, whether raw data were used or cube root transformed data for improved statistical behaviour.

Further linear regression analysis was applied to the emission results from the ADR37 and Petrol CUEDC tests. The regression found that there was a linear transformation function that could be used for each emission that could adequately transform ADR37 results into equivalent Petrol CUEDC results. Based on the 60 vehicle sample size the regressions were statistically sound. However it would be recommended that the final transformation equations be derived after the main phase testing in order to incorporate results from the larger sample size. This will give the transformation equations greater robustness across the whole of the Australian light vehicle petrol fleet.

This study has not investigated closely differences in performance over the various phases of the various cycles but it is noted that inclusion of a freeway phase in the Petrol CUEDC cycles could alter correlations for emissions (eg Table 6) and fuel consumption (Table 11) over the full CUEDC cycle by measurable amounts. Once the main phase testing has been completed, and hence a greater sample size achieved, the merits of transformingADR37 emission results to Petrol CUEDC results for each road flow category will be investigated further.

The testing and analysis work that has occurred in the Preliminary Phase of NISE2 has provided a good basis to proceed with the main phase testing. The framework for the vehicle sampling, statistical testing, correlation and regression analysis that has been performed on the 60 vehicle sample has been shown to work well, and provide sound results. On completion of the main phase testing, comparisons with the 1996 study will also be performed, allowing deterioration analysis of vehicles' emission performance to be determined. Once this framework and further analysis is applied to the main phase testing, the results will provide an invaluable body of knowledge of the in-service emissions performance of the Australian light duty petrol fleet. As light duty petrol vehicles contribute more than any other vehicle class to transport emissions (see national greenhouse gas inventory and national pollutant inventory 2005). It is hoped that the final body of information obtained will feed into these inventories hence making them a more accurate and reliable reflection of Australia's greenhouse gas and air quality performance. These same emission factors could also be used by emission modellers throughout Australia, in this way maintaining an accurate reliable and most importantly consistent set of factors for these types of vehicles.

REFERENCES

Australian Greenhouse Office (2003) ENERGY Workbook for Transport (Mobile Sources) 3.1, Commonwealth Government.

Environment Australia (2002) National Pollutant Inventory Emission Estimation Manual for Combustion Engines Version 2.2, Environment Australia.

Federal Office of Road Safety (1997). Motor Vehicle Pollution in Australia - Report on the National In-Service Vehicle Emissions Study. FORS, 1997.

Orbital Engine Company (2005). NISE 2 – Contract 2 Drive Cycle and Short Test Development. Federal Departmnet of Environment and Heritage,

APPENDIX 1

Number of motor vehicles in Australian metropolitan areas by manufacturer, model and year of manufacture, to 2002, in descending order of numbers

(first few entries only)

Make	Model	Year of manufacture	Count of registered motor vehicles in metropolitan area (Number)
Holden	Commodore	1998	85064
Holden	Commodore	2001	82053
Holden	Commodore	2000	79702
Holden	Commodore	1999	78413
Holden	Commodore	1996	75807
Holden	Commodore	1995	72855
Holden	Commodore	1997	69085
Holden	Commodore	1994	66153
Holden	Commodore	2002	59175
Holden	Commodore	1993	51800
Holden	Commodore	1989	50534
Holden	Commodore	1990	49571
Ford	Falcon	1995	46767
Holden	Commodore	1992	45910
Toyota	Camry/Vienta	1998	43842
Hyundai	Excel	1998	42789
Ford	Falcon	1994	42776
Ford	Falcon	1993	40671
Ford	Falcon GLi/S	2002	40279
Holden	Commodore	1991	40188

Ford	Falcon	1988	40049
Toyota	Camry/Vienta	1994	39250
Toyota	Camry/Vienta	1999	38976
Ford	Falcon	1990	37498
Hyundai	Excel	1997	36909
Holden	Commodore	1988	36446
Ford	Falcon	1989	36421
Ford	Falcon GLi/S	2001	36244
Ford	Falcon	1987	35326
Mitsubishi	Magna	1994	35208
Ford	Falcon GLi/S	2000	34655

APPENDIX 2

Number of vehicles by age group (year of manufacture to 2002) and type in metropolitan Australia in 2004, in descending numbers greater than 6000

Age group: Old = yom 1986-1993; Medium = 1994-1998; New = 1999-2002				
		Sedans includes station wagons		
MAKE	MODEL	BODY TYPE	AGE GROUP	Thousands
Holden	Commodore	Sedans	Medium	367
Holden	Commodore	Sedans	Old	339
Holden	Commodore	Sedans	New	296
Ford	Falcon	Sedans	Old	262
Mitsubishi	Magna	Sedans	Old	192
Ford	Laser	Sedans	Old	180
Toyota	Corolla	Sedans	Old	180
Toyota	Camry/Vienta	Sedans	Old	175
Toyota	Camry/Vienta	Sedans	Medium	171
Mitsubishi	Magna	Sedans	Medium	162
Hyundai	Excel	Sedans	Medium	154
Ford	Falcon	Sedans	Medium	151
Ford	Falcon GLi/S	Sedans	New	131
Toyota	Corolla	Sedans	New	122
Toyota	Camry/Vienta	Sedans	New	121
Toyota	Corolla	Sedans	Medium	114
Nissan	Pulsar	Sedans	Old	104
Holden	Astra	Sedans	New	87
Mitsubishi	Magna	Sedans	New	83
Nissan	Pulsar	Sedans	New	79
Ford	Festiva	Sedans	Medium	71
Ford	Falcon/Fairmont	Sedans	Medium	69

Mitsubishi	Lancer	Sedans	New	69
Mitsubishi	Lancer	Sedans	Medium	61
Ford	Falcon GLi/S	Sedans	Medium	57
Nissan	Pulsar	Sedans	Medium	54
Ford	Falcon/Fairmont	Sedans	New	52
Nissan	Pintara	Sedans	Old	52
Ford	Laser	Sedans	Medium	51
Ford	Fairmont	Sedans	Old	48
Ford	Laser	Sedans	New	48
Hyundai	Accent	Sedans	New	48
Mazda	323	Sedans	New	47
Ford	Telstar	Sedans	Old	45
Holden	Barina	Sedans	Old	43
Holden	Barina	Sedans	Medium	43
Honda	CRV	Sedans	New	43
Hyundai	Excel	Sedans	New	43
Mazda	323	Sedans	Medium	43
Daihatsu	Charade	Sedans	Old	41
Mitsubishi	Lancer	Sedans	Old	40
Hyundai	Excel	Sedans	Old	39
Nissan	Skyline	Sedans	Old	37
Toyota	Rav4	Sedans	New	37
Holden	Holden Ute	Utilities	New	36
Honda	Civic	Sedans	Medium	36
Holden	Holden Ute	Utilities	Medium	35
Honda	Civic	Sedans	Old	35
Mazda	121	Sedans	Medium	35
Hyundai	Lantra/Elantra	Sedans	New	34
Subaru	Forester	Sedans	New	33
Toyota	Hilux	Utilities	Old	33
Mazda	323	Sedans	Old	32
Mitsubishi	Pajero	Sedans	Old	32
Toyota	Echo	Sedans	New	32
Holden	Barina	Sedans	New	31

Hyundai	Lantra/Elantra	Sedans	Medium	31
Toyota	Hilux	Utilities	Medium	31
Toyota	Hilux	Utilities	New	31
Mazda	626	Sedans	Old	30
Holden	Rodeo	Utilities	New	29
Toyota	Avalon	Sedans	New	29
Toyota	Starlet	Sedans	Medium	29
Daewoo	Lanos	Sedans	New	28
Ford	Fairmont	Sedans	Medium	28
Honda	Civic	Sedans	New	28
Daewoo	Cielo	Sedans	Medium	27
Mitsubishi	Pajero	Sedans	New	27
Toyota	Landcruiser	Sedans	Medium	27
Ford	Fairlane	Sedans	Old	26
Ford	Falcon Ute	Utilities	New	26
Holden	Apollo	Sedans	Old	26
Holden	Vectra	Sedans	New	26
Subaru	Impreza	Sedans	New	26
Subaru	Liberty	Sedans	Old	26
Ford	Festiva	Sedans	New	24
Honda	Accord	Sedans	Medium	24
Mitsubishi	Pajero	Sedans	Medium	24
Holden	Camira	Sedans	Old	23
Holden	VY Commodore	Sedans	New	23
Hyundai	Sonata	Sedans	Medium	23
Toyota	Lexcen	Sedans	Old	23
Daihatsu	Charade	Sedans	Medium	22
Holden	Rodeo	Utilities	Medium	22
Subaru	Liberty	Sedans	Medium	22
Subaru	Liberty	Sedans	New	22
Toyota	Landcruiser	Sedans	Old	22
Toyota	Prado	Sedans	New	22
Toyota	Rav4	Sedans	Medium	22
Ford	Falcon GLi/S/Fairmont	Sedans	Medium	21

Mitsubishi	Mirage	Sedans	Medium	21
Subaru	Outback	Sedans	New	21
Holden	Astra	Sedans	Old	20
Holden	Rodeo	Utilities	Old	20
Mazda	121	Sedans	Old	20
Mitsubishi	Colt	Sedans	Old	20
Nissan	Patrol	Sedans	Old	20
Toyota	Hiace	Panel vans	New	20
Toyota	Tarago	Forward control passenger vehicles	Old	20
Holden	Calais	Sedans	Old	19
Holden	Nova	Sedans	Old	19
Holden	Statesman	Sedans	Medium	19
Holden	Statesman	Sedans	New	19
Mitsubishi	Express	Panel vans	Old	19
Subaru	Impreza	Sedans	Medium	19
Suzuki	Swift	Sedans	Medium	19
Toyota	Landcruiser	Sedans	New	19
Daewoo	Nubira	Sedans	New	18
Mazda	626	Sedans	Medium	18
Toyota	Celica	Sedans	Old	18
Toyota	Hiace	Panel vans	Medium	18
Toyota	Prado	Sedans	Medium	18
Toyota	Toyota Unknown Model	Sedans	Old	18
BMW	318i	Sedans	Medium	17
Ford	Falcon GLi/S	Sedans	Old	17
Honda	Accord	Sedans	Old	17
Subaru	L Series	Sedans	Old	17
Toyota	Cressida	Sedans	Old	17
Toyota	Hiace	Panel vans	Old	17
Ford	Falcon	Utilities	Old	16
Holden	Calais	Sedans	Medium	16
Holden	Calais	Sedans	New	16
Suzuki	Swift	Sedans	Old	16

Ford	Falcon	Utilities	Medium	15
Ford	Falcon Ute	Utilities	Old	15
Mitsubishi	Mirage	Sedans	New	15
Mitsubishi	Verada	Sedans	Medium	15
Nissan	Navara	Sedans	Old	15
Daewoo	Lanos	Sedans	Medium	14
Ford	Falcon Ute	Sedans	Medium	14
Ford	Festiva	Sedans	Old	14
Ford	Mondeo	Sedans	Medium	14
Honda	Prelude	Sedans	Old	14
Jeep	Cherokee/Comanche	Sedans	Medium	14
Kia	Rio	Sedans	New	14
Mitsubishi	Triton	Utilities	Old	14
Nissan	Nissan Unknown Model	Sedans	Old	14
Toyota	Corona	Sedans	Old	14
BMW	318i	Sedans	New	13
Ford	Fairmont	Sedans	New	13
Ford	Falcon	Sedans	New	13
Holden	Holden Unknown Model	Sedans	Old	13
Mazda	Tribute	Sedans	New	13
Mitsubishi	Express	Panel vans	Medium	13
Mitsubishi	Triton	Sedans	Medium	13
Mitsubishi	Triton	Utilities	New	13
Toyota	Lexcen	Sedans	Medium	13
BMW	318i	Sedans	Old	12
Daihatsu	Applause	Sedans	Old	12
Ford	Corsair	Sedans	Old	12
Ford	Courier	Utilities	Medium	12
Mazda	121	Sedans	New	12
Mazda	626	Sedans	New	12
Nissan	Pathfinder	Sedans	New	12
Subaru	Brumby	Sedans	Old	12
Toyota	Hilux	Cab-chassis	New	12
Ford	Econovan	Panel vans	Old	11

Ford	Falcon Ute/Van	Utilities	New	11
Holden	Rodeo	Cab-chassis	New	11
Hyundai	Sonata	Sedans	New	11
Nissan	X-Trail	Sedans	New	11
Suzuki	Vitara	Sedans	Old	11
Toyota	Hilux	Cab-chassis	Old	11
Toyota	Hilux	Cab-chassis	Medium	11
Toyota	Tarago	Forward control passenger vehicles	Medium	11
Volkswagen	Golf	Sedans	New	11
Ford	Econovan	Panel vans	Medium	10
Holden	Apollo	Sedans	Medium	10
Holden	Astra	Sedans	Medium	10
Holden	Holden Ute	Sedans	Old	10
Holden	Rodeo	Sedans	Medium	10
Holden	Vectra	Sedans	Medium	10
Mitsubishi	Verada	Sedans	Old	10
Nissan	Patrol	Sedans	Medium	10
Toyota	Camry	Sedans	Old	10
Daewoo	Nubira	Sedans	Medium	9
Daihatsu	Sirion	Sedans	New	9
Holden	Rodeo	Cab-chassis	Old	9
Honda	Accord	Sedans	New	9
Honda	CRV	Sedans	Medium	9
Land Rover	Discovery	Sedans	Medium	9
Mazda	B2600	Utilities	Medium	9
Mitsubishi	Verada	Sedans	New	9
Nissan	Maxima	Sedans	Medium	9
Nissan	Maxima	Sedans	New	9
Nissan	Patrol	Sedans	New	9
Suzuki	Sierra	Sedans	Old	9
Suzuki	Vitara	Sedans	Medium	9
Toyota	4Runner	Sedans	Old	9
Toyota	Celica	Sedans	Medium	9

Toyota	Tarago	Forward control passenger vehicles	New	9
Ford	Capri	Sedans	Old	8
Ford	Courier	Utilities	Old	8
Ford	Courier	Utilities	New	8
Ford	Explorer	Sedans	Medium	8
Ford	Fairlane	Sedans	Medium	8
Holden	Jackaroo	Sedans	Old	8
Holden	Jackaroo	Sedans	Medium	8
Holden	Jackaroo	Sedans	New	8
Kia	Carnival	Sedans	New	8
Mazda	626/MX6	Sedans	Old	8
Mazda	929	Sedans	Old	8
Mazda	MX6	Sedans	Old	8
Peugeot	306	Sedans	Medium	8
Subaru	Forester	Sedans	Medium	8
Toyota	Camry	Sedans	New	8
Daewoo	Matiz	Sedans	New	7
Honda	Integra	Sedans	Old	7
Jeep	Grand Cherokee	Sedans	New	7
Kia	Sportage	Sedans	New	7
Mitsubishi	Challenger	Sedans	New	7
Mitsubishi	Galant	Sedans	Old	7
Mitsubishi	Starwagon	Forward control passenger vehicles	Old	7
Nissan	Bluebird	Sedans	Medium	7
Nissan	Navara	Utilities	Medium	7
Volkswagen	Golf	Sedans	Medium	7
Volkswagen	Golf/Bora	Sedans	New	7
Daihatsu	Terios	Sedans	New	6
Ford	Escape	Sedans	New	6
Ford	Explorer	Sedans	New	6
Ford	Fairlane	Sedans	New	6
Ford	Fairlane/LTD	Sedans	Medium	6
Ford	Maverick	Sedans	Old	6

Holden	Nova	Sedans	Medium	6
Holden	Statesman	Sedans	Old	6
Honda	Prelude	Sedans	Medium	6
Hyundai	Lantra/Elantra	Sedans	Old	6
Kia	Mentor	Sedans	Medium	6
Mercedes Benz	Mercedes Benz Unknown Model	Sedans	Old	6
Mitsubishi	Express	Panel vans	New	6
Mitsubishi	Sigma	Sedans	Old	6
Nissan	Nissan Unknown Model	Utilities	Old	6
Saab	38054	Sedans	New	6
Saab	900	Sedans	Old	6
Subaru	Outback	Sedans	Medium	6
Suzuki	Baleno	Sedans	Medium	6
Suzuki	Grand Vitara	Sedans	New	6
Toyota	Townace Van	Panel vans	Medium	6