Auckland UniServices Limited

VEHICLE EMISSIONS PILOT PROJECT — DIESEL VEHICLES

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Preface

Some conclusions drawn from the Pilot work have been based on relatively small vehicle samples. Due to the small sample sizes, care is required in extrapolating these findings to the New Zealand fleet, as the results are indicative only unless supported by appropriate statistical analysis.

1. Executive Summary

1.1. Introduction

This report concerns the trial of simple emissions testing of diesel vehicles that was carried out in late 2004, known as the Vehicle Emissions Pilot Project (the Pilot). The report follows on from the report (Campbell et al) *Vehicle Emissions Pilot Project – Petrol Vehicles*, which detailed the trial work and analysis carried out for simple emissions testing of petrol vehicles. These trials were instigated in response to the Government's decision at the time to introduce a simple emissions testing regime, specifically the idle simple test for petrol vehicles and the snap acceleration test for diesel vehicles. Experiences and analysis from the trials were intended to support the development of this testing regime.

The work carried out for the Pilot comprised: appraising the indicative current performance of the vehicle fleet with respect to simple emissions by testing a sample of vehicles using simple emissions test methods; piloting simple emissions testing in order to gain the experience which would be needed in the development of a simple emissions test regime for New Zealand; and developing an understanding of the improvements in vehicle performance that might arise from the introduction of such a regime. The findings from this work are summarised below.

1.2. Simple Emissions Performance of the Diesel Fleet.

Snap acceleration testing was trialled at 13 sites around New Zealand. The sites chosen represented a range of different test site options, from sites where only warrant of fitness inspections were otherwise carried out, to vehicle repair workshops. Testers of a variety of different backgrounds and competency were also involved in the trial.

The Pilot tested around 800 diesel vehicles to the Pilot-developed snap acceleration test procedure, a procedure very close to that used in the UK. Emissions profiling analysis was conducted on data from a smaller sample of vehicles (197 light diesel vehicles and 255 heavy diesel vehicles), the smaller set the result of screening the field data by various quality assurance tests, among others. Analysis techniques used included multiple variable regression analysis using Statistical Analysis Software (SAS), a method by which many variables can be considered at the same time instead of confining analysis to two- or three-dimensional comparisons.

The emissions performance profiling analysis found:

- there is a high degree of variability in the snap acceleration results from diesel vehicles;
- the variability in snap acceleration results for the sample analysed was best described by a model using the four variables, engine technology, secondary performance indicator (SPI, a variable calculated from odometer and year of manufacture), visible smoke (as judged by the tester by sight) and gross vehicle mass (GVM). The factors used in the model indicated a trend towards lower snap acceleration results for: more advanced engine technology; lower distance travelled; more recent year of manufacture; lower visible emissions; and higher GVM. This model had a coefficient of determination (R^2) of 0.24; that is, only 24% of the variability in snap acceleration results could be described by a model using these four variables. In this model all variables were statistically significant above the 95% confidence level (that is, p-value <0.05). The significance of visual smoke in this model provides some support for the use of simple visual checking of vehicles as a possible screen for emissions testing vehicles (rather than metered snap acceleration testing);
- the emissions performance profiling analysis considered engine technology described in three simple ways: (simple) non-turbocharged; (simple) turbocharged; and turbocharged plus oxidation catalyst (advanced technology), which was a kind of shorthand description of major advances made in diesel engine design. For the sample analysed, engine technology was found to be a statistically significant variable, although only between simple and advanced engine technologies, with no statistically significant difference between the two simple engine technologies. Note that the data sample analysed only contained four heavy diesel vehicles and 13 light diesel vehicles that also had advanced engine technology, and these were all relatively recent year of manufacture. It would therefore be difficult to draw strong conclusions from this particular analysis, although the results are in line with the emissions performance expected when a practical, technical appraisal of the design of the technology involved is conducted. This strengthens this, otherwise weak, conclusion;
- vehicle origin was found to be a statistically significant variable when considered by itself: that is, without also considering other variables at the same time. However, when engine technology and year of manufacture were also considered, vehicle origin was no longer statistically significant indicating that vehicle origin was very weak in describing the variability in snap acceleration results;
- ‘percentile plots’ were created, plotting vehicles in order of increasing snap acceleration result, allowing the proportion of vehicles failing to meet given cutpoints[1] to be determined. 23% of light vehicles and 12% of heavy vehicles in the analysis data set did not meet a cutpoint set of $K=2.5m^{-1}$ for non-turbocharged vehicles and $K=3.0m^{-1}$ for turbocharged vehicles (a cutpoint set which is in use in the UK, and is based in turn on the requirements for Europe);
- the average snap acceleration performance for Used-Japanese vehicles entering the fleet was found to similar to marginally better to the average for the existing fleet. At this level of performance, their entry to the fleet produces no significant improvement. New vehicles, by contrast — or, at least, vehicles of

[1] A result above which vehicles are considered to have failed the test.

more recent manufacture, which are more likely to feature more advanced engine technologies — are expected to perform better than the existing fleet average, and their entry would produce an overall improvement in fleet performance;

- engines designed in the 1960s and before, and some of more recent design, may exhibit elevated snap acceleration results even when in good condition, and some allowance would need to be made for these vehicles should an in-service snap acceleration testing regime be introduced to New Zealand;
- diesel vehicles fitted with oxidation catalysts are beginning to enter the fleet. Removal of a functioning oxidation catalyst from a diesel vehicle is not expected to change the snap acceleration result significantly (but is expected to affect the emission of other species).

1.3. Snap Acceleration Testing as an Indication of On-Road Emissions Performance.

The Pilot tested 39 light vehicles and 80 heavy vehicles both over vehicle dynamometer drive cycles (used to indicate on-road emissions performance) and to the snap acceleration test. The comparison of drive cycle emissions results with the snap acceleration results found there to be a poor relationship between the two for the emission species measured (PM, NOx , HC and CO, in the case of drive cycle tests) and for a range of test cycles.

As an example, the comparison of the IM240 PM measurement versus the snap acceleration result for light diesel vehicles provided a coefficient of determination (R^2) of 0.38: that is, the snap acceleration result describes 38% of the variability in the expected on-road PM result as given by the response to the IM240 test cycle. Simply put, while a positive trend exists, whereby a vehicle with a high snap acceleration is more likely to emit higher PM in on-road driving, overall the snap acceleration test is a poor predictor of on-road emissions performance – the snap acceleration test does not reliably tell us whether a vehicle is a low or high emitter of PM in on-road operation.

1.4. Emissions-Related Repair

The evaluation of the emissions-related repair of diesel vehicles included: the analysis of data from the snap acceleration testing of 27 vehicles before and after repair; consideration of three vehicles dynamometer tested before and after repair; consideration of various international papers on the subject, and consideration of information from the industry provided during the Pilot. The principal findings were:

- emissions-related repair is expected to lower the snap acceleration result and the average reduction in the result is expected to be significant for vehicles exhibiting high levels of visible smoke emission (of the order of a $K=3.0m^{-1}$ reduction, on average);
- on average, repair of diesel vehicles exhibiting high visual smoke emission is expected to decrease PM emission and increase NOx emission. Any change in fuel consumption is expected to be small to negligible;

- a high proportion of the repairs of vehicles exhibiting high levels of smoke emission is expected to include servicing of the injectors. Blocked air filters and pumps that are not correctly calibrated are also common faults. A blocked air filter is less likely to be the cause of high visual emissions by itself;
- the range of costs for the repair of a diesel vehicle exhibiting high levels of visual smoke emissions is from around $150 for a simple injector service to many thousands of dollars for a major overhaul or the replacement of an engine;
- the snap acceleration test was not that useful for fault diagnosis other than as a simple check of general visible smoke emission. Even then, the acceleration test does not need to be performed to a stringent test procedure to provide near its full worth for diagnosis – the engine either produces high smoke emissions or it does not;
- the vehicle repair industry in New Zealand appears sufficiently tooled and skilled for the repair of diesel vehicles, including those vehicles fitted with more advanced engine technologies;
- the replacement of cambelts is believed to have been deferred on many light vehicles and, should snap acceleration testing be introduced across the fleet, then it is likely many vehicles will require cambelt replacements.

1.5. Implementation of Snap Acceleration Testing

The implementation of snap acceleration testing in New Zealand was considered through analysis of all the information gathered during the Pilot, from experiences during field testing to the detailed information gained through laboratory testing of various snap acceleration procedures. The major conclusion of this analysis is that snap acceleration testing is not recommended for New Zealand as the basis of a mainstream vehicle emissions control programme. The main factors on which this conclusion was based were:

- around one-quarter of the fleet were not built to any emissions standard and it may be difficult to require these vehicles retrospectively to meet a given emissions performance standard, unless it were a very lenient pass-fail cutpoint;
- the poor relationship between snap acceleration results and on-road emissions means that there is a risk the results of snap acceleration testing would be challenged;
- implementation of snap acceleration testing is expected to be relatively expensive and there is a risk that the industry would over-invest in the initial years of the regime;
- the snap acceleration test has limited applicability for the modern vehicles now entering the fleet;
- there was a good correlation between the snap acceleration result as given by a smoke meter and that as judged by eyesight by the tester. A visual test may be more appropriate for New Zealand in the short term.

Nonetheless, snap acceleration testing may be useful for awareness purposes, for the emissions testing of specific targeted vehicles, or in support of other vehicle emissions programmes. For example, the snap acceleration testing of used imports before they are permitted to enter the fleet for the first time is recommended. This might be replaced by a more reliable short-test indicator of on-road emissions performance, should such an appropriate short test be found in the future. Note that used diesel vehicles now entering the fleet would have been designed to meet an acceleration test and the introduction of meeting a snap acceleration requirement should therefore be relatively straightforward from a compliance point of view. On the other hand, the development of a regime based on an alternative short test may be a protracted process, as arguments may arise over the suitability of any test which vehicles have not been specifically designed to meet, even if it is a test that they would pass if they were in good condition.

There is currently no mechanism to demand the repair of a high-emitting diesel vehicle unless it emits continuous visible emissions. This less-than-satisfactory situation will persist unless a snap acceleration test regime or high-emitter test and cutpoint of some sort is introduced. This weakens the authority upon which other emissions reduction programmes could be supported.

Alternatives to the snap acceleration test have been suggested. These include: visual inspection for visible emissions at the time of safety inspection; a mechanism to forbid, or at least discourage, tampering with emissions-related equipment; introducing a minimum emissions build for vehicles entering the fleet for the first time; broadened enforcement of the 10-second Rule; and (as has been mentioned) the snap acceleration testing — or a more robust check of emissions performance — of used imported vehicles before their entry to the fleet. Note that the use of remote sensing to detect high emitting vehicles has not been included in this range of suggestions, as it is unlikely to provide a reliable indication of emissions performance for diesel vehicles unless there is strict control over how a vehicle is operated at the time of sensing.

Should snap acceleration testing be introduced, a recommended test procedure for New Zealand has been identified. This includes the provision of a 'fast pass' option to dispatch vehicles showing very low emissions quickly. Such a snap acceleration test regime would require a number of supporting systems, including:

- a Standard or Code of Practice for snap acceleration testing, including the specification of smoke meters;
- a minimum proficiency standard for testers;
- a quality control programme to manage the maintenance and calibration of smoke meters, including an accreditation system for laboratories and technicians performing this work;
- a quality control system to monitor test site performance, with the ability to intervene where necessary.

It is expected that to support the testing and repair work required by a snap acceleration programme involving two-yearly testing of vehicles manufactured between 1985 and 2000 (a scenario developed for Pilot analysis purposes), the industry would require the addition of at least 300 full-time personnel or their equivalent. The introduction of snap acceleration testing would require careful management, as this step increase in industry capacity would take several years to achieve, at best, and also risk the industry over-investing in the earlier years. An over-optimistic introduction would also risk the quality of the programme being compromised.

Once introduced, a snap acceleration test would be expected to take 5 to 20 minutes and cost around $33 on average, ranging from $20 to $56 depending upon the facility type and whether vehicles may be tested easily. Higher costs would be expected during the regime start-up period.

The snap acceleration test is expected to be difficult to integrate into an existing safety inspection without extending the duration of the inspection, and flexibility must be allowed as to how these two systems are integrated.

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Glossary

Catalyst	For this report, this refers to the exhaust catalyst used to reduce the emission of harmful emission species.
CBDC	Central Business District Congested drive cycle: a vehicle test cycle carried out on a dynamometer representing congested city driving.
Centralised testing facilities	Facilities where only testing is carried out.
Chassis dynamometer	A dynamometer which allows vehicles to be operated and loaded, the vehicle wheels running on rollers.
Clearout	A snap acceleration carried out to clear the engine and exhaust system of loose deposits.
Compression ignition engine	Engine designed for the use of diesel and like fuels with combustion initiation by compression.
Confidence interval	An estimate of the population parameter that consists of a range of values bounded by upper and lower confidence limits, within which the value of a parameter is expected to be located.
Confidence limit	The value at each end of a confidence interval, statements about which the probability of a result falling above or below can be made.
Constant Volume Sampling	A laboratory test method for taking a sample of a vehicle's exhaust emission.
Cutpoint	Result above which vehicles are considered to have failed the test.
De-centralised testing facilities	Facilities where both the testing and repair of vehicles are carried out.
Dilution tunnel	Apparatus used in sampling exhaust gases during laboratory dynamometer testing of a vehicle.
DustTrak	A brand name of light scattering photometer, an instrument that can be calibrated to provide a measure of PM emission.
Engine-out	Emissions at the exhaust port of an engine: that is, before the exhaust catalyst, where one is present.
Engine technology	The technology of the engine and any exhaust after-treatment system.
Euro 4	A shortened name for a set of European emissions standards for road vehicles and engines that began to be phased in, in Europe, on 1 January 2005.
Exhaust gas recirculation	Where a proportion of exhaust gases is returned to the combustion chamber.
Fast pass	A simple test option where a vehicle can be passed on the results of the first component of the test and not required to be subjected to the full test.
Free acceleration	Accelerating an engine whilst out of gear.
General export quality	A standard to which vehicles are built which are destined for countries that do not have emissions build requirements — and, by implication, defining vehicles

	which are unlikely to have been built to an emissions standard.
Heavy vehicle	A vehicle with mass greater than 3500 kg.
Heavy-light vehicle	A light vehicle with mass close to 3500 kg.
High governed engine speed	The engine speed attained with full accelerator and the engine not loaded and out of gear.
Hydrocarbons	Compounds made predominantly of carbon and hydrogen.
Idle	Operation of an engine under no-load conditions at normal (natural) idle speed.
Idle Simple Testing	An emissions test procedure that measures exhaust emissions whilst the engine is idling.
Individual acceleration result	The smoke meter result of an individual acceleration carried out on a diesel engine.
K-value	A calculated measure of smoke density with unit m^{-1}.
Light vehicle	A vehicle with mass 3500 kg or less.
Mean	The sum of a list of numbers divided by the total number of numbers (also commonly referred to as the average).
Median	This is the middle value of a list of values.
New-Japanese	Vehicles imported new from Japan.
New Zealand new	Vehicles imported new to New Zealand.
OBD	Onboard diagnostics, an onboard vehicle system where an alert is given when expected operating conditions, with given allowance, are breached.
Odometer	The odometer reading in kilometres.
Other-New	Predominantly vehicles imported new from countries other than Japan, but including scratchbuilt and other minority vehicle types.
Percentile plots	Plots where vehicles are in order of increasing or decreasing performance.
Petrol Report	*The Vehicle Emissions Pilot Project – Petrol Vehicles*, Campbell et al, report for the MoT January 2006.
Pilot	The Vehicle Emissions Pilot Project.
Profiling snap acceleration data set	The quality-assured snap acceleration field data set used to profile the emissions performance of the diesel fleet.
p-value	A statistical term representing the decreasing index of the reliability of a result: that is, a measure of how much evidence is against the null hypothesis.
R^2	Coefficient of determination – a statistical measure of the relationship between two result sets.
Remote sensing	Measuring exhaust gas concentration or particulate as a vehicle passes through a beam of light across the road.
rpm	Revolutions per minute.
Scratchbuilt	Vehicles built from parts from other of vehicles but given a new identity (that is, not taking the identity of any of the vehicles from which the parts have come).
Shot	The delivery of one injection from a pump and injector.
Simple test	Tail-pipe emissions test for diesel vehicles, normally consisting of a measure of smoke emission during a snap acceleration of the engine and, for petrol vehicles, normally consisting of measuring exhaust species

	concentrations at (natural) idle and fast idle conditions by a simple emissions analyser.
Smoke Chart	A chart of different grey scales used to assign a number to the density of smoke.
Smoke density	A measure of smoke opacity in units of m^{-1}.
Snap acceleration	A simple test for diesel vehicles in which the engine is rapidly accelerated and tail-pipe ‘smoke’ is measured.
Snap acceleration test result	The average of a number of consecutive individual acceleration results carried out to the Pilot’s snap acceleration test procedure.
Spark ignition engine	Engine designed for use with fuels such as petrol, CNG and LPG, initiation of combustion achieved by a spark.
SPI	Secondary (emissions) Performance Indicator, being a factor derived from a combination of the year of manufacture and odometer reading of a vehicle.
Standard deviation	Describes the variability of the data in a distribution, with around 63.5% of data within ± 1 standard deviation of the mean and around 95% of the data within ± 2 standard deviations of the mean.
Statistical significance	The estimated probability that the observed relationship (e.g., between variables) or a difference (e.g., between means) did not occur by chance.
Tech (n)	Short form of Technology (*n*), defined as follows:
Technology 1	For diesel vehicles, vehicles that are fitted with simple non-turbocharged engines.
Technology 2	For diesel vehicles, vehicles that are fitted with turbocharged engines without an exhaust catalyst.
Technology 3	For diesel vehicles, vehicles that are fitted with turbocharged engines and are also fitted with an exhaust catalyst (with the presence of the catalyst signifying the presence of a range of advanced technologies).
Turbocharger lag	During acceleration or load increase of a turbocharged engine the turbocharger can take a small amount of time to accelerate up to speed (lag), and the amount of air provided to the engine during this time may be reduced compared to steady speed or steady load engine operation.
Type approval standards	Standards provided by various jurisdictions to which vehicles are built.
Used-Japanese	Vehicles imported used from Japan.
Vehicle Variant	Describing vehicles of different emissions configuration, whether a different vehicle or the same vehicle with a different emissions configuration (including after repairs, where before and after repair yields two vehicle variants).
Visible smoke	Smoke visible by eyesight.
YoM	Year of manufacture.

Abbreviations

BAR 90	California Bureau of Automotive Repair, 1990.
BAR 97	California Bureau of Automotive Repair, 1997.
CO	Carbon monoxide.
CO_2	Carbon dioxide.
CoF	Certificate of Fitness.
CVS	Constant volume sampling.
EGR	Exhaust Gas Recirculation.
EFRU	Energy and Fuels Research Unit, University of Auckland.
DTA	Diesel Test Australia
FTP	Federal Test Procedure.
HC	Hydrocarbons.
IM240	Inspection and Maintenance test cycle – 240 seconds duration.
LANDATA	Vehicle data held by the Transport Registry Centre.
LSP	Light scattering photometer.
NO	Nitrogen oxide, sometimes also referred to as Nitric oxide.
NOx	Oxides of nitrogen.
O_2	Oxygen.
OBD	Onboard diagnostics.
OEM	Original Engine Manufacturer.
OMIL	International Organisation of Legal Metrology.
PM	Particulate matter.
ppm	Parts per million.
R^2	Coefficient of determination.
SAS	Statistical Analysis Software.
SMF	Sustainable Management Fund.
SO_2	Sulphur dioxide.
US	United States.
VOSA	Vehicle & Operator Services Agency,UK.
WoF	Warrant of fitness.
YoM	Year of Manufacture.

Preface

Some conclusions drawn from the Pilot work have been based on relatively small vehicle samples. Due to the small sample sizes, care is required in extrapolating these findings to the New Zealand fleet, as the results are indicative only unless supported by appropriate statistical analysis.

2. Background

2.1. Background to the Pilot

This report concerns the work relating to diesel vehicles for a pilot of vehicle emissions testing ('the Pilot') carried out for the Ministry of Transport in late 2004. Pilot results and analysis concerning petrol vehicles have previously been reported in the report *Vehicle Emissions Pilot Project – Petrol Vehicles* ('the Petrol Report').

The Petrol Report provides a detailed background on the Pilot. In summary, a simple form of the emissions screening of vehicles was one option presented to the Government as a vehicle emissions mitigation option and the Government made the decision to introduce simple emissions testing of in-service and imported used vehicles. The Pilot was devised to trial simple emissions testing of vehicles to provide information to support the development of such a simple emissions programme for New Zealand. It was also seen as an opportunity to understand the physical characterisation of the fleet better. To these ends, the primary objectives were to:

- profile and benchmark the emissions performance of the vehicle fleet, using simple testing (Contractual Objectives 1 and 2 in the Pilot's Project Plan: see Appendix A);
- evaluate simple testing by comparing the results of the simple testing programme with expected vehicle on-road emissions performance (Contractual Objective 5 in the Project Plan: see Appendix A);
- identify the causes of poor emissions performance and predict the benefit for emissions and fuel economy performance to be gained through repair (Contractual Objectives 3, 4 and 7 in the Project Plan: see Appendix A), and
- identify implementation considerations and issues for simple testing in New Zealand (Contractual Objective 6 in the Project Plan: see Appendix A).

This diesel volume considers the four main objectives, provided above, in Sections 3, 4, 5 and 6, respectively.

2.2. Background on Diesel Engines and Vehicles.

Diesel engines operate in a different manner to petrol engines and are tested differently. This section describes those differences, as they are fundamental to the way in which the Pilot work was carried out and to understanding the analysis and results. This section also sets out the background on the snap acceleration test that was trialled as part of the Pilot, how smoke emissions are formed, how the diesel engine has evolved and the ways in which the diesel engine is co-dependent with fuel specification and quality.

This section also includes base information on the makeup of the diesel fleet in New Zealand, to provide the context in which the work was carried out.

2.2.1. The Snap Acceleration Test

A diesel engine is expected to produce most smoke when it is operating under high loads. The snap acceleration test trialled in the Pilot involved depressing an idling engine's accelerator quickly and fully and not releasing it until the engine had reached something close to its high governed engine speed. Accelerating it in this way, against its own inertia, puts a high load on the engine, albeit for a short (1-2 second) period. A smoke meter is used to sample the exhaust during this procedure and provides the near-peak smoke density result, which is the result of an individual snap acceleration (termed the *individual acceleration result* for the purposes of this report). There is potential for variation between individual acceleration results and therefore a snap acceleration test usually involves several snap accelerations and the *snap acceleration test result* (for the purposes of this report) is the average of a number of consecutive individual acceleration results.

It is also useful to refer to the evolution of the diesel engine when considering the appropriateness of the snap acceleration test. Table 10, Appendix B, describes the evolution of the diesel engine and comments on the appropriateness of the snap acceleration test from an engine design perspective. In summary:

- engines of pre-1960s design were not designed to undergo the physically harsh snap acceleration test. Engines were not built to emissions standards that required meeting a snap acceleration test until the 1980s. A conclusion that may be drawn from this is that engines before this time should not be subject to the (full governed-speed) snap acceleration test;
- engines of post year-2000 design are expected to emit very low smoke levels during a snap acceleration test, levels that are near the detection limits for the smoke meters used. This casts doubt on the appropriateness of the snap acceleration test for these engines, other than as a fast emissions check, which arguably could be carried out visually for the majority of vehicles;
- engines fitted with catalyst exhaust systems may exhibit slightly elevated visual emissions due to added conversion of (non-visible) NO to (visible) NO_2, which could provide a falsely high snap acceleration result. This would only be an issue if cutpoints for modern vehicles were substantially reduced;
- future engines are likely to be fitted with on-board diagnostic systems that may provide a more accurate assessment of a vehicles emissions performance than a snap acceleration test.

The second point was demonstrated in the Pilot with a number of field-tested vehicles exhibiting such low smoke emission during the snap acceleration test that the smoke meter would not be triggered to move through the test sequence.

Governing bodies in Europe are currently considering revising the snap acceleration protocol in order to provide some form of sensible testing for vehicles fitted with engines of more advanced technologies. A limit of K-factor of 0.5 has been proposed for 'Euro 4'[2] vehicles.[3] At the other end of the scale, older vehicles tend to be tested to

[2] Euro 4 is a set of European emissions standards for road vehicles and engines that began to be phased in, in Europe, on 1 January 2005.
[3] John Fitch, VOSA, personal communication.

less physically demanding engine acceleration tests. For example, the UK test allows for acceleration only to around half high governed engine speed, or 2500rpm, whichever is the lesser, for vehicles in use before 1 August 1979.

2.2.2. Diesel Engine Operation

Like a petrol engine, the diesel engine is a piston engine where power developed by the combustion of fuel is transferred to the pistons and then to the crankshaft to which they are connected.

The combustion cycle of a diesel engine consists of the injection of diesel under high pressure into the combustion air, which has been made hot by compression by the rising pistons, just before piston *top-dead-centre*. The diesel atomises, vaporises, mixes with air, and the fuel-air mixture formed then auto-ignites as a result of the high temperatures developed. Combustion generates heat that causes an increase in pressure in the combustion chamber. This pressure drives the piston down and the work is transferred to the engine crankshaft.

Diesel engines generally operate with a high degree of excess air, one reason for the inherently low levels of carbon monoxide (CO) and hydrocarbon (HC) that are emitted — typically an order of magnitude less than for a petrol engine when measured at '*engine-out*' (i.e., before any exhaust after-treatment that may subsequently take place). Oxides of nitrogen (NOx), on the other hand, can be a factor higher and particulate matter (PM) is typically an order of magnitude or more higher than for a petrol-fuelled counterpart.

The technology advances that have been made to the diesel engine during its recent evolution include the use of higher injection pressures, improved fuel delivery control through the likes of 'common rail' fuel injection systems, complex turbocharging, *intercooling*,[4] the use of *exhaust gas recirculation,*[5] improved combustion chamber design and the optimisation of combustion chamber air swirl and squish.[6] The changes in emissions performance that have been achieved for the diesel engine over the last few years are similar in magnitude to the large step improvement in petrol engine emissions performance realised when catalysts began to be used (overseas) in the 1970s.

Again, as with petrol engines, emissions regulations in the four major jurisdictions have become sufficiently stringent that exhaust after-treatment methods are becoming mainstream. Diesel oxidation catalysts became standard on light diesel vehicles in Europe as the introduction of Euro 3 emission regulations approached (Euro 3 emission requirements for light vehicles were introduced 1 January 2000) in order to meet the more stringent CO and HC requirements. More advanced exhaust after-treatment devices are necessary to meet more recent emissions standards, or those to be introduced over the next few years. Exhaust after-treatment devices that will be used

[4] A turbocharger compresses the air charge, and this compression causes the temperature of the air charge to increase significantly. Intercooling is where the air charge is cooled between the turbocharger and entry into the engine combustion chamber.
[5] Where a portion of the exhaust gases are recirculated into the combustion chamber, which has the effect of diluting the oxygen available for combustion, lowering peak temperatures and NOx formation as a result.
[6] Designed-for squashing of air in the combustion chamber.

include diesel particulate filters (DPF, also called ‘particulate traps’, which principally reduce PM emission), the combination of engine calibration for low PM and the use of NOx-reducing technology such as selective catalyst reduction (SCR) or a NOx filter.

2.2.3. Visible Smoke Emissions

The visible component of a diesel engine’s exhaust emission is made up of many different species, including soot from pyrolisation of fuel,[7] and sulphates formed by the oxidation of fuel-borne sulphur, and water vapour. This composition is affected by many variables, and the visibility of the composition is affected by many more variables and therefore, at best, a poor correlation is expected between total PM and the opacity of exhaust (opacity is used here as a measure of visible emissions). One component of the Pilot was to check this relationship between visible emission and PM (which includes a non-visible component).

A diesel engine requires excess air in order to combust the diesel fuel fully (by contrast with a petrol engine, where fuel and air are normally maintained within strict ratios). Maximum power is typically limited by the amount of air that can be taken into the combustion chamber — the combustion of any additional fuel beyond this maximum power setting is likely to be compromised due to a lack of available oxygen and PM emission — including the proportion that is emitted as visible smoke — would be expected to increase sharply.

Likewise, any reduction in airflow or compromise in the mixing of air with fuel is expected to bring about an increase in PM, including smoke. For example, a dirty air filter that severely restricts the airflow into the engine is expected to cause an increase in visible smoke emission unless this reduced airflow is compensated for.

The combustion process is also extremely dependent upon the effectiveness of the diesel atomisation, mixing and vaporisation processes — the more so in smaller, high-speed diesel engines, where the period of time in which the whole combustion process must take place is very small. As an example of how this can affect emissions performance, an injector in poor condition may not adequately atomise the fuel, initiating a chain of events leading to the poor mixture of fuel with air, poor fuel vaporisation, delayed ignition and a reduced combustion period. Any one of these has the potential to increase PM emission.

The general condition of the engine also plays a part. An engine in poor condition may have less efficient compression of air (say, due to air leakage past the piston rings) lowering the amount of air but also lowering the temperature of the air into which the fuel is injected. This can retard the ignition timing or even cause misfire in worst cases. Engines in poor condition also risk pulling lubricating oil into the combustion or exhaust gases which are then partially combusted and expelled, predominantly as PM emission.

[7] Where combustion of fuel provides heat to break up the fuel molecules — one step in the combustion of fuel — but insufficient oxygen is available (say, through poor mixing of fuel with air) to enable complete combustion of fuel, and a carbonous or soot-like substance is produced instead.

Injection timing, a setting that can be changed by engine technicians, can also cause considerable changes to exhaust emissions. Advanced injection timing is expected to decrease PM emission, increase NOx emission and possibly decrease fuel consumption. When considering gross emitters, however, little change in visible PM emission is expected.

Following on from above, poor engine condition leading to increased visible PM emission can be divided into four main sets of issues:

- insufficient air for the amount of fuel used;
- insufficient preparation of the fuel through poor injection characteristics;
- a mechanical fault in the engine preventing attainment of good combustion conditions;
- a mechanical fault causing lubrication oil loss to the combustion gases or exhaust gases.

The original performance of the engine must also be taken into consideration. Diesel engine designs were not controlled by emission standards until the 1970s. Some earlier engine designs were such that some smoke is expected under high load operation or under sudden changes in load.[8]

2.2.4. Co-dependence of Engine Technology and Fuel Specification

Advanced engine designs that provide low emission performance normally require the use of advanced fuels — that is, more stringently specified fuels — to avoid compromising the integrity of some engine components, which could lead to a fall-off in emissions performance. Fuel of appropriate specification must also be made available when advancing the technology of the fleet, so that the operation of any early new-technology entrants is not compromised. In this regard, the adoption of stringently specified fuels is a technology enabler, although the added costs of providing more stringently specified fuels must be considered when few vehicles would benefit. For example, little improvement in overall emissions performance would be expected from the current diesel fleet should the specification for sulphur be reduced from its current maximum of 50ppm to 10ppm — the next progression of specification stringency required for emerging diesel engine technologies. It is suggested it would therefore be difficult to justify the additional cost to produce the 10ppm sulphur specification fuel at this stage.

Note that the specification regarding the sulphur content in diesel was 500 ppm pool average and a maximum of 600 ppm when the Pilot test work was carried out. A decrease in sulphate PM mass[9] would be expected in moving to fuel with a 50ppm sulphur specification, but overall any change is expected to be small, as there are many other factors involved in changes in fuel specification and in the formation of PM. Further, a significant change in visual emissions is not expected. Hence, conclusions

[8] A viewpoint common amongst engine reconditioners, engine service personnel and representatives of engine manufacturers.

[9] Oxidation of sulphur leads to the formation of sulphate particulate matter.

from the Pilot work are expected to remain valid for the current diesel fleet for the use of diesel specified with a maximum of 50 ppm sulphur.

2.3. Vehicle Classifications and Origin for Diesel Vehicles in the New Zealand Fleet

Figure 1 provides the proportion of diesel vehicles by *gross vehicle mass* (GVM).[10]. 78% of the active New Zealand diesel fleet have gross vehicle mass (GVM) of 3500 kg or less, 13% have GVM in the range of 3501 kg to 12000 kg and 9% have GVM of over 12000 kg.[11]

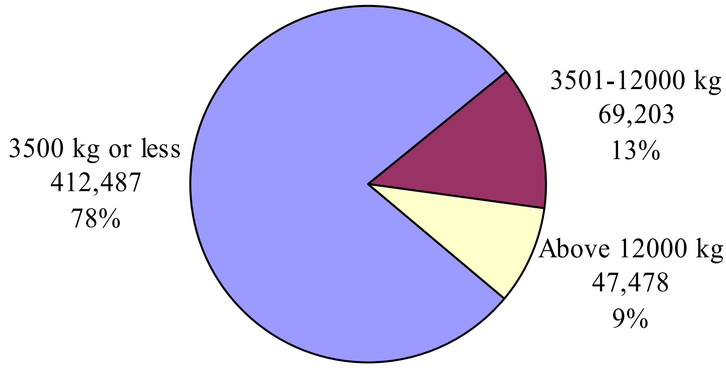

Figure 1: The Active Diesel Fleet as Divided by Difference in Gross Vehicle Mass (LANDATA, post 1970 YoM active fleet as at December 2004).

For New Zealand, various vehicle-related regulations define ‘light vehicles’ as those of gross vehicle mass (GVM) of 3500 kg or less. Above 3500 kg, a vehicle is defined as a heavy vehicle and classifications within this definition further divide ‘heavy vehicles’ into various weight-defined subsets, depending upon the main vehicle function. For example, goods vehicles are further defined as ‘medium goods vehicles’ if their GVM is in the range 3501-12000 kg and heavy goods vehicles if greater than 12000 kg (the GVM divisions provided in Figure 1 but applied to other vehicle types as well for this Figure) whereas there are four weight divisions of passenger buses of GVM above 3500 kg.

Generally speaking, there are similarities in the engines used in light vehicles and there are similarities in the engines used in heavy vehicles, and there tend to be reasonable differences between engines used in these respective categories. Engines fitted to light vehicles tend to be of lighter construction, to operate at higher revolutions, and have different emissions build requirements (as defined by the emissions standards to which they are built), where such apply; whereas engines fitted to heavy vehicles tend to be of

[10] The *gross vehicle mass* (GVM) is the design mass of the vehicle plus payload when fully loaded.
[11] Based on LANDATA data for post-1970 year of manufacture active diesel vehicles as at December 2004, ‘active’ referring to vehicles that have been registered for use on the road in New Zealand sometime in the 12 months prior to that date.

heavier construction and to operate at lower revolutions. For this reason, discussion in this report in the main considers light and heavy vehicles separately.

New Zealand receives new and used vehicles from a number of countries. As shown by Figure 2, the greatest proportion of light diesel vehicles are those imported used from Japan (the source for around 60% of the current light diesel vehicle fleet). The next most prominent category is that of new diesel vehicles from Japan (the source for around 24% of the current light diesel vehicle fleet). The proportion of vehicles given as new from other countries also includes vehicles built by Japanese manufacturers in the likes of Thailand. Taking this into consideration, over 90% of active[12] light diesel vehicles in New Zealand are of Japanese origin or make. Note 'other' vehicles, Figure 2, is predominantly made up of scratchbuilt[13] and re-registered vehicles.

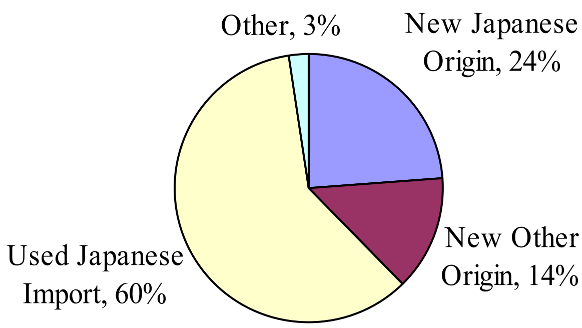

Figure 2: The Light Diesel Fleet as Divided by Used Japanese Origin, New Japanese Origin, New Other Origin and Other (LANDATA, post 1970 YoM active fleet as at December 2004) .

For heavy vehicles, around one-third of the current fleet are used vehicles from Japan, around one-third new from Japan and around one-third are new from other countries: see Figure 3. As for the previous figure, 'other' is predominantly made up of scratchbuilt[14] and re-registered vehicles (the latter of which may have come from any source).

Analysis described in the following sections shows vehicle origin to be a weak indicator of emissions performance when the technology of the engine system, distance travelled and year of manufacture – among others – are known. However, analysis also shows that the average recent used import enters the fleet exhibiting a snap acceleration emissions performance similar to the average of the existing fleet, instead of realising an improvement in overall emissions performance, as would be expected for new vehicles entering the fleet. The proportion of used diesel vehicles that have entered the fleet is therefore pertinent.

[12] 'Active' refers to vehicles that were registered to operate on the road within the 12 months prior to the inquiry date.
[13] A scratchbuilt vehicle can be a modified, mass-produced vehicle or a vehicle assembled in New Zealand from parts that are not usually assigned to a particular make or model of vehicle.
[14] A scratchbuilt vehicle can be a modified mass-produced vehicle or a vehicle assembled in New Zealand from parts that are not usually assigned to a particular make or model of vehicle.

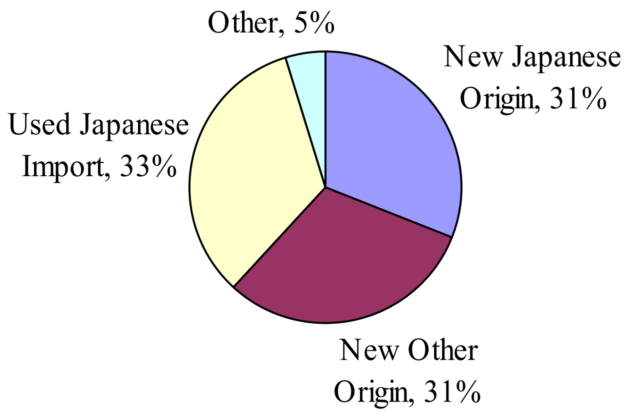

Figure 3: The Heavy Diesel Fleet as Divided by Used Japanese Origin, New Japanese Origin, New Other Origin and Other (LANDATA, post 1970 YoM active fleet as at December 2004).

3. Profile and Benchmark the Emissions Performance of the Fleet

This section describes work carried out to profile and benchmark the emissions performance of the active light and heavy diesel fleets, using the results from snap acceleration testing.

3.1. Methodology

3.1.1. General

The emissions profiling and benchmarking of the active light and heavy diesel fleets comprised the following steps:

1. set up test sites for snap acceleration testing;
2. subject vehicles to snap acceleration testing, visually inspect vehicles and record data so generated;
3. retrieve LANDATA records for the vehicles tested;
4. screen and refine data;
5. analyse data.

Thirteen sites around New Zealand were selected for snap acceleration testing. Test site selection was determined by:

- the need to provide a spread of test locations around New Zealand;
- the need to provide a range of facility types;
- access to smoke meters of suitable type (basic form described below);
- availability of suitable testing personnel;
- access to a believed representative sample of vehicles;
- co-operation of the chosen site's proprietor.

Table 1 lists the test site locations of the 13 snap acceleration test sites and their respective test sample sizes (after screening out data that did not meet data quality criteria), site types and smoke meter used.

Table 1: Snap Acceleration Testing Site Locations and Their Respective Site Type and Smoke Meter Used.

Location	Sub-location	Quality Tested Sample Size	Site Type	Smoke Meter	Smoke Meter Source
Whangarei		8	Workshop and repair[(1)]	Bosch BEA250	Own.
Auckland	UniServices	19	Selected test vehicles.	Various	Own and loan.
	UniServices	32	Various safety inspection only sites.	Bosch RTM430	D & T.
	VINZ, Mt Wellington	104	Safety inspection only.	Motorscan 8020	Stocks.
	Diesel Injection Services	0[2]	Repair.	Bosch BEA250	Own.
Waitakere		11	Safety inspection only.	Bosch	Diesel & Turbo.
Hamilton		28	Various commercial sites.	Sun ASA200	EW.
Claudelands		18	Safety inspection only.	Sun ASA200, Bosch RTM430	EW and D&T.
Tauranga		43	Workshop and repair.	Bosch BEA250	Own.
Palmerston North		0[2]	Safety inspection only, workshop and repair.[2]	Bosch BEA250	Own.
Wellington		0[2]	Repair.	Bosch BEA250	Own.
Christchurch	VINZ	175	Safety inspection only.	Airrex HO400	Stocks.
	Diesel Injection Services	39	Repair including non-repair testing.	Bosch BEA250	Own.
Dunedin		0[2]	Workshop and repair.	Bosch BEA350	Own.
	Total Sample	477			

D&T: Diesel & Turbo.
EW: Environment Waikato.
Stocks: George Stock & Co.
Note 1: 'Workshop' refers to a place where general vehicle repairs take place. 'Repair' refers to a place where repairs specific to how the engine runs take place. "Commercial" refers to bases for commercial fleets such as the base used for the Hamilton City Council for heavy and light commercial vehicles.
Note 2: Sample size insufficient to warrant addition to combined sample set

3.1.2. Smoke Meters

All smoke meters used for snap acceleration testing were of the type which measures the density of smoke in a continuous flow of exhaust and were designed for snap acceleration testing according to one or other of the snap acceleration procedures in use in Europe (each country has taken a different interpretation of the European test requirements resulting in small differences in the likes of how the test is progressed to the number of individual snap accelerations carried out[15]). A description of this type of smoke meter and an assessment of various smoke meters available in New Zealand at the time of the Pilot is provided in Appendix B. A high proportion of the smoke meters used were made by Bosch and these were considered to be at the higher-quality end of the range of snap acceleration smoke meters available in New Zealand at the time.

Before use in the Pilot, smoke meters were calibrated either by the Energy and Fuels Research Unit (EFRU) personnel (University of Auckland) or by the testers, where they were competent to do so. Calibration work carried out at the EFRU was augmented with back-to-back comparative testing of different smoke meters.

One cheaper smoke meter provided for use in the Pilot could not be calibrated and was not used further. Another smoke meter, found to be two years from its last service, was given to the service agent (for that particular smoke meter) for checking. It was found to require servicing, which was done at a cost of $570.

Back-to-back comparisons of smoke meters on the same vehicle found reasonable variation in results between smoke meters and results were subsequently scaled.[16] The scaling factors used are further described in Section 3.2.2.

3.1.3. Testers

Testers of varying competence were used across the test sites. Testers were regular site-based staff at some of these locations, and specifically hired to carry out the emissions test work at others.

Testers were trained in how to test to the project test protocol[17] and, as there was the chance that variation in test results would arise from different interpretations of the test protocol, testers were checked from time to time as it was deemed necessary. Data received from the various sites was also checked as it was made available. The early test results from one site were not used, such were the concerns over the ability of the tester to follow the Pilot's test protocol sufficiently (this aspect is further discussed in Section 6: Implementation).

3.1.4. Test Procedure

The protocol for performing the snap acceleration test at the various sites was:

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[15] Chris Hunt, Crypton (a UK manufacturer of emissions test equipment) – personal communication.

[16] The factors used in scaling results were derived by comparing the mean results from back-to-back comparative testing of smoke meters, offsetting these values by the factor so the scaled results were one on top of the other (i.e., applying an offset from regression analysis to the mean of comparative snap results, and then using this offset as a proportional factor).

[17] In some cases, training consisted of checking the tester's understanding of the test protocol only, as opposed to leading them through the test, as some testers were already familiar with the general procedures involved as they used snap acceleration testing in their usual line of work.

- vehicle selection:
    - for safety inspection-only test sites, this was the next diesel vehicle to be presented after the smoke meter became available and, for some sites where the practice was to obtain consent for the driver,[18] where this had been obtained;
    - for workshop and repair test sites, this was every vehicle where time permitted the test to be carried out;
- assessing the engine was safe to test; [19]
- carrying out a visual inspection of the vehicle and filling in the visual inspection form provided to testers (a sample appears in Appendix C) in order to determine the engine technology (defined later in this section) of the test vehicle;
- ensuring the engine was warm;[20]
- visually checking for excessive smoke during a two-second 'snap acceleration': that is, pushing the accelerator quickly to the floor and holding it there for two seconds. This component of the procedure also comprised one 'clear-out';[21]
- checking the governor operation, if this had not been apparent in the previous snap acceleration check, this action providing one further clear-out;
- zeroing the smoke meter, if this was not done automatically by the meter itself, and inserting the smoke meter's probe into the exhaust pipe;
- carrying out at least four consecutive snap accelerations: that is, putting a foot quickly down on the accelerator and holding it there until high governed engine speed had been attained, then releasing the accelerator;
- continuing snap accelerations where results were not consistent and the smoke meter allowed for further results to be recorded;[22]
- printing out results; and, for some test sites —
- providing results to drivers;
- recording the last four snap acceleration results for analysis (i.e., the snap acceleration test comprised at least six snap accelerations altogether), the last three of which were averaged and used as the overall snap acceleration test result.

The above test protocol was derived from early field trials of snap acceleration testing. These trials attempted to follow SAE J1667, a snap acceleration test protocol developed and standardised in the US. Problems arose when this standard test was applied to the New Zealand fleet such that it was not practical to use it. The problems encountered included:

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[18] The original intent was to obtain consent from the drivers of all vehicles tested, but this was found to significantly hinder the number of vehicles that could be tested and it was therefore decided to not ask for consent at some sites where this was thought appropriate.
[19] Based on the absence of any disturbing engine noise or vibration, answers to questions given to the driver and general appearance of the engine or vehicle.
[20] Testers were recommended to check that the engine or radiator was hot to touch and the temperature gauge registered a normal operating temperature. The actual method used was left open to the tester. Other options are discussed in Section 6; Implementation.
[21] A diesel engine can have a temporary build-up of carbonous matter in the engine and exhaust system which can be dislodged by the first snap accelerations, potentially giving rise to higher-than-normal snap acceleration results. These early snap accelerations are sometimes referred to as 'clear-outs' for this reason.
[22] Noting that for some smoke meters, there was a limit to the number of individual accelerations results that could be recorded.

- one recent year-of-manufacture light diesel vehicle exhibited 'valve bounce'[23] when held at governed speed (SAE J1667 requires holding at governed speed for between one and four seconds). Valve bounce can lead to engine damage and therefore it is not wise to hold a vehicle at high governed engine speed if it is prone to this condition.[24] The Pilot's test method accordingly allowed the release of the accelerator as soon as governed speed was reached. Laboratory tests conducted at the EFRU indicated there was little difference in the test result for this variation, but the snap acceleration result was lowered if the accelerator was released before governed speed was reached;
- testers knowledgeable in engine repair were concerned with the severity of the snap acceleration test, to the point where few diesel vehicles were tested at two sites despite the fact that both were set up for snap acceleration testing for the Pilot;
- one particular engine model had a reputation in the industry as a "weak" engine and testers who knew of this did not wish to take this engine close to governed speed. The accelerator was instead released earlier. A lower snap acceleration result would be likely, based on results from laboratory testing at the EFRU;
- there appeared to be a threshold for the number of consecutive snap accelerations that concerned drivers would tolerate when snap acceleration tests were carried out in front of them.[25] In such circumstances, testing was limited to 6 to 7 snap accelerations (including the clear-out accelerations);
- for some smoke meters, the use of the standard test protocols programmed into the smoke meters limited the number of consecutive acceleration tests that could be recorded to four (excluding clear-outs).

The principal source of potential differences between results gleaned from the Pilot's test procedure, described above, and those from the SAE J1667 test procedure was the limited number of individual accelerations that were carried out for the Pilot's procedure. For some data sets recorded, the individual acceleration results were still decreasing, suggesting the engine was still clearing out during the test procedure and that a lower snap acceleration result may have been attained should the testing have continued. The SAE J1667 test procedure, by contrast, requires testing to continue until recorded consecutive results are stabilised.

To illustrate this further, Figure 4 provides a sequence of consecutive individual acceleration results where there was a significant reduction in the results yielded by the first four. Using the Pilot's test protocol, the first three results were effectively ignored (number one a clear-out, number two a governor check, number three recorded but not used) and the test result was the average of the results for acceleration numbers four, five and six (a result of around K=3.0 m^{-1} for this example). Had testing continued — as it would in the SAE J1667 test procedure — the result would have been around K=2.6 m^{-1} (the average of the last four results), K=0.4 m^{-1} less than for the Pilot test protocol.

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[23] Where the piston and valves hit one another due to the failure of the valves to return as quickly as they should. The engine makes a loud clattering noise under such operation.

[24] Also noting SAE J1667 originated from the testing of engines used in heavy duty vehicles. These engines are normally governed to lower engine speeds and have greater inertia than small automotive diesel engines. By comparison, the fast accelerations and high engine speeds possible for some light vehicle engines means the snap acceleration test can be very demanding for these smaller engines.

[25] The snap acceleration test is an extreme test in that it takes an engine to high governed engine speed without otherwise loading the engine. The noise and the apparent high engine speed was unsettling to vehicle drivers and this was found to be a significant obstacle to obtaining vehicles for testing.

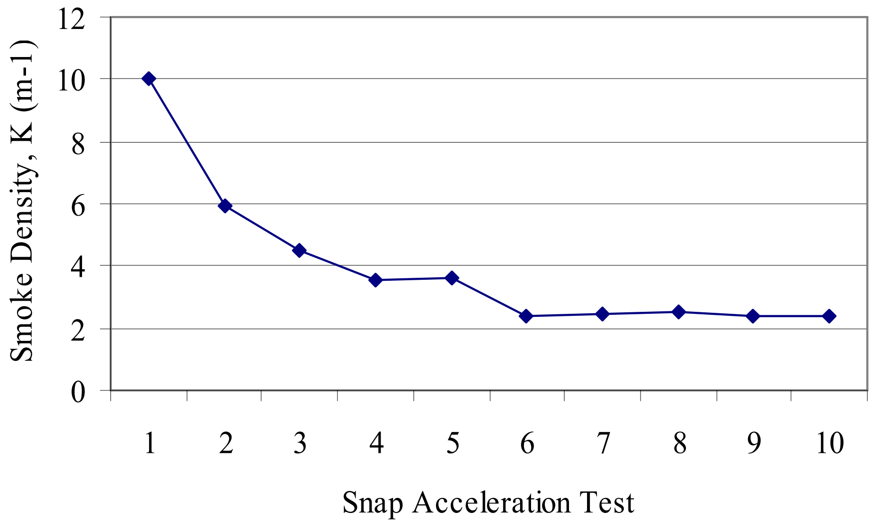

Figure 4: Consecutive Individual Acceleration Results for a Light Diesel Vehicle (Reg. No. RQ3666) Exhibiting Lowered Results with First Accelerations.

Data quality assurance checks also included screening out data sets where the last three individual acceleration results varied by more than K=2.0m^{-1} as a means of excluding data, where initial clear-outs were obviously not sufficient. The overall variation from the SAE J1667 procedure was tested by comparing the Pilot's quality-assured snap acceleration test results (using the 'last-three-average' approach) with that derived by considering where a vehicle's consecutive individual acceleration results were going (i.e., identifying any trends in consecutive individual acceleration results and using this to derive an overall snap acceleration test result for the vehicle); this latter method was believed to provide results similar to those which would have yielded had the test been allowed to continue (as it would in the SAE J1667 procedure). This test found the average of the total quality-assured snap acceleration data set using the result derived from the 'last-three-average' approach to be 0.2 m^{-1} higher than the 'trend'-derived result. This difference in the results was considered to be small compared to the potential errors arising from variations in smoke meter response or tester methodology, and accordingly no further correction was applied.[26]

It is worth noting that the snap acceleration test procedure in the UK is very similar to that developed for the Pilot. The UK procedure stipulates that individual accelerations be carried out until 'either: the mean of any three consecutive readings is at or below the appropriate limit, or six accelerations have been achieved.'[27]

[26] Note the 'last-three-average' derived result was used rather than the 'trend' result, as it was statistically a more robust result to use.
[27] Vehicle and Operator Services Agency (VOSA), *The MOT Inspection Manual - Car & Light Commercial Vehicle Testing*, Issue date: August 2004.

The Pilot and SAE J1667 test procedures are otherwise similarly exposed to variations in how the tester conducts the test and from smoke meter-related variations. This potential for variation was managed by:

- calibrating smoke meters and using the results from back-to-back testing of different smoke meters to scale results;
- site visits, including validating the test procedure being used by testers;
- data quality assurance checking, including:
    - the use of the last three individual snap acceleration results to derive an average K result, as has been mentioned;
    - the removal of data where the variation in individual results was greater than K=2.0 m^{-1}, as has also been mentioned;
    - the removal of data for vehicles found to have incompatible technology configurations: for example, diesel vehicles fitted with carburettors (which are a feature of petrol engines).

Typically, around 10% of data from any one site was removed by this data quality assurance checking process.

3.1.5. Analysis

Two streams of analysis were carried out on the data. Statistical modelling of emissions was carried out using multiple variable statistical analysis carried out in Statistical Analysis Software (SAS, Version 9.1) and allowed GVM to be considered as a variable (i.e., across the wide range of vehicle weights found). Emissions profiling, on the other hand, required vehicles to be considered in groups and a division was made between light vehicles (vehicles with GVM of 3500 kg or less) and heavy vehicles (vehicles of GVM exceeding 3500 kg). In the main, this divided the quality-assured field sample into a group that had comparatively light-build, high-speed engines (i.e., those used in light vehicles) and a group with heavier-build, high-speed engines (i.e., those used in heavy vehicles).[28] At a more detailed level, there were 31 vehicles between 3490 and 3500 kg that had engines more akin to those used in heavy vehicles. It would perhaps have been appropriate to group these vehicles with the heavy vehicles for emissions purposes; however, their official light-heavy status, as derived by the 3500 kg GVM cut-point, was acknowledged and they were kept in the light vehicle group.

Dividing the quality-assured field sample in this way provided a total of 197 light vehicles and 255 heavy vehicles. Newer light vehicles are not required to be presented for warrant of fitness inspections as frequently as older vehicles,[29] and this presents a sampling bias where sampling was carried out at the time of safety inspection. To take this into account, data from newer vehicles was duplicated, the number of data entries increasing for light vehicles from 197 (from 197 vehicles) to 233 (from 197 vehicles). Depending upon the analysis being carried out, this data could also be augmented by a

[28] Note both light and heavy vehicles are fitted with 'high-speed' engines, the speeds at which they operate being high compared to large medium- and low-speed engines used in ships and for power generation (revolving at speeds as low as 100 rpm).
[29] 'Vehicles first registered anywhere less than six years ago must have WoF inspections every 12 months. All other vehicles must have WoF inspections every six months.' Land Transport NZ website, http://www.ltsa.govt.nz/vehicle-ownership/warrant.html). Heavy vehicles are subject to a six-monthly Certificate of Fitness (CoF) inspection, regardless of age.

further (WoF adjusted) 25 data entries where year of manufacture or odometer was not required to be known (i.e., this information was not available for these 25 data sets). The resulting combined data set, the 'profiling snap acceleration data set', was used for emissions profiling analysis in this section. A breakdown of the adjusted sample size, by location, is provided in Table 2.

Table 2: Sample Size of Quality-Assured Data from Snap Acceleration Testing for Light and Heavy Diesel Vehicles, by Test Site, and Resulting WoF-Adjusted Sample Size in the Case of Light Vehicles.

Site No.	Location	Sub-location	Light Vehicle Sample Size	Adjusted Light Vehicle Sample Size	Heavy Vehicle Sample Size
1	Whangarei		8	10	0
2	Auckland	UniServices (dyno)	19	19	0
3		UniServices (outside)	4	4	28
4		VINZ, Mt Wellington	18	21	86
5		Diesel Injection Services	0	0	0
6	Waitakere		11	14	0
7	Hamilton and Claudelands		19	27	27
8	Tauranga		39	44	4
9	Palmerston North		0	0	0
10	Wellington		0	0	0
11	Christchurch	VINZ	67	84	108
12		Diesel Injection Services	37	39	2
13	Dunedin		0	0	0
		Total Sample	222	262	255

Note that vehicles were presented for snap acceleration testing during the Pilot without any pre-test conditioning. It is expected that some vehicles would exhibit lower snap acceleration test results after pre-test conditioning and it is expected a small percentage of vehicle owners would carry out minor work or other pre-test conditioning if simple emissions testing was mandatory. Thus it is suggested that snap acceleration test results found during the Pilot would err on the higher side than for vehicles presented as part of a snap acceleration test regime, all else being equal.

3.2. Results and Analysis

3.2.1. Sampling Quality

The quality of the field sampling technique was considered by comparing the age profile of the field sample with that of the New Zealand diesel fleet (as given by LANDATA data) and by comparing the proportion of vehicles making up light-heavy and vehicle origin divisions with those for LANDATA. Three broad vehicle-origin divisions were used: 'Used-Japanese' imports, 'New-Japanese' imports, and 'Other-New', the latter made up predominantly of new vehicles from countries other than Japan but also including a minor proportion of the likes of scratchbuilt, re-registered and used vehicles from countries other than Japan.

Note that the simple test analysis carried out for petrol vehicles considered the two vehicle-origin options, New Zealand-New and Used-Japanese. For the diesel vehicle analysis, it was chosen to divide the New Zealand-New division further into those originating from Japan and those that did not, as it was believed there could be reasonable variation in emissions performance for vehicles of these two origins due to differences in their respective emissions build requirements.

Figure 5 for light vehicles and Figure 6 for heavy vehicles illustrate the age profile comparisons. Both show similarities in the age distributions of the profiling snap acceleration data set (lower distributions in each figure) compared to LANDATA data[30] (upper distributions in each figure) although, at a more detailed level, some variations are also evident. Importantly, the main distribution of diesel vehicles in New Zealand (as given by LANDATA data) was covered, with the exception of a small proportion of pre-1985, light, New Zealand-new vehicles that were present in LANDATA data (upper right plots in Figure 5) but represented by only a single vehicle in the Pilot's sample. This small proportion of vehicles is likely to be made up of New Zealand-assembled vehicles, such as Toyota Landcruisers and Bedford vans. These vehicles make up around 2% of the light diesel fleet,[31] and at this level are not considered significant so far as characterising the main diesel fleet is concerned. However, it still represents to the order of 10,000 vehicles: should snap acceleration testing be introduced and it is not proposed to exclude these vehicles from the testing regime due to age or other considerations, it is recommended that specific sampling and testing of this type of light diesel vehicle is carried out before the regime's introduction.

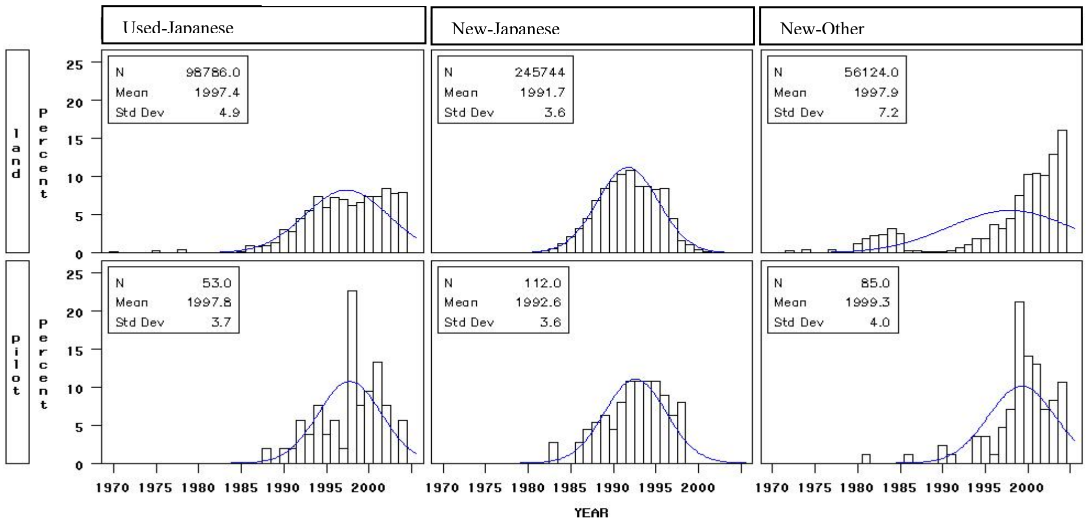

Figure 5: Age Distribution of Light Diesel Vehicles for the Pilot's Profiling Snap Acceleration Data Set and for LANDATA Data (Active Fleet at as 1 December 2004), for the Fleet Divided by Used-Japanese Imports, New-Japanese Imports and Other-New.

[30] For post-1970 year-of-manufacture, 'active' diesel vehicles as at 1 December 2004. 'Active' refers to vehicles that have been registered for use on the road in the last 12 months.

[31] Note the proportion of vehicles represented by each cell in Figure 5 is different. In particular, the New-Other cell (right-most) represents a small proportion of the fleet (around 14%) and the 'distribution blip' is far less apparent when considered across all vehicle divisions.

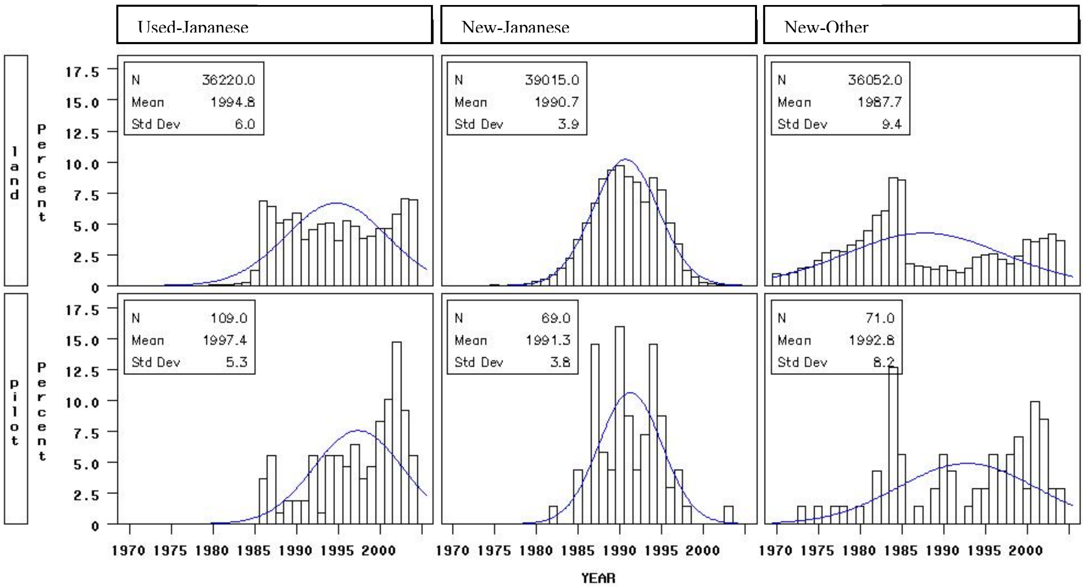

Figure 6: Age Distribution of Heavy Diesel Vehicles for the Pilot's Profiling Snap Acceleration Data Set and for LANDATA Data (Active Fleet at as December 2004), for the Vehicle Divisions Used Japanese Imports, New Japanese Imports and Other-New and Other.

A component of the Pilot also visually inspected approximately 650 further diesel vehicles to determine the engine technology makeup of a greater number of vehicles from a wider range of locations, and this data was also used to compare the makeup of the Pilot's samples with that of LANDATA data. Table 3 provides that comparison: the "Snap Acceleration" sample (third principle column) uses the profiling snap acceleration data set; and the "Visual" sample uses a data set made up of the combination of the profiling snap acceleration and visual data sets (the latter adjusted by quality assurance testing and wof period for light vehicles). This resulted in an 'adjusted visual inspection' data set for light vehicles of 759 entries and an 'adjusted visual inspection' data set for heavy vehicles of 296 entries. Detailed data for the profiling snap acceleration and adjusted visual inspection data sets, by test site, is provided in Appendix D.

Table 3: Comparison of the Relative Vehicle-Origin Makeup of the Profiling Snap Acceleration and Visual Samples (WoF-Corrected in the case of Light Diesel Vehicles) with LANDATA Data.

Sample Set:	LANDATA			Snap Acceleration		Visual	
Vehicle Division	Sample size	Percent (%) that Vehicle Type is of Total Sample	Range of Vehicle Types Found at Different Locations (%)	Sample size	Percent (%) that Vehicle Type is of Total Sample	Sample size	Percent (%) that Vehicle Type is of Total Sample
Light Diesel							
Other-New	68639	17	10-18	68	29	159	21
Used-Japan	245793	60	60-75	95	41	456	60
New-Japan	98055	24	14-23	53	30	144	19
Total Sample	412487	100		233	100	759	100
Heavy Diesel							
Other-New	41446	36	23-35	74	29	88	30
Used-Japan	39015	33	33-40	69	27	100	34
New-Japan	36220	31	28-36	112	44	108	36
Total Sample	116681	100		255	100	296	100

Shown also in Table 3 for LANDATA data is the variation in the makeup of fleet origins found for the centres where the majority of Pilot data was sourced, namely Waitakere, Hamilton and Christchurch. The origin-makeup of the visual data sample compared well with this LANDATA data, for both light and heavy vehicles. The origin makeup of the snap acceleration data, on the other hand, exhibited a lower proportion of light Used-Japanese vehicles — around 40%, compared with around 60% to 75% as given by LANDATA data for the main test areas. We were unable to isolate a sound reason for this variation. As it happened, vehicle origin was found to contribute little towards describing the snap acceleration result of vehicles and therefore this sampling bias was expected to have little effect on the results and conclusions drawn from the Pilot's analysis. Further, vehicle origin was kept as a variable for the majority of the analysis carried out, making the proportion of vehicles sampled by origin largely unimportant.

3.2.2. Snap Acceleration Results Quality

Despite the various controls used in the snap acceleration testing of vehicles, there is expected to be some variation in the result from a snap acceleration test arising from differences in tester, smoke meter and vehicle pre-conditioning. The potential for variation was assessed in laboratory testing carried out at the EFRU, and a description of this testing and discussion on the results are provided in Section 6.2.5.2. In summary, the variations that may arise include:

- variations in the snap acceleration test result of up to the order of 20% due to differences in the speed at which the tester depresses the accelerator. Variations of over 40% may arise in unmanaged testing; [32]

[32] That is, the Pilot's variation in snap acceleration result due to differences in the speed of accelerator depression was expected to be less than 20%, but unmanaged, the result is expected to vary as much as 40%.

- variations in the snap acceleration test result of up to the order of 20% due to differences between individual smoke meters or their setup on individual vehicles, and differences in comparative snap acceleration results of up to 40% if the responses of different smoke meters are not taken into account;[33]
- differences of up to the order of 20% due to pre-test conditioning.[34]

Snap acceleration results were scaled to reduce the potential for measurement differences between individual smoke meters: SAS was used to analyse the results of back-to-back testing of smoke meters to derive scaling factors for the different smoke meters used, based on the derived offset at centre-scale (i.e., at K=5.0 m^{-1}). Bosch smoke meters were taken as the standard smoke meter and provided a correction factor of 1.0, with the correction factors for other smoke meters scaled accordingly from this. The correction factors used, by smoke meter, are listed in Table 4.

Table 4: Correction Factors used for Smoke Meters Based on Analysis of Results from Back-To-Back Testing.

Smoke meter	Correction Factor
Airrex	0.91
Bosch	1.0
Celesco	0.71
Lucas	1.35
MotorScan	1.04
Sun	0.72

Despite the scaling and other test management practices, there was potential for significant site-to-site variations in snap acceleration results, which is of concern given that should such testing be introduced it will be necessary for data generated up and down the country to be comparable. By comparison, the potential for variation in snap acceleration results due to differences in fuel quality was expected to be small, and this variable was therefore not tested for or monitored during the Pilot.

Note that despite the significant potential for variation, the results are representative of what they are: the results yielded by testing vehicles according to a snap acceleration test procedure that can be repeated in the future. Much the same potential for variation is expected to remain if testing is carried out in New Zealand in the future.

[33] Note that for this reason, many countries using snap acceleration testing specify the use of particular smoke meters which have been referenced against a standard smoke meter or other measurement as part of the meters' approval process.

[34] To the order of 20% is derived from consideration of consecutive snap acceleration results, where results continued to reduce with further testing even after 6-7 snap accelerations. *Ad hoc* testing on this was also carried out by one of the testers at VINZ, Christchurch, and it was reportedly found a K=1.0-0.5 m^{-1} lower snap acceleration test result could be achieved for some vehicles when they were taken for a loaded run before re-testing. Unfortunately, the second test was not always recorded (testing was carried out on the tester's own initiative) and therefore these results could not be verified to a level which allowed them to be reported with confidence.

The quality of visual inspection data, by contrast, is considered to be reasonably robust as far as the determination of base engine technology (engine technology for this report also including the exhaust system) is concerned, as the means by which engine technology was divided into three divisions for this purpose was quite simple. This data could, what is more, be checked to some degree, given the expected build of certain vehicles models. The three base engine technologies categories so used were:

1. Technology 1: Non-turbocharged (using the commonly referred to "Euro" emissions standard reference, this would align with Euro 0 to Euro 2);
2. Technology 2: Turbocharged, no catalyst (aligning with Euro 1 to Euro 3);
3. Technology 3: Turbocharged and exhaust catalyst (aligning with Euro 3 and more advanced technologies).

Note these simple descriptions somewhat mask the advances in technology involved in going from one to another. For example, an engine fitted with an exhaust catalyst is likely also to be fitted with advanced diesel injection equipment, advanced combustion chamber design and an advanced EGR system.

These simple divisions were further supported by seeking information on whether the engine had indirect or direct injection,[35] had EGR [exhaust gas recirculation] or not, and what type of diesel injection pump system was fitted. The combination of these and 'Technology', as described above, provided a more detailed assessment of the technology of the engine. However, many vehicles were reported as 'unknown' for these last items and, in fairness, these attributes were difficult to determine through simple visual inspection alone (and hence the reason for devising a simple description of base technologies that could be reasonably easily recognised).

A vehicle's year of manufacture was also expected to inform the assessment of a vehicle's engine technology, as advances in technology would be expected over time within the technology divisions described.

3.2.3. Base Analysis

Initial analysis of the snap acceleration data was aimed at isolating the most significant identifiers of vehicle snap acceleration performance. For this, the adjusted snap acceleration data set was subjected to multiple variable statistical analysis, using SAS, to test the snap acceleration test result for the statistical significance of the effects of a range of variables, whether in concert with other variables or by themselves (notwithstanding the variability in emissions result that may arise from the variability due to other parameters, as detailed in Section 2 of the Petrol Report). The variables so tested were year of manufacture (YoM), odometer reading ('odometer'), engine technology ('technology' as defined above), vehicle origin (New-Japanese, Used-Japanese of Other-New), indirect or direct injection, the presence or not of exhaust gas circulation (EGR),[36] diesel injection system type, under-bonnet appearance, exhaust showing visible blue smoke, exhaust showing visible black smoke (as judged by the

[35] That is, whether diesel was injected directly into the combustion chamber.
[36] EGR is used to reduce NOx emission; a proportion of exhaust gas is recirculated to the combustion chamber, which has the affect of lowering peak combustion chamber temperatures, which in turn lowers the rate of formation of NOx.

tester by sight, the two combined in some analysis as 'visible smoke'), engine size, GVM and engine power.[37]

It was understood that the variables considered were not necessarily independent. An obvious example is that vehicles of less recent YoM would be expected to have higher odometer. With this in mind, the 'significance' analysis began with a base statistical model that attempted to describe the snap acceleration result by technology and secondary performance indicator (SPI),[38] the most efficient statistical model found in the petrol emissions analysis work. Other variables were then added or removed from the base model and their individual ability to describe the snap acceleration result was thus established.

The statistical model that could best describe the variability in the snap acceleration result using the tested variables was one using the four variables: technology, SPI, visible smoke and GVM. The factors used in the model indicated a trend towards lower snap acceleration results for: more advanced engine technology; lower distance travelled; more recent year of manufacture; lower visible emissions; and higher GVM. This model had a coefficient of determination (R^2) of 0.24; that is, only 24% of the variability in snap acceleration results could be described by a model using these four variables. In this model all variables were statistically significant above the 95% confidence level (that is, p-value <0.05).[39] A similar model using odometer rather than SPI had an R^2 of 0.22, the small decrease (compared to the earlier $R^2=0.24$) indicating that whilst odometer was statistically significant, its effect was small.

A visual representation of the variability in the snap acceleration result and the difficulty in describing it — even when SPI and technology are considered (i.e. close to the best emissions prediction model developed) — is illustrated in Figure 7, which provides a balloon plot of the snap acceleration results for light vehicles positioned on a technology versus SPI plane. This shows a scatter of results. If the snap acceleration result was well described by SPI and technology, the snap acceleration results would have been confined to a limited fog across each technology axis. The balloon plot for heavy vehicles (see Appendix E) exhibits a similar plot of scattered results.

[37] Engine power is not a compulsory field on LANDATA source datasheets, reducing the sample size for this test to around 200 vehicles.
[38] SPI is the product of YoM and odometer and, as for petrol vehicles, was found to describe the simple test emissions result better than YoM or odometer by themselves. Co-joining these two variables also avoided dividing variables that were likely to exhibit co-dependence. The use of the term 'SPI' — rather than 'YoM-Odo' factor, say — was to draw attention to the possibility that there may be other variables co-dependent to this factor.
[39] The 'statistical significance' of a parameter refers to the observer's confidence that the parameter has some effect or is correlated to a trend in the model. If the statistical significance of a parameter is 50% or lower, it does little to reduce the unknown variability of the model, so that particular parameter does not really add much to the model. A parameter that has a statistical significance of 90% or more has a 'high confidence', does reduce the unknown variability of the data, and does represent a real correlation.

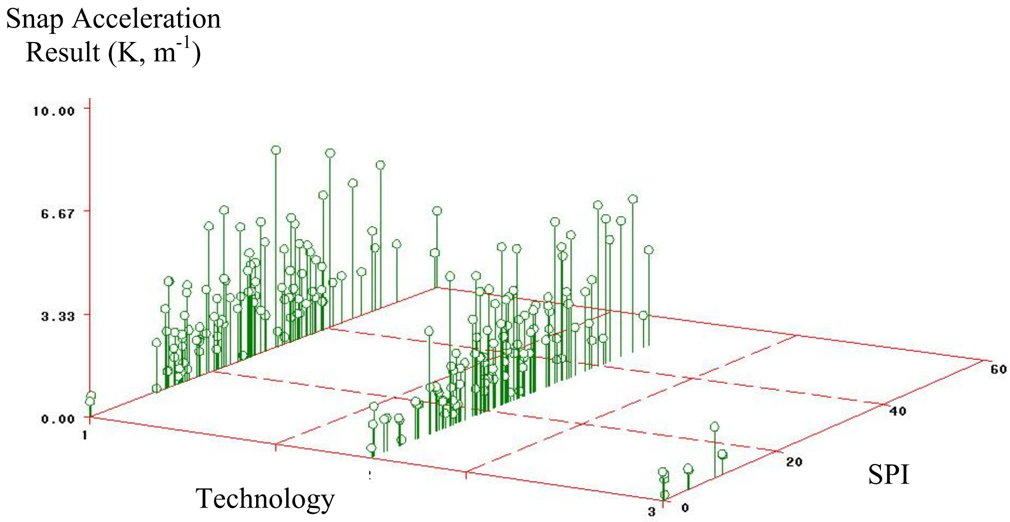

Figure 7: Balloon Plot of the Snap Acceleration Results for Light Diesels from the Pilot's Profiling Snap Acceleration Data Set Versus Technology and SPI.

Figure 7 also illustrates one of the issues of the sampling method and resulting sample used, namely the small number of Technology 3 vehicles (13 for light vehicles and only four for heavy vehicles) that were captured. The introduction of Technology 3 engine systems for diesel vehicles has been only relatively recent, for New Zealand, and only a minor proportion of the fleet would be expected to be fitted with this technology, and this is reflected by the small number of such vehicles in the sample. The small number of Technology 3 vehicles does not allow strong technology-related conclusions to be drawn from the statistical analysis by itself, however, the conclusions drawn are strengthened when the practicalities of the design of Technology 3 engine systems are also taken into consideration – their different design to Technology 1 and 2 lends them to possess far improved emissions performance. Note the long-term performance characteristics of Technology 3 vehicles is also an unknown – there were no Technology 3 vehicles of high distance travelled or less recent year of manufacture (a function of being a relatively recently introduced technology).

Note that the best emissions model included visible smoke, a different type of variable than the others as it is a tester-assessed result and not a physical attribute of a vehicle.[40] Its significance (as has been previously discussed, visual smoke is a statistically significant variable above the 95% confidence level in describing the results of the snap acceleration testing of vehicles) supports the use of simple visual checking of vehicles as a possible screen for emissions testing vehicles.

The statistical significance of a number of variables was also tested when each was considered by themselves (that is, as a single variable describing the variability in snap

[40] The analysis carried out was an attempt to describe the variability in the simple test result by using physical attributes of vehicles, the better to characterise emissions performance. When done for petrol vehicles, the physical parameter emissions model could better describe the expected on-road emissions performance of the test sample of vehicles than could the simple test results. However, in the case of diesel vehicles the inclusion of the 'measured' result of visible smoke better described the variability in the snap acceleration result, and so was included as a variable.

acceleration result). This analysis found technology to be statistically significant (above 90% significance, that is p-value <0.1) in its own right, but only statistically significant for Technology 3 (advanced technology) versus Technology 1 and 2 (simple technologies) with no statistical difference between Technology 1 and 2. It is again stressed that the data sample analysed only contained four heavy diesel vehicles and 13 light diesel vehicles that also had advanced engine technology, and these were all relatively recent year of manufacture. It would therefore be difficult to draw strong conclusions from this particular analysis, although the results are in line with the emissions performance expected when a practical, technical appraisal of the design of the technology involved is conducted. This strengthens what would otherwise be a weak conclusion.

Vehicle origin was also found to be statistically significant by itself. However its statistical significance soon became inconsistent as other variables were added to the model, indicating it was a weak descriptor of the variability in snap acceleration result, its original significance surviving on its interdependence with other variables and this significance lost as other variables were taken into consideration. This implies that there is no evidence to suggest a used diesel vehicle from Japan would, on average, exhibit a statistically significantly higher snap acceleration result than the average expected from a vehicle of other origin, where of similar technology, SPI and GVM.

This aspect is further explored in the following figures which show the distribution of the log of the snap acceleration for the adjusted snap acceleration data set for light vehicles (Figure 8) and heavy vehicles (Figure 9), versus technology and origin. Analysis has been carried out in log-space as distributions of vehicle emissions results are usually highly skewed to the zero-emissions axis, but when such distributions are normalised in log-space, the use of standard statistical analyses becomes possible. (This approach is discussed in more detail in Section 2.2.7 of the Petrol Report: it is a method routinely applied in the course of research undertaken overseas).

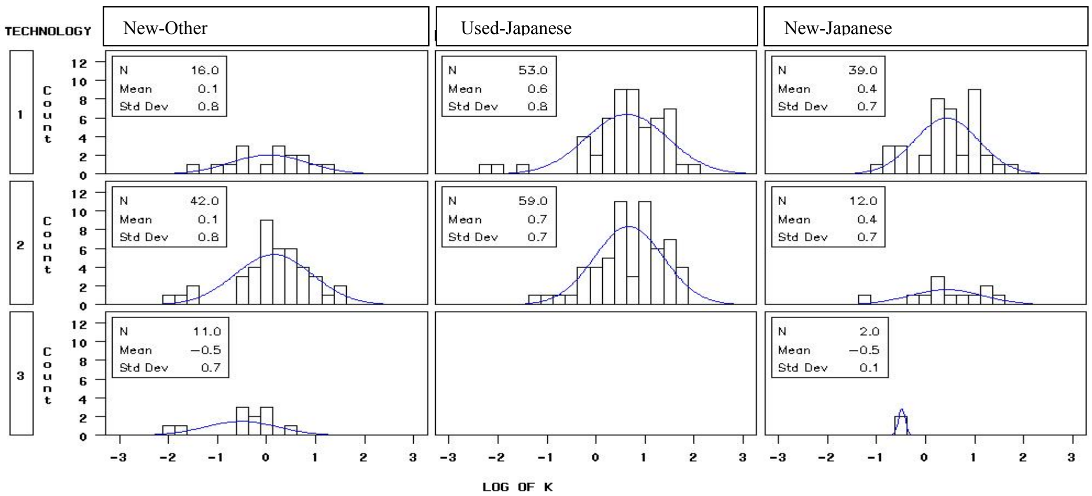

Figure 8: Log K for the Adjusted Snap Acceleration Sample of Light Diesel Vehicles Divided by Technology and Origin.[41]

[41] Note the sample size for New-Other Technology 1 vehicles has decreased for Figure 8 compared to Figure 5, due to the removal of data entries for two vehicles that had snap acceleration results outside five standard deviations from the mean (i.e., results that were some distance from the others).

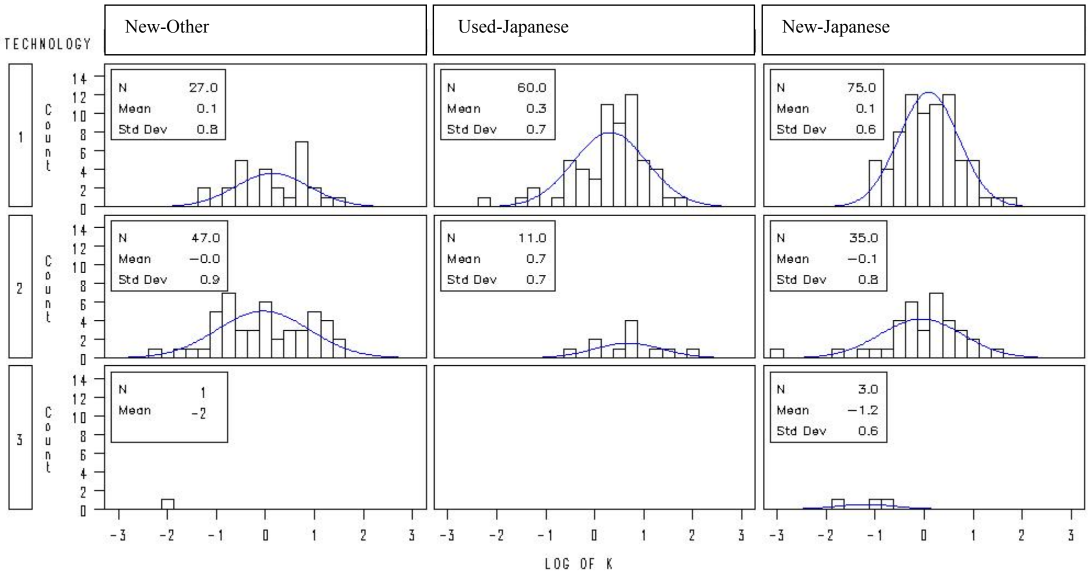

Figure 9: Log K for the Adjusted Snap Acceleration Sample of Light Diesel Vehicles Divided by Technology and Origin.

Figure 10 plots the resulting log-space-derived mean snap acceleration results, but with results then converted into real space. This data shows the similarity between Technology 1 and 2 (triangles and circles, respectively) and the lower snap acceleration results for Technology 3 (diamonds), quantifying the earlier statistical significance findings. Also shown, Used-Japanese vehicles have higher average snap acceleration results than vehicles of other origins and, generalising, New-Japanese vehicles have higher average snap acceleration results than for Other-New vehicles. From the raw data it is evident, however, that Used-Japanese vehicles tend to be older and, when YoM is also taken into consideration, vehicle origin drops out as no longer statistically significant.

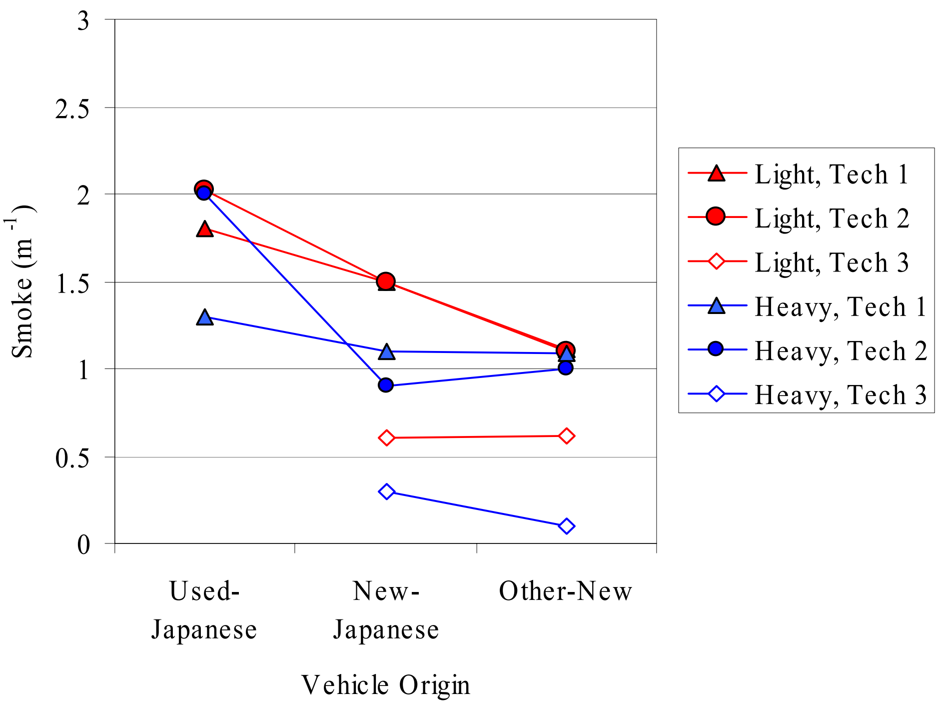

Figure 10: Median Snap Acceleration Results (Smoke Density, K m^{-1}) for Light and Heavy Diesel Vehicles by Technology and Origin for the Adjusted Snap Acceleration Data Set.

The findings were repeated when median snap acceleration results and 90% confidence intervals were compared in plots (rather than using SAS) for the various YoM, technology and light-heavy vehicle divisions used. This analysis has been deferred to Appendix F as it does not take what has already been presented further, although some may find it useful to see the comparison plots that resulted.

Note that three-dimensional plots of the statistical modelling carried out, similar to those provided for petrol vehicles in the Petrol Report, have not been offered due to the low R^2 of models and therefore low relevance of these plots.

3.2.4. Emissions Profiling

The results of the profiling snap acceleration data set described in the previous subsection were best represented by a model using the variables: technology, SPI, visual smoke and GVM. Use of YoM rather than SPI is a close next-best option and preferred when considering policy options, due to the inconsistencies that may arise in odometer reading. For this reason, emissions profiles are offered here which divide the profiling data set into YoM bands (rather than SPI), technology and light and heavy vehicles. These profiles are provided for light vehicles (Figure 11) and for heavy vehicles (Figure 12) as ‘percentile plots’, where vehicles are ordered with their level of emissions ranging from low to high. Using these plots it is easy to identify the percentage of vehicles not meeting a given cutpoint, or the cutpoint that would ‘fail’ a given percentage of vehicles within each vehicle division. Note YoM ranges, pre-1992, 1992 to 1997 and post-1997, were chosen in an attempt to align with significant changes in emissions build standards in overseas jurisdictions — in Japan there was a significant decrease in permitted emissions limits for diesel vehicles phased in during 1997 and 1998 and this timing is similar to when Euro 2 took effect for diesel vehicles in Europe.

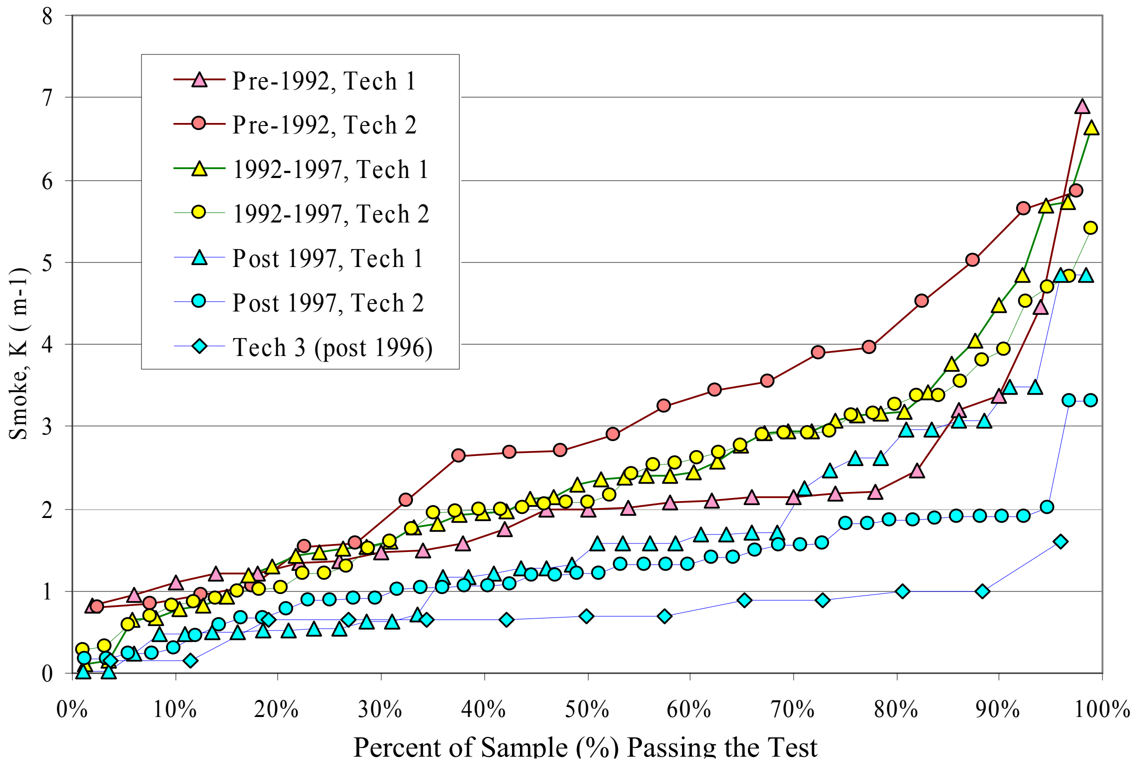

Figure 11: Percentile Plots for the Profiling Snap Acceleration Data Set for Light Diesel Vehicles Divided by Technology and YoM Groups.

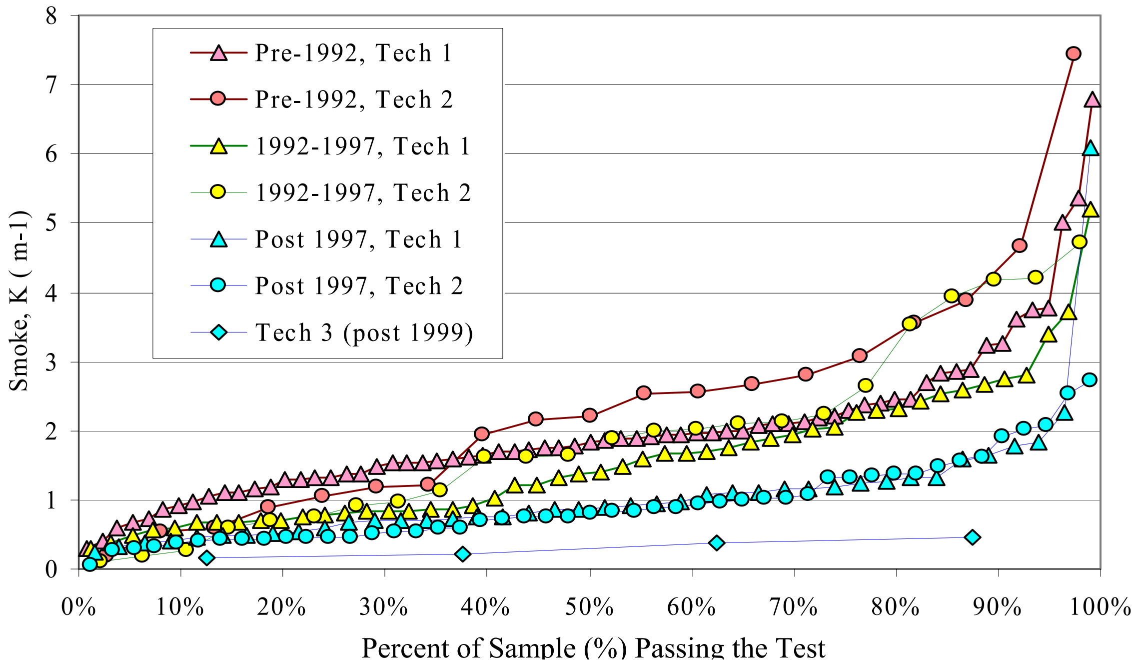

Figure 12: Percentile Plots for the Profiling Snap Acceleration Data Set for Heavy Diesel Vehicles Divided by Technology and YoM Groups.

Figure 11 and Figure 12 exhibit the findings mentioned earlier, namely that Technology 3 vehicles have lower snap acceleration results, on average, than Technology 1 and 2 vehicles, and the overall performances of Technology 1 and 2 vehicles are similar. At a more detailed level, the difference in performance between Technology 1 and Technology 2 vehicles does appear reasonably pronounced for older (pre-1992 YoM) light diesel vehicles (difference in red markers on Figure 11) and were present but far less pronounced for older (pre-1992 and 1992—1997 YoM) heavy vehicles (red and yellow markers in Figure 12). However, it must be reiterated that these are trends and not statistically significant differences.

The small difference between Technology 1 and Technology 2 performance is likely to be the result of *turbocharger lag*. Turbocharger lag is where the turbocharger can take a small amount of time to accelerate up to speed when the engine is accelerating, and the amount of air provided to the engine during this time may be reduced as a result. If the fuelling is not reduced to compensate a higher emission of smoke is likely, as is exhibited here for older vehicles. More modern engine designs typically feature turbocharger-related fuel compensation and do not exhibit this trait.

As mentioned, Figure 11 and Figure 12 can be used to identify the number of vehicles that would not meet given cutpoints. This has been done for the use of the snap acceleration cutpoints of $K=2.5m^{-1}$ and $K=3.0m^{-1}$ and the results reported in Table 5. These are the cutpoints in use in the UK: $K=2.5m^{-1}$ for non-turbocharged vehicles and $K=3.0m^{-1}$ for turbocharged vehicles.

Table 5: Proportion of Vehicles from the Adjusted Snap Acceleration Data Set Not Meeting $K=2.5m^{-1}$ and $K=3.0m^{-1}$ Smoke Cutpoints for Light and Heavy Vehicles with the Cutpoint Relevant to the Engine Technology Highlighted by Shading.

	Technology 1			Technology 2			Technology 3		
	Proportion of Vehicles Not Meeting Cutpoint		Total sample size of cell	Proportion of Vehicles Not Meeting Cutpoint		Total sample size of cell	Proportion of Vehicles Not Meeting Cutpoint		Total sample size of cell
Year Range	$K=2.5m^{-1}$	$K=3.0m^{-1}$		$K=2.5m^{-1}$	$K=3.0m^{-1}$		$K=2.5m^{-1}$	$K=3.0m^{-1}$	
Light vehicles									
Pre-1992	16%	16%	25	65%	45%	20			
1992-1997	39%	27%	44	45%	26%	47			
Post-1997	25%	15%	40	4%	4%	46	0%	0%	13
Heavy Vehicles									
Pre-1992	18%	12%	67	47%	26%	19			
1992-1997	17%	6%	48	25%	21%	24			
Post-1997	3%	3%	40	4%	0%	47	0%	0%	4

*[1] Based on rank from best (0%) to worst (100%) performance within given vehicle division).

Overall, 23% of light vehicles and 12% of heavy vehicles did not meet the UK 2.5-3.0m^{-1} cutpoint set. The proportion of vehicles that did not meet given cutpoints appeared inconsistent across the vehicle divisions used. One such inconsistency was the unusually high proportion of post-1997 Technology 1 vehicles failing to meet the K=2.5m^{-1} cutpoint. The great majority of these vehicles were New Zealand-New vehicles and were likely to have been of 'general export quality' and thus unlikely to have been built to meet an emissions standard. The five-fold increase in failure rate for these vehicles, compared to their counterparts from other origins, is likely a direct consequence of this. There is insufficient evidence to say whether or not these vehicles would then go on to become worse performers than Used-Japanese vehicles at advanced distances travelled.[42]

Checking failure rates of Used-Japanese vehicles to the UK 2.5-3.0m^{-1} cutpoint set, within the technology, YoM and light-heavy vehicle divisions used, found their failure rates to be relatively consistent with the proportion of the total number of vehicles they comprised within those divisions; that is, Used-Japanese vehicles were exhibiting average fleet emissions performance within the divisions used.

3.3. Other

3.3.1. Recent Imports

It was a specific requirement of the Pilot to consider the snap acceleration results of recent used imports. A mobile tester was used to test vehicles waiting for their first inspection for this purpose, but the rate at which vehicles could be tested was very low: vehicles had to be adequately warmed, which took time, and gaining access to vehicles was difficult. As a result, few pre-inspection vehicles were captured.

Instead, snap acceleration results for Used-Japanese vehicles from the profiling snap acceleration data set that were recent imports — that is, imported after October 2002 (within 24 months from when the majority of field test work was carried out for the Pilot) — were compared to results for the whole data set. This netted 25 light and 18 heavy recent-entry Used-Japanese vehicles. The average rank of the snap acceleration result for Used-Japanese vehicles was compared to the range from the best (0% rank) to the worst (100% rank) results for the full data set. Table 6 provides the results of this analysis for the various vehicle divisions considered. For most divisions, there was only a small number of recently imported Used-Japanese vehicles and ranking results have not been offered due to the risk that such a small sample may not be representative (as one out of characteristic vehicle could skew the results). In those divisions that included reasonable numbers of recently imported Used Vehicles, the average rank of those vehicles ranged from 39% to 54%, meaning the average snap acceleration performance for Used-Japanese vehicles entering the fleet was around the average to marginally better than for the existing fleet, when comparing vehicles of similar characteristics.

[42] That is, no odometer-related emissions trend could be identified for post-1997 YoM vehicles, possibly a result of the relatively low average distance travelled by these vehicles.

Table 6: Snap Acceleration Results for Newly Imported Used-Japanese Vehicles Compared to the Full Adjusted Snap Acceleration Data Set in Terms of Average Rank Within Given Vehicle Divisions Plus The Number of Vehicles In Question.

Year Range	Technology 1		Technology 2		Technology 3	
	Average Rank in Division[*1]	Number of Vehicles	Average Rank in Division	Number	Average Rank in Division	Number
Light Vehicles - 25 vehicles of 233 light vehicles in adjusted snap acceleration data set.						
Pre-1992	-	0	N.A.	1	-	0
1992-1997	39%	7	54%	14	-	0
Post-1997	N.A.	1	N.A.	2	-	0
Heavy Vehicles - 18 vehicles of 255 heavy vehicles in adjusted snap acceleration data set.						
Pre-1992	N.A.	2	N.A.	1	-	0
1992-1997	44%	10	N.A.	2	-	0
Post-1997	N.A.	2	-	0	N.A.	1

[*1] The average rank of the snap acceleration result for Used-Japanese vehicles was compared to the range from the best (0% rank) to the worst (100% rank) results for the full data set. Thus a rank less than 50% indicates an improvement in performance for newly imported used vehicles relative to all vehicles (representing the existing fleet).

Six of the 25 recently imported light Used-Japanese vehicles, or 24%, did not meet a $2.5m^{-1}$-$3.0m^{-1}$ (non-turbocharger-turbocharger) cutpoint set — similar to the proportion of light vehicles in the adjusted snap acceleration data set that did not meet this cutpoint set (at around 20%). Three of the 16 recently imported heavy Used-Japanese vehicles, or 18%, did not meet a $2.5m^{-1}$-$3.0m^{-1}$ cutpoint set, reasonably similar to the proportion of heavy vehicles in the adjusted snap acceleration data set that did not meet this cutpoint set (at around 12%). This again showed the similarity in the snap acceleration performance of recent used-vehicle additions to that of the existing fleet.

At this level of performance of recent used imports, there is no significant improvement gained with their entry to the fleet. This compares with the entry of new vehicles — or at least vehicles of more recent manufacture — that are expected to exhibit improved performance compared to the fleet average.

It is not possible to determine the proportion of used imported vehicles likely to fail to meet a $K=2.5$-$3.0m^{-1}$ cutpoint set, should snap acceleration testing be a pre-entry requirement, as there are many other market influences at play. Whilst there would be some advantage to importers in importing vehicles in better mechanical condition, as repair work would be avoided, other overseas markets are demanding higher quality vehicles and New Zealand importers may be prepared to take lower quality vehicles in the future in order to maintain competitive prices. Increased fuel prices may also see a shift in the market's preferred vehicle models, and many potential effects may follow on from this.

As shown by Table 6 the majority of recently imported Used-Japanese vehicles in the profiling snap acceleration data set were in the 1992-1997 YoM range. The average

YoM was 1995 for both light and heavy vehicles (that is, an average of nine years of age at time of import). This is in very good agreement with LANDATA data, the average YoM for used imported diesel vehicles during 2004 at 1995 and 1994 for light and heavy vehicles respectively.[43]

The technology makeup of recently imported diesel vehicles is also indicative of the less recent manufacture of Used-Japanese imports. For recent imports, Technology 3 is the most advanced engine technology and Technology 2 is likely to be more advanced than Technology 1.[44] Figure 13 provides the technology split of the existing fleet, recent New Zealand-New additions (recent New-Japanese plus recent Other-New additions) and recent Used-Japanese additions for the Pilot's adjusted visual data set (of 1077 entries). As is shown, recent New Zealand-New additions include a greater proportion of vehicles featuring more advanced technology (a greater proportion of Technology 3, *et al*) than do recent Used-Japanese additions, which in turn appear to have a more advanced technology split than does the existing fleet. For heavy vehicles, there is a distinct advance in the technology split for recent New Zealand-New additions over recent Used-Japanese additions, as given by the absence of Technology 3 vehicles in the Used-Japanese division.

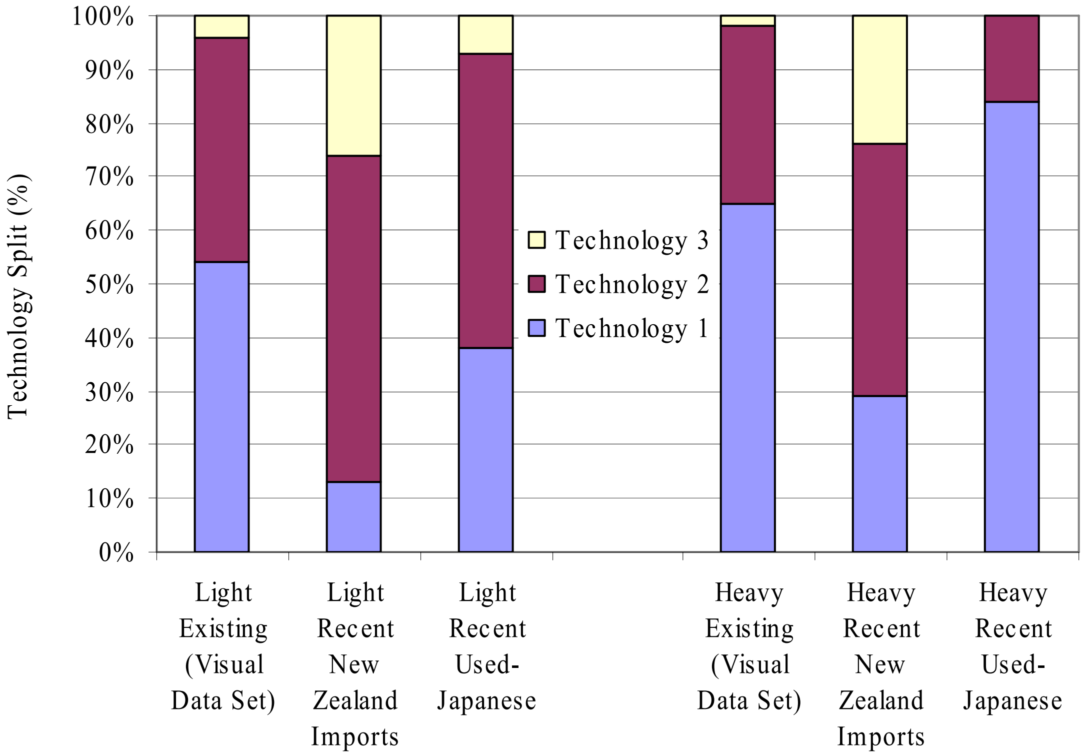

Figure 13: Technology Split of the Adjusted Visual Inspection Data Set for the Divisions Existing Diesel Fleet, Recent New Zealand-New Imports and Recent Used-Japanese Imports.[45]

[43] 2004 LANDATA data, calculated results provided by Transport Registry Centre, Land Transport New Zealand.
[44] Care is required, as this may not necessarily be the case for vehicles of less recent YoM.
[45] 'Recent' imports refer to vehicles first registered in New Zealand after 1 October 2004.

Note that discussions with people working in the vehicle industry[46] in New Zealand yielded anecdotal evidence that some Used-Japanese light diesel vehicles have engines in very poor mechanical condition, because these have spent a significant proportion of their time idling or otherwise operating at low power in heavily congested driving conditions in Japan.[47] There is also anecdotal evidence to suggest that some used Japanese vehicles are not well maintained in the latter years of their use in Japan,[48] and their engine condition may be poor as a result. If this were generally true, then vehicle origin would not have dropped out of significance as other variables were added to the emissions model. This is not to say the suspicions of industry sources are incorrect: it merely suggests that the problems suspected are uncommon — or at the very least, that the Pilot sample did not provide any evidence to support these suspicions.

3.3.2. Regional Variations

Adjusted snap acceleration data from the main test areas Auckland (the combination of UniServices, VINZ, and Waitakere data), Tauranga, Hamilton and Christchurch were compared. There was no statistically significant difference in average snap acceleration result for these sites, with the 90% confidence limits of the snap acceleration results for each site overlapping. Had data been gathered from other sites around New Zealand, it is anticipated that this too would not exhibit any statistically significant difference in snap acceleration result, such is the wide standard deviation. Note that a larger sample size is not expected to decrease the standard deviation significantly either (although this assertion cannot be proved until testing on a larger sample is carried out), as the wide standard deviation reflects the high variability of the data captured; the addition of further data would be unlikely to change that variability.

It had been anticipated that the average snap acceleration result for a group of vehicles could be described to some meaningful extent by a knowledge of their technology and average age or SPI; to this end, visual inspection of vehicles at many WoF and CoF sites in New Zealand was carried out for extrapolating emissions profiles to the New Zealand fleet. A meaningful prediction model could not be developed, however, and hence this technique could not be used to predict average snap acceleration results in other centres.

3.3.3. Fuel Considerations

Differences in fuel quality have the potential to affect the snap acceleration results. Testing was carried out at a time when the majority of the diesel in use in the country would have been supplied to meet a sulphur specification of a maximum of 600 ppm and a maximum pool-average of 500 ppm,[49] and fuel quality, with respect to sulphur

[46] In this particular case, referring to discussions with two technical personnel representing two different overseas vehicle manufacturers, the IMVDA, and a senior mechanic at a repair workshop.
[47] Evidence included reports of high wear on the upper cylinder liner for some vehicles found in poor condition.
[48] There are many (unsubstantiated by the consultant) reports that the oil was very thick in some as-received used Japanese vehicles, indicating it had not been changed for many years. It is also understood vehicle servicing is very expensive in Japan and vehicles have little to no value there as they near their end-of-life, providing little incentive for owners to maintain them.
[49] The specification for sulphur in diesel changed on 1 August 2004 to the lower values given. Fuel to meet this specification would have been supplied far earlier to ensure fuel of higher sulphur specification had moved through

content, would have ranged considerably within this specification.[50] Whilst an increase in sulphur content is often associated with an increase in particulate emissions, all else being equal, this response is far from consistent, as other fuel quality characteristics (that likely vary with a change in sulphur content), engine design and an engine's response with respect to visual emissions (which the snap acceleration test measures) can have equal influence. In any case, the effect of fuel quality on the snap acceleration test result was believed to be small in comparison to the variations that could arise through differences in test setup or how the snap acceleration test was performed, and therefore fuel quality was not considered an important variable to take into account (given the range in fuel quality expected).

The temperature of the fuel can also affect the snap acceleration result. Fuel metering for a diesel engine is normally volumetric and as the fuel temperature increases, the fuel expands and there is less hydrocarbon per *shot*[51] of fuel. Consequently, the amount of excess air increases and lower smoke is expected. This variable is moderated to some extent by requiring the engine to be warm for the snap acceleration test, but there can be reasonable variation in the temperature of the fuel delivered from the fuel tank nonetheless.[52] The variation in the snap acceleration result from this source, however, compared to the variation that could arise through differences in setup or how the snap acceleration test was performed, was considered slight and therefore this variable, too, was not monitored or otherwise taken into consideration in the Pilot analysis.

3.3.4. Older Engine Designs

The maximum power of a diesel engine is often limited by the amount of smoke or particulate emitted at that setting, with any increase in fuelling beyond that point (to increase power) causing a rapid increase in smoke and particulate emission. A higher degree of visible smoke emission was allowed for older engine designs — say, those of the 1960s and before, and even some more recent models[53] — in part to compensate for the simple fuel pump control systems of the time. The snap acceleration test demands full power operation, albeit for a short period, and hence an engine of older design may exhibit elevated snap acceleration results even if in good mechanical condition. Allowance would be required for these vehicles if they were included in a snap acceleration testing programme.

Note also that earlier diesel engines were not designed to be free accelerated to governed speed and the accelerator ought to be released at lower engine speed.

These two issues are taken into account for earlier vehicles (vehicle first used before 1 August 1979) in the UK testing system (which is based on the European requirements) by subjecting them only to a single rapid acceleration to 'around 2500 rpm, or half the

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the distribution system. However, some vehicles may still have had fuel with a higher sulphur content in their fuel tanks.

[50] Ulrik Olsen, Retail Operations Manager, Gull Petroleum. Personal communication.

[51] A 'shot' of fuel is the technical term for the injection of fuel into one cylinder over one engine cycle.

[52] Most diesel fuel systems have a return line to the main fuel tank, with this flow of warmed diesel gradually increasing the temperature of the fuel in the tank during normal engine operation. A vehicle that has been operating longer and in a warm climate would be expected to have fuel at higher temperature. Checking the fuel tank temperature of a number of vehicles found temperatures ranged from 10°C to 25°C.

[53] Engine reconditioners can almost provide a list of 'offending' engine models.

maximum engine speed if this is lower' and noting that 'older vehicles, particularly pre-1960, sometimes emit unavoidable smoke due to their design' and 'such smoke is not a reason for rejection'.[54]

3.3.5. Modified Engines

Diesel engines are not normally associated with performance vehicles and little 'performance' modification is expected to have been carried out on them.

Modifications that may be carried out include increasing the maximum fuelling through simple adjustment of the maximum fuelling screw, increasing the maximum fuelling coupled with increasing the *turbocharger boost*[55] and re-chipping on modern diesel vehicles.

Adjustment of the maximum fuelling screw is a relatively simple procedure that increases the maximum fuelling, the maximum engine power and, generally, the visible emissions at maximum power. The maximum fuelling screw setting is normally wire sealed and tampering with this seal is normally relatively easy to detect. A check for tampering may act as a deterrent to such modification, although this may then introduce the unauthorised application of wire seals.

Changing the maximum fuelling coupled with an increase in turbocharger boost is a legitimate method used by engine manufactures to increase maximum engine power. If carried out correctly, there is no reason for the on-road or snap acceleration emissions to change substantially.

The modern diesel engine is controlled by electronics and can be 're-chipped' to change performance — say, to increase engine power. There is evidence to suggest re-chipping is carried out on some diesel engines in New Zealand, but it is believed that it is rare.[56] A diesel engine re-chipped for increased power would more likely exhibit elevated snap acceleration results although, being a modern engine, the results would likely be low in the first place and it would be difficult to detect whether a vehicle had been re-chipped or not based on the result of a snap acceleration test.

3.3.6. Catalysts and their Removal

There is a variety of exhaust after-treatment devices used in modern diesel engines. An oxidation catalyst is standard on later-model light diesel vehicles in New Zealand and is also found on many new heavy vehicles. The primary function of an oxidation catalyst is to reduce HC and CO emission, although they can also reduce PM emission to some (minor) extent when low-sulphur fuels (50 ppm sulphur and below) are used. They can also increase the PM emission when fuel sulphur levels are in the range of 500-1000

[54] Vehicle & Operator Services Agency (VOSA), *The MoT Inspection Manual – Car and Light Commercial Vehicle Testing*. Issue date: August 2004.
[55] That is, the 'boost' in inlet manifold air pressure brought about by the action of the turbocharger (this increases the amount of available air in the combustion chamber, increasing the amount of fuel that can be delivered before over-fuelling brings about a significant increase in emissions).
[56] Based on discussions with two suppliers of chips in New Zealand.

ppm or above, due to the increased production of sulphates (from the added oxidation of fuel-borne sulphur). For the latter, whilst the PM mass may have increased, the effects in the visible spectrum — that metered during the snap acceleration test — are expected to be negligible.[57]

Removal of a functioning oxidation catalyst from a diesel vehicle is not expected to change the snap acceleration result significantly (unlike the removal of the catalyst on a petrol vehicle, where an increase in idle simple test emissions is expected).[58]

Other forms of exhaust catalyst for diesel vehicles include particulate reduction systems, fitted to some recent European models of light vehicles now coming to New Zealand, and NOx reduction systems, fitted to recent models of light and heavy vehicles overseas. These technologies are associated with modern, low-emission engines and it is suggested catalyst removal would not normally be contemplated for these vehicles. Nor would removal be expected to alter the already low value of their snap acceleration result.

3.4. Conclusions

Profiling and benchmarking results from snap acceleration testing diesel vehicles found:

The results from analysis of the profiling snap acceleration data set (which was based on the results of testing 477 vehicles tested at various centres around New Zealand) were:

- there is a high degree of variability in the snap acceleration results from diesel vehicles;
- the variability in snap acceleration results for the sample analysed was best described by a model using the four variables, engine technology, secondary performance indicator (SPI, a variable calculated from odometer and year of manufacture), visible smoke (as judged by the tester by sight) and gross vehicle mass (GVM). The factors used in the model indicated a trend towards lower snap acceleration results for: more advanced engine technology; lower distance travelled; more recent year of manufacture; lower visible emissions; and higher GVM. This model had a coefficient of determination (R^2) of 0.24; that is, only 24% of the variability in snap acceleration results could be described by a model using these four variables. In this model all variables were statistically significant above the 95% confidence level (that is, p-value <0.05). The significance of visual smoke in this model provides some support for the use of simple visual checking of vehicles as a possible screen for emissions testing vehicles (rather than metered snap acceleration testing);
- the emissions performance profiling analysis considered engine technology described in three simple ways: (simple) non-turbocharged; (simple) turbocharged; and turbocharged plus oxidation catalyst (advanced technology), which was a kind of shorthand description of major advances made in diesel engine design. For the sample analysed, engine technology was found to be a

[57] Based on fundamental engine design principals.
[58] Note, unlike a catalyst on a petrol vehicle which creates a significant change in emissions by itself, a diesel oxidation catalyst has limited affect on PM and smoke emission. The presence however signifies the engine is of advanced design and is expected to exhibit low PM and smoke emission due to that advanced technology.

statistically significant variable, although only between simple and advanced engine technologies, with no statistically significant difference between the two simple engine technologies. Note that the data sample analysed only contained four heavy diesel vehicles and 13 light diesel vehicles that also had advanced engine technology, and these were all relatively recent year of manufacture. It would therefore be difficult to draw strong conclusions from this particular analysis, although the results are in line with the emissions performance expected when a practical, technical appraisal of the design of the technology involved is conducted. This strengthens this, otherwise weak, conclusion;

- vehicle origin was found to be a statistically significant variable when considered by itself: that is, without also considering other variables at the same time. However, vehicle origin was no longer statistically significant when engine technology and year of manufacture were also considered, indicating vehicle origin was very weak in describing the variability in snap acceleration result;
- 'percentile plots' were created, plotting vehicles in order of increasing snap acceleration result, allowing the proportion of vehicles failing to meet given cutpoints to be determined. 23% of light vehicles and 12% of heavy vehicles in the Pilot's profiling snap acceleration data set did not meet a cutpoint set of $K=2.5m^{-1}$ for non-turbocharged vehicles and $K=3.0m^{-1}$ for turbocharged vehicles (a cutpoint set in use in the UK and based on the requirements for Europe). There appeared to be no consistency in the proportion of vehicles failing to meet these cutpoints when data was divided into various engine technology and year of manufacture divisions, apart from the fact that no advanced engine technology vehicles failed this cutpoint set;
- the average snap acceleration performance for Used-Japanese vehicles entering the fleet was found to similar to marginally better to the average for the existing fleet. At this level of performance, their entry to the fleet produces no significant improvement. New vehicles, by contrast — or, at least, vehicles of more recent manufacture, which are more likely to feature more advanced engine technologies — are expected to perform better than the existing fleet average, and their entry would produce an overall improvement in fleet performance;
- engines of 1960s design and before, and some of more recent design, may exhibit elevated snap acceleration results even when in good condition and some allowance would need to be made for these vehicles should an in-service snap acceleration testing regime be introduced to New Zealand;
- diesel engines are not normally associated with performance vehicles and little 'performance' modification is expected to have been carried out on them;
- diesel vehicles fitted with oxidation catalysts are entering the fleet. Removal of a functioning oxidation catalyst from a diesel vehicle is not expected to change the snap acceleration result significantly.

3.5. Recommendations for Further Work

The amount of exhaust smoke as determined visually by the tester was found to be a statistically significant variable and it is recommended that a visual check of emissions be considered as an alternative to a snap acceleration test regime. This is further discussed in Section 6.3.

The current importation of used diesel vehicles does not offer an emissions advantage to the vehicle fleet and it is therefore recommended that options are considered to manage better which used imports are allowed to enter the fleet. Vehicles fitted with engines of advanced technology on average exhibit substantially lower snap acceleration results than less-advanced technologies, and it is expected that this is also true for on-road emissions performance. It is therefore recommended that limiting entry of used vehicles to those using advanced engine technologies be investigated.

4. Evaluation of Snap acceleration Testing

This section describes work carried out to evaluate snap acceleration testing against emissions results from the detailed dynamometer testing of diesel vehicles — the transient loads of dynamometer testing are expected to provide a better indication of on-road emissions performance of vehicles. The approach used for light and heavy vehicles was slightly different: the dynamometer at the EFRU could test vehicles to drive cycles but its size limited its use to the testing of light vehicles only. There is no dynamometer available in New Zealand that could provide similar flexibility for testing heavy vehicles. Instead a less sophisticated dynamometer was set up for testing heavy vehicles in New Zealand, using a far more simple loaded test cycle, and testing was also carried out in Australia by Diesel Test Australia to drive cycles using a more sophisticated heavy vehicle chassis dynamometer. The specifications of the various dynamometer test arrangements are given in Appendix G.

Although the testing carried out in Australia was limited to testing of Australian vehicles, all the vehicles tested as part of the Pilot happened to have identical engine models to those fitted to vehicles in New Zealand, used similar fuel and were subject to similar maintenance practices. The results of testing were therefore expected to be comparable to those from testing New Zealand vehicles, had this been possible. This belief was further supported by the Pilot's analysis for petrol vehicles, which indicated no discernible difference in emissions performance between the Pilot's New Zealand dynamometer test sample and the performance of a sample of Australian vehicles dynamometer-tested in Australia, when engine technology, odometer and YoM were taken into account (despite differences in engine models between the petrol vehicle samples).

In total, 20 light diesel vehicles were tested at the EFRU, two of which were re-tested as variants of their first test configuration;[59] four heavy vehicles were dynamometer tested in New Zealand, 19 light vehicles were tested in Australia and 76 heavy vehicles were tested in Australia. The low number of heavy vehicles tested in New Zealand was a consequence of several compounding problems: test equipment failures; the extended time necessary to test individual vehicles with sufficient repeatability in the results; and project time restrictions.

4.1. Methodology

4.1.1. Vehicle Selection

The vehicle selection process differed according to the test site location. The ideal for dynamometer testing was to test a wide range of different vehicle variants, allowing the emissions assessment to consider a wide range of the diesel vehicle variants available in New Zealand (as distinct from a random selection, which was prone to select and re-test common vehicle variants). A wide selection of vehicle variants was in fact managed for the light diesel vehicle dynamometer test programme at the EFRU.

[59] One vehicle was specified by two GVM weights, 2500 kg and 3500 kg, and testing with the different inertia test weights associated with these presented two different vehicle configurations.

The EFRU dynamometer test vehicles were sourced from the University of Auckland campus. Email and car park notices invited staff or departments to make their vehicles available for testing and selections were then made from the pool of vehicles offered. A number of vehicles were also hired in order to expand the range of test vehicles into heavier light vehicles.

For the other test site locations, vehicle availability and test site circumstances dictated less ideal vehicle selection:

- for heavy vehicle dynamometer test work in New Zealand, vehicles were selected on availability — testing potentially removed a vehicle from its commercial service for a number of days, and few vehicles could be made available for this length of time — and fit within the specific engine technology specifications sought, either current mainstream engine technology (direct injection, in-line diesel injection pump) or emerging mainstream technology (direct injection, high-pressure electronically governed diesel injection system);
- for dynamometer test work in Australia, testing for the Pilot was conducted as an addition to a vehicle test programme already in progress in Australia. This meant that vehicle selection was dependent on the selection process employed by the Australian programme: vehicles tested were from small and large fleets randomly selected from around the Sydney area. This selection process did not provide a wide range of different vehicle types, although analysis went on to find that the range was sufficiently broad for the purposes of the Pilot's analysis work.

4.1.2. Vehicle Test Arrangements

The dynamometer test cycles used for the EFRU light diesel dynamometer test programme were: the Jap10-15 — the emissions compliance test for light diesel vehicles in Japan, chosen because of the high proportion of Japanese-origin vehicles in the New Zealand fleet; the IM240, which provides test conditions representing mixed urban and inter-urban driving; and the DT80, a short test developed and adopted in Australia and chosen to consider a possible alternative test option for use in New Zealand.[60]

The DT80 is a transient mixed-mode test and has idle periods, three full-load accelerations against a simulated inertia, and a steady-speed 80 km/h cruise. Details of the drive cycle are provided in Appendix G. The test takes around four minutes (the actual duration depending upon the time it takes for the vehicle to accelerate to 80 km/h, which is different for different vehicles). Tests in Australia found the results of the DT80 to have a high correlation with expected on-road emissions performance.[61]

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[60] Trial of various in-service vehicle tests in Australia found the snap acceleration test to be a poor indicator of emissions performance. The DT80 test was developed as a possible, and better performing, alternative, albeit one that requires a dynamometer in order to test vehicles.

[61] *Proposed Diesel Vehicle Emissions National Environmental Protection Measure Preparatory Work — In-Service Emissions Performance — Phase 2: Vehicle Testing*, Anyon et al, Prepared for the National Environmental Protection Council, November 2000, ISBN 0 642 323 348.

The DT80 was also used because it was a test that could be simulated on the simple dynamometer used for testing heavy vehicles in New Zealand, offering a common test across the New Zealand-based and Australian-based light and heavy vehicle test programme through which the various sets of test data might be compared.

The basic specifications of the light vehicle test cycles are provided in Table 7. Further detail is provided in Appendix G. Dynamometer test vehicles were also subjected to a snap acceleration test, in accordance with the SAE J1667 test procedure, before and after the dynamometer tests.

Table 7: Test Cycle Details

	Jap10-15	IM240	DT 80
Duration seconds	660	240	~250
Distance travelled km	4.2	3.152	~3.0
Average speed km/h	22.7	47.3	~40
Max speed km/h	70	91.3	~80
Idle time %	32	4.5	~30
Number of stops per km	1.68	.6	~1

The Jap10-15 and IM240 emissions test cycles were also used in vehicle testing carried out on light diesel vehicles in 1998 by the EFRU, as part of the MoT's vehicle fleet modelling (VFEM) work.[62] This allowed data for seven diesel vehicles from this earlier work to be included in the Pilot's analysis.[63]

The central business district drive cycle (CBDC), a test used in the Pilot to test petrol vehicles, was not used to test light diesel vehicles as the CBDC is a comparatively lightly-loaded cycle and hence not well suited to indicate emissions from a diesel vehicle.[64]

Heavy vehicle testing in New Zealand consisted of the snap acceleration test carried out before and after a pseudo DT80 test. "Pseudo" is in reference to the slight variations to the DT80 test procedure that were necessary due to dynamometer limitations. These variations were compensated for (the calibration of which was one reason why the time taken to test vehicles at this facility was extended).

Light and heavy vehicle testing in Australia consisted of the DT80, the Composite Urban Emissions Drive Cycle (CUEDC, also developed in Australia to replicate typical on-road driving conditions[65]), maximum power and maximum torque, carried out as part of the Australian test programme, followed by a visual inspection and the snap acceleration test carried out for the Pilot.

The test arrangement involved DTA's mobile transient heavy duty dynamometer (see Appendix E for details), dilution tunnel exhaust sampling, real time measurement of HC and NOx by gas analyser and light-scattering photometer (LSP), calibrated for diesel

[62] *Exhaust Emission Measurement of New Zealand Vehicles for the Ministry of Transport Vehicle Fleet Emission Strategy: Stage 2 (Diesel Vehicles)*, report prepared for the Ministry of Transport, Wellington by the Energy and Fuels Research Unit, Department of Mechanical Engineering, The University of Auckland, 1998.
[63] Note that care was taken to differentiate between Pilot-tested and earlier-tested vehicles (i.e., the difference provided as a variable) in case there were time-related differences involved, which would include the likes of differences in fuel specification.
[64] For diesel engines, PM and NOx emissions increase substantially under loaded operation.
[65] Note the CUEDC cycle is different for different vehicle types.

exhaust, to measure PM. The snap acceleration test was carried out using an AVL smoke meter of the same model as that laboratory-tested at the EFRU.

4.2. Results

Due to the general differences between light and heavy vehicles and their different test programmes in the Pilot, analysis here considers these two vehicle divisions separately.

4.2.1. Light Vehicles

The assessment of the snap acceleration test as an indicator of a vehicle's expected emissions performance for light diesel vehicles was reached by comparing the IM240, Jap10-15 and DT80 emissions results against the snap acceleration results, using the data from the EFRU dynamometer test programme. The snap acceleration test is a visual test, expected to respond to the amount of visible particulate and it is therefore expected that the dynamometer emission test result most likely to correlate with the snap acceleration test would be the PM (as measured by the weight gained by a paper filter subjected to a continuous partial flow of exhaust for the duration of the test cycle). Figure 14 compares the IM240 PM measurement versus the snap acceleration result and shows a scatter of results, indicating a poor relationship, confirmed by the low coefficient of determination (R^2) of 0.38: that is, the snap acceleration result describes 38% of the variability in the expected on-road PM result as given by the response to the IM240 test cycle. Simply put, even after a snap acceleration test has been performed, whether a vehicle is a high or low emitter of PM in on-road operation is still largely unknown. A trend[66] exists, nonetheless, whereby a vehicle with a high snap acceleration result is more likely to emit higher PM in on-road driving.

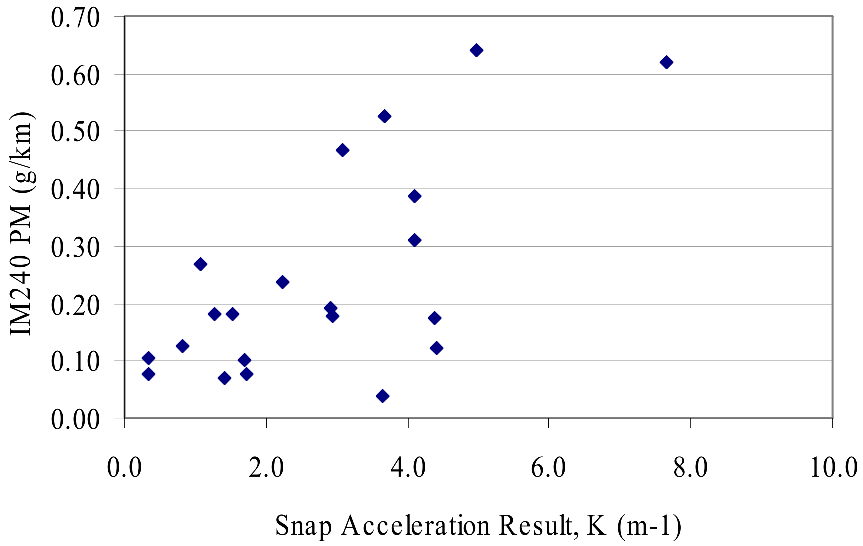

Figure 14: IM240 PM Versus Snap Acceleration Result for Light Diesel Vehicles Subject to Detailed Dynamometer Testing at the EFRU Laboratory.

[66] That is, there is some likelihood of its occurrence, but it is without statistical significance.

Comparisons using other emission species and other test cycles were also made and no better correlations were found. For example, the R^2 for the Jap10-15 versus snap acceleration result was less than 0.1 and the slope was negative (a higher snap acceleration result corresponding to a lower PM result from the Jap10-15 test procedure). A sample of comparison plots for other test cycles and emission species is provided in Appendix H.

Figure 15 provides a cumulative emissions plot for PM as measured by the Jap 10-15 (by weight), IM240 (by weight) and DT80 (by LSP) test cycles and the results from snap acceleration testing for the light diesel vehicles subject to dynamometer testing. At the 90% of the sample mark it can be seen that the worst 10% of the sample was responsible for around 25% of total fleet emissions by the IM240, DT80 and snap acceleration results, and around 15% by the Jap 10-15 results. Note that although the plots for IM240 PM and DT80 PM and snap acceleration happen to exhibit similarities, for this particular data set, this does not mean the snap acceleration test results can be used as a proxy for percentage of emissions contribution for another vehicle sample – the dynamometer test sample was of small size, sampling was not random, and there were not other data sets that these results could be compared with for verification (as was done when a similar plot was developed for the sample of petrol vehicles that were dynamometer tested).

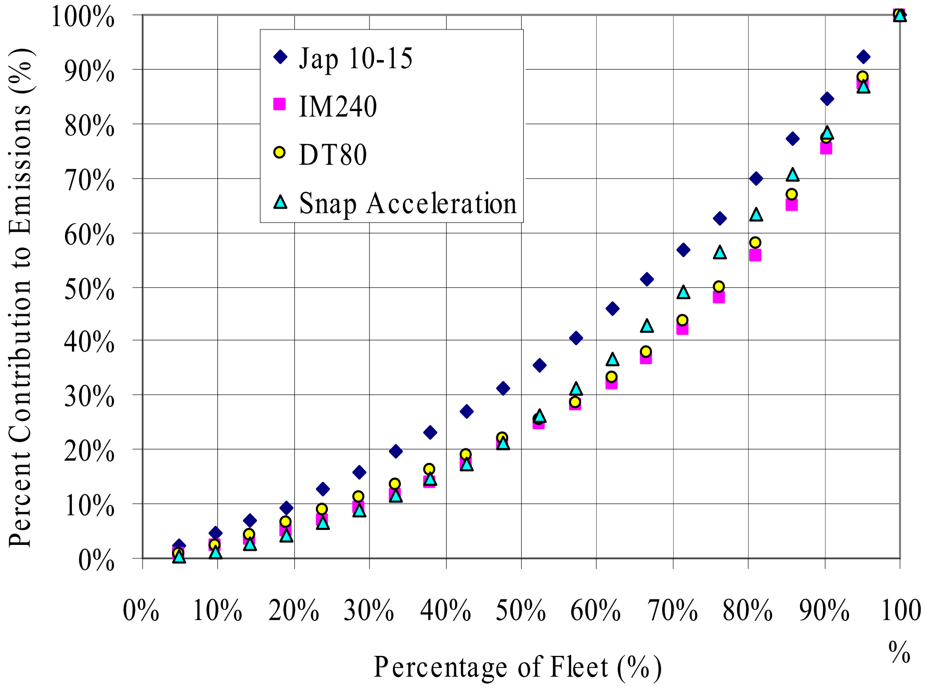

Figure 15: Cumulative PM Emissions by the Jap 10-15, IM240 and DT80 Test Procedures and Pilot's Snap Acceleration Procedure for the Light Diesel Vehicles Subject to Dynamometer Testing at the EFRU Laboratory.

4.2.2. Heavy Vehicles

The original intention of the Pilot's heavy vehicle dynamometer test programme was to use data from limited testing of heavy vehicles in New Zealand (limited due to the dearth of suitable test equipment in New Zealand) to 'calibrate' data from testing heavy vehicles in Australia. However, the number of heavy vehicles which in the event could be tested in New Zealand was very small, rendering this procedure worthless. Fortuitously, however, a check on the engine models of the vehicles tested in Australia established that the same engine models were in use in New Zealand, and hence the test data from Australia was directly relevant to the New Zealand situation. Since the purpose of this component of work was to compare the on-road emissions results against snap acceleration results for a range of vehicle (engine) variants, any differences which might exist between the countries — in how vehicles are maintained, say — would do little to weaken the value of this analysis to the Pilot.

The heavy vehicle tests carried out in Australia included testing to the CUEDC test cycles, which are expected to provide better simulation of on-road driving conditions than the DT80 drive cycle test. Figure 16 plots CUEDC PM versus the snap acceleration result for the heavy vehicles tested in Australia and, as for light vehicles, it shows a scatter of results and a low R^2 value of 0.24. Comparisons for other emissions species and for other test cycles were made using the Australian and, where appropriate, New Zealand heavy vehicle data sets. Interestingly, a small improvement in correlation was found for DT80 PM versus the snap acceleration result (Figure 17) — an R^2 of 0.33 — but this still amounts to a poor relationship, and the snap acceleration test is therefore considered a poor indicator of expected on-road PM emission for heavy vehicles.

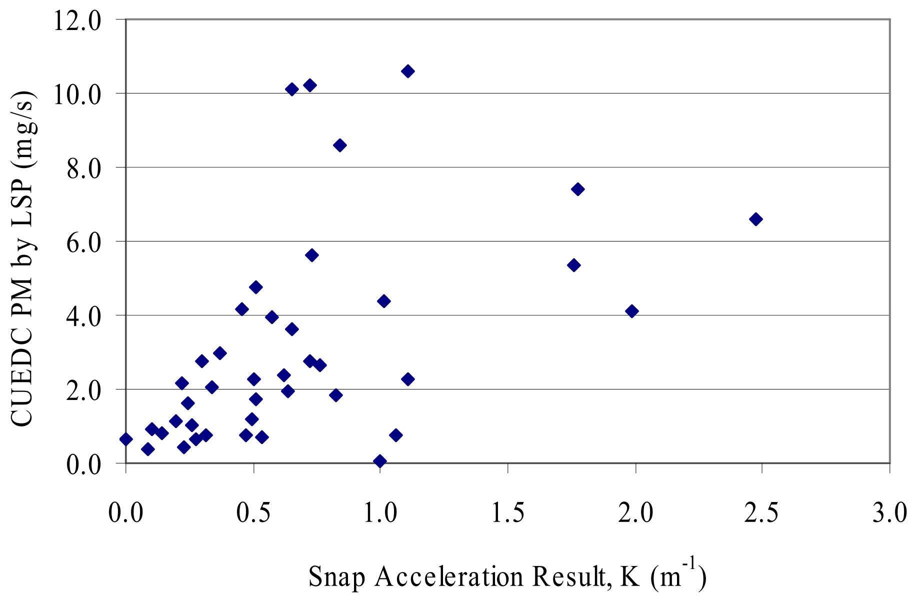

Figure 16: CUEDC PM Versus Snap Acceleration Result for Heavy Vehicles Tested in Australia.

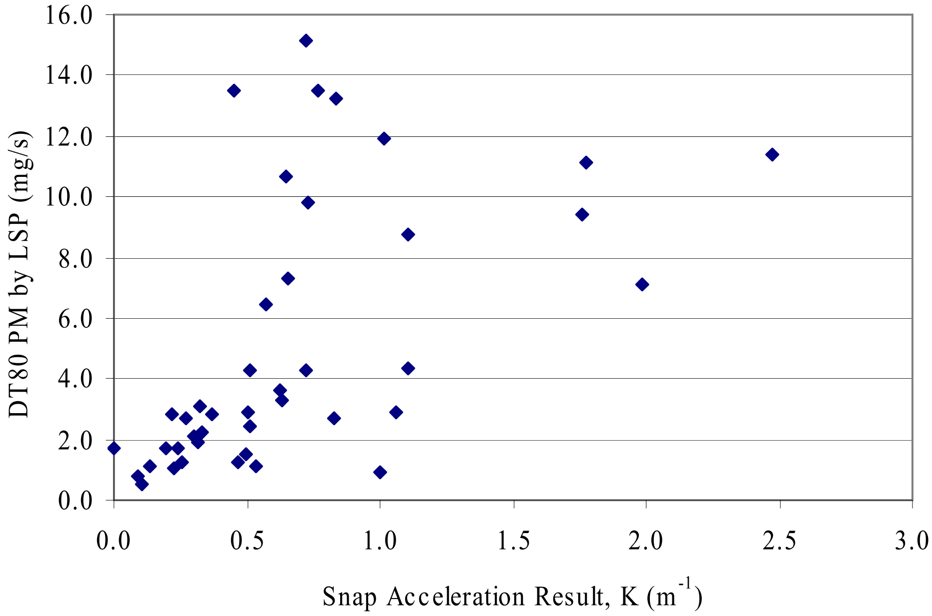

Figure 17: DT80 PM Versus Snap Acceleration Result for Heavy Vehicles Tested in Australia.

The reason for the poor relationship between the snap acceleration result and drive cycle PM emissions for both light and heavy vehicles was considered by analysing the modal PM results over a drive cycle, as measured by a light-scattering photometer (LSP)[67] calibrated to measure PM from diesel engines. Figure 18 is an example of the results found, in this case the results for a Nissan Laurel tested in an earlier programme[68] over the *suburban interrupted*[69] drive cycle. As shown, PM emission rates were relatively low for much of the time, broken by high peaks where high engine power was required. The peak near the 300-second mark of Figure 18 is closest to the snap acceleration test and shows a very high PM emission rate at this time, suggesting the snap acceleration test measures emissions produced at the time of an extreme event rather than from normal engine operation. This would not help the snap acceleration test to reach a result comparable to (varied engine operation) drive cycle PM.

[67] A device that measures the intensities of scattered light, at various angles, from a laser passed through a sample of exhaust gas. A complex algorithm is used to provide a result from this.
[68] *Effect of Low Sulphur Diesel on Exhaust Emissions from Light-Duty Vehicles,* a report prepared for BP Oil NZ Ltd, Wellington, prepared by the Energy and Fuels Research Unit, Department of Mechanical Engineering, The University of Auckland, 2001.
[69] A drive cycle developed for the 1998 MoT SMF programme that was based on data taken during actual on-road driving.

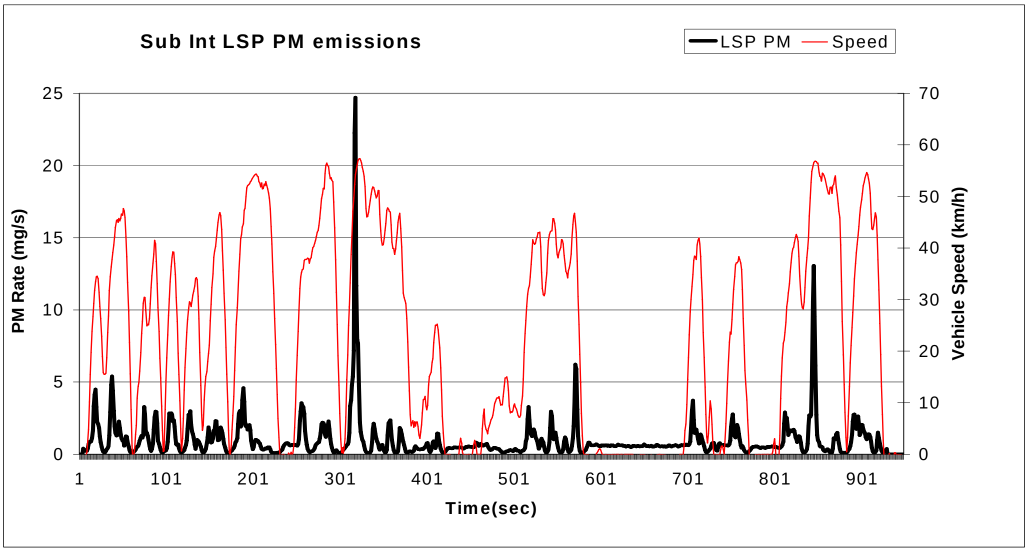

Figure 18: LSP Emissions Measured over the Suburban Interrupted Driving Schedule for a Nissan Laurel (results from a 2001 BP test programme using low-sulphur diesel for the vehicle in as-received condition).

The poor relationship between the snap acceleration result and drive cycle PM was further considered by concentrating on peak-results data. Figure 19 provides a comparison of peak DT80 PM and peak DT80 smoke density and peak DT80 PM and the snap acceleration result (which is a measure of near-peak smoke density during that test[70]). Shown, there is high correlation between peak DT80 PM and peak smoke density during the DT80 test cycle, with an R^2 of around 0.8. This compares with a low R^2, of less than 0.4, between peak DT80 PM and the snap acceleration result. It appears from this that the snap acceleration test is a poor test from which to judge the drive cycle PM emissions performance of a vehicle. The result is then weakened further by a less than ideal correlation between PM and opacity.

[70] The actual peak is filtered out by the meter's (calibrated) electronics.

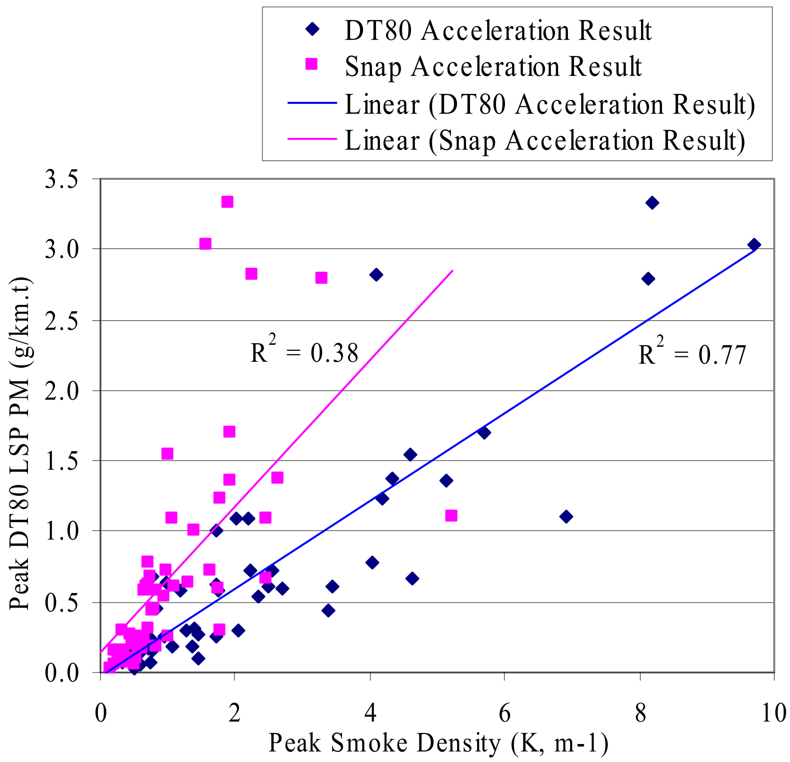

Figure 19: Peak DT80 PM (LSP) Versus Peak Smoke Density Measured During That DT80 Test and During a Snap Acceleration Test of Same Vehicles.

4.3. Consideration of Other Emissions Indication Options

4.3.1. DT80

Figure 20 compares PM as measured by the DT80 short test procedure with PM as measured by the CUEDC drive cycle test. The latter is expected to provide a reasonable simulation of on-road driving conditions, as it was developed from real on-road vehicle monitoring. A high correlation is shown, with an R^2 of around 0.8 (i.e., 80% of the variation in the CUEDC PM result is described by the DT80 result). A similar correlation coefficient was found during the original development of the DT80 test cycle, for a more uniform spread of data, and hence, relative to the snap acceleration result, the DT80 provides a reasonable to good indication of on-road PM performance as judged by performance to the CUEDC test.

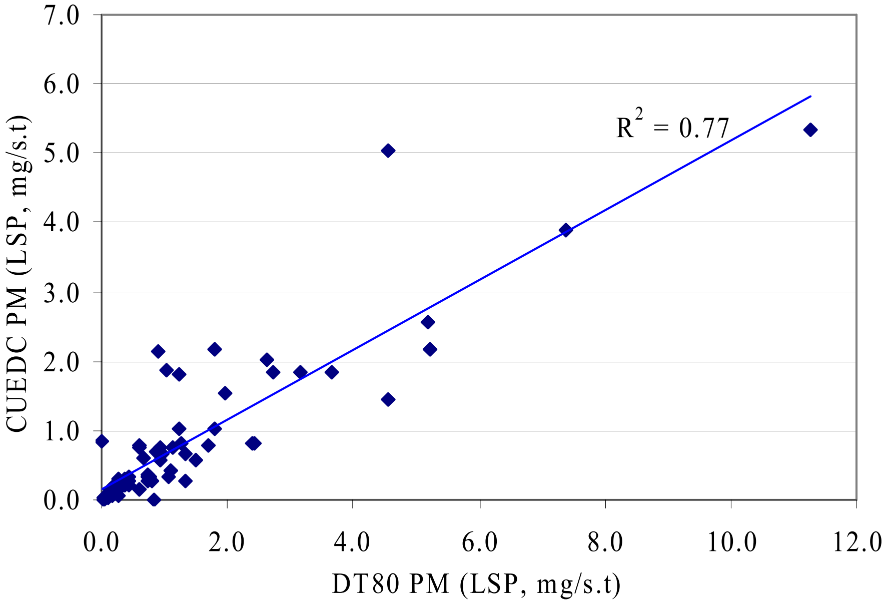

Figure 20: CUEDC PM (mg/s.t) versus DT80 PM (mg/s.t) for Light and Heavy Vehicles Tested in Australia.

The DT80 does require the use of a dynamometer and therefore any proposal to use this or a similar test widely would be an expensive option. However, it may be an option for targeted vehicle testing: for example, in testing used vehicles before their first entry into the fleet.

4.3.2. Physical Attributes

Just as was done for petrol vehicles, an attempt was made to describe the expected on-road PM emissions performance of a fleet of diesel vehicles based on its known physical characteristics (in the case of petrol vehicles, almost 70% of the variability in the on-road emissions performance of a group of vehicles could be described by considering vehicle technology, YoM and odometer, compared to only 35% using the results from idle simple testing). For diesel engines, modelling first considered the statistical significance of a range of variables through multiple variable statistical analysis,[71] carried out in SAS and applied to the detailed dynamometer results from New Zealand and Australia. Correlation coefficients were then calculated for those variables or groups of variables that exhibited the greatest significance. The variables so checked were: YoM; odometer reading ('odometer'); engine technology ('technology' as defined in Section 3.2); vehicle origin (New-Japanese, Used-Japanese or Other-New); indirect or direct injection;[72] EGR or not, under-bonnet appearance; exhaust showing visible smoke; engine size; GVM; and engine power.

A best R^2 of 0.20 was achieved for predicting IM240 PM results for light diesel vehicles by using SPI (secondary performance indicator, a variable calculated from YoM and odometer) plus GVM, with PM increasing slightly with increase in GVM. This compares to an R^2 of 0.10 for predicting IM240 PM for light diesel vehicles using YoM

[71] Note it was understood that the variables being considered were not necessarily independent, as has been discussed in Section 3.1.
[72] That is, whether diesel was injected directly into the combustion chamber.

alone. The R^2 for predicting IM240 HC and IM240 NOx using SPI and GVM was 0.34 and 0.44, respectively. No better correlations were found across the other data sets. At this level of correlation, the greater part of the variability in emissions performance is still unaccounted for.

Note Technology 3 vehicles were represented by only one vehicle in the detailed dynamometer data sets, and for this reason technology did not appear to be statistically significant in the analysis that considered on-road emissions performance (as compared to the analysis of snap acceleration results, which featured a number of Technology 3 vehicles and where technology was found to be a statistically significant variable) despite the very low emissions results exhibited by that vehicle. The reason for considering the technology variable at all, despite there being only one Technology 3 vehicle in the sample, was the vehicle exhibited very low emissions as was expected, based on a design appraisal.

Note at R^2 values of around 0.30 — beneath which most of the comparative relationships lie — only 30% of the variability of the data is explained. A simple way to view this is as a linear regression (representing the relationship as a line) with one out of three data points within close range of the line of regression, the other two not and on opposite sides of the regression line. One of those other two would likely be a vehicle that is falsely failed by the simple test result compared to its on-road performance. The risk, it is suggested, is that unless snap acceleration testing is introduced as a test to be met in its own right (instead of as a test aimed at reducing on-road emissions performance of individual vehicles), the results from snap acceleration testing may be challenged.

4.3.3. Remote Sensing

Modal[73] emissions of HC, NOx and PM were measured during all dynamometer drive cycle tests on diesel vehicles tested carried out by the EFRU, and these results provide an indication of the results a remote sensor[74] would register. HC, NOx and PM were found to vary considerably over a test cycle. An example of this is provided in Figure 21 which shows real time indication of PM levels using a LSP to monitor the performance of a light diesel vehicle in poor condition (showing excessive visible smoke emission under load) tested over the IM240 drive cycle. This high degree of variability would make it difficult to gain useful information from the remote sensing results from diesel vehicles without imposing strict controls on how a vehicle was operated at the time of sensing.

[73] That is, real-time, second-by-second.
[74] Where the emissions from a vehicle are measured as it passes through a light beam. The measured interference of that light beam combined with knowledge of combustion chemistry provides a ‘snapshot’ estimation of the exhaust emissions of concern of the passing vehicle.

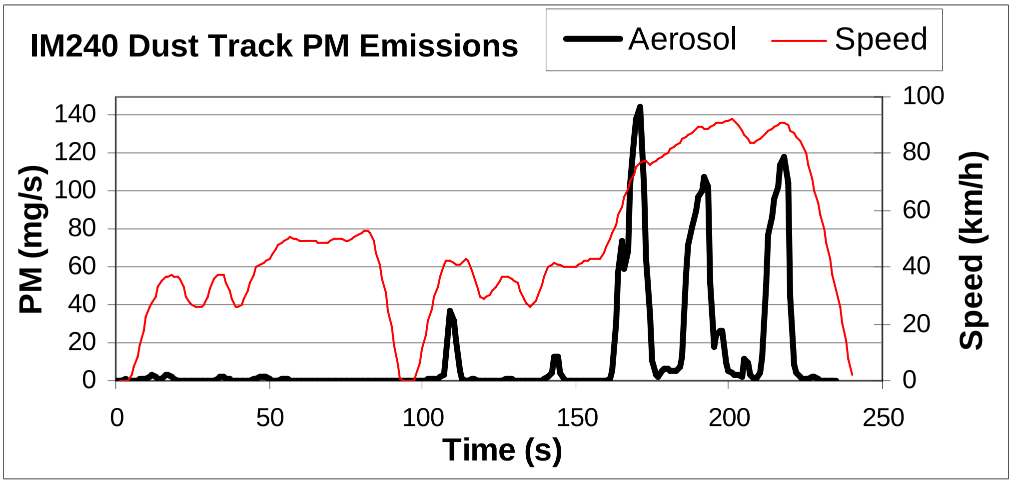

Figure 21: Real Time PM, as Measured by Light Scattering Photometer over the IM240 Test Cycle, for a Light Diesel Vehicle in Poor Condition (the Toyota Estima in As-Received Condition).

4.4. Conclusions

There is a poor relationship between an individual vehicle's on-road emissions performance, as indicated by various dynamometer drive cycle tests, and that vehicle's snap acceleration testing results. Nor would the knowledge of the various physical attributes of that group of vehicles provide a better indicator of their expected on-road emissions performance.

An alternative short test, the DT80, provides a far better indication of expected on-road PM emissions, but the DT80 — and any test of similar ilk — requires the use of a dynamometer and is therefore likely to be too expensive to be practical. However, the likes of a DT80 programme may be an appropriate option for targeted vehicle testing, such as testing used imports before initial entry into the fleet.

Remote sensing is unlikely to provide a reliable indication of emissions performance for diesel vehicles, unless the way in which a test vehicle is operated at the time of sensing is strictly controlled.

4.5. Recommendations

It is recommended the DT80, or a short test of similar ilk, is further examined as a possible option for testing used imported vehicles.

5. Repair and Servicing Effectiveness

This section describes work carried out to evaluate the effectiveness of repair and servicing of vehicles for emissions improvement.

Evaluating repair and servicing of vehicles consisted of three main components:

1. Evaluating repair effectiveness, based on the results of snap acceleration testing;
2. Obtaining information from the industry regarding repair of engines;
3. Consideration of data from previous tests.

This section has been divided to consider these three aspects separately.

5.1. Repair Effectiveness Based on Results from Snap Acceleration Testing

5.1.1. Methodology

One general repair and three diesel injection specialist workshops were selected to carry out the testing for this component of work. They were instructed to test all diesel vehicles before and after their repair, where this was possible, and where the repair might change the emissions performance.

Testers were issued instruction and test forms identical to those provided to testers carrying out snap acceleration testing at the time of safety inspection, along with a further test sheet on which to detail the reason for and nature of the repairs carried out (an example of which is provided in Appendix C).

Only one of the specialist workshops, Diesel Injection Services (DIS), Christchurch, provided data from a sufficient number of repair vehicles for the data to be considered for analysis. The other test sites reported a range of problems including: low remuneration (the test fee was subsequently raised, but this did not seem to change the *status quo*); insufficient workshop personnel available to carry out the testing; inconvenience — a repair vehicle required to be tested at least twice, which also required the vehicle to be warmed up at least twice; and (in the case of the general repair workshop) a low number of candidate vehicles.

Quality assurance checking further reduced the field repair sample to 27 light diesel vehicles. Care is required when extrapolating the findings of this work due to this small sample size. As well, no heavy vehicles appeared in this sample. This was due to a combination of factors: for heavy vehicles, DIS mostly services diesel injection equipment provided by other repairers, and thus few candidate heavy vehicles were available for testing; and, even when they were available — given the process of warming up and testing a vehicle is time consuming — their owners were usually keen to return their vehicles to revenue-earning service as soon as possible.

5.1.2. Results

Figure 22 compares the before- and after-repair snap acceleration results for the field repair data set. Line A-A represents the line where no change in emissions was achieved through repair and, as can be seen, almost all data is to the right of this line, indicating that an improvement in snap acceleration results can be expected through repair. The only vehicle which failed to show an improvement exhibited only a marginal increase in snap acceleration result.

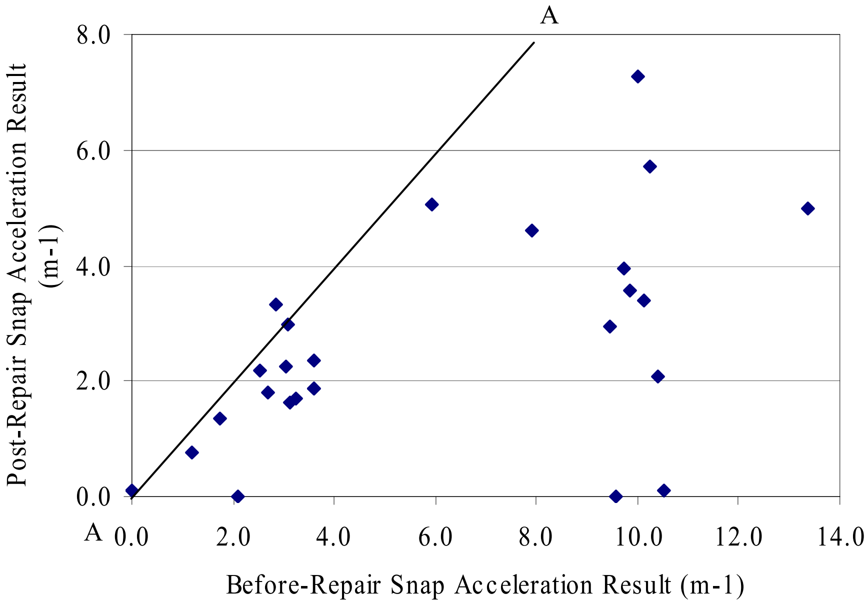

Figure 22: After-Repair Snap Acceleration Results Versus Before-Repair Snap Acceleration Results for the 27-Vehicle Field Repair Data Set.

The average reduction in snap acceleration results for the field repair vehicles was K=3.2 m^{-1} and the cost of repairs ranged from $140 (inclusive of GST) for an air filter change and injector service to $1,270 (inclusive of GST) for an injector service. The average cost of repair was $600 (inclusive of GST).

Eighty percent of the repairs involved servicing the injectors. Servicing injectors can range from an ultrasonic clean, which can cost as little as $120 (inclusive of GST), to requiring parts replacement, which could cost upwards of $1,500 (inclusive of GST) for some light vehicles to over $2,000 (inclusive of GST) for some heavy vehicles. No correlation was found between the cost of repair and the improvement in snap acceleration result realised or the before-repair snap acceleration result. The latter comparison is illustrated in Figure 23, the absence of a trend indicated by the scatter of data.

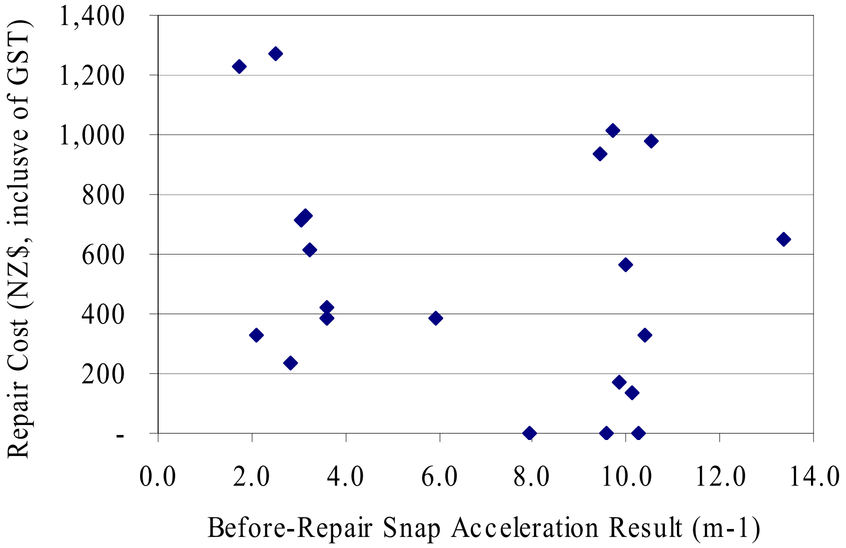

Figure 23: Cost of Repair (Inclusive of GST) Versus Before-Repair Snap Acceleration Result for the 27-Vehicle Field Repair Data Set.

Air filters were replaced on seven of the repair vehicles. All seven of these vehicles also had their injectors serviced and it is not possible to attribute the change in emissions performance solely to changing the air filter based on these results. In other tests carried out by the author,[75] a reduction in smoke density the equivalent[76] of around K=2-3 m^{-1} was achieved through replacing air filters alone, although this effect must be put into perspective: the air filters replaced were all in extremely poor condition, the engines were also in poor condition and the snap acceleration results were still above the equivalent of K=4-5 m^{-1}, even with new air filters fitted.

Previous studies show a similar response to repair of diesel vehicles. For example, McCormick et al[77] found repair of 26 heavy vehicles, selected due to their high on-road emission of smoke, decreased the snap acceleration result by an average of K=3.0 m^{-1}.[78] Drive cycle emissions were also measured, and PM was found to decrease by an average of over 40% and NOx to increase by an average of 25% upon repair. Note that an increase in NOx is expected where an engine experiencing poor fuel combustion is repaired, as higher peak combustion pressures and temperatures are expected after repair, and these increase the formation of NOx.

The majority of repairs in the McCormick study consisted of injector replacement or servicing. Recalibration or replacement of the fuel pump was the next most common repair work carried out. The average cost for repairs was around NZ$1,900.[79] Note

[75] A vehicle test programme carried out for the Government of Fiji in 2004.
[76] Testing used a paper filter method — where a fixed volume of exhaust is pulled through a paper filter and the filter's reflectivity measured — with the result provided in terms of smoke number. There is not a direct correlation between smoke number and smoke density, and hence results converted to smoke density K are approximate only.
[77] *Quantifying the Emissions Benefit of Opacity Testing and Repair of Heavy-Duty Diesel Vehicles*, McCormick et al, Colorado Institute for Fuels and Engine Research;, Kado et al, Department of Environmental Toxicology, Duleep, Energy and Environmental Analysis Inc, Final Report to the Colorado Department of Public Health and Environment, May 31, 2001.
[78] Note this figure has been drawn from data originally provided in terms of smoke opacity reading (%) converted to K values using a standard conversion formula.
[79] At an exchange rate of US63¢=NZD$1 and appreciated to today's value.

McCormick et al also found the relation between the snap acceleration result and drive cycle PM to be poor, with an R^2 of 0.2. This is consistent with the findings of the Pilot.

5.2. Results from Detailed Dynamometer Testing of Repair Vehicles.

Results from detailed dynamometer test work carried out on three diesel vehicles that underwent repair are provided here, two from previous test programmes and one from the Pilot programme.

Mitsubishi Pajero, 1989, 100,000 km.

This vehicle was identified as a very high emitter in the course of testing carried out for the MoT in 1998.[80] The vehicle was serviced — involving repair of two collapsed inlet valve rockers (costing approximately $900, inclusive of GST), and the replacement of all 4 injectors nozzles (costing approximately $700, inclusive of GST) — and re-tested, whereupon it achieved a significant reduction in both IM240 PM (4.1 g/km to 0.32 g/km) and IM240 HC emissions (2.80 g/km to 0.16 g/km). There was little change in NOx emission. The snap acceleration result reduced from $K=28m^{-1}$ to $K=8m^{-1}$. This post-repair result is still very high and did not reflect the comparatively low IM240 PM result achieved by repair. The engine was turbocharged and it was possible turbocharger lag was poorly compensated for (which could lead to a high snap acceleration result yet comparatively low drive cycle PM result).

The vehicle was re-tested in 2001 and no significant difference was found in the IM240 PM result, indicating there was little deterioration in the PM emissions performance over this period.

Nissan Laurel, 1993, 83,000 km and 147,000 km.

This vehicle featured in both the 1998 MoT test programme and a test programme carried out for BP in 2001.[81] For the latter test programme, the vehicle was tested on two fuels (differing in sulphur content) and to different test cycles (Jap10-15, suburban interrupted[82] and EUDS,[83] in as-received condition, after injector servicing, and then after pump servicing. The total cost of remedial work was $2,000, inclusive of GST.

Small improvements were found in post-repair fuel economy, with a maximum improvement of 6% for the EUDC drive cycle. However, it is difficult to conclude anything from this single-vehicle test, as different vehicles could respond quite differently. In theory, a small (0-4%) improvement in fuel economy may arise due to improved combustion characteristics (for example, improved atomisation leading to an

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[80] *Exhaust Emission Measurement of New Zealand Vehicles for the Ministry of Transport Vehicle Fleet Emission Strategy: Stage 2 (Diesel Vehicles)*, report prepared for the Ministry of Transport, Wellington by the Energy and Fuels Research Unit, Department of Mechanical Engineering, The University of Auckland, 1998.
[81] *Effect of Low Sulphur Diesel on Exhaust Emissions from Light-Duty Vehicles,* a report prepared for BP Oil NZ Ltd, Wellington, prepared by the Energy and Fuels Research Unit, Department of Mechanical Engineering, The University of Auckland, 2001.
[82] A test cycle based on real driving conditions developed for the MOT 1998 SMF programme (*Exhaust Emission Measurement of New Zealand Vehicles for the Ministry of Transport Vehicle Fleet Emission Strategy: Stage 2 (Diesel Vehicles)*, report prepared for the Ministry of Transport, Wellington by the Energy and Fuels Research Unit, Department of Mechanical Engineering, The University of Auckland, 1998).
[83] European Urban Driving Schedule, the statutory cold start drive cycle in use in Europe.

effective advance in combustion timing and the effects of this[84]); however, the improvement in fuel consumption due to more complete combustion of fuel (deduced from the reduced level of unburnt fuel being emitted in the form of carbonous soot) is expected to have little effect on fuel consumption.[85]

The emissions response varied: the snap acceleration result reduced from K=17 m^{-1} (at which this vehicle was obviously a high emitter) to K=4 m^{-1}; post-repair PM was similar or decreased, depending upon the drive cycle; and NOx and HC increased for all cycles, with an average increase of around 25% and 60% respectively.

Toyota Estima, 1994, 80,000 km.

This vehicle was tested as part of the Pilot. It was identified as exhibiting high visible emissions and was also the highest emitter of PM over the IM240 cycle and the second highest emitter over the DT80 cycle. An example of the modal LSP emissions (used to indicate PM emissions rates during a cycle, as discussed in Section 4.2) is provided in Figure 18, page 45. The peaks in LSP result were found to be higher and longer in duration compared to those for vehicles exhibiting lower drive-cycle PM.

New injectors were fitted at a cost of $780, inclusive of GST, and the snap acceleration test result reduced from a range between K=5.2 and K=7.6 m^{-1} to K=2.5 m^{-1}. The engine was also found to be in need of an overhaul, which was not performed. Nor, for this reason, was the vehicle subjected to further detailed dynamometer testing.

Other Test Work

Previous test work carried out at the EFRU also attempted to quantify the effects of using a dirty air filter.[86] For these tests, a new air filter element from a medium-sized truck engine was wrapped in adhesive tape, apart from a small (30mm by 50mm) section that was left open. No significant change in emissions was found despite this substantial occlusion. This indicates that there is little restriction to airflow in a new air filter element.

In previous tests carried out by the author, air filters from five vehicles used as taxis in Suva (notorious for its very high levels of suspended particulates in the air, especially along road corridors) were weighed two-weekly over three months of operation. The vehicles travelled an average of 23,000 km during this time. No increase in the weight of the air filter elements was detected during this time, despite a noticeable change in their colour.[87] A very small (just detectible) decrease in vacuum was found in one vehicle where this could be tested for (an indication the air filters were beginning to shows signs of blockage). It is therefore suggested that the weight of particulate that can effectively block an air filter is very small and also, compared with the 'test'

[84] Which in general leads to a more efficient power cycle but with higher NOx.
[85] The amount of fuel from which PM is derived is a minor fraction of total fuel used.
[86] *Exhaust Emission Measurement of New Zealand Vehicles for the Ministry of Transport Vehicle Fleet Emission Strategy: Stage 2 (Diesel Vehicles)*, report prepared for the Ministry of Transport, Wellington by the Energy and Fuels Research Unit, Department of Mechanical Engineering, The University of Auckland, 1998.
[87] In fact all filters decreased in weight over the trial, thought to be due to the loss of solvent from the air filter's elastomer casing. The decrease in weight arising from this source is reasonably limited, and therefore the weight of dirt in the air filters must also have been very small.

environment in Suva, it may take a number of years before a filter exhibits signs of blockage in normal driving conditions in New Zealand.

5.3. Information from the Industry Concerning Repair

Interviews with managers from repair workshops, equipment suppliers and equipment manufacturers were undertaken, with the aim of identifying:

- the common engine faults associated with diesel engines;
- how effective snap acceleration testing was for fault diagnosis, and
- how competent the industry was believed to be to carry out emissions-related repair work.

The interview process used is detailed in Appendix J.

5.3.1. Common Faults

Generalising the views of those interviewed:

- a diesel engine can still operate even if it is in poor condition, unlike a petrol engine, which requires the fuel metering and spark ignition systems to be in reasonably good condition in order to operate satisfactorily. The ability of diesel engines to ‘tolerate’ wear and tear, together with the typically high cost of repairs, encourages owners to defer servicing and repair;
- the main direct causes of high smoke emission were considered to be: injectors in poor condition; the injection pump out of calibration, and dirty air filters. Opinion on which was the more prevalent of these was mixed, but the majority of interviewees claimed fuel injectors in poor condition to be main primary problem. One reason for the difference in opinion may be the relative severity of effects — the ‘average’ faulty fuel injector has the potential to cause a more significant deterioration in visible emissions performance than the ‘average’ dirty air filter, but the ‘average’ dirty air filter may be more prevalent. The effect of a dirty air filter in increasing smoke emission is also not significant until engine operation approaches full load (when the lower quantity of excess air available has a greater effect on smoke emission), and this may not be called upon in around-town driving in flat areas;
- less common causes of high emissions from diesel vehicles include: carbon build-up, including around the EGR valve and ports, restricting the airflow through the engine; manifold leaks; or a faulty turbocharger, where one is fitted; and engine wear, such that compression pressures fall below those required for dependable combustion (although industry sources suggested engines worn to the latter extent would be poor starters — a natural method of elimination until they have been repaired).
- combustion of lubrication oil results in smoke with a bluish tinge, compared to the black smoke associated with poor combustion of fuel. There are many ways in which lubrication oil can get entrained in combustion or exhaust gases,

including finding its way past worn piston rings, leakage past valve guides and leaking turbocharger seals;

- most high smoke emission from diesel vehicles was believed to arise from poor maintenance: fuel filters require regular replacement to protect the fuel injection equipment; the air filter requires replacement to protect the engine and also to maintain airflow adequate for the good combustion of fuel; and the oil and oil filter require regular replacement to protect the engine and fuel injection equipment.

Table 8 lists the common faults along with the severity of their effect, the believed frequency of their occurrence and the approximate repair cost, based on a compilation of responses from personnel working in vehicle repair workshops. These personnel consisted of:

- four senior technicians from three different repair workshops specialising in the repair of diesel injection systems; and
- three senior technicians from three different general repair workshops.

The variability is response is reason for the spread in frequency of occurrence in the faults listed.

As shown by Table 8, there is a wide range of costs associated with the repair of a vehicle exhibiting visible smoke, ranging from $16 for the replacement of an air filter to many thousands of dollars for an engine replacement.

Using this information, the combination of the expected frequency of occurrence with cost estimates suggests that a high proportion of the repair costs for diesel vehicles exhibiting high levels of smoke emission are expected to be in the range of $150 to $1200 for light vehicles and up to $2000 for heavy vehicles. The estimate for light vehicles agrees well with that found for the field repair data set.

5.3.2. Snap Acceleration as a Tool for Fault Diagnosis

The general concept of the snap acceleration test — simply loading the engine and checking the visual emissions — is commonly used as an easy and fast indication of condition for diesel engines, but it is not normally carried out to any particular set procedure in this capacity. It provides a gauge of the severity of any problem but, as there are many reasons for high emission of smoke to occur, it does not provide a fault diagnosis in its own right. Nor does a snap acceleration test, even when carried out to the rigours of a set procedure, offer much improvement over this.

Table 8: Common Faults Leading to the Emission of Visible Smoke from a Diesel Engine, their Expected Severity of Effect, Frequency of Occurrence and Typical Repair Cost.

Fault	Result	General Severity of Effect	Frequency of Occurrence as a Proportion of All Faults	Typical Repair Cost ($ including GST)
Dirty air filter.	Insufficient air to enable good combustion under high engine load.	Small.	20-30%	$16 light car to $300 for heavy vehicle plus $30 for fitting if applicable.
Diesel injectors in poor condition.	Poor atomisation of fuel leading to incomplete combustion.	Medium to high.	30-40%	Requires services of a specialist. $150 clean and reset, to $800 (for light vehicles)[1] and $2000 (for heavy vehicles) for full servicing of injectors.
Incorrect pump setting.	Where resulting in over-fuelling, insufficient air for amount of fuel delivered resulting in poor combustion.	Medium to high.	20-30%	$300-$800 for specialist calibration but home mechanic adjustment possible for mainstream pumps, albeit with uncertain calibration.
Faulty EGR valve.	Blockage reducing airflow leading to poor combustion of fuel.	Small to medium.	10%	$100-$300 for deposit removal and repair at general repair workshop. Possible for home mechanic to do.
Valve setting incorrect.	Lower airflow leading to poor combustion of fuel under high load.	Small to medium.	Up to 5%	$60-$200 for resetting at general repair workshop. Possible for home-mechanic to do. At the extreme, the camshaft is worn and requires replacement which could cost $800-$2000.
Deposit build-up on valve and engine inlet system.	Lower airflow leading to poor combustion of fuel under high load.	Small to medium.	Up to 10%	$200 for deposit removal at general repair workshop. Possible for home mechanic to do.
Poor engine mechanical condition.	Low compression leading to poor starting and poor combustion of fuel. May also have loss of oil to combustion gases.	High.	Up to 5%	$4000-$10,000 light vehicle to $20,000-$30,000 heavy vehicle for major overhaul. Used engines available beginning at around $1200-$2000 for light vehicles plus $500-$1000 for fitting.
Turbo-charger fault	Low compression leading to low power and possibly increase smoke emission. If oil loss, blue smoke.	High.	Up to 5%	$60 for adjustment to $300 for turbocharger overhaul to $300-$1000 for replacement. Requires skilled technician.

[1] Note: in a modern vehicle, an additional four to five hours may be required in order simply to remove and replace the injectors due to their inaccessibility.

5.3.3. Industry Competence

There are around 30 specialist fuel injection shops in New Zealand. There are also many more general repair workshops that have the basic diesel injection test equipment required to set up injectors, and some workshops also possess test stands for testing old-style diesel injection pumps.

There have been significant advances in the technology of diesel injection equipment over the last five or so years, and this has required diesel injection workshops to re-tool and upskill in order to service the more modern equipment, particularly modern diesel injection pumps. Four or five diesel injection workshops in New Zealand appear to have attained a basic capability to work on the latest diesel injection equipment, and one has carried out significant re-tooling for this purpose. Whilst this seems a small number of capable workshops, the workshops themselves feel they have sufficient capacity to meet the national repair requirements, as it is becoming increasingly common for diesel injection equipment to be removed and refitted by one workshop and the specialist repair work to be carried out by another.

Note that in order to subject an engine to the snap acceleration test, it must be in sound condition. Engines used for light vehicles typically use a cambelt to drive the valve mechanism, and these wear with use. The snap acceleration test puts a high load on the cambelt and there is a risk the cambelt will break if it is in poor condition – with the high likelihood of severe engine damage if it does. A number of failures occurred during the introduction of snap acceleration testing in the UK (VOSA, personal communication).

Manufacturers tend to recommend a 100,000 km replacement interval for cambelts, but it is believed the $200 to $1500 replacement cost, together with a general lack of understanding of the need for this work among owners of diesel vehicles — and petrol vehicles, for that matter — is reason why this maintenance is often deferred. It is suggested a catch-up on engine maintenance would be required if snap acceleration testing were to be introduced as a fleet-wide test. Those testing vehicles may require evidence that a vehicle has had a recent cambelt replacement, as currently the liability for any damage occurring during vehicle inspections rests with the vehicle tester, a risk the vehicle tester would doubtless wish to minimise.

5.4. Conclusions

The conclusions of the work that considered the repair of vehicles are:

- emissions-related repair is expected to lower the snap acceleration emissions result and the average reduction is expected to be significant for vehicles exhibiting high levels of visible smoke emission;
- a large proportion of the repairs of vehicles exhibiting high levels of smoke emissions are expected to include servicing the injectors. Blocked air filters and incorrectly calibrated pumps are also common faults. A blocked air filter by itself is unlikely to be the cause of high visual emissions;
- the range of costs for the repair of a diesel vehicle exhibiting high levels of visible smoke emissions is from around $150 for a simple injector service to

many thousands of dollars for the major overhaul — or replacement — of an engine. A plot of pre-repair snap acceleration results with repair costs exhibited a scatter of points indicating a poor correlation between these two for the repair sample analysed. However, it must be stressed that the repair sample was small (27 vehicles) and therefore there is risk that this conclusion would not hold outside this sample;

- on average, repair of diesel vehicles exhibiting high visible smoke emission is expected to decrease PM emission and increase NOx emission. Any change in fuel consumption is expected to be small to negligible;
- the vehicle repair industry in New Zealand appears sufficiently tooled and skilled for the repair of diesel vehicles, including those using more advanced engine technologies;
- it is believed the replacement of cambelts has been deferred on many light vehicles, and should snap acceleration testing be introduced across the fleet, then many vehicles will require cambelt replacements.

5.5. Recommendations

The effectiveness of replacing air filters to reduce diesel vehicle PM emissions has not been determined and it is recommended more work be carried out in this area.

6. Implementation

This section considers the implementation aspects of snap acceleration testing and draws together information from a wide range of sources.

A section has also been provided on alternative options to snap acceleration testing. Although this discussion is over and above the contractual requirements of the Pilot, it is believed to be important, as the alternative options presented may be more appropriate for New Zealand than snap acceleration testing.

6.1. Methodology

Consideration of the implementation of snap acceleration testing drew information from many sources, including:

- field snap acceleration testing — experiences from the Pilot's field snap acceleration testing, including discussions with vehicle drivers;
- information from the industry, including industry personnel, both in New Zealand and overseas;
- overseas in-service testing standards;
- laboratory assessment of the test protocol for the snap acceleration test;
- laboratory assessment of smoke meters.

6.1.1. Field Snap acceleration Testing:

As discussed in Section 3.1, 13 sites were set up for snap acceleration testing of vehicles. Four were dedicated vehicle safety inspection sites; five were repair garages that could also issue WoFs, two were repair garages only, one was a roving tester from EFRU (for testing at a number of sites) and one was the EFRU vehicle testing laboratory. This provided a range of test site types. Site specifics were also such that testers of a range of competences were used and the time taken to carry out the test varied depending on the other inspection, repair or test work which was underway at the same time. Also, as discussed in Section 3.1, testers were led through the various test sheets supplied to them. One test sheet provided space for comments about the test or about the vehicle being subjected to it, and testers were encouraged to use this. Testers were also normally contacted every one to two weeks and asked to outline their experiences. Most sites were visited sometime during the Pilot, some, where there were found to be particular issues, on a daily basis.

A number of managers at various test sites were also interviewed towards the end of the snap acceleration testing programme, in order to identify which aspects of the programme went well and to collect recommendations for potential improvements. By this stage, these managers had first-hand experience of the introduction of snap acceleration testing into their respective work programmes.

6.1.2. Information from the Industry

Many potential problems in implementing a regime based on snap acceleration testing were identified during the Pilot. These were explored in discussions with various personnel from the motor-trade-related industry. These discussions ranged from an as-required basis, as where solutions were urgently required to restore testing at a number of problem test sites, to more formal interviews, working through a set of subject areas, as was the case when discussing snap acceleration testing with overseas groups that had experience in its implementation. Those contacted included:

- four principle suppliers of garage equipment in New Zealand (including suppliers of gas smoke meters of the type used for snap acceleration testing);
- seventeen snap acceleration test testers;
- twenty-one managers of vehicle inspection facilities;
- twelve Motor Trade Association (MTA) members, including Executives and Branch Presidents;
- fourteen managers of vehicle repair workshops or senior technicians (separate to the MTA members counted above) noting that all the managers involved were also skilled technicians themselves;
- two Motor Industry Training Organisation (MITO) Officers;
- John Fitch, Vehicle & Operator Services Agency (VOSA), UK — the officer involved in the original design and implementation of snap acceleration testing in the UK;
- Bernd Baumgar, Operations Engineer for SGS, the company contracted to manage the emissions testing of vehicles across Ireland;
- Chris Hunt, Crypton — a UK manufacturer of emissions test equipment. Answers to specific questions were also received from other overseas manufacturers through their New Zealand representatives.

6.1.3. Overseas In-Service Testing Standards

Many European countries have snap acceleration testing regimes in place. Detail was taken from the test standards in use in the UK which are similar to those in other European countries. An officer at VOSA also allowed the history of the development of snap acceleration testing to be explored.

6.1.4. Laboratory Assessment of the Test Protocol

The robustness and efficiency of the various elements making up the snap acceleration test procedure were examined through a series of tests carried out at the EFRU vehicle testing laboratory. The test vehicles used were those vehicles made available for detailed dynamometer testing.

6.1.5. Laboratory Assessment of Smoke meters

Seven smoke meters of the type used for snap acceleration testing were assessed in testing carried out at the EFRU testing laboratory. This assessment included checking calibration, calibration method and stability, ease of smoke meter use (as appraised by the technician carrying out the test programme) and smoke meter functions. Detail of the methodology used is provided in Appendix B.

6.2. Results and Discussion

Consideration of implementation covers a very wide range of subjects. The order in which they have been discussed here is:

1. Test duration;
2. Testing facilities and how snap acceleration testing could fit into existing processes;
3. Testers;
4. Smoke meters;
5. Testing including test protocol, cutpoints, test frequency and exemptions;
6. Capacity of the industry;
7. Snap acceleration test costs.

Note there is some crossover in the discussion provided, as many of the subjects cannot be discussed in isolation.

6.2.1. Test Duration

Field testing found the duration of a snap acceleration test to range from four to forty-five minutes. The typical test duration was five to ten minutes,[88] five minutes being the time taken when a vehicle arrives warm and the smoke meter is immediately ready for the test. It is expected the time taken to emissions-test a vehicle could be reduced to around three minutes if a 'fast pass' option were allowed. A fast pass option is provided in the UK and allows a vehicle to pass the test where the first snap acceleration result is very low (K=1.50 m^{-1} or less, in the case of testing in the UK). It is recommended this option be allowed in New Zealand, should snap acceleration testing be introduced.

Engine warm-up issues could add up to 20 minutes to a snap acceleration test. An engine requires more than simply running it at idle in order to warm it up sufficiently for testing. As could be imagined, driving a large vehicle around in order to warm the engine up sufficiently adds significant time and inconvenience to a snap acceleration test.

Some heavy vehicles were also found difficult to test due to their physical design — it was difficult to reach and connect the smoke meter probe to a vehicle's exhaust outlet

[88] Note that a visual inspection was also carried out on vehicles during the snap acceleration test period, to gather information for data analysis. A visual inspection is not normally a component of a snap acceleration test, and the time involved in filling out the associated form has been extracted from the test durations recorded.

when the vehicle was long, the end of the exhaust pipe was on the opposite side to that of the smoke meter or the vehicle had a vertical exhaust stack. For many of these vehicles, the smoke meter and its various test cycle prompts were not then visible to the tester. Some smoke meters had wired remotes which could be taken into the vehicle cab, and this helped in such circumstances. Wireless remotes are offered on some models of smoke meters available overseas.

Note that some experimentation was carried out using a smoke meter with an extended sampling hose, providing easier access to the exhaust pipe exit for those vehicles where this was less than conveniently located. Use of the extension typically decreased the snap acceleration result to the order of 10-20%. There was insufficient time to verify the consistency of this — that is, to calibrate the extension hose — and therefore it was not used for obtaining data used in the emissions profiling analysis.

A further complication for snap acceleration testing was that the smoke meter's probe was frequently dirty and required careful handling to avoid transfer of its fine black carbon to a client's vehicles. Gloves were provided to many testers but they found wearing them inconvenient. Even walking around the test area would allow the fine black carbon from testing to be picked up on the soles of shoes, and testers were likely taking this into vehicles when testing. One way around this would be for two people to be involved in testing a vehicle, one person inserting the probe, the other not alighting from the vehicle at all when it is in the test area.

6.2.2. Testing Facilities

Type of Facilities

The three types of test facility considered in the Pilot were: inspection-only sites, sometimes referred to as 'centralised testing facilities'; repair workshops, where safety inspections are also carried out, sometimes referred to as 'de-centralised testing facilities'; and repair workshop facilities, a subset of de-centralised testing facilities. There is a fourth type of emissions test facility that could be used and that is centralised testing where only the emissions test is carried out. An indication of how such a dedicated facility would operate, and the costs involved, can be gleaned from consideration of the centralised safety inspection findings.

There was no evidence to suggest the quality of snap acceleration testing would differ between inspections at centralised or de-centralised testing facilities. However, testing at centralised facilities would be expected to be less costly, and the higher vehicle throughput would likely afford the use of more expensive and reliable smoke meters. There would, what's more, be higher risks associated with smaller, garage-type operations that were reliant on the operation of a single smoke meter.

It is suggested the range of vehicle population densities in New Zealand lends itself to the use of a hybrid network of centralised and de-centralised emissions testing, as exists for the safety inspection of light vehicles.

Centralised, emissions-test-only facilities would be expected to yield test cost and smoke meter quality benefits similar to centralised safety inspection testing facilities.

However, emissions-test-only sites would prove inconvenient to the typical vehicle owner, who would be required to drive to and from another test facility — occasioning further 'downtime' — unless it operated at the front or back door of an existing safety inspection facility.

Placement of Snap Acceleration Testing Within Existing Facilities

There are several physical layouts and methods that could be used to integrate snap acceleration testing into existing, centralised, de-centralised or repair-only facilities. As with the simple testing of petrol vehicles, the Pilot's field experience found there were many site-specific factors involved in the final options chosen for snap acceleration testing, including: physical space availability; minimising the impact that snap acceleration testing had on the mainstream work being carried out at the site; the (perceived) requirement to test out of view of vehicle drivers, and managing exhaust emissions generated during the test. The smoke meters themselves take up little physical space — ranging from the size of a shoebox for the smaller smoke meters to no more than the size of a domestic washing machine in the case of smoke meters fitted into mobile workshop trolleys — and this tended not to be a deciding factor in where they were used.

Experiences from the field trial found several disadvantages to snap acceleration testing at repair workshops. Physical workshop space tended to be at a premium and moving either the vehicle to the smoke meter or the smoke meter to the vehicle was often time-consuming and inconvenient. The issue was heightened where exhaust extraction equipment was also required to be re-positioned. Engines also tended to be cold when worked on and ensuring they were adequately warm for a snap acceleration test then took additional time. The alternative of testing vehicles when they were first presented at the workshop, whilst their engines were still warm, was not a practical option as many vehicles tended to arrive within a short time period in the morning and there were simply not the staff and smoke meter capacities to deal with this. Nor would testing when vehicles were first presented solve the warm-up issues for vehicles after they were repaired.

Due to the time involved in conducting it, it was very difficult to integrate snap acceleration testing into an existing vehicle safety inspection process working near capacity without affecting vehicle throughput. Instead, the combination of safety inspection plus emissions test could take 30% to 50% longer than a safety inspection only. This was the case even where the duration of an emissions test could be taken down to five minutes — a feat initially requiring two testers — as five minutes is a comparatively long time for a vehicle to be in one place on a vehicle safety inspection process line. For example, at one site the emissions smoke meter was set to capture vehicles as they came off the brake tester. This soon became a point of congestion and often required vehicles to be skipped to avoid a build-up of vehicles at that point. This relief would not have been possible if emissions testing was mandatory. One option which would partially resolve this would be to provide multiple smoke meter stations for each safety inspection line, but this would come at considerable added cost due to the requirement of additional space and smoke meters. What's more, smoke meters in this scenario would not be well-utilised during times of less than high throughput, making their purchase less cost-effective.

Emissions testing outside the safety inspection process, on vehicle arrival and exit, was also trialled at some centralised facilities. Testing on vehicle arrival worked well at Claudelands (Hamilton), largely due to good management of arriving vehicles and because there was generally a queue of waiting vehicles at the entry to the inspection bays. In this case, the emissions test did not increase the 'downtime' of a vehicle so far as the driver was concerned. Engines also tended to be warm as they arrived, avoiding the requirement to warm up engines.

Emissions testing on vehicle arrival did not work well at Mt Wellington, however, because it was difficult to manage vehicles when they arrived, due to the layout of the entry area, and there was frequently insufficient time for the test to be carried out before the vehicle was expected to be rolled forward to begin its safety inspection. Neither did emissions testing at the exit area work well at this site, as drivers did not wish to spend any more time at the facility than strictly necessary.

Emissions testing at the facility exit worked well at Christchurch, since vehicles exited from one door and the testers involved, who were quite personable, managed to get drivers to pull their vehicles over to a side testing area without too much difficulty.

The general experience was that, well managed, there seemed to be value in carrying out the emissions test in front of drivers, as in this way the test seemed to have more meaning to drivers. A particular advantage for snap acceleration was the results were highly visible for a vehicle exhibiting a high snap acceleration test result (by contrast with the normally invisible emissions results and the reliance on a meter readout for the simple test used to test petrol vehicles).

For some drivers this was the first opportunity they had to see the emissions from their vehicles. A number were surprised at the high degree of smoke and suggested they would be getting their vehicle checked as a result. This also seemed an opportune time to provide advice to the drivers and it was an advantage where this could be provided by the tester — one tester at VINZ, Christchurch, had a good background in diesel mechanics and could offer well-informed advice to drivers which was gratefully received. At the very least, an information pamphlet could be offered to those drivers with vehicles exhibiting high snap acceleration results. Test-site protocols regarding recommending repairers may influence what could be done in this regard: for example, some inspection facilities may have a policy of not recommending specific repairers.

Note that there are no rules with regard to the timing of emissions testing in the UK, but the recommended practice provided in training videos is to test vehicles soon after their arrival so as to ensure the engine is warm.

Extraction of Exhaust Emissions from Testing

The Health and Safety in Employment Regulations (1995) require prevention of harm to employees at work, which would require employee exposure to exhaust emissions to be adequately managed. Current workshop practices may not meet the Regulations' associated Occupational Safety and Health (OSH) guidelines, let alone if emissions testing were introduced, and it is expected most facilities would need to install positive exhaust emissions extraction equipment to carry out snap acceleration testing.

Over 50 centralised or de-centralised facilities were visited during the Pilot and only one had specific exhaust extraction equipment that was considered to be adequate for managing emissions from snap acceleration testing. The majority of facilities relied upon open doors and natural ventilation, which is a concern considering how closed some workshop spaces were. Whilst many safety-inspection-only facilities had air extraction systems to pull air from inspection pits, the systems would not have been capable of adequately managing the emission from a snap acceleration test.

Emissions extraction equipment is expected to cost to the order of $3,000 to $10,000 per emissions test bay.[89] It is recommended that guidelines be developed and provided for the design and use of extraction equipment so as to minimise the costs involved to facility owners and their risk of contravening OSH requirements.

Note that during the Pilot, two testers complained they did not feel well whenever they carried out a reasonably full day of emissions testing. In both cases, idle simple testing of petrol vehicles and snap acceleration testing of diesel vehicles were being carried out. Exhaust extraction equipment was subsequently installed at both sites and carbon-filter masks were also provided, although it was found masks were not used much beyond the first week.[90] The testers did not report any further issues after this, although it is doubtful whether harmful exposure could be identified in this way in the short term. Due to the links between particulate emissions and health problems, it is recommended significant care be given to the management of emissions from testing.

Carbon masks were also sent to three other test sites where it was believed there may be problems in adequately managing emissions from testing. As in the previous example, the masks were not used beyond a cursory trial stage — if at all — testers reporting that masks made it difficult to communicate with drivers and 'put drivers off' having their vehicles tested. Experience from other industries also suggests the use of safety equipment is reasonably low unless it is made mandatory.

Vehicle Responsibility and Insurance

According to managers at a number of sites, the responsibility for the vehicle is effectively passed to the facility when the keys are handed over. All project test sites had existing insurance that was expected to provide cover in the event of engine damage during the snap acceleration test. Separate insurance was taken out by the consultant in case this was not the situation.

6.2.3. Testers

Seventeen different testers were involved in the Pilot's snap acceleration testing, the group including a range of people from the least-ranked safety inspectors within centralised testing facilities to one of the highest-ranked safety inspectors; automotive technicians; enthusiasts; and a university student with little automotive experience.

[89] Based on quotes provided by companies expert in dust and fume extraction.
[90] Testers reported wearing of masks was inconvenient and also did not provide a good image to vehicles' drivers when touting for test vehicles.

Testing was not compulsory and therefore persuading drivers to volunteer their vehicles for testing somewhat relied upon the charisma of the tester; testers who had a good rapport generally did not have difficulty accessing vehicles. What's more, approached in the right manner, many drivers seemed genuinely interested in knowing what the emissions test result was and what it meant, and in the emissions programme in general. At the other extreme, where poor rapport existed between tester and drivers at one location, few drivers allowed their cars to be tested, and this was one of the reasons for taking testing out of the view of drivers at that particular location.

Testers exhibited varying levels of proficiency in carrying out the snap acceleration test in the manner prescribed by the Pilot's test protocol. Unlike idle simple testing of petrol vehicles, changes in test method could have a significant effect on the results and hence many test site inspections were put in place during the trial period, particularly where data checks had raised concerns in this regard.

If testers were ranked from worst performers to best performers, based on visual assessment of their test methodology as witnessed during site inspections, the low-ranked safety inspectors would fall at the worst-performing end of the spectrum. At the high end would be the high-ranked safety inspector, with the university student not far behind. Curiously, the same order would also result if rapport with drivers were ranked.

However, this ranking was not necessarily supported by the measured results from testing. It is expected that comparison of test-to-test results from a snap acceleration test sequence should provide some indication of a tester's ability to perform the test consistently. When results were so analysed, some degree of consistency was found only in the results from tests conducted by the senior safety inspector and EFRU staff. Performance was generally quite varied across the remainder of the testers (for example, as gauged by the proportion of data exhibiting significant step increases in results within snap acceleration test sequences rather than steady or falling results). There does seem to be the potential for some measure of tester assessment through the analysis of test results, and it is recommended this is further investigated, should snap acceleration testing be introduced. This would require data entry of all results, not just the overall result.

An emissions programme would also benefit from using testers of good aptitude and attitude. It is recommended that, at the very least, testers meet a minimum proficiency test and these qualities be considered therein.

6.2.4. Smoke Meters

The seven smoke meters assessed and tested at the EFRU laboratory constituted a wide range of the smoke meters that could be made available for snap acceleration testing in New Zealand, ranging from low-end market smoke meters costing around $4,000 to high-end market smoke meters costing around $23,000. The same smoke meters or same models were used for the majority of the field test work.

The base components of a smoke meter, of the type trialed in the Pilot, are a volume continuously purged with exhaust gases from a vehicle's exhaust and a light emitter and light sensor located at either end of that volume. The amount of light transmitted between light emitter and sensor (i.e. across the optical path) is used to calculate 'smoke density' (K, m^{-1})[91] and is expressed in units of m^{-1}.

At a detailed level, smoke meters are designed to capture the near-least transmittance of light, corresponding to the near-highest degree of smoke density during an individual snap acceleration test. The offset from capturing the peak results is dictated by signal filtering (which removes the short-duration 'spikes') which can differ between smoke meters and is either directly specified in testing standards or is calibrated in original equipment performance compliance testing. The amount of filtering required in a test regime may differ from one country to another (and hence the importance of the back-to-back testing carried out as part of the Pilot: among other reasons, the amount of filtering applied by the various smoke meters was not known).

Back-to-back testing of smoke meter models used in field testing found the measured result for different smoke meters 30% lower to 40% higher than the Bosch smoke meter used as the Pilot's field reference smoke meter. These differences could be caused by factors other than differences in signal filtering. For example, the flow of exhaust gases through the probe, sampling hose and meter cavity may segregate on tight turns, resulting in a metered smoke density (i.e., of exhaust gases between the light source and sensor) differing from the average smoke density.

The large differences in measured results between smoke meters illustrate that a specification is a fundamental requirement in order for there to be comparability between different meters. Specification options include requiring smoke meters to perform within an allowed tolerance of a standard reference smoke meter (one component of the specification for smoke meters used in the UK), and the stipulation of a wide range of physical attributes, including response time and filtering (the basis of the specification of smoke meters used for the SAE J1667 protocol). Either way, it is suggested flexibility would be required for a New Zealand regime to avoid the over-specification of smoke meters, which could reduce the number of manufacturers providing equipment and lead to higher prices. A possible exception to this is specifying a data download protocol that permitted automatic retrieval of individual snap acceleration data, which would provide a range of options for testing data quality.

Note that smoke meters come supplied with a 'verification neutral density filter' used for time-to-time calibration of the meter. This is accomplished by physically placing the filter between the light source and light sensor for a set time. This tests the smoke meter calibration over a long period of time compared to that of an individual snap acceleration test and it does not test the calibration of the signal filtering or peculiarities in how the smoke density may be biased as it flows through the meter. Calibration using the verification neutral density filter does not therefore guarantee that any two so-'calibrated' meters will provide the same result when testing the same vehicle, even if the test procedure were meticulously executed.

Laboratory testing and field trial found the ease of use of difference smoke meters varied significantly. Some had complex command requirements, compared to the

[91] Smoke density is a function of the density of smoke particles, their size distribution and their light scattering and absorption characteristics. It cannot be measured directly and is instead calculated using the Beer-Lambert Law, which describes the physical relationship between the smoke density (K) and the smoke parameters of opacity and effective optical path length.

simple single-button test progression of others. As mentioned above, some also had remotes which allowed easier use, particularly where the vehicle was large and the main meter display could not be seen from the driver's seat. Some were combination smoke meters and four-gas analysers (the latter used for idle simple testing of petrol vehicles) and the switch from one function to the other could take several minutes (which was considered unworkable by some involved in safety-inspection-only facilities).

One smoke meter — one of the less expensive units which was nevertheless new at the start of the Pilot — failed in field use.

One smoke meter was found not to have been recently calibrated and, before it was used for the Pilot, it was sent to the recommended repairer for that particular meter. Although appearing to work before being sent, it required an extensive re-build. The repairer commented that smoke meters would normally require annual maintenance, costing to the order of $500, to maintain them in working condition. It was also remarked that the poor condition of the smoke meter provided was fairly typical of smoke meters handed in for recalibration.

Some meters were found to be specified as accurate to a standard and others as conforming to a standard. The latter is a more demanding requirement, as 'approval' of conformity can only be gained through rigorous testing at an independent certified laboratory. Four smoke meters remained with the EFRU for reasonable time (more than one week) and all exhibited good calibration stability over their respective assessment periods.[92]

More detailed results from the assessment and testing of smoke meters are provided in Appendix B.

6.2.5. Testing

6.2.5.1. Pre-Test Conditioning of Vehicles

Pre-test conditioning of vehicles could influence the snap acceleration result on some vehicles, particularly those exhibiting initially high snap acceleration results. Pre-test conditioning options include use of fuel additives, which clean fuel system components (there are additives available that do legitimately do this), carrying out several snap accelerations or simply driving the vehicle hard before testing. As is the case for safety inspections, it is likely some people will check and prepare their vehicle for inspection and some pre-test conditioning is likely to occur in a snap acceleration regime environment.

Very few vehicles were given pre-test conditioning in the Pilot, as the majority of drivers were unaware when they presented them that their vehicle was to be tested. The governor check and first clear-out provided some degree of pre-test conditioning but, as evidenced by decreasing snap acceleration results for some vehicles even at the end of the Pilot's snap acceleration test sequence, some vehicles would benefit from further pre-test conditioning.

[92] As determined by checking the calibration of smoke meters with the calibration filter provided with the meter.

Discussions with testers from programmes overseas established that it was normal to re-test a vehicle straight away if that vehicle at first failed but the sequence of snap acceleration results was found to be decreasing to the point where the vehicle stood a chance of passing on the subsequent test. Suggesting drivers return the vehicle after giving the vehicle a hard run with additive in the fuel was also reported.

6.2.5.2. Test Procedure

The specification for each component of the Pilot's snap acceleration test procedure is considered in this subsection, with recommendations provided for the snap acceleration test protocol, should snap acceleration testing be introduced to New Zealand. The following were the components:

1. a pre-test inspection to assess whether the vehicle was fit to test;
2. an engine temperature check (and possible engine warm-up period if the engine was found to be cold);
3. checking the operation of the governor;
4. a clear-out snap acceleration;
5. a sequence of measured snap accelerations;
6. recording of data;
7. completion of a visual inspection form (a requirement for the Pilot and not of the snap acceleration test).

1. Pre-test Inspection

The pre-test inspection is considered a necessary component of the snap acceleration test as it provides an opportunity to fail vehicles where there is perceived to be a risk of damaging the engine during the snap acceleration test — or even of damaging the smoke meter, such are the high levels of emissions (obvious entailing failure of the vehicle, should the test continue).

The pre-test inspection included checking for the emission of dense blue or clearly visible black smoke from the exhaust at idle, a pass-fail check taken from the UK test procedure,[93] and checking for low oil pressure light on the dash, abnormal engine noise or any other indication that the engine was not fit to test. A small number of diesel vehicles did not pass this pre-test inspection. These were older vehicles that had engines that did not seem to be running well (for example, unsteady engine vibration or harshness in the noise of the engine as engine speed was increased). The proportion of diesel vehicles that would fail the pre-inspection test is expected to be to the order of one in one hundred to one in five hundred, based on interviews with testers. This is true although one tester was found during a site inspection to reject vehicles at a much higher rate. It was believed this tester was taking an extremely risk-averse stance, as the consultant inspecting on the day considered the rejected vehicles suitable for testing.

Interviews with those carrying out visual inspections of vehicles as part of the Pilot programmes established there was also the occasional diesel vehicle that exhibited

[93] For vehicles first used before 1 August 1979, Vehicle & Operator Services Agency (VOSA), *The MoT Inspection Manual – Car and Light Commercial Vehicle Testing*. Issue date: August 2004.

excessive smoke during the visual inspection for smoke. As mentioned, the pre-test inspection presents an opportunity to fail such vehicles before subjecting them to a metered test.

Note that the pre-inspection procedure in use in the UK advises checking the oil level. It was not a requirement for the Pilot's field testing as permission would need to be sought from the vehicle owner,[94] and this together with and oil level check would take additional time. However, it is a recommended practice should snap acceleration testing be introduced in New Zealand.

2. *Engine Temperature Check*

An engine temperature check is important, as a cold engine may exhibit higher emissions and testing a cold engine also adds to the risk of engine damage occurring.

The Pilot's test protocol provided various options for testers to check that the engine was sufficiently warm, circumstances playing a significant part in determining which was chosen — if the vehicle had just rolled off the road, it was likely the engine was warm, but if the vehicle had been parked for a time, added care was required to ensure it was sufficiently warm. Most testers used the general warmth of the vehicle's engine bay area as an indication of engine temperature, including a 'touch test' of the radiator, a check that could be carried out during the visual inspection also carried out as part of the Pilot. This compares with the UK test procedures, which stipulate the use of temperature measuring devices, where 'suitable engine temperature measuring devices are only those accepted by the Vehicle Inspectorate'.[95]

One such UK-test approved method was the use of an oil dipstick temperature probe and many smoke meters were so equipped. Initial trials of using oil dipstick temperature probes found them difficult to use — primarily due to difficulty in physically placing them in the right place — and their use could add five minutes or more to the test. They were not offered for use during the Pilot, as the duration of the test had already been noted as a problem by testers. Omitting their use would pose problems for the Bosch smoke meters used in the Pilot as, unmodified, these meters followed the UK test protocol and would not register an 'OK' on the results printout unless the oil dipstick temperature probe recorded a temperature of 80^{o}C or higher.

It is recommended the method by which a tester verifies whether a vehicle is at a suitable temperature for testing is left to the discretion of the tester with guidelines provided instead of rigid check methods. Options include the use of an infrared thermometer, which can provide a recorded measurement that would permit the test procedure to stand up to later interrogation (say where a vehicle did not meet cutpoints and the vehicle owner wanted proof that the correct procedure had been followed).

[94] A safety inspection is a visual inspection and vehicle components should not be required to be removed during the inspection. If removal of a component is required then approval is first required.
[95] Vehicle and Operator Services Agency (VOSA), *The MOT Inspection Manual - Car & Light Commercial Vehicle Testing*, Issue date: August 2004.

3. Checking the Operation of the Governor

A governor check requires the accelerator to be depressed to raise the engine speed until it is governed by the diesel pump's governor and further accelerator depression has little effect on the engine speed. This is a less severe test than a snap acceleration test as the engine is not accelerated hard against its own inertia. However, the sound of a high-revving engine in the governor check is just as unsettling for the owner as it is in the snap acceleration test. In the case of one light Japanese diesel vehicle of recent manufacture, what's more, the governor test was inappropriate as it caused the valves and pistons to clash when high governed speed was sustained for more than around two to five seconds (and this would have likely resulted in engine damage had this have been allowed to continue). On the other hand, it is important to establish that the engine would not 'run away' (i.e., the engine would not be over-revved) and hence, as a compromise, it is recommended that the operation of the governor be checked. This could be accomplished by a steady 'free acceleration' of the engine, depressing the accelerator over a period of around three seconds with the accelerator released on first indication of reaching high-governed speed, or if engine noise is considered excessive, and for the severity and duration of the subsequent snap acceleration testing to be based on the results of this governor check.

4. Clear-Out Snap Acceleration

There is potential for exhaust deposits from within the engine and exhaust system to be loosened and released during the first engine accelerations, giving rise to a falsely high emission indication. The governor check and clear-out snap acceleration elements of the test are intended to 'clear out' these easily-removed deposits before introducing the smoke meter, thereby avoiding unnecessary exposure of the smoke meter to high levels of deposit emission. The practice is recommended for this reason.

5. Measured Snap Accelerations

It is standard procedure to prompt the smoke meter to carry out a zero check before each snap acceleration test sequence then follow the meter prompts through that sequence.

The rate at which the accelerator is depressed can have a significant effect on the results. Figure 24 provides the individual snap acceleration results for a Mitsubishi Canter tested with different rates of accelerator depression and shows a higher smoke density result with faster accelerator depression. The method of depression stipulated in the UK test protocol is 'following the meter prompts, depress the accelerator pedal quickly and continuously but not violently, to reach full fuel position in less than 1 second'. The upper two sets of data in Figure 24 meet this requirement but exhibit a difference of around 10%. Improved test-to-test repeatability was found using a more rapid depression of the accelerator, say taking around 0.5 seconds or less, and for this reason, this more rapid rate of depression is recommended. 'Violent' depression was also tested and exhibited similar results to the 0.5-second depression, but is considered inappropriate for the operation of equipment.

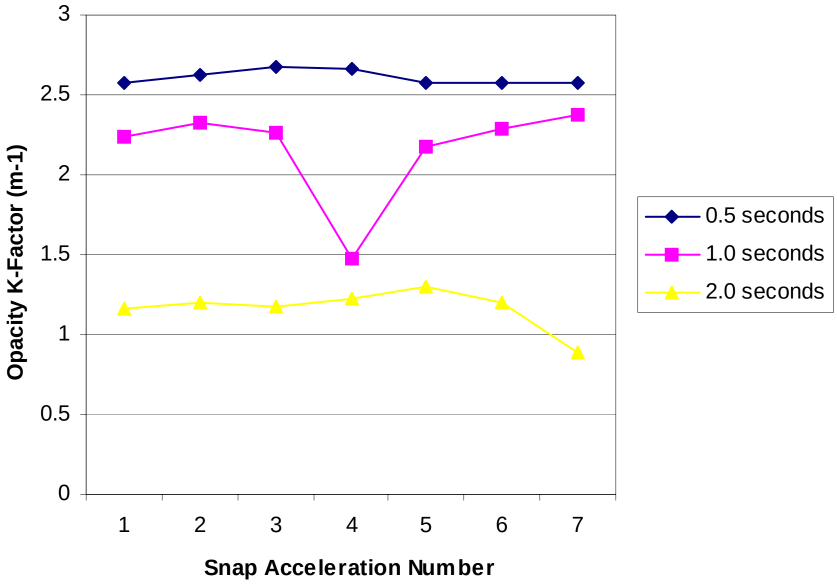


Figure 24: Successive Snap Acceleration Results for a Mitsubishi Canter Tested at Different Rates of Accelerator Depression.

The requirement for the SAE J1667 test procedure is for the accelerator to be released after governed speed has been reached (two to five seconds afterwards, to be exact). The requirement for the UK test procedure is to hold the full-fuel accelerator position until the smoke meter provides a release prompt, which has the same effect as waiting for governed speed to be reached whereupon the release prompt message is displayed. As there were concerns operating light engines at their high governed speed,[96] tests were carried out to check the effect on results for earlier release of the accelerator. An example of the results is provided in Figure 25, in this case also for the Mitsubishi Canter tested. The smoke density results decreased around 25% with earlier accelerator release — that and earlier release would be difficult to repeat. Hence, this is not an acceptable option, as a tester could orchestrate a pass in the way they carried out the test.

[96] The pistons and valves were found to collide when testing one Japanese import of recent manufacture.

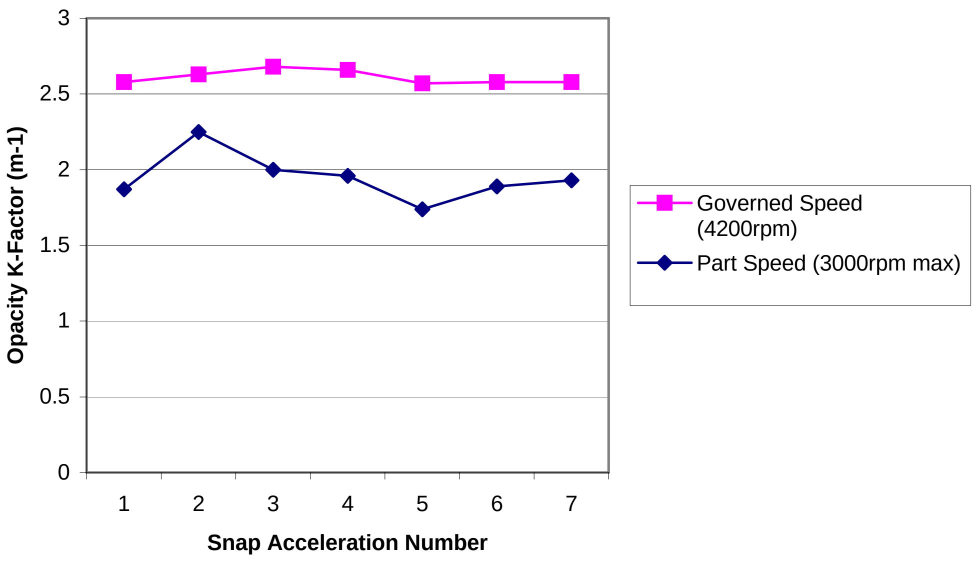


Figure 25: Successive Snap Acceleration Results for a Mitsubishi Canter Tested with the Accelerator Released After Reaching High Governed Speed and After Reaching a Lesser Engine Speed.

Note that for the smoke meters tested in this manner, it was possible to release the accelerator earlier than when prompted without recording a failed test. This creates an opportunity to pass vehicles that would otherwise fail, although the risk of this is small compared to where the duration of the acceleration is not monitored at all.

6. Recording of Data

All smoke meters had printouts that were used to provide a hard copy of individual snap acceleration results, and this was considered acceptable for the Pilot. Most smoke meters also had RS232 interfaces which could reportedly allow download of data. This was attempted for one smoke meter, but the task was found to be more time-consuming than expected and the attempt was abandoned. The automated download of data would provide a number of benefits, as has been mentioned.

It is recommended any test procedure be developed into a New Zealand Standard or Code of Practice to allow easy citing of or reference to it.

6.2.5.3. Cutpoints

It is beyond the scope of the Pilot to recommend cutpoints. However, the following discussion is provided to highlight some of the issues that apply to the New Zealand situation.

Current Diesel Fleet

It is expected over one-quarter of diesel vehicles currently in New Zealand were not built to any emissions standard and it is suggested it would be difficult to apply a retrospective emissions requirement to these vehicles. Acceptance by the vehicle supply industry of some nominated cutpoint for snap acceleration testing risks making the industry responsible where a vehicle in normal state of tune and condition does not meet the cutpoint, a risk the industry need not assume.

On the other hand, the cutpoints of $K=2.5m^{-1}$ for non-turbocharged vehicles and $K=3.0m^{-1}$ for turbocharged vehicles in use in Europe are lenient for modern engine designs (say post-1990 year of manufacture) regardless of their emissions build, and it is considered by the consultant that there are grounds for requiring this minimum performance, even when such was not a requirement of the original engine build, for modern engines.

It is possible a very small number of diesel engines have non-standard diesel pump settings, to increase the full-fuelling rate to boost the power of the engine. This report's author has personal experience in working the diesel injection industry and it is known that some diesel injection shops make after-pump calibration 'corrections' themselves where a vehicle was believed unduly underpowered. Smoke emission is expected to increase under increased full-fuelling operation: the increase is unlikely to be a problem where the work was carried out by a diesel injection shop but it may be a problem where it results from home-mechanic tampering. An indication that unauthorised tampering has been carried out is a break in the seals used on the diesel injection pump.

Future Fleet Additions

All light and heavy vehicles now entering the New Zealand fleet for the first time must be built to minimum emissions standards, as far as exhaust emissions are concerned, as detailed in the Emissions Rule 2003. The emissions standards referred to are the European, Japanese, US and Australian standards (with the Australian standards referring to either US or European standards, depending upon the year of manufacture of the vehicle). European and Japanese vehicle emissions standards refer specifically to a snap acceleration smoke test for both light and heavy diesel vehicles,[97] as do the US vehicle emissions standards for heavy vehicles.[98] (It is rare for a light diesel vehicle to come from the US, and even then other emissions regulations in force would require a vehicle in normal condition to have low smoke emission). From a vehicle compliance point of view, then, there does not appear to be any case to be made against the introduction of a snap acceleration check for used vehicles entering the fleet for the first time. New vehicles have been excluded from this as they would be expected to meet the standards to which they were built and further testing is unnecessary.

There are differences in the referenced snap acceleration test across the jurisdictions from which New Zealand receives vehicles. However, it is considered by the consultant that the test procedure developed for the Pilot would be a comparable test to those referred to by the European, Japanese and US standards, and it is recommended snap acceleration testing of diesel vehicles, using this procedure, be introduced for testing used vehicles entering the New Zealand fleet for the first time. It is further recommended to use the pass-fail cutpoints of $K=2.5m^{-1}$ for non-turbocharged vehicles

[97] *Safety Regulations for Road Vehicles (Japan), Article 31 – Emission Control Device* in the case of Japan, although the reference is to smoke emission measured using a filter paper method and not light transmission; and *UN/ECE Regulation No. 24* in the case of Europe.
[98] Federal Regulation 40 CFR Part 86.

and $K=3.0m^{-1}$ for turbocharged vehicles, taken from the requirements for simple emissions testing of diesel vehicles as described in European emissions regulations.[99]

Most imports of used diesel vehicles come from Japan. It is difficult to forecast the implications of the introduction of a pre-entry snap acceleration test. Used vehicles from Japan tend to be purchased at large auction houses and it is not normally possible to check a vehicle's emissions performance before its purchase.[100] Had a snap acceleration scenario been considered in 2004, it would be expected that vehicle importers would move to the purchase of higher-quality vehicles to minimise their risk of carrying out anything other than minor maintenance or repair work. However recent (2006) changes in the market — notably high competition for Japanese vehicles from Russia and Eastern and Middle-Eastern countries — have placed a premium on higher-quality used vehicles,[100] and New Zealand purchasers may now opt for a lower grade of vehicle in order to meet demand for lower-priced vehicles in the New Zealand market, meanwhile accepting the risk that some repair for emissions reasons may be required. Under this latter scenario, the emissions performance of vehicles would merely be lifted so that they passed the snap acceleration test, which is different from encouraging vehicle importers to import vehicles of generally higher quality.

There are benefits to be had in the control of the emissions performance of vehicles at the time of entry to the fleet, as at least vehicles then enter the fleet with a minimum emissions performance capability. An option the consultant feels is worthy of consideration is to go further and demand the equivalent of a minimum technology build for diesel vehicles, as the Pilot shows Technology 3 vehicles, in general, exhibit substantially lower PM emissions than vehicles of less-advanced technologies. Technology 3 is now the mainstream technology for the post-2000 year-of-manufacture light diesel vehicles that New Zealand receives. Technology 3 is not yet a mainstream technology for recent model heavy vehicles, and a deferral in the application of such a rule would be necessary to avoid imposing an overly stringent emissions build requirement on this class of vehicle.

Practically, it would be easier to demand a minimum emissions build standard for vehicles entering the fleet. An option would be to add minimum emissions standards to the list of approved emissions standards set out in Land Transport Rule - Vehicle Exhaust Emissions 2003.

Note that interrogating a vehicle's onboard diagnostic system (OBD), an option considered for checking emissions performance of petrol vehicles, does not appear to be an option for diesel vehicles in the short or medium term, as these systems are just now developing for diesel vehicles.

6.2.5.4. Frequency of Snap Acceleration Testing

There are many factors to be considered in determining the appropriate frequency of snap acceleration testing. As detailed in the Pilot's petrol report, the cost and inconvenience to vehicle owners and the limited capacity of the industry suggest

[99] That is, *UN/ECE Regulation No. 40* which (in its different forms) describes the base emissions build requirement plus other regulations that demand on-going, in-service compliance.
[100] IMVDA, personal communication.

extended intervals between tests, particularly during the regime's introduction. In view of this, and given the small proportion of vehicles of recent YoM expected to exhibit poor emissions, it is suggested that vehicles less than four (perhaps as old as six) years old need not be tested (unless a vehicle has been directed to undergo testing, having been visually identified on the road, say, as a high emitter). This YoM cutoff also currently aligns well with the point at which overseas jurisdictions adopted more stringent emissions standards for vehicle build, with the notable exception of the majority of New Zealand-New diesel vehicles of Japanese manufacturer origin (i.e., including vehicles of Japanese make actually built in Thailand, a significant source of New Zealand-New light diesel vehicles: a proportion of these vehicles may not have been built to any emissions standard until relatively recently).

It is expected a diesel vehicle would normally exhibit only a slow deterioration in emissions performance and hence once a vehicle has passed a snap acceleration test, it is expected to maintain this performance for some time afterwards (unless a poor-quality repair is involved). In consideration of this, and the limited capacity of the industry (detailed below), it is recommended that vehicles be tested every two years rather than more frequently, at least initially, if snap acceleration of in-service vehicles is introduced.

6.2.5.5. Exemptions

It is suggested there are political and public awareness benefits in involving all diesel vehicles used on the road in at least an initial emissions screen, say, the purpose of which is to see if a vehicle is then required to undergo a snap acceleration test. Possible emissions screen options include vehicle designation, vehicle age and visual emissions inspection. Note that there was no consistently significant difference found between the emissions of New Zealand-new vehicles and used imported vehicles when technology and YoM were taken into consideration, so whether a vehicle is New Zealand-new or a used import is not considered to be a useful emissions screen option.

Exemption options for vehicles that do not meet given cutpoints, even after repair, are expected to be more at issue. The Pilot identified a number of vehicles that could not meet a $K=3.0m^{-1}$ cutpoint, the most lenient provided in the UK snap acceleration test program, even after specialist repair. For three, repair costs were above $800 each. The consultant suggests it would be difficult to disqualify these vehicles from use after the owner had just spent this amount of money attempting to repair their vehicle. Exemption options considered in overseas programmes include a minimum repair spend plus preventing ownership change or limiting the time the vehicle can then be used before it is retired (or meets the given cutpoint).

Detailed dynamometer testing also indicated that some vehicles exhibit a high snap acceleration test result even though they are expected to exhibit low on-road emissions. As the intention of an emissions programme is to reduce fleet vehicle emissions, it is suggested a vehicle owner be given the opportunity, at their own risk and cost, to seek alternative quantification of their vehicle's emissions using an accepted, internationally recognised drive cycle test carried out at an appropriate facility.

An option provided in the UK and Ireland that may be pertinent to New Zealand is for vehicles used on islands not connected to the mainland to be exempt.

6.2.6. Capacity of the Industry

The industry would be required to support snap acceleration testing by providing testers, repairers and support personnel. This subsection estimates the number of additional personnel required for a conservative, base-case scenario that:

- tests vehicles with YoM of 1985 to 2000 (the 'target' vehicles, totalling 420,000: pre-1985 vehicles are exempt on the basis of age, but may be subject to a visual inspection; post-2000 vehicles are exempt due to their expected low emissions);
- tests target vehicles every two years (i.e., 210,000 initial tests per year plus 50,000 re-tests, say);
- has an average test duration of 20 minutes, which includes training and equipment set-up;
- requires repair on 10% of target vehicles (believed to be a conservatively low figure when it is considered that opacity test failure rates in California were around 30% in 1990 and around 8% in 2000, after a further ten years of in-service test programme had elapsed[101]) with an average of three hours per repair;
- requires a 'catch-up' in engine cambelt[102] replacements for light vehicles (detailed below).

For this base-case scenario, it is estimated the equivalent of 70 new full-time positions will be required just to test vehicles, plus the equivalent of 70 new full-time positions required in support (based on a 1:1 ratio of testers to support personnel, including trained instrument technicians, trainers, programme managers and quality assurance staff).

It is estimated the equivalent of 60 new full-time diesel technician positions would be required to provide additional vehicle maintenance or repair, plus the equivalent of 60 new full-time positions in support (based on a 1:1 ratio).

It is also expected that the introduction of snap acceleration testing would increase the number of engine cambelt replacements carried out, as the snap acceleration test elevates the risk of the cambelt breaking and this is expected to act as an incentive to replace cambelts at their recommended replacement interval (rather than deferring their replacement as long as possible, which appears to be the normal practice in New Zealand). This is expected to provide an initial peak in demand for mechanics as the fleet works through a 'catch-up' phase — different from an on-going, sustained demand — with the peak dependent upon the rate at which light diesel vehicles (cambelts are not normally fitted to heavy duty engines) are introduced to snap acceleration testing. It is estimated this demand would require the addition of the equivalent of at least 20 full-

[101] Diesel Engines: Environmental Impact and Control ISSN 1047-3289 *J. Air & Waste Manage. Assoc.* 51:809-847, Copyright 2001 Air & Waste Management Association

[102] A cambelt is used on light diesel engines to drive the engine's valve train, and breakage would likely cause the valves and pistons to collide, causing severe engine damage.

time mechanics to the workforce (based on an estimate that 50% of seven- to ten-year-old vehicles have deferred cambelt replacements: that is, 45,000 vehicles and three hours per cambelt replacement), plus the equivalent of 20 additional full-time positions in support (based on a 1:1 ratio).

In total, the number of equivalent full-time positions required to support the base-case scenario for snap acceleration testing of in-service vehicles is 300, and this is considered a conservative figure. It is questionable whether the industry — which, according to many repair workshops, is struggling to achieve sufficient workforce numbers as it is, without also supporting an emissions programme — could provide the required staffing without a reasonably extended introduction phase. What's more, there is the potential for the number of regime-related repairs to peak then decrease as the fleet evolves, which carries with it the risk that the industry will over-invest in the programme. As a result, the introduction of any snap acceleration testing regime will require careful management.

Management options for reducing the step increase in capacity required of the industry would include:

- providing snap acceleration testing initially for awareness purposes only, allowing vehicle owners to manage any non-compliance found over a longer term. Such a programme could have a relatively short commissioning period for spot (primary issue) locations, and would allow the infrastructure to be built up gradually, but it does pose the question of who would volunteer to carry out such early testing without financial incentive;
- setting initially lenient cutpoints, so as to pick out the worst offenders while still creating valuable awareness;
- progressively introducing vehicles to the snap acceleration test regime based on their year of manufacture or technology.

6.2.7. Snap Acceleration Test Cost

Table 9 provides estimates of the cost of snap acceleration testing for various implementation scenarios, based on the Pilot's field experiences. These estimates have been based upon:

- smoke meter cost of $30,000 for centralised testing, $15,000 for garage-type testing, financed at 20%;
- emissions extraction cost of $10,000 (specific to snap acceleration testing[103]) financed at 20% plus 10% annual maintenance costs;
- annual smoke meter calibration and maintenance costs of $1,000 irrespective of whether operations were of the centralised or garage-type; this includes the cost of a loan unit for the duration of the service period;

[103] That is, above and beyond whatever extraction equipment may already exist (there was only one workshop, out of all the workshops inspected, that had existing extraction equipment that would have been sufficient for the purposes of snap acceleration testing).

- additional insurance of $5,000 and $2,000 for centralised and garage-type operations respectively, to cover for smoke meter loss and damage and added vehicle liability;[104]
- rent of $7,000 and $3,000 per annum for centralised and garage-type operations respectively, to account for the space taken up by emissions testing (or lost opportunity, where testing is conducted within the existing facility space);
- consumables at $1 per test;
- labour cost at $85 and $110 per hour for centralised and garage-type operations respectively, based on the expected return on charged labour (specific to the facility) to cover for costs and profit;
- the time per test for a centralised operation ranging from 10 to 30 minutes to consider various vehicle throughput rates, with this time including periods where there is no testing carried out as there are no vehicles available to test. The time per test in a garage-type operation is based on the range of times found in field testing;
- tester and smoke meter availability in centralised operations based on seven hours per day, 200 days per year;
- no cost has been provided for vehicle and driver downtime.

Table 9: Estimated Costs of Snap Acceleration Testing Under Various Scenarios.

	Centralised Costs ($)			De-centralised Costs ($)		
Total Emissions-Related Facility Costs ($/year)	19,000	19,000	19,000	9,000	9,000	9,000
Total Labour Charge ($/year)	119,000	119,000	119,000	18,333	9,167	18,333
Consumables ($/year)	8,400	5,600	2,800	1,000	500	500
Minutes per Test	10	15	30	10	10	20
Tests per Year	8,400	5,600	2,800	1,000	500	500
Resulting Test Cost ($/test)	$17	$26	$50	$28	$37	$56

The results of the simple analysis provided in Table 9 yield a potential range of costs for snap acceleration testing, from around $20 to $50 per test for testing at centralised facilities to around $30 to $56 for testing carried out at de-centralised facilities. The weighed average test cost using these figures, based on the proportion of vehicles tested at centralised and de-centralised operations, is around $33. This cost does not take into consideration the time and associated costs involved in presenting a vehicle for snap acceleration testing. Also omitted from the centralised testing figures is the cost associated with reduced peak throughput of vehicles, which could increase the testing cost to the order of 10-30% for the facilities so affected.

The expected cost for snap acceleration testing is of similar order to the current cost of a safety inspection test, and combined with the safety inspection would constitute a

[104] Whilst existing insurance at the various test sites was expected to cover the testing carried out as part of the Pilot, it is believed additional insurance costs would be incurred if snap acceleration testing was a regular occurrence.

doubling in vehicle compliance fees. It is submitted that it would be beneficial, for the sake of perception, to keep the two fee mechanisms separate.

Higher costs would be expected during the introduction phase, a function of lower smoke meter utilisation, among other things. The cost of testing during the Pilot was over $100 per vehicle for some sites and this was for a discounted rate on the hire of the smoke meters and staff charge-out fee.

The order of magnitude of added costs for operating a diesel vehicle for a snap acceleration test programme based on two-yearly testing would include: the cost of testing — at an average of $33, say, every two years; the cost of repair — at around $1,000 for 10% of vehicles, say; and the cost of more frequent cambelt replacements — the cost of one added replacement over the life of a vehicle, at $1,200 over 20 years, say. The respective annualised sums are $17, $50 and $60, a total cost for the average diesel vehicle of $127.

6.3. Other Implementation Options

Many issues have been identified with the introduction of a fleet-wide emissions regime for diesel vehicles based on the snap acceleration test, and these would need to be fully addressed prior to implementing such a regime in New Zealand. This may result in a different application of snap acceleration testing. For example, snap acceleration testing could be used as an awareness tool, as a vehicle-specific, targeted emissions test or as a support test for the repair of vehicles or for vehicles reported by the police or public as being visibly high emitters. A recommended alternative integrated regime would have the following elements, and the reasons for their recommendation are given:

- Visual inspection for (visible) emissions at the time of safety inspection using a short test such as that prescribed by the UK simple emissions testing procedure.[105] Benefits and potential drawbacks include:
    - it is expected to be relatively easy to introduce and to cost less than snap acceleration testing;
    - it introduces vehicle owners to emissions testing, and through this presents the opportunity to promote emissions awareness;
    - against it, a visual test would be subjective, and may therefore be open to abuse.

  Note that many safety inspection items are or have been just as subjective as the proposed visual emissions test, and the definition of what constitutes an unacceptable condition tends to get more accurately defined over time. Options to define an unacceptable visual emissions performance test more accurately include: referring to a maximum allowable smoke density using a 'smoke density chart' (sometimes also referred to as a 'smoke chart') — an example of which, from the Canada Shipping Act,[106] is reproduced in Appendix J, and referring to a metered test using the snap acceleration procedure developed by the Pilot, say, where the results from the visual inspection are disputed.

[105] Vehicle and Operator Services Agency (VOSA), *The MOT Inspection Manual - Car & Light Commercial Vehicle Testing*, Issue date: August 2004.
[106] Canada Shipping Act, Air Pollution Regulations, CRC, Vol. XV, c. 1404 as established by the Consolidated Regulations of Canada, 1978.

- A mechanism to forbid or at least discourage tampering with emissions-related equipment, supported by visual inspection carried out at the time of safety inspection, and a related database of visual inspection results:
    - This is expected to have little benefit initially in lowering emissions from diesel vehicles, compared to a comparable programme for petrol vehicles, due to the relatively low technology of the current diesel fleet and the little that visual inspection can accomplish other than checking diesel injection equipment seals for tampering. However, it sets an important precedent for vehicles fitted with newer engine technologies, the performance of which can greatly change with the removal of the likes of exhaust components.[107]
- Introducing a minimum emissions build for diesel vehicles first entering the fleet at the equivalent of a Technology 3 specification, say, as described by a minimum emissions build standard (or standards) equivalent to that which can be achieved by a Technology 3 vehicle:
    - the ground for such a rule is the dramatic improvement in emissions performance expected for Technology 3 or later technologies (compared with less advanced technologies) for PM especially, analogous to the difference in gaseous emissions performance between petrol vehicles fitted and not fitted with exhaust catalysts;
    - such a rule would introduce a *de facto* age restriction on the import of diesel vehicles and an improvement in fleet emissions performance, over business-as-usual performance, is expected to be realised with time.
- Snap acceleration testing of used imported vehicles, at a minimum, to ensure a minimum emissions performance for vehicles entering the fleet for the first time, followed by the introduction of a more reliable test (if an appropriate test is found). This provides an entry requirement that can later be applied as an in-service requirement, if found necessary, setting up the basis of a future emissions test regime.
- Broadened enforcement of the 10-second Rule (including enforcement based on public reporting), supported by snap acceleration testing in cases of dispute. Note that for this, the snap acceleration test would still be required to be a recognised standard for minimum emissions performance assessment with known cutpoint values against which to test compliance of a vehicle. The differences between this and the introduction of snap acceleration testing at the time of safety inspection include the method by which vehicles are selected for testing and the infrastructure required to support such a regime. Vehicle selection could target specific areas or regions of concern.

It is recommended these options be further considered as components of an emissions control regime in New Zealand.

[107] Note that comment was made in an earlier section that removal of an oxidation catalyst from a diesel vehicle would be unlikely to cause a substantial change to the snap acceleration result. On the other hand, CO and HC emission would be expected to increase appreciably. More of concern would be the removal of particulate traps.

6.4. Conclusions

There are problems peculiar to New Zealand that would make it difficult to implement a fleet-wide regime based on snap acceleration testing:

- around one-quarter of the fleet were not built to any emissions standard and it may be difficult to require these vehicles retrospectively to meet a given emissions performance standard, unless it were a very lenient pass-fail cut-point;
- the ability of the industry to provide sufficient capacity to support such a regime is questioned;
- the poor relationship between snap acceleration result and on-road emissions performance means that there is a risk the results of snap acceleration testing would be challenged;
- implementation of snap acceleration testing is expected to be relatively expensive and would risk the industry over-investing in the programme's formative years.

When all these aspects and alternative options are considered, snap acceleration testing is not recommended for New Zealand as a mainstream vehicle emissions control programme. However, snap acceleration testing may be useful for awareness purposes, for emissions testing of specific, targeted vehicles or in support of other vehicle emissions programmes.

Elements that may make up an alternative vehicle emissions programme include: visual inspection for visible emissions at the time of safety inspection; a mechanism to forbid or at least discourage the tampering with emissions-related equipment; introducing a minimum emissions build for vehicles entering the fleet for the first time; snap acceleration testing, or a more robust check of emissions performance, of used imported vehicles before entry to the fleet; and broadened enforcement of the 10-second Rule.

Note that there is currently no mechanism to demand the repair of a high-emitting vehicle unless it emits continuous visible emissions. This less-than-satisfactory situation will persist if no snap acceleration test regime or high emitter test and cutpoint of some sort is adopted. This weakens the authority that could be used to support other emissions reduction programmes.

Should snap acceleration testing be introduced, a recommended test procedure for New Zealand has been identified. This includes the provision of a 'fast pass' option to dispatch vehicles showing very low emissions quickly. Such a snap acceleration test regime would require a number of supporting systems including:

- a Standard or Code of Practice for snap acceleration testing, including the specification of smoke meters;
- a minimum proficiency standard for testers;
- a quality control programme to manage the maintenance and calibration of smoke meters, including an accreditation system for laboratories and technicians performing this work;

- a quality control system to monitor test site performance with the ability to intervene where necessary.

Should snap acceleration testing be introduced as a fleet-wide requirement, it is expected that, for two-yearly testing of vehicles, the industry would require the addition of (the equivalent of) at least 300 full-time personnel to support the testing and repair work. The introduction of snap acceleration testing would require careful management, as this step increase in industry capacity would take several years to achieve, at best, and also risk the industry over-investing in the earlier years. An over-optimistic introduction would also risk the quality of the programme being compromised.

Once introduced, a snap acceleration test would be expected to take 5 to 20 minutes and cost around $33 on average, ranging from $20 to $56 depending upon the facility type and whether vehicles may be tested easily. Higher costs would be expected during the regime start-up period.

The snap acceleration test is expected to be difficult to integrate into an existing safety inspection without extending the duration of the inspection, and flexibility must be allowed as to how these two systems are integrated.

6.5. Recommendations

It is recommend snap acceleration testing not be introduced as a fleet-wide in-service test regime for diesel vehicles in New Zealand.

Other vehicle emission mitigation options have been provided and it is recommended these options be further investigated for introduction in New Zealand.

7. Recommendations For Further Work

It is recommended that snap acceleration testing not be introduced as a mainstream vehicle emissions control programme in New Zealand. For this reason, the recommendations provided below are based on the assumption that snap acceleration testing will not be introduced (and hence recommendations on the makeup of the snap acceleration test have not been brought back to this section).

It is recommended an integrated vehicle emissions control strategy be expertly devised.[108] Elements that may make up an alternative vehicle emissions programme include: visual inspection for visible emissions at the time of safety inspection; a mechanism to forbid or at least discourage the tampering with emissions-related equipment; introducing a minimum emissions build for vehicles entering the fleet for the first time; snap acceleration testing, or a more robust check of the emissions performance, of used imported vehicles before entry to the fleet; and broadened enforcement of the 10-second Rule.

The effectiveness of replacing air filters to reduce diesel vehicle PM emissions has not been determined and it is recommended more work be carried out in this area.

Business-as-usual fleet turnover is expected to provide improvement in the emissions performance of the diesel fleet. It is recommended expert analysis be carried out to quantify this effect.

[108] It is understood there has been much investigative groundwork already carried in this area in New Zealand and put into the New Zealand context; hence it is not suggested the process start from raw beginnings.

Appendix A: Pilot Project Aims and Objectives

The aims of the project, as provided by the Pilot's Project Plan, are to:

1. estimate the current emissions performance of the New Zealand vehicle fleet;
2. estimate the reduction in emissions, and the improvement in fuel consumption, for high-emitting vehicles which could be achieved by vehicle maintenance and repair; and to
3. enhance public awareness by providing participating vehicle owners with feedback on emissions test results.

The objectives of the project, as provided by the Pilot's Project Plan, are to:

1. Characterise the emissions profile of used imports and the in-service vehicle fleet.
   Identify the emissions profile of the New Zealand fleet by vehicle type, age and engine technology (with confidence limits stated, based on vehicles tested).

2. Benchmark the existing vehicle fleet based on the determined characterisation.
   Analyse the emission performance of vehicles representative of the New Zealand fleet by vehicle type, age, engine technology and condition.

3. Project possible emissions reductions from improved maintenance from specific vehicle categories and on a fleet-wide basis.
   Estimate the likely emissions reductions (in g/km or other suitable units) from improved maintenance for specific vehicle categories and on a fleet-wide basis.

4. Identify the causes of poor emissions performance and determine the cost and effectiveness of repairs.
   Identify the likely causes of poor emission performance and the cost and effectiveness of emissions-related repairs undertaken.

5. Compare and assess simple test results and testing procedures against detailed tests.
   Compare simple test results for individual vehicles with recognised transient loaded tests and the remote sensing test used by the Auckland Regional Council (if available).
   Assess the simple in-service emissions testing procedures and equipment (for accuracy, repeatability, ease of use and time to conduct test), and their ability to indicate how effective repair will be.

6. Identify operational issues.
   Provide recommendations on operational and process systems including information collection, quality assurance system processes, the application of the simple emissions test and visual inspection, and any relevant comments regarding integration with existing vehicle inspection processes.

7. Estimate likely fuel efficiency gains.
Estimate the likely fuel efficiency gains from improved maintenance for specific vehicle categories and on a fleet-wide basis.

Appendix B: The Evolution of Diesel Engine Technology and Relevance of Snap Acceleration Testing

Table 10: The Evolution of Diesel Engine Technology and Relevance of Snap Acceleration Testing

Overseas Circa	Evolution of Diesel Vehicle Technology	Relevance of Snap Acceleration Testing
Pre-1960s	Simple diesel injection systems used with (generally) fixed diesel injection timing. Some larger heavy vehicle engines were fitted with turbochargers and superchargers in order to increase power. The diesel pump calibration was generally set to provide an acceptable level of visual emissions.	The snap acceleration test was devised after 1960. Earlier diesel vehicles were not designed to meet the snap acceleration test nor were they designed to be subjected to such a physically demanding requirement. In the UK, vehicles of this era are subjected to a less harsh visual acceleration test. For this test, the UK MOT Inspection Manual[109] states: 'Older vehicles, particularly pre-1960, sometimes emit unavoidable smoke due to their design. Such smoke is **not** a reason for rejection'.
1960-1995	Improvements in diesel injection characteristics and combustion chamber design introduced to meet emission regulations introduced in overseas jurisdictions. Changes included increasing injection pressures to aid atomisation of fuel and improved control of injection timing. Improvements in driveability performance were gained through the use of indirect injection. This also allowed smaller high-speed diesel engines to be developed beginning the use of diesel engines in light vehicles.	Earlier engines were not designed to free accelerate (i.e., with the engine out of gear) up to governed speed. A less harsh visual acceleration test is provided in the UK. The snap acceleration test was introduced as an emissions build requirement in the 1970s to early 1980s, depending upon jurisdiction and vehicle class. This test still requires the engine to be in good condition to minimise the risk of engine damage. Earlier turbocharged engines with relatively simple fuel control systems are expected to emit more smoke during a snap acceleration test than for a non-turbocharged engine and were given a higher pass-fail cutpoint.
1995-2000	More stringent emission regulations introduced in overseas jurisdictions, requiring the use of more sophisticated diesel injection technology and more complex combustion chamber designs. Electronic fuel control, higher injection pressures and EGR became common for engines for light vehicles. Oxidation catalysts were also being introduced on European light diesel vehicles. Turbocharging became an emissions reduction tool as compared with its earlier primary use to increase power.	The four major jurisdictions[110] refer to a snap acceleration test in their respective build requirements for vehicles and therefore it is expected engines from this era can be tested to a snap acceleration test if in suitable mechanical condition. Fuel control devices compensate for turbocharger lag[111] such that snap acceleration results of a turbocharged and non-turbocharged vehicle are similar. However, a higher cutpoint is still offered for turbocharged vehicles.

[109] Vehicle and Operator Services Agency (VOSA), *The MOT Inspection Manual - Car & Light Commercial Vehicle Testing*, Issue date: August 2004.
[110] Australia, Europe, Japan and the United States.
[111] A turbocharger takes time to spin up to speed on the acceleration of an engine and this causes the *boost* in air pressure to lag, termed 'turbocharger lag'.

2000-2005	Introduction of more stringent emissions build requirements in overseas jurisdictions and the introduction of advanced fuel control systems and combustion chamber designs to match.	Vehicles have been designed to meet a snap acceleration test. The level of emission during the test can be below detection levels plus the resolution of smoke meters is such that the results could be relatively coarse and unreliable if considering a lower cutpoint. The consultant therefore questions how appropriate the snap acceleration test is for these vehicles.
Future	Electronic controlled fuelling, very high pressure diesel injection, complex turbocharging, intercooling and cooled EGR are expected as standard equipment. Advanced exhaust after-treatment systems such as regenerating particulate filters and de-NOx catalysts will likely be required in some jurisdictions, the latter requiring the use of very low sulphur content fuels. Research is currently looking at even more advanced combustion systems that may provide required emission levels with more simple exhaust after-treatment strategies and exhaust catalyst systems that are more tolerant of sulphur.	Current snap acceleration test unlikely to be relevant.

Appendix C: Smoke Meters Used for Snap Acceleration Testing

C.1 Introduction

Diesel smoke meters of the type used in the Pilot were first introduced in the United States in the late 1960s to measure an engine's exhaust gas opacity both under load on dynamometers and in the snap acceleration test. The US smoke meter specification and snap acceleration test protocol were finalised in 1973 and have undergone little modification since then. Because of its simplicity, the snap acceleration test, using a smoke meter, was later adopted in many countries as the standard test to check visible smoke emission from diesel vehicles.

The snap acceleration test standard used in Japan is similar, in that it requires the same engine acceleration, but measurement is made by determining the reduction in reflectance of a paper filter through which a fixed volume of exhaust has passed during the period of the snap acceleration. Measurement is given in terms of *smoke number*, a scale from 0 (paper filter has no change in reflectance) to 10 (the paper filter is blackened to the point that it does not reflect light from the meter's source light to the meter's light meter.

Units of Measurement of Smoke Meters

The smoke meter of the type trialled in the Pilot reads in units of smoke density (K). The smoke density is a function of the number of smoke particles per unit gas volume, the size distribution of the smoke particles and the light absorption and scattering of the particles and is presented in units (m^{-1}).

The smoke density (K) is calculated using the Beer-Lambert Law, which describes the physical relationship between the smoke density (K) and the smoke parameters of opacity and effective optical path length (L) between the meter's light emitter and sensor.

C.2 Smoke Meter Specifications

Standards Identified

The main international standards identified in various standards for smoke meters are:

- California Bureau of Automotive Repair BAR 90 (superseded by BAR 97).
- OIML (International Organisation of Legal Metrology) R99 Class 1 (superseded by Class 0).

There is some level of equivalence between BAR 90 and OIML 1, also BAR 97 and OIML 0, with the latter two having the higher specification.

All manufacturers of smoke meters used in the Pilot describe their instrument as capable of meeting (or in some cases, exceeding) at least one of the above standards, or state conformity (approval) to at least one of these standards.

To obtain approval, the standard requires extensive testing to be performed by an independent certified laboratory to ensure all aspects are conformed to so that they may then guarantee the performance of the instrument.

An example is provided here of the compliance procedure required for the smoke meters in the UK. The Vehicle and Operator Service Agency (VOSA) stipulates the following requirements for smoke meters:

1 The category of instrument as:

Category A: Cars and light commercial vehicles (MOT Class IV and VII and single Vehicle Approval Scheme vehicles).

Category B: Public Service Vehicles and private buses (including MOT Class V and VI vehicles) and Heavy Goods Vehicles.

2 Measurement ability for smoke meters. They must:

- be able to measure accurately (safeguard against the possibility of condensation influencing the measurements, for example), record, display and retain the peak value of the smoke output during each snap acceleration test;
- be able to maintain a fixed effective optical path length irrespective of the exhaust tailpipe size or shape;
- be able to maintain correct sampling and purge air pressure at all times to ensure the consistent filling of the measurement chamber with no variations in effective optical path length;
- be able to perform an uninterrupted sequence of 10 snap acceleration test and display each value, regardless of the smoke level;
- have an engine temperature sensor that is capable of matching the length of the dipstick for all Category A vehicles (measurements for Category A meters);
- be able to operate reliably in all conditions likely to be encountered within a vehicle testing station;
- have a Resolution of Indication;
- have a minimum scale range of $K = 0\ m^{-1}$ to at least $9.99\ m^{-1}$;
- provide an indication of the Measured Result;
- have the ability to withstand shock and vibration.

3 Operational requirements. They must:

- prompt user when the meter is due for any calibration and automatically prevent measurements of smoke;
- perform zero checks immediately before each series of snap acceleration tests and reset zero if necessary;
- remind the operator before the start of the test to fully depress the accelerator in under one second;
- enable the operator to anticipate the prompt to depress the accelerator by a countdown system;

- allow the operator to proceed with the test only when the oil temperature is greater than or equal to 80ºC;

4 Results and print-outs:

- data transmission from the instrument should be designed so that the results cannot be falsified;
- print-outs should clearly state the testing station, date and time, engine temperature (or state that no engine temperature was taken), test limit, each peak smoke reading, drift between tests, and the mean value of the final valid accelerations, followed by test results as pass, fail, void, aborted;
- the meter must give the operator the choice to print out another copy of the results.

5 Calibration & Verification:

- the meter should be supplied with a verification neutral density filter in the region 1.6 to 2.0m^{-1};
- the meter should prompt the operator to do a verification check every seven and a half days. If the verification filter differs from the actual measured value by more than ± 0.1 m^{-1}, then testing shall stop;
- calibration must be performed at regular intervals by an approved operator, using a more comprehensive check at 3 points in the range of the meter.

6 Pattern Approval Procedures:

Correlation is carried out on two units, and environmental testing shall be carried out on at least one unit.

Part 1: Verify correlation with reference meter and take back-to-back snap acceleration tests over a range of vehicles.

Part 2: Environmental testing by an approved test house using a neutral density filter to simulate smoke measurements.

Other tests include electrical safety checks, mechanical shock tests and environmental tests.

C.3 Comparison of Smoke Meters

General Specification

Table 11 presents basic manufacturer data for the smoke meters that were assessed during the Pilot. The information was sourced from manufacturers' information brochures and websites, where manufacturers have stated certain levels of accuracy in their specifications. This list does not represent a total list of equipment available in New Zealand.

Performance Assessment

Assessing smoke meter performance included physically measuring their response by using the verification filters supplied with the meters, checking the ease of operation during vehicle testing, verifying performance, checking functions and calibration requirements. Table 12 summarises the assessment of the smoke meters, as judged by the laboratory test technician using a simple five-star rating system (one star: poor; five stars: very good). Most smoke meters achieved good or higher ratings for their assessments.

Instrument Inter-Comparisons

Extensive testing (of the type required for standard approval) to assess performance of the smoke meters fully could not be conducted. However, some basic back-to-back comparison checks were carried out to compare the acceleration results from one meter against another for use on the same vehicle. The test procedure used for back-to-back testing included repeating the acceleration tests until the results stabilised (compared to accepting the average of individual results for accelerations four, five and six, as was the effective Pilot test procedure used in field testing). Summarised results are provided in Table 13.

Back-to-back testing found the relative performance between two smoke meters to change when testing a different vehicle. This is far from ideal, as it is then difficult to calibrate one meter to another. It also questions the ability of smoke meters to provide a reliable measurement of exhaust smoke density. For example, comparison of the Celesco and Sun smoke meters show relative result ratios of 1.33 and 0.8 for measuring vehicles with average $K=0.3m^{-1}$ and $K=3.4m^{-1}$, respectively. Whilst this appears a wide variation — 35% high to 12% under — considering the many factors which can contribute to this variability, this could be considered to be actually quite a reasonable agreement between instruments.

Table 11: Comparison of Smoke Meters – Manufacturers' Specifications

	AVL DIGAS 4000	SUN ASA200	AIRREX HG400	BOSCH RTM430 Interface	Motorscan 8020 / 9010	SPTC Autochek	Celsco Model 300
K, m^{-1} Range	0 – 99.99	0 – 9.99	0 – 9.99	0 - 10		N/A	0 - 30
Vehicle Class	A & B	A & B	?	A & B	A & B	?	
Third Party Calibration	Yes	No	?	Yes	Yes	?	
VOSA (UK) Accepted List	Yes	Up to Dec 2008	No	Yes	A only Up to Dec 2008	No	
OIML R99	Class 1		No		Class 0	No	
Test Procedure							
Country of Origin	Austria		Korea	Germany	Italy	Korea	
Bench Manufacturer	?		?	Bosch	Siemens	?	
Approximate Cost	$23,500		$6,000	$4,000 Measure head Interface unit?	$13,900	$12,000	

Table 12: Smoke Meter Features and Performance Assessment.

Features	AVL DIGAS 4000	SUN ASA200	AIRREX HO400	BOSCH RTM430	Motorscan 8020 / 9010	SPTC Autochek	Celsco
Size	Large	Small	Medium	Large	Large	Medium	Medium
Display	Integral	Remote	Integral	Integral	Integral	Integral	Integral
Control	Integral	Remote	Integral	Integral	Integral	Integral	Integral
Remote Control?	?	Yes	No	Yes	Yes	No	Yes
Dual Gas / Smoke	Yes	No	No	No	Yes	Yes	No
Partial / Full Flow	Partial	Partial	Partial	Partial	Partial	Partial	Full
Printer	Integral	Separate	Integral	Integral	Integral	Integral	Integral
Recording	Yes	No	?	?	?	?	
Oil Temp/RPM	Yes	No	Yes	Yes	Yes	Yes	Oil Only
Official Procedure	Yes	No	No	Yes	Yes	No	
Star Ratings							
Ease of Use	*****	****	?	****	****	****	**
Maintenance	?	****	?	****	*****	?	****
Ease of Verifying Calibration	?	*****	?	****	****	?	****
Accuracy Gas 1							****
Calibration Drift	?	*****	?	*****	*****	?	****
Sample line / probe	****	****	****	****	***	****	****
Confidence	*****	*****	?	**	****	*	*****

Star Ratings * Poor *** Average ***** Very Good

Table 13: Smoke Meter Performance Comparisons Based on Snap Acceleration 'Back to Back' Measurements.

Instrument		mean K	ratio A/B	mean K	ratio A/B	mean K	ratio A/B	mean K	ratio A/B	mean K	ratio A/B
A:	Celesco	1.14	2.77	1.01	1.83						
B:	Bosch	0.41		0.55							
A:	Bosch	1.79	1.33	1.80	1.09						
B:	Motorscan	1.34		1.65							
A:	Celesco	0.26	1.08	1.23	1.33	0.95	1.14	3.07	0.88	3.41	1.00
B:	Sun	0.24		0.93		0.83		3.47		3.42	

Appendix D: Test Sheets Used for Snap Acceleration Testing.

Visual Inspection Sheet to be sent to Fuel Technology
If also emissions testing, staple any Emissions Test Printouts to this sheet

Vehicle Registration No: **Inspector:** **Date:**

Check ▼		Petrol ▼		Diesel ▼
1 Fuel System	►	☐ Carburettor ☐ EFI	►	☐ Direct Injection ☐ Indirect Injection ☐ Common Rail ☐ Rotary Pump ☐ Inline Pump ☐ Unsure
2 Air	►	☐ Turbocharged? ☐ Intercooled?	►	☐ Turbocharged? ☐ Intercooled?
3 Exhaust Gas Recirculation	►	☐ Yes ☐ No ☐ Unsure	►	☐ Yes ☐ No ☐ Unsure
4 Catalytic Converter	►	☐ Near Engine ☐ Mid Chassis ☐ Removed ☐ None ☐ Unsure	►	☐ Yes ☐ Removed ☐ No ☐ Unsure
5 Oxygen Sensor	►	☐ Connected ☐ Unlikely Working ☐ Removed ☐ None ☐ Unsure		
6 Fuel Filler Cap	►	☐ Simple ☐ Complex ☐ Good Sealing ☐ Seal Damaged	►	☐ Simple ☐ Complex ☐ Good Sealing ☐ Seal Damaged
7 Under Bonnet Appearance	►	☐ Good / Clean ☐ Fair ☐ Poor / Dirty	►	☐ Good / Clean ☐ Fair ☐ Poor / Dirty
8 Noticeable Exhaust Smoke ("Blip" a diesel)	►	☐ None ☐ Blue, Slight ☐ Blue, Significant	►	☐ Insignificant ☐ Blue ☐ Black ☐ Significant
9 Exhaust Deposits on Back of Vehicle	►	☐ None / Insignificant ☐ Light ☐ Significant	►	☐ None / Insignificant ☐ Light ☐ Significant

If Wof/Cof vehicle, result of WOF ☐ Pass ☐ Fail
Reason if failed:

If simple emissions testing: Date of last service:
Service due:

Any Comments:

REPAIR REPORT to be stapled to vehicle's Visual Inspection Sheet

Vehicle Registration No: Inspector: Date:

Make:
Model:
Engine:
Size (cc):
Date of last WOF/COF

_ _ _ _ _ _ _ _ _ _ _ _

Pre-repair Symptoms

- ☐ Smokey
- ☐ Low power
- ☐ Hard starting
- ☐ Engine stumbles
- ☐ Miss (petrol)
- ☐ Regular service/lube (incl. Cam belt replace)
- ☐ Electronic
- ☐ Fuel leak
- ☐ Other:

Visual Condition Inspection:

Date last service		(sticker?)	
Air filter condition	☐ Light grey	☐ Heavy grey	☐ Black
Breather pipes condition	☐ Good	☐ Fair	☐ Poor
EGR condition (where fitted)	☐ Good	☐ Fair	☐ Poor

Repair/Diagnostics:

- ☐ Engine wear/poor condition
- ☐ Air filter replace
- ☐ Injector service
- ☐ Pump service
- ☐ Fuel blockage/filter replace
- ☐ Fuel system air leak
- ☐ Glow plug system fault
- ☐ EGR service
- ☐ Turbocharger service
- ☐ Exhaust repair
- ☐ Electronics repair
- ☐ Cam belt replace
- ☐ General lube service
- ☐ General repair
- ☐ Spark plugs replace
- ☐ HT lead replace
- ☐ Other ignition problem
- ☐ Other:

Cost of Repair: **Parts: $** **Labour: $** **Total: $**

☐ New Parts Fitted ☐ Used Parts Fitted

☐ No post-repair test required

DIESEL REPAIR EMISSIONS TEST RESULTS

Provided to Vehicle Owner for their information

Thank you for taking part in the pilot emissions testing programme being carried out for the Ministry of Transport.

The pre-repair emissions test result was

m^{-1}

And indicates the emissions performance of the engine was:

Good **Fair** **Poor**

The post-repair emissions test result was

m^{-1}

And indicates the emissions performance of the engine is:

Good **Fair** **Poor**

The test used provides an indication of the vehicle's emissions performance. The following table has been used as a guide to provide the emissions performance of your vehicle.

Indicated Performance	Pre-1980 NA	Pre-1980 Turbocharged	Post-1980 NA	Post-1980 Turbocharged
Good	0-1.8	0-2.1	0-1.6	0-1.9
Fair	1.9-2.4	2.2-2.9	1.7-2.2	2.0-2.7
Poor	>2.5	>3.0	>2.3	>2.8

Table 1: Indication of Emissions Performance of the Engine Based on Test result and Engine Type and Age

Want Further Information?

If you have any comments or wish to register a complaint please email the Project Manager on acampbell@fueltechnology.net.

EMISSIONS TEST RESULTS

Provided to Vehicle Owner for their information

Thank you for taking part in the pilot emissions testing programme being carried out for the Ministry of Transport.

The emissions test result for diesel was:

m^{-1}

And indicates the emissions performance of the vehicle is:

Good	Fair	Poor

The emissions test result for petrol was:

% CO	**ppm HC**

And indicates the emissions performance of the vehicle is:

Good	Fair	Poor

The test used provides an indication of the vehicle's emissions performance. The following tables have been used as a guide to provide the emissions performance of your vehicle.

Indicated Performance	Pre-1980 NA	Pre-1980 Turbocharged	Post-1980 NA	Post-1980 Turbocharged
Good	0-1.8	0-2.1	0-1.6	0-1.9
Fair	1.9-2.4	2.2-2.9	1.7-2.2	2.0-2.7
Poor	>2.5	>3.0	>2.3	>2.8

Table 1: Indication of Emissions Performance of a Diesel Engine Based on Test result and Engine Type and Age.

Indicated Performance	Pre-1990 %CO	Pre-1990 ppm HC	1990-1996 and no cat %CO	1990-1996 and no cat ppm HC	Catalyst %CO	Catalyst ppm HC
Good	0-2.0	0-500	0-1.5	0-500	0-0.2	0-200
Fair	2.0-4.0	500-1200	1.5-3.0	500-1000		
Poor	>4.0	>1200	>3.0	>1000	>0.2	>200

Table 2: Indication of Emissions Performance of a Petrol Engine Based on Test Result and Engine Type and Age (Take Worst Result).

Contact?

If you have any comments or wish to register a complaint please email the Project Manager on acampbell@fueltechnology.net.

EMISSIONS TESTING – NATIONAL SURVEY

Consent form to be given to vehicle presenters then sent to Fuel Technology

We wish to check the emissions of your car as part of a **national survey** being carried out for the Ministry of Transport.

The check takes a few minutes. For petrol vehicles, the test involves increasing the engine speed to about mid-speed …similar to that cruising down a flat road at city speeds. For diesel engines, the accelerator is quickly depressed several times whilst the vehicle is stationary and the engine is out of gear.

The test is **free.** There is no obligation to have a check taken but you will get **valuable information** on the emission performance of your vehicle.

This check is currently not part of the WOF/COF inspection. Hence we require your consent. The result will not have any bearing on your WOF/COF result.

If you consent to the check could you please sign below. We would also appreciate you answering the questions below.

Name:______________________________ Vehicle Registration:__________________

Signature:____

Thank you for your cooperation.

QUESTIONNAIRE

PRIVATE VEHICLE ▼

Number of vehicles in your household

☐ 1 ☐ 2 ☐ 3 +

This vehicle the

☐ main ☐ 2nd ☐ 3rd vehicle

Time since last service

☐ 1mth ☐ 2mths ☐ 3mths ☐ 6mths ☐ 1yr+

Who does service?

☐ Self ☐ Sml Workshop ☐ Lge Workshop

How often do you have your vehicle serviced?

☐ 3mths ☐ 6mths ☐ 1yr ☐ 2yr+

Weekly usage of car

☐ less than 50 km
☐ 50 km to 100 km
☐ 100 km to 200 km
☐ more than 200 km

COMPANY VEHICLE ▼

Main use of car

☐ Personnel Transport

☐ Open road – goods / sales

Vehicle Ownership

☐ Company ☐ Leased

Number of vehicles in Company

☐ 1-5 ☐ 6-10 ☐ 11-20 ☐ 20+

Servicing

☐ Company ☐ Contracted

Weekly usage of car

☐ less than 50 km
☐ 50 km to 100 km
☐ 100 km to 200 km
☐ more than 200 km

Can we also contact you about this programme? If so, please provide your contact details.

Day: ___________________ After Hours: __________________

Email:____________________________________

Check ***'Clean up your vehicle's emissions'*** or visit the Ministry of Transport's website: www.transport.govt.nz/business/land/vehicle-exhaust-emissions-2003.php

THANK YOU

Please return this form to the Inspector

Testing Protocol – General Guide

The following is a general guide for the testing protocol.

The key elements of the testing protocol required are:

Initial Contact with Vehicle Presenter:

- Introduce the vehicle testing programme referring to the notes provided in the Vehicle Test Consent Form. These notes inform the vehicle presenter:
    - Testing is being carried out for the Ministry of Transport
    - There is no obligation
    - There is no cost to the presenter
    - Information will be kept confidential
    - A copy of the results will be provided.
- Obtain a signature consenting to the test. The possible exception to this is for vehicles that are being repaired as the testing may be considered as part of the repair, by some workshops, and therefore consent would not be required.
- Inform the driver of the test being conducted:
    - For petrol vehicles, the engine is operated at 'high idle', which is similar to an easy drive down a level road. The engine is also checked at normal idle. Inform the vehicle presenter the engine may sound far noisier than expected due to them not being inside the sound-insulated cabin of the vehicle.
    - For diesel vehicles, the test involves accelerating the engine in neutral up to governed speed a number of times. The engine will sound as though it is 'revving' at a high speed. The engine is not under any external load and this operation is well within the engine's capabilities. The test is based on the compulsory emissions test used in the UK and other countries in Europe.
- Kindly ask the vehicle presenter to also fill in the questionnaire at the bottom of the Consent Form and ask them to return the form to the counter.
- If a diesel vehicle, ascertain the condition of the engine:
    - Ask if the cam belt has been replaced.
    - Ask if the vehicle is serviced regularly.

  Do not test if you have concerns about the integrity of a diesel engine.

The vehicle presenter may ask questions about the programme. The following provides background on the programme and current Government thinking:

- Emissions screening will be introduced at the time of WOF/COF for all vehicles beginning mid 2006. This testing is a pilot to trial various emissions tests that will possibly be used in the 2006 emissions screening.
- Emissions screening will also be introduced for imported used vehicles before they can be used on the road in New Zealand.
- The aims of the pilot include:
    - Considering how good simple tests used in other countries are in identifying gross emitters.
    - Identifying an emissions profile for the vehicles in New Zealand
    - Identifying a technology profile of existing vehicles in New Zealand, it being somewhat unknown how many vehicles of any given engine technology exist in this country, and what their general condition is.
- The tests used are based on internationally recognized standard emissions tests.

- Vehicle-specific emission information will be kept confidential. Registration details will only be used to identify the basic vehicle characteristics.
- A wide sample of vehicles is required to be captured. This will likely require targeting of certain vehicle types. Hence not all vehicles that turn up for a WOF/COF may be appropriate for testing. For example, the sample of recent model petrol vehicles may be quickly reached and no further testing of this vehicle type would then be required.
- The simple testing is being complemented by sophisticated 'rolling road' dynamometer vehicle testing. The dynamometer testing is carried out to provide an indication of on-road emissions using internationally recognized drive cycles. The results can then be compared with the simple test results to gauge how good the simple tests are at indicating on-road emission performance.
- It is very, very, unlikely that engine damage will result from carrying out the test. This is the experience found in the UK. However, due to the concerns raised by some vehicle presenters to date we have taken out insurance to cover for the engine damage incurred as a result of the testing being carried out. It is also noted that tests for petrol operate the engine in a manner similar to very light load operation of the vehicle on the road. The diesel test loads the engine for only a short time and the peak engine speed is governed by fuel pump governor. This governing occurs on the road as well.

Please note any major concerns or interesting feedback from vehicle presenters. This is also valuable information for the pilot.

The test procedures are described in Schedule 3: Test Method-Petrol and Schedule 4: Test Method-Diesel.

Note that part of the procedure for the diesel test is to ascertain whether the engine is in a suitable condition for being tested. This requires the vehicle presenter to be asked about the service history of the vehicle. It is suggested this questioning be carried out once the vehicle presenter has offered consent to having the vehicle tested.

- Enter the test result (average of the last three accelerations in the case of diesel) onto the appropriate Emissions Feedback Form.
- Kindly ask if the vehicle presenter has returned the questionnaire to the counter.

Schedule 3: Test Method – Diesel

1. Locate vehicle in designated test area and put the handbrake firmly on
2. Engage park if an automatic or neutral if a manual select gearbox
3. Check for:
    - Exhaust leaks
    - Abnormal noise
    - Indications there has been no service on the engine for a very long time (ask vehicle presenter)

    → if one of the above DO NOT PROCEED FURTHER and inform vehicle presenter
4. Zero analyzer if analyser does not do this automatically
5. Check engine is fully warmed
    - Water temperature gauge showing off cold
    - Radiator warm
    - Vehicle arrived within last 5 minutes from use of road

    → if not, operate engine at 2000 rpm for 120 seconds
6. Check for excessive smoke
    - Snap accelerate engine (that is, a fast foot to floor throttle movement, holding for 2-seconds then releasing throttle) and check for exhaust smoke level.
    - If the smoke is excessive, that is, still quite dense smoke in the air 10-seconds after this test, record "**fail to test due to excessive smoke**" on the visual inspection sheet.

    → DO NOT PROCEED FURTHER and inform vehicle presenter.
7. Check the engine's maximum speed governor is working:
    - Depress the throttle over about 5 seconds and ensure the engine is controlled to its governed speed

    → If no governing DO NOT PROCEED FURTHER and inform vehicle presenter. Record on visual inspection sheet.
8. Insert the appropriate probe the set amount into the exhaust pipe. (Different probes from different analysers have different insertion distances. The probe must be at least 150mm into the exhaust pipe).
9. Select the test to begin on analyzer
10. Operate the engine as directed by the analyzer
    - When depressing the throttle, depress it quickly and firmly to the floor in less than 0.5 seconds. A slower rate will provide an unreliable measurement.
    - Hold maximum engine speed for 1 seconds and release the throttle.
    - Carry out 4 to 10 snap accelerations, stopping when there is reasonable consistency in the results or at 10, whichever occurs first.
    - Do not continue testing if during the testing you suspect the engine is not in an appropriate condition to test.
11. Tear off print out, record the vehicle's data on the print out and attach to the vehicle's Visual Inspection Form. Attach both before and after printouts in the case of a repair likely to affect the vehicle's emissions.

End of Emissions Test.

Appendix E: Data From Visual Inspection of Vehicles

Table 14: Summary Visual Inspection Data, WoF-Timing Corrected, By Location.

Light Vehicles – Adjusted Snap Acceleration Sample		Technology T1	T2	T3	Total
Whangarei (total sample size = 10)					
New-Other	Sample size		4		4
	As percent (%)		100		40
	Average YoM		2002.0		
	Average Odo		5.2		
Used-Japan	Sample size	2	3		5
	As percent (%)	40	60		50
	Average YoM	1988.5	1989.0		
	Average Odo	18.9	19.5		
New-Japan	Sample size	1			1
	As percent (%)	100			10
	Average YoM	1993.0			
	Average Odo	21.6			
Auckland Combined (total sample size = 44)					
New-Other	Sample size	10	12		22
	As percent (%)	45	55		50
	Average YoM	1996.4	1998.0		
	Average Odo	11.2	31.3		
Used-Japan (total sample size = 10)	Sample size	7	5		12
	As percent (%)	58	42		27
	Average YoM	1992.6	1991.8		
	Average Odo	18.6	14.7		
New-Japan	Sample size	7	3		10
	As percent (%)	70	30		23
	Average YoM	1997.1	1998.0		
	Average Odo	22.5	8.8		

Waitakere (total sample size = 14)					
New-Other	Sample size	1	2		3
	As percent (%)	33	67		21.42857
	Average YoM	1981.0	2003.0		
	Average Odo	16.9	25.6		
Used-Japan	Sample size	5	4		9
	As percent (%)	56	44		64
	Average YoM	1993.4	1993.0		
	Average Odo	15.0	13.7		
New-Japan	Sample size		2		2
	As percent (%)		100		14
	Average YoM		2001.0		
	Average Odo		6.5		
Tauranga (total sample size = 41)					
New-Other	Sample size	1	6	1	8
	As percent (%)	13	75	13	20
	Average YoM	1997.0	1999.7	2001.0	
	Average Odo	13.3	14.5	5.7	
Used-Japan	Sample size	14	11		25
	As percent (%)	56	44		61
	Average YoM	1992.0	1993.8		
	Average Odo	16.7	11.3		
New-Japan	Sample size	7	1		8
	As percent (%)	88	13		20
	Average YoM	1996.0	2001.0		
	Average Odo	20.5	6.7		
Hamilton (total sample size = 22)					
New-Other	Sample size	2	2		4
	As percent (%)	50	50		18
	Average YoM	1999.0	1996.0		
	Average Odo	9.4	2.9		
Used-Japan (total sample size = 10)	Sample size	3	1		4
	As percent (%)	75	25		18
	Average YoM	1990.0	1992.0		
	Average Odo	20.5	17.5		
New-Japan	Sample size	14			14
	As percent (%)	100			64
	Average YoM	1997.9			
	Average Odo	12.0			

Christchurch Combined (total sample size = 102)					
New-Other	Sample size	2	16	9	27
	As percent (%)	7	59	33	26
	Average YoM	2000.0	1999.2	2003.7	
	Average Odo	17.4	19.6	0.8	
Used-Japan (total sample size = 10)	Sample size	22	35		57
	As percent (%)	39	61		56
	Average YoM	1993.0	1992.9		
	Average Odo	16.2	15.0		
New-Japan	Sample size	10	6	2	18
	As percent (%)	56	33	11	18
	Average YoM	1997.5	1998.2	2002.0	
	Average Odo	15.6	8.5	8.1	
Total Sample					
New-Other	Sample size	16	42	10	68
	As percent (%)	24	62	15	29
Used-Japan	Sample size	40	54	1	95
	As percent (%)	42	57	1	41
New-Japan	Sample size	46	22	2	70
	As percent (%)	66	31	3	30
Total	Sample size	102	118	13	233
	As percent (%)	44	51	6	100

Heavy Vehicles – Snap Acceleration Sample		Technology T1	T2	T3	Total
Auckland Combined (total sample size = 115)					
New-Other	Sample size	14	23		37
	As percent (%)	38	62		32
	Average YoM	1986.5	1993.4		
	Average Odo	27.9	31.3		
Used-Japan	Sample size	24	5		29
	As percent (%)	83	17		25
	Average YoM	1992.8	1989.8		
	Average Odo	18.6	17.9		
New-Japan	Sample size	30	17	2	49
	As percent (%)	61	35	4	43
	Average YoM	1996.1	2000.8	2002	
	Average Odo	19.2	16	10.1	
Tauranga (total sample size = 3)					
Used-Japan	Sample size	1	1		2
	As percent (%)	50	50		67
	Average YoM	1995	1995		
	Average Odo	9.1	9.2		
New-Japan	Sample size	1			1
	As percent (%)	100			33
	Average YoM	1988			
	Average Odo	15.4			
Hamilton (total sample size = 27)					
New-Other	Sample size	4		1	5
	As percent (%)	80		20	19
	Average YoM	1988.3		2000	
	Average Odo	14.5		34.2	
Used-Japan	Sample size	6			6
	As percent (%)	100			22
	Average YoM	1991.2			
	Average Odo	21			
New-Japan	Sample size	15	1		16
	As percent (%)	94	6		59
	Average YoM	1998.7	1992		
	Average Odo	10.7	14.1		

Christchurch Combined (total sample size = 110)					
New-Other	Sample size	8	24		32
	As percent (%)	25	75		29
	Average YoM	1988.3	1998.1		
	Average Odo	48.8	40.2		
Used-Japan	Sample size	27	5		32
	As percent (%)	84	16		29
	Average YoM	1989.8	1992		
	Average Odo	19.2	23.3		
New-Japan	Sample size	28	17	1	46
	As percent (%)	61	37	2	42
	Average YoM	1995.4	1998.9	2003	
	Average Odo	20	23	2	
Total Sample					
New-Other	Sample size	26	47	1	74
	As percent (%)	35	64	1	100
Used-Japan	Sample size	58	11	0	69
	As percent (%)	84	16	0	100
New-Japan	Sample size	74	35	3	112
	As percent (%)	66	31	3	100
Total	Sample size	158	93	4	255
	As percent (%)	62	36	2	100

Light Vehicles – Adjusted Visual Inspection Sample		Technology			Total
		T1	T2	T3	
Whangarei (total sample size = 85)					
New-Other	Sample size	17	7		24
	As percent (%)	71	29		28
	Average YoM	1995.7	2000.0		
Used-Japan	Sample size	37	23		60
	As percent (%)	62	38		71
	Average YoM	1991.4	1991.9		
New-Japan	Sample size	1			1
	As percent (%)	100			1
	Average YoM	1993.0			
Auckland Combined (total sample size = 45)					
New-Other	Sample size	10	13		23
	As percent (%)	43	57		51
	Average YoM	1996.4	1998.0		
Used-Japan	Sample size	7	5		12
	As percent (%)	58	42		27
	Average YoM	1992.6	1991.8		
New-Japan	Sample size	7	3		10
	As percent (%)	70	30		22
	Average YoM	1997.1	1998.0		
Waitakere (total sample size = 53)					
New-Other	Sample size	9	6		15
	As percent (%)	60	40		28
	Average YoM	1994.6	2002.0		
Used-Japan	Sample size	16	20		36
	As percent (%)	44	56		68
	Average YoM	1991.8	1992.7		
New-Japan	Sample size	2			2
	As percent (%)	100			4
	Average YoM	2001.0			
Tauranga (total sample size = 44)					
New-Other	Sample size	2	8	1	11
	As percent (%)	18	73	9	25
	Average YoM	1997.0	1999.7	2001.0	
Used-Japan	Sample size	14	11		25
	As percent (%)	56	44		57
	Average YoM	1992.0	1993.8		
New-Japan	Sample size	7	1		8
	As percent (%)	88	13		18
	Average YoM	1996.0	2001.0		

Hamilton (total sample size = 28)					
New-Other	Sample size	6	3		9
	As percent (%)	67	33		32
	Average YoM	1999.2	1996.0		
Used-Japan	Sample size	4	1		5
	As percent (%)	80	20		18
	Average YoM	1990.5	1992.0		
New-Japan	Sample size	14			14
	As percent (%)	100			50
	Average YoM	1997.9			
Palmerston North (total sample size = 91)					
New-Other	Sample size	18	9	2	29
	As percent (%)	62	31	7	32
	Average YoM	1998.0	1998.3	1998.0	
Used-Japan	Sample size	23	36	3	62
	As percent (%)	37	58	5	68
	Average YoM	1991.7	1993.5	1996.0	
New-Japan	Sample size				
	As percent (%)				
	Average YoM				
Wellington (total sample size = 33)					
New-Other	Sample size	14	2	2	18
	As percent (%)	78	11	11	55
	Average YoM	1999.2	1998.5	1998.0	
Used-Japan	Sample size	13	2		15
	As percent (%)	87	13		45
	Average YoM	1993.0	1995.5		
New-Japan	Sample size				
	As percent (%)				
	Average YoM				
Blenheim (total sample size = 57)					
New-Other	Sample size	18	8		26
	As percent (%)	69	31		46
	Average YoM	1994.3	2000.3		
Used-Japan	Sample size	18	13		31
	As percent (%)	58	42		54
	Average YoM	1991.6	1994.0		
New-Japan	Sample size				
	As percent (%)				
	Average YoM				

Nelson (total sample size = 96)					
New-Other	Sample size	20	13	2	35
	As percent (%)	57	37	6	36
	Average YoM	1996.4	1998.5	2000.0	
Used-Japan	Sample size	26	34	1	61
	As percent (%)	43	56	2	64
	Average YoM	1990.5	1992.9	1996.0	
New-Japan	Sample size				
	As percent (%)				
	Average YoM				
Christchurch Combined (total sample size = 114)					
New-Other	Sample size	3	20	9	32
	As percent (%)	9	63	28	28
	Average YoM	2000.0	1999.2	2003.7	
Used-Japan	Sample size	23	40		63
	As percent (%)	37	63		55
	Average YoM	1993.0	1992.9		
New-Japan	Sample size	10	7	2	19
	As percent (%)	53	37	11	17
	Average YoM	1997.5	1998.2	2002.0	
Timaru (total sample size = 52)					
New-Other	Sample size	8	2		10
	As percent (%)	80	20		19
	Average YoM	1997.4	2000.0		
Used-Japan	Sample size	27	15		42
	As percent (%)	64	36		81
	Average YoM	1992.1	1990.8		
New-Japan	Sample size				
	As percent (%)				
	Average YoM				
Alexandra (total sample size = 37)					
New-Other	Sample size	7	4	3	14
	As percent (%)	50	29	21	38
	Average YoM	1990.3	1991.8	1997.3	
Used-Japan	Sample size	7	12	4	23
	As percent (%)	30	52	17	62
	Average YoM	1990.3	1992.0	1995.8	
New-Japan	Sample size				
	As percent (%)				
	Average YoM				

Dunedin (total sample size = 25)					
New-Other	Sample size	9			9
	As percent (%)	100			36
	Average YoM	1994.4			
Used-Japan	Sample size	13	3		16
	As percent (%)	81	19		64
	Average YoM	1992.4	1991.7		
New-Japan	Sample size				
	As percent (%)				
	Average YoM				
Invercargill (total sample size = 17)					
New-Other	Sample size	4	2		6
	As percent (%)	67	33		35
	Average YoM	1998.8	2003.0		
Used-Japan	Sample size	5	3	3	11
	As percent (%)	45	27	27	65
	Average YoM	1993.0	1991.3	1995.3	
New-Japan	Sample size				
	As percent (%)				
	Average YoM				
Total Sample					
New-Other	Sample size	145	97	19	261
	As percent (%)	56	37	7	34
Used-Japan	Sample size	233	218	11	462
	As percent (%)	50	47	2	59
New-Japan	Sample size	41	11	2	54
	As percent (%)	76	20	4	7
Total	Sample size	419	326	32	777
	As percent (%)	54	42	4	100

Heavy Vehicles – Visual Inspection Sample		Technology T1	T2	T3	Total
Auckland Combined (total sample size = 114)					
New-Other	Sample size	13	23		36
	As percent (%)	36	64		32
	Average YoM	1985.1	1993.4		
Used-Japan	Sample size	25	4		29
	As percent (%)	86	14		25
	Average YoM	1992.6	1990.0		
New-Japan	Sample size	30	17	2	49
	As percent (%)	61	35	4	43
	Average YoM	1996.1	2000.8	2002.0	
Tauranga (total sample size = 4)					
New-Other	Sample size	1	1		2
	As percent (%)	50	50		50
	Average YoM	1995.0	1995.0		
Used-Japan	Sample size	2			2
	As percent (%)	100			50
	Average YoM	1988.0			
New-Japan	Sample size				
	As percent (%)				
	Average YoM				
Hamilton (total sample size = 29)					
New-Other	Sample size	6	1		7
	As percent (%)	86	14		24
	Average YoM	1992.7	2000.0		
Used-Japan	Sample size	6	15		21
	As percent (%)	29	71		72
	Average YoM	1991.2	1998.7		
New-Japan	Sample size	1			1
	As percent (%)	100			3
	Average YoM	1992.0			
Christchurch Combined (total sample size = 110)					
New-Other	Sample size	8	24		32
	As percent (%)	25	75		29
	Average YoM	1988.3	1998.1		
Used-Japan	Sample size	27	5		32
	As percent (%)	84	16		29
	Average YoM	1989.8	1992.0		
New-Japan	Sample size	28	17	1	46
	As percent (%)	61	37	2	42
	Average YoM	1995.4	1998.9	2003.0	

Timaru total sample size = 43)					
New-Other	Sample size	21	7		28
	As percent (%)	75	25		65
	Average YoM	1985.1	1990.3		
Used-Japan	Sample size	13	2		15
	As percent (%)	87	13		35
	Average YoM	1987.0	1988.0		
New-Japan	Sample size				
	As percent (%)				
	Average YoM				
Total Sample					
New-Other	Sample size	49	56	0	105
	As percent (%)	47	53	0	35
Used-Japan	Sample size	73	26	0	99
	As percent (%)	74	26	0	33
New-Japan	Sample size	59	34	3	96
	As percent (%)	61	35	3	32
Total	Sample size	181	116	3	300
	As percent (%)	60	39	1	100

Appendix F: Snap Acceleration Balloon Plot for Heavy Diesel Vehicles.

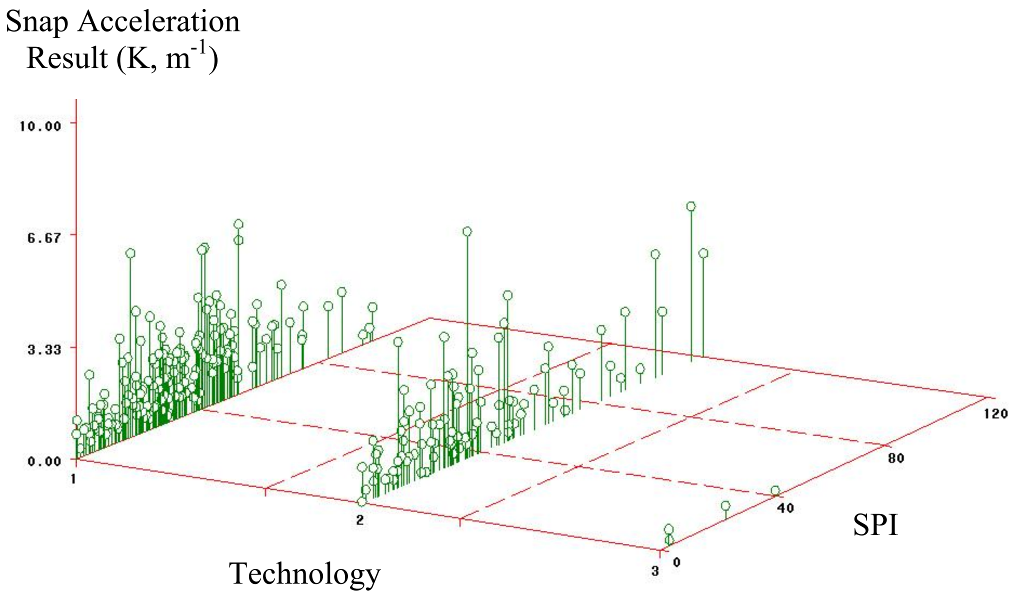


Figure 26: Balloon Plot of the Snap Acceleration Results for Heavy Vehicles in the Pilot's Snap Acceleration Data Set.

Appendix G: Additional Data Analysis Carried Out on the Profiling Snap Acceleration Data Set.

Figure 27 and Figure 28 provide the median snap acceleration results and 90% confidence intervals for various technologies and YoM groups[112] for the profiling snap acceleration data set. The 90% confidence intervals for Technology 1 and 2 consistently overlap, indicating there is no statistically significant difference between the results for Technology 1 and 2 (as found using other analysis). On the other hand the median result for Technology 3 is statistically significantly different to those for Technology 1 and Technology 2 for heavy vehicles and is almost so for light vehicles (as gauged by the separation of the 90% confidence intervals). Analysis using SAS, which considers YoM as a continuous variable, also shows this to be the case across the light vehicle YoM range, suggesting the comparison illustrated by Figure 27 is compromised by considering year ranges rather than on a continuous-year basis.

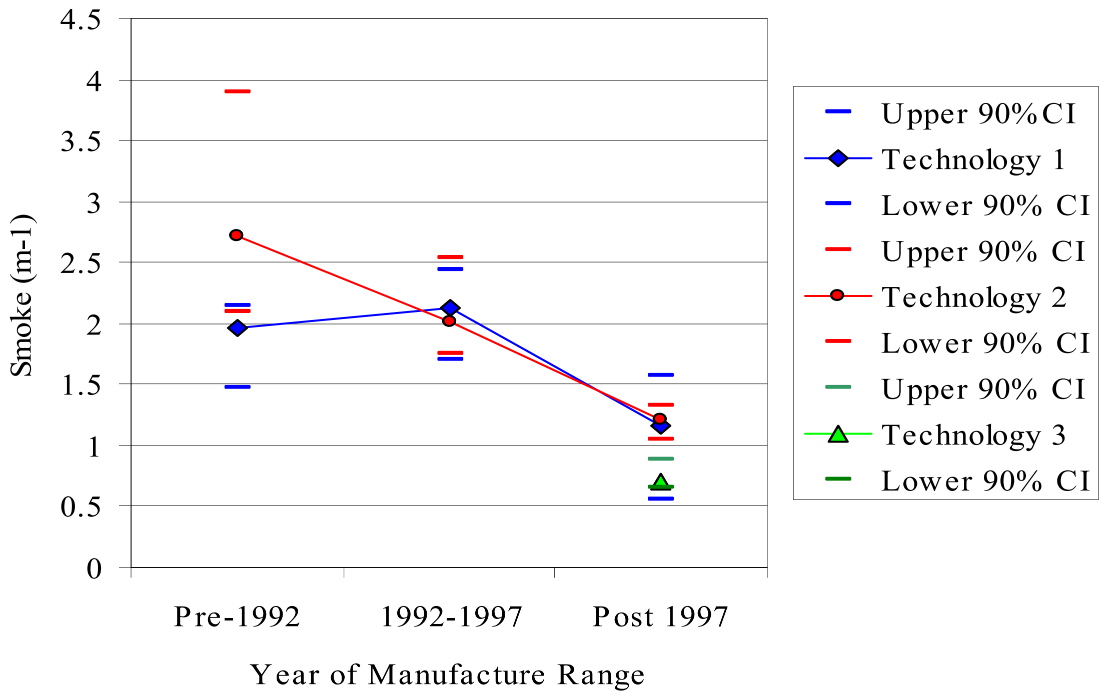


Figure 27: Median Snap Acceleration Results (Smoke Density, K, m^{-1}) for Light Diesel Vehicles by Technology and YoM Range for the Adjusted Snap Acceleration Data Set.

[112] These YoM ranges were chosen in an attempt to align with significant changes in emissions build standards in overseas jurisdictions — in Japan there was a significant decrease in permitted emissions limits for diesel vehicles phased in during 1997 and 1998 and this timing is similar to when Euro 2 took effect for diesel vehicles in Europe.

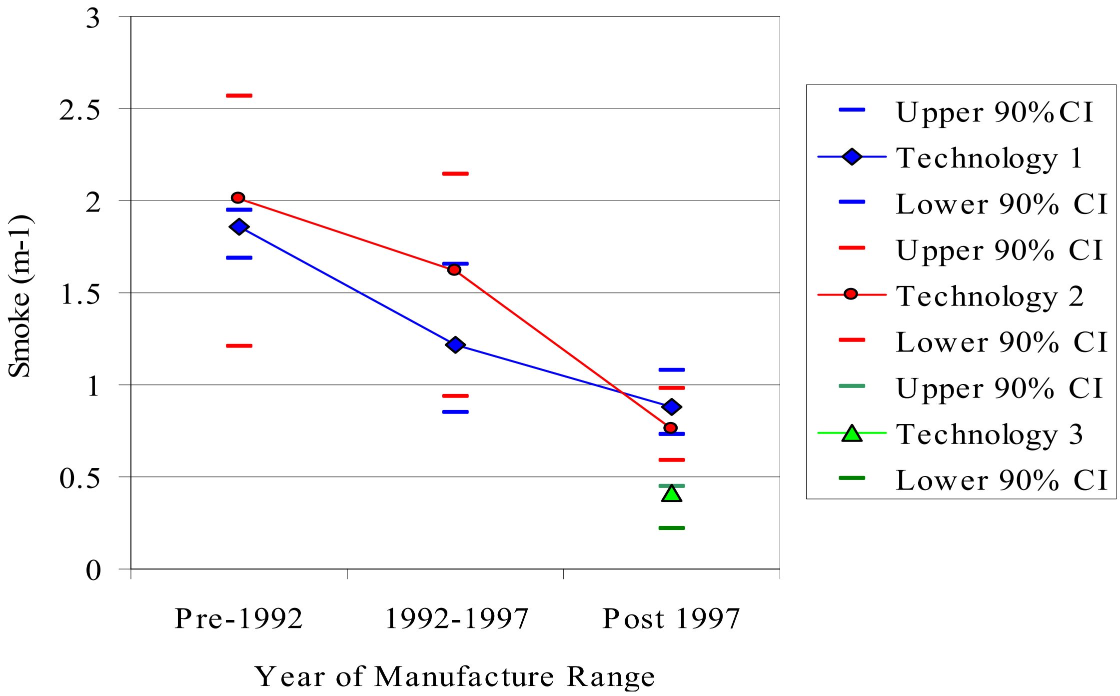


Figure 28: Median Snap Acceleration Results (Smoke Density, K, m^{-1}) for Heavy Diesel Vehicles by Technology and YoM Range for the Adjusted Snap Acceleration Data Set.

Earlier turbocharged vehicles (Technology 2, circles) are expected to exhibit a higher snap acceleration than non-turbocharged vehicles (Technology 1, diamonds), all else being equal, due to turbocharger lag, whereby it takes time for the turbocharger to spin up and develop air flow commensurate with the fuelling demanded. While there was a general trend indicating this may be the case for vehicles of earlier manufacture, this trend was not statistically significant. A difference is not expected for more modern vehicles due to better control of fuelling for these vehicles and this would likely be an overriding factor to the lack of statistical significance for this attribute.

Appendix H: Specification of the Various Dynamometer Test Arrangements.

H.1 Testing at the EFRU — Light Vehicles

General Dynamometer Arrangement

The EFRU chassis dynamometer arrangement consists of two rollers, set into the floor, on which the driven wheels of the vehicle sit. A load absorption unit absorbs power from the driven wheels and is designed to reproduce the tractive load versus speed relationship of typical vehicles. Flywheels are commonly used to simulate the inertia of the vehicle under acceleration and deceleration.

The chassis dynamometer at the University of Auckland's EFRU is a Schenck twin-roller unit. The dynamometer uses an eddy current absorption unit, electronically controlled to provide a fully programmable road load power absorption curve to represent a vehicle's rolling and aerodynamic load demands. A set of five flywheels provides inertia simulation from 600 to 2500 kg in 115 kg increments, allowing for vehicles of varying mass. The details of the dynamometer are:

Model:	Schenck 364/230
Maximum power absorption:	230 kW
Maximum tractive load:	5,000 N
Maximum Speed:	200 km/h
Roller Configuration:	2 x 364 mm diameter
Maximum axle load:	1.5 tonnes
Inertia simulation:	Flywheels in 115 kg steps to 2.5 tonnes
Road Load Simulation:	Fully programmable quadratic load curve

The dynamometer inertia and road load factors were set in accordance with procedures set out in Australian Design Rule (ADR) 37 (ADR 37 was the standard applied for emissions determination in Australia when Australia was using the FTP cycle for vehicle emissions compliance, and has been used in New Zealand since testing to the IM240 drive cycle required that a similar procedure be followed).

Emissions Measurement — Constant Volume Sampling System

The EFRU utilises a constant volume sampling (CVS) system to measure drive cycle emissions. The CVS system is the internationally accepted method of measuring a vehicle's transient cycle emissions for both certification and inventory purposes.

Measurement of Exhaust Emissions for Gaseous Emission Species

A schematic of a CVS system is shown in Figure 29. For the measurement of gaseous emissions species, this system collects the entire vehicle exhaust, dilutes it with ambient air so as to maintain a constant total volumetric flow rate, draws a small fixed proportion of the diluted flow and stores this in inert bags.

At the end of a test the sample in the bag is analysed for the concentrations of the emission species of interest. Emissions are calculated as grams per kilometre (g/km) or grams per second (g/s), knowing the volume of diluted exhaust gas measured by the CVS system and the concentration of the pollutant from the bag analysis. These emissions represent the average emissions rates per unit distance/time, over the whole drive cycle operation.

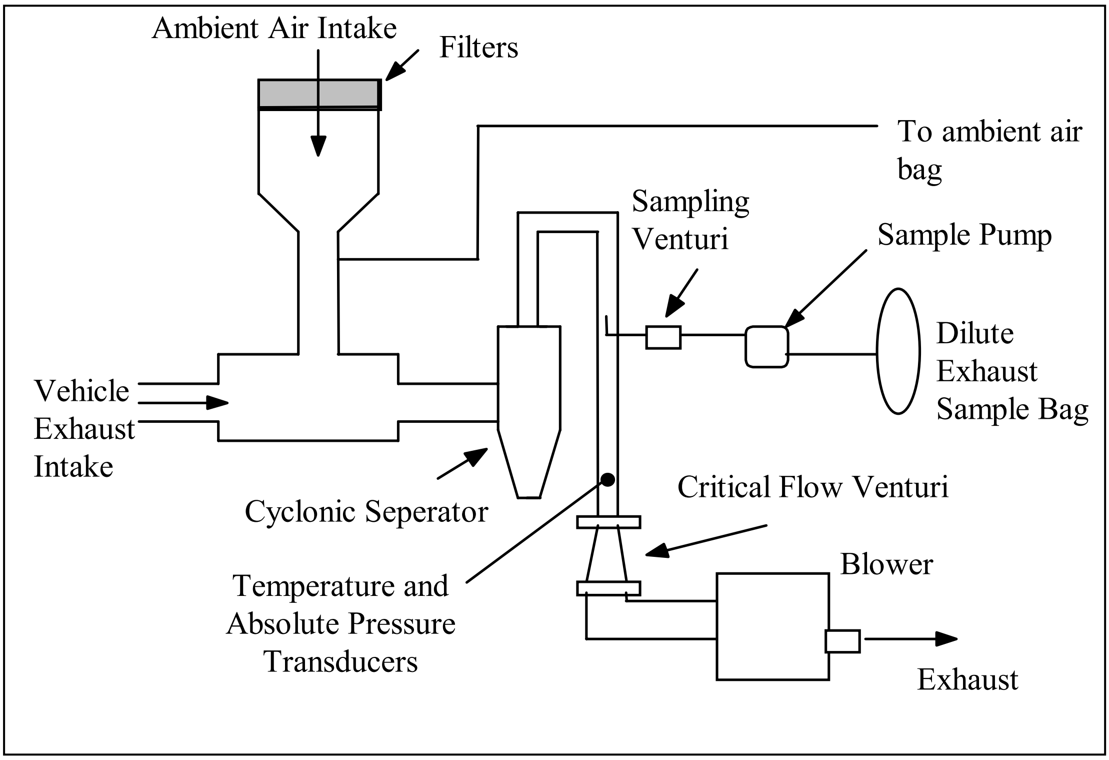


Figure 29: Schematic of the CVS System.

The CVS unit at the EFRU is a Beckman CCU-80 unit. This unit uses a critical flow venturi to maintain a constant total flow rate (exhaust plus dilution air). A venturi giving 150 litres per second nominal flow rate was used. Six bags are provided, three for ambient air and three for dilute exhaust samples.

Laboratory standard exhaust gas analysers are used to analyse the concentration of carbon monoxide (CO), carbon dioxide (CO_2), total hydrocarbons (THC) and oxides of nitrogen (NO_x) in the ambient air and dilute sample bags at the end of a test. The ambient air bag measurements are used to correct for background levels of the emission species being measured. The analysers used at the EFRU are:

Hydrocarbons Analyser:	Signal 3000 HM heated FID total hydrocarbons analyser, auto-ranging, 10,000, 4,000, 1,000, 400, 100, 40 10 and 4 ppm ranges. Response time <1.5s.
Oxides of Nitrogen:	Signal 4000 VM Chemiluminescent Analyser, ranges same as 3000 HM. Response time <1.5s.

Carbon Monoxide:	ADC Series 5000 non-dispersive infra-red (NDIR) rotating filter analyser, ranges 200 and 1000 ppm,
	ADC NDIR, ranges 2% and 10%.
Carbon Dioxide	ADC NDIR, ranges 3%, 15%.

A calibration check was conducted on the CVS system by admitting a measured quantity of propane span gas into the sampling system using a precision mass flow meter, and comparing this known amount with that calculated by the standard CVS bag analysis. The results agreed to within 1%, verifying the calibration of the emissions system and the calculation procedure.

In addition HC and NOx was measured modally, using a 4-gas analyser, to allow emission rates to be considered within drive cycles.

Measurement of Particulate Matter Emissions

Particulate Matter (PM) emissions were measured by passing an air-diluted sample of exhaust gas through a paper filter and measuring the increase in weight of the filter. The hardware and procedures used to collect filter samples are in general conformance with United States Federal Regulations.

Note this method collects total PM but, as individual particles from a diesel engine are expected to be less than 2.5µm across (a human hair ranges in diameter from around 25µm to 150µm) the same value could be used for PM_{10} or $PM_{2.5}$, the subscript referring to the maximum size of particle measured. PM_{10} and $PM_{2.5}$ are often referred to in reference to air quality.

The raw exhaust is first diluted in a primary tunnel of 304.8 mm diameter, and 3.5 m long (the *dilution tunnel*). The dilution tunnel is located between the point at which the raw vehicle exhaust and the dilution air mix. The purpose of a dilution tunnel is to simulate the mixing of the raw exhaust and air as occurs in the exhaust plume of a vehicle operating on the road. The length and sizing of the tunnel is to provide turbulent flow so as to provide a fully mixed and homogeneous flow at the sampling point. The diluted exhaust stream is further diluted in a secondary dilution tunnel. The purpose of the secondary tunnel is to ensure that the temperature limit of 52^{o}C is met at the sampling point. This is to simulate the degree of condensation and absorption of the heavier hydrocarbons onto the particulates, as occurs during the mixing process in the exhaust plume of a vehicle on the road.

Figure 30 is a schematic of the particulate tunnel and sampling system. Particulate matter is drawn from a 13 mm diameter probe located in the centre of the tunnel at the downstream end. A constant volume pump draws a fixed flow rate through the particulate filter. The filters are weighed before and after the test to determine the mass of particulate matter deposited onto the filters. A calculation is applied to convert this data into a particulate emission factor (g/km). A six-digit balance is used to weigh the filters.

The specifications of the tunnel system were:

Primary tunnel diameter:	304.8 mm
Primary tunnel length:	3.5 m
Primary tunnel flow rate:	Adjustable up to 350 l/s
Transfer probe diameter:	13 mm
Secondary tunnel diameter:	76 mm
Secondary tunnel length:	1 m
Secondary tunnel dilution air flow	0-170 litres /minute
Secondary tunnel total flow:	0-170 litres /minute
Secondary tunnel particulate filters:	Pallflex T60A20 70 mm diameter.

The sizing and flow rates of the two-stage dilution system are such as to allow testing of continuous engine power outputs of 100 kW without exceeding any temperature requirements in the US Federal Regulations. Higher transient power outputs are possible if the thermal capacity of the tunnel is used.

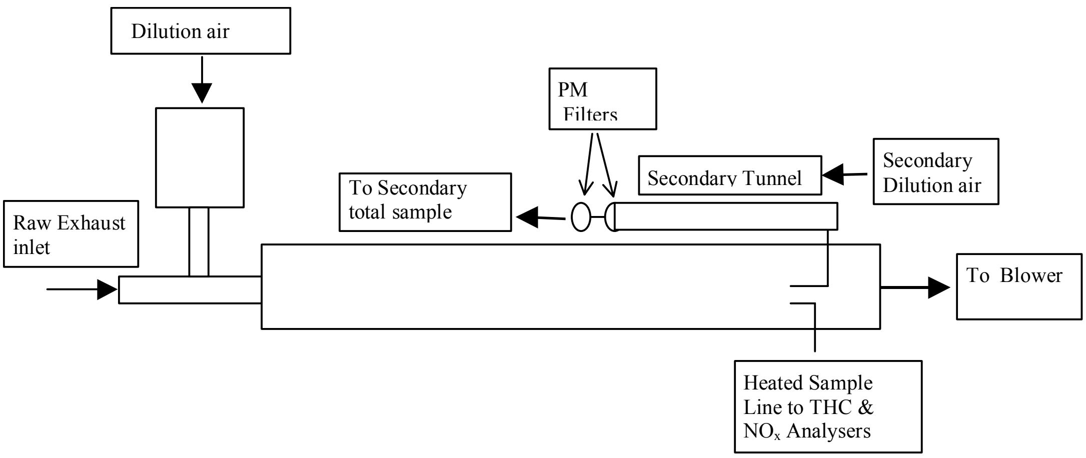


Figure 30: Schematic of the Diesel Particulate Sampling System.

In addition, an assessment of PM emission was made using a TSI DustTrak (LSP) with data collected modally during the drive cycles. The specification and settings used for the TSI DustTrak were:

PM concentration range:	0-100 mg/m^3
PM concentration resolution:	0.001 mg/m^3
PM particle size range:	0.1 to 10 µm
Accuracy:	not specified
Time averaging constant:	1 to 60 seconds (set to 1 second)
Sample rate:	1.4.to2.4 lpm

As well, vehicles were tested for modal exhaust opacity during drive cycles using the Celesco model 300 smoke meter, the same smoke meter used for snap accelerating testing dynamometer test vehicles.

Drive Cycle Tests

The drive cycle tests specific to light diesel vehicles tested at the EFRU are illustrated in Figures 31, 32 and 33.

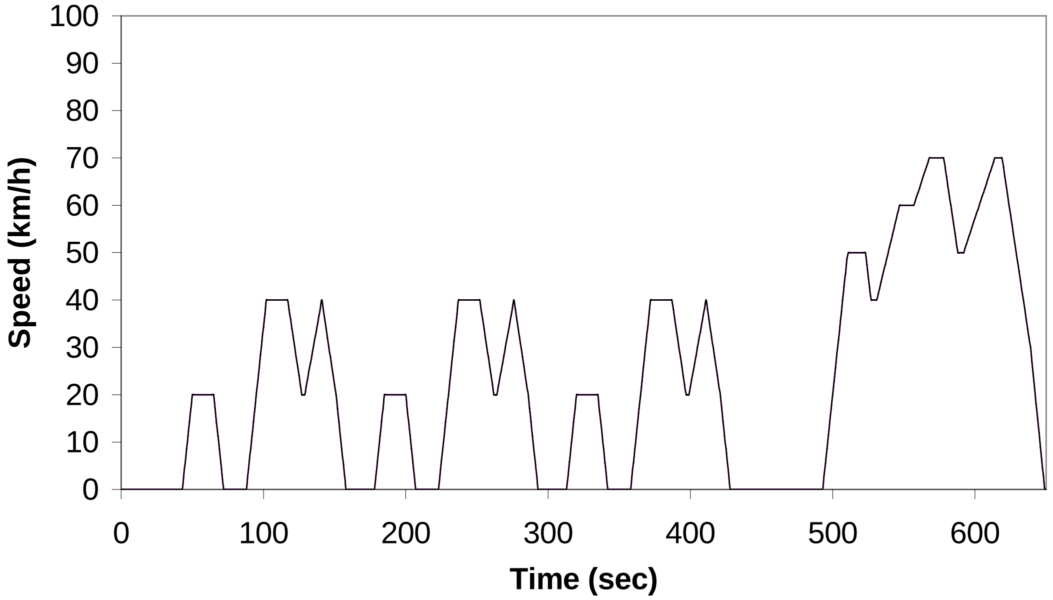


Figure 31: Vehicle Speed During the Jap10-15 Drive Cycle.

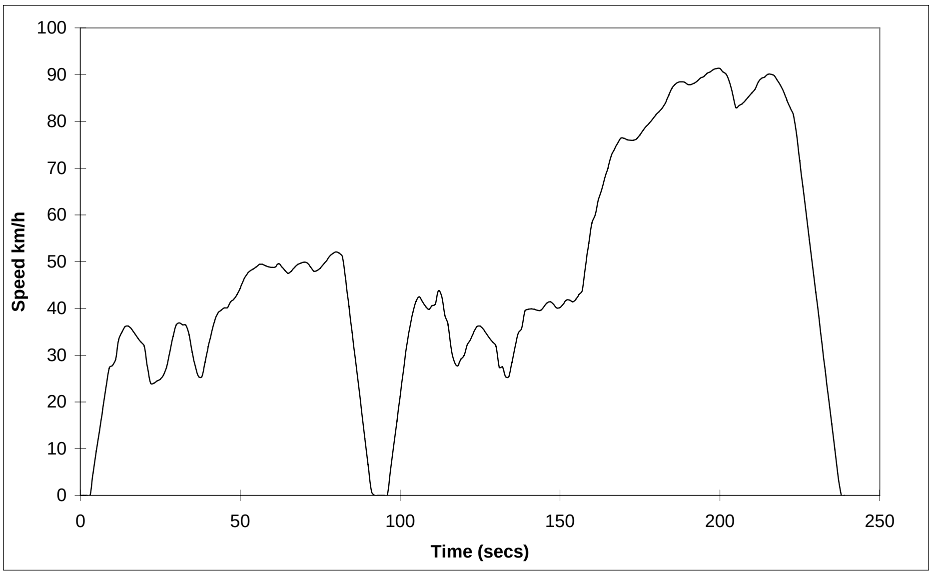


Figure 32: Vehicle Speed During the IM240 Drive Cycle.

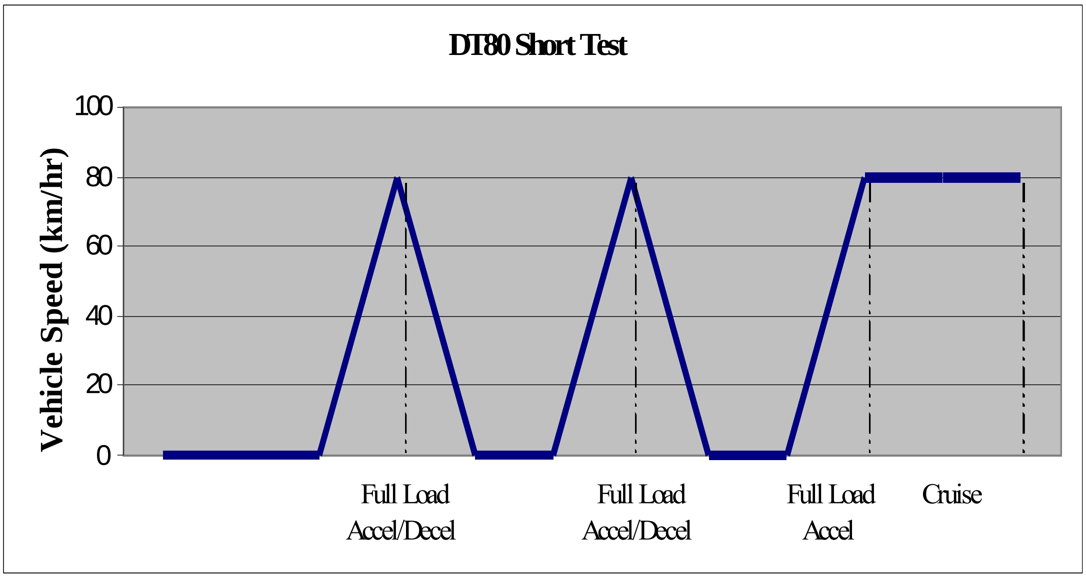


Figure 33: Vehicle Speed During the DT80 Test Procedure.

H.2 New Zealand Testing of Heavy Vehicles

New Zealand heavy vehicle testing was carried out at Gough Gough and Hamer Limited, Auckland, using their heavy vehicle dynamometer. Emissions instrumentation was as for testing carried out at the EFRU laboratory.

H.3 Diesel Test Australia — Light and Heavy Vehicles

Chassis Dynamometer

Diesel Test Australia's (DTA) chassis dynamometer is a mobile trailer unit capable of testing heavy vehicles to controlled transient loads. Power absorption is by eddy current brake. Figure 34 is a schematic of the DTA test arrangement.

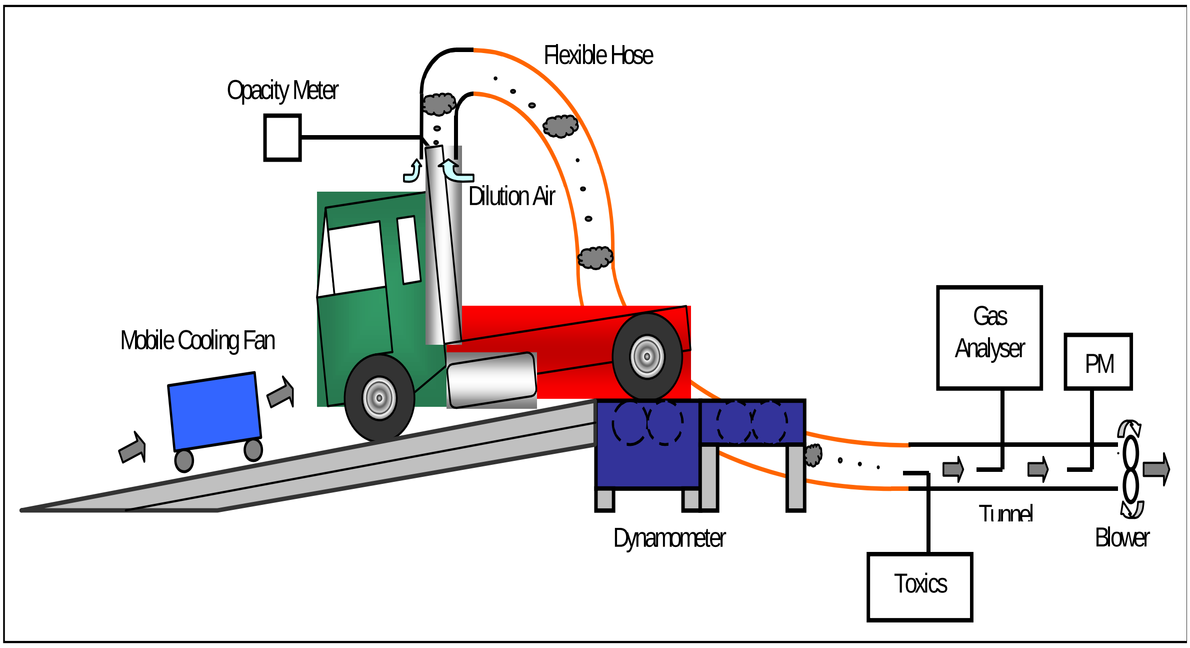


Figure 34: Schematic of the Diesel Test Australia Chassis Dynamometer Test Arrangement

Emissions Sampling and Measurement

The emissions sampling system captures all the exhaust from the vehicle's tailpipe and an amount of dilution air. The mixed sample passes through a tunnel housing various sample probes to which emissions analysers (NOx, PM and smoke) are connected.

Emissions Measuring System

Modal emission rates were measured during drive cycles using an LSP calibrated for diesel exhaust to measure particulate matter and a Horiba Mexa instrument (using zirconian sensor) to measure NOx. Emissions mass flows were then calculated from the modal measurements.

An AVL smoke meter was used to measure smoke density using the SAE J1667 test procedure, the same test procedure used for dynamometer test vehicles in New Zealand.

Appendix I: Results from Detailed Dynamometer Testing

Table 15: New Zealand Light Duty Diesel Data - Vehicle Details.

			Year	Manufacture	Model	NZ NEW	Techology	Odometer km	Engine size cc	Fuel sys	Turbocharged
1		CAR	1999	NISSAN	LAUREL	NO	2	82170	2800	ROTARY/IDI	NO
2		CAR	1994	NISSAN	PULSAR	NO	1	174117	1680	ROTARY/IDI	NO
3		CAR	1991	NISSAN	SERENA	NO	2	74112		ROTARY/IDI	YES
4		CAR	1990	TOYOTA	CORONA	NO	1	213601	1974	INLINE/IDI	NO
5		LT	2004	DAIHATSU	DELTA	YES	2	3710	2765	ROTARY/IDI	YES
6		LT	1996	MITSUBISH	CANTER 2	YES	1	134524	3567	INLINE/IDI	NO
7		LT	1996	MITSUBISH	CANTER 3	YES	1	134561	3567	INLINE/IDI	NO
8		LT	1986	DAIHATSU	DELTA	YES	1	75446	2770	ROTARY	NO
9		RV	1998	ISUZU	MU	NO	2	83583	3000	COMMON RAIL / DI	YES
10		RV	1997	MITSUBISH	CHALLENG	NO	2	98948	2800	ROTARY/IDI	YES
11	R	RV	1994	TOYOTA	ESTIMA EM	NO	2	74276	2200	ROTARY/IDI	YES
12		RV	1994	TOYOTA	ESTIMA EM	NO	2	74202	2200	ROTARY/IDI	YES
13	S	RV	1994	TOYOTA	HILUX SWT	NO	2	123020	2982	ROTARY/IDI	YES
14		RV	1994	TOYOTA	HILUX SWT	NO	2	122760	2982	ROTARY/IDI	YES
15		RV	1987	ISUZU	BIGHORN	NO	2	193414	2800	ROTARY/IDI	YES
16		VAN/UT	2004	MAZDA	BOUNTY	YES	2	2553	2500	ROTARY/IDI	YES
17		VAN/UT	1999	FORD	ESCORT	YES	1	88891	1800	ROTARY/IDI	NO
18		VAN/UT	1999	MERCEDES	VITO 108	NO	3	85110	2200	COMMON RAIL / DI	YES
19		VAN/UT	1997	MITSUBISH	L300	YES	2	123846	2500	ROTARY/IDI	YES
20		VAN/UT	1995	TOYOTA	HIACE	YES	2	53580	2779	ROTARY/IDI	YES
21		VAN/UT	1995	TOYOTA	HILUX	YES	1	63776	2446	ROTARY/IDI	NO
22		VAN/UT	1995	TOYOTA	HILUX	YES	2	183560	2446	ROTARY/IDI	YES

Key		
	LT	Light Truck
	VAN/UT	Van or light utility goods vehicle
	RV	Recreatioanal vehicle typically 4 wheel drive
	CAR	Passenger car
	R	Repeat test
	S	Vehicle repeat tested to include snap acceleration test

Table 16: New Zealand Light Duty Diesel Data – Jap10-15 Cycle Data.

	Year	Manufacturer	Model	CO g/km	CO2 g/km	HC g/km	NOx g/km	PM g/km	LSP PM g/km	FC l/100km	
1	1999	NISSAN	LAUREL	0.42	252.77	0.10	0.53	0.11	0.08	9.38	1.00
2	1994	NISSAN	PULSAR	0.45	212.01	0.13	0.46	0.16	0.07	7.88	2.00
3	1991	NISSAN	SERENA	0.46	271.64	0.14	0.45	0.10	0.09	10.08	3.00
4	1990	TOYOTA	CORONA	0.46	235.90	0.11	0.58	0.19	0.13	8.76	4.00
5	2004	DAIHATSU	DELTA	0.88	384.53	0.17	2.52	0.21	0.19	14.29	5.00
6	1996	MITSUBISHI	CANTER 2 tonne	1.49	280.80	0.34	2.08	0.21	0.35	10.51	6.00
7	1996	MITSUBISHI	CANTER 3 tonne	1.40	266.39	0.36	1.91	0.21	0.37	9.97	7.00
8	1986	DAIHATSU	DELTA	1.57	351.56	0.30	1.58	0.10		13.12	8.00
9	1998	ISUZU	MU	0.04	266.57	0.09	0.29	0.16	0.07	9.87	9.00
10	1997	MITSUBISHI	CHALLENGER	0.33	318.27	0.12	1.02	0.06	0.04	11.80	10.00
11	1994	TOYOTA	ESTIMA EMINA	0.62	269.00	0.09	0.65	0.09		9.99	11.00
12	1994	TOYOTA	ESTIMA EMINA	0.42	271.11	0.09	0.61		0.08	10.06	12.00
13	1994	TOYOTA	HILUX SWT	0.58	304.39	0.16	0.42	0.12	0.11	11.31	13.00
14	1994	TOYOTA	HILUX SWT	0.54	328.58	0.14	0.58	0.12		12.20	14.00
15	1987	ISUZU	BIGHORN	1.67	250.47	0.50	0.91	0.22	0.44	9.42	15.00
16	2004	MAZDA	BOUNTY	0.79	278.39	0.21	0.68	0.07	0.05	10.36	16.00
17	1999	FORD	ESCORT	0.55	192.43	0.21	0.57	0.07	0.04	7.17	17.00
18	1999	MERCEDES	VITO 108	2.79	260.26	0.58	0.77	0.14	0.15	9.85	18.00
19	1997	MITSUBISHI	L300	0.12	256.21	0.05	0.94	0.07	0.04	9.34	19.00
20	1995	TOYOTA	HIACE	0.56	290.21	0.14	1.01	0.11	0.08	10.78	20.00
21	1995	TOYOTA	HILUX	0.29	271.12	0.11	1.44	0.15	0.16	10.05	21.00
22	1995	TOYOTA	HILUX	0.54	248.55	0.14	1.14	0.14		9.24	22.00
		Max		2.79	384.53	0.58	2.52	0.21	0.37	14.29	
		Min		0.04	192.43	0.05	0.29	0.06	0.04	7.17	
		Average		0.74	275.69	0.19	1.04	0.13	0.13	10.36	

Table 17: New Zealand Light Duty Diesel Data –IM240 Cycle Data

	Year	Manufacturer	Model	CO g/km	CO2 g/km	HC g/km	NOx g/km	PM g/km	LSP PM g/km	FC l/100km	
1	1999	NISSAN	LAUREL	0.34	227.17	0.04	0.48	0.08	0.11	8.42	1.00
2	1994	NISSAN	PULSAR	0.30	221.90	0.06	0.49	0.11	0.09	8.23	2.00
3	1991	NISSAN	SERENA	0.62	258.41	0.08	0.56	0.18	0.20	9.60	3.00
4	1990	TOYOTA	CORONA	0.43	233.07	0.09	0.60	0.18	0.22	8.65	4.00
5	2004	DAIHATSU	DELTA	1.09	361.69	0.15	1.98	0.24	0.32	13.45	5.00
6	1996	MITSUBISHI	CANTER 2 tonne	1.35	298.39	0.29	2.22	0.39	0.58	11.14	6.00
7	1996	MITSUBISHI	CANTER 3 tonne	1.24	298.32	0.30	2.14	0.31	0.70	11.14	7.00
8	1986	DAIHATSU	DELTA	2.44	337.77	0.51	1.25	0.47	0.65	12.69	8.00
9	1998	ISUZU	MU	0.18	243.24	0.05	0.71	0.13	0.12	9.01	9.00
10	1997	MITSUBISHI	CHALLENGER	1.43	304.10	0.23	0.84	0.18	0.29	11.35	10.00
11	1994	TOYOTA	ESTIMA EMINA	5.74	280.76	0.10	0.51	0.64	0.96	10.72	11.00
12	1994	TOYOTA	ESTIMA EMINA	4.01	280.28	0.10	0.49	0.62	0.93	10.61	12.00
13	1994	TOYOTA	HILUX SWT	0.60	291.79	0.12	0.53	0.18	0.16	10.84	13.00
14	1994	TOYOTA	HILUX SWT	0.58	324.66	0.12	0.68	0.17	0.22	12.05	14.00
15	1987	ISUZU	BIGHORN	1.91	269.79	0.36	0.85	0.53	1.00	10.13	15.00
16	2004	MAZDA	BOUNTY	0.50	276.72	0.10	0.71	0.07	0.06	10.27	16.00
17	1999	FORD	ESCORT	0.32	186.21	0.08	0.49	0.08	0.07	6.91	17.00
18	1999	MERCEDES	VITO 108	1.52	261.68	0.27	0.78	0.27	0.27	9.79	18.00
19	1997	MITSUBISHI	L300	0.14	247.29	0.02	0.74	0.04	0.06	9.15	19.00
20	1995	TOYOTA	HIACE	0.50	275.17	0.07	0.79	0.10	0.10	10.21	20.00
21	1995	TOYOTA	HILUX	0.23	222.25	0.10	1.25	0.12	0.14	8.24	21.00
22	1995	TOYOTA	HILUX	0.48	254.22	0.09	0.94	0.19	0.24	9.44	22.00
		Max		5.74	361.69	0.30	2.22	0.64	0.96	13.45	
		Min		0.14	186.21	0.02	0.48	0.04	0.06	6.91	
		Average		1.23	269.33	0.13	0.98	0.23	0.32	10.04	

Table 18: New Zealand Light Duty Diesel Data –DT 80 Cycle Data.

	Year	Manufacturer	Model	CO g/km	CO2 g/km	HC g/km	NOx g/km	PM g/km	LSP PM g/km	FC l/100km	
1	1999	NISSAN	LAUREL	1.07	358.82	0.05	0.71	0.63	0.42	13.33	1.00
2	1994	NISSAN	PULSAR	0.44	354.70	0.06	0.88	0.17	0.12	13.15	2.00
3	1991	NISSAN	SERENA	1.12	412.38	0.09	0.97	0.90	0.69	15.32	3.00
4	1990	TOYOTA	CORONA	0.60	307.96	0.15	0.73	0.31	0.37	11.44	4.00
5	2004	DAIHATSU	DELTA	2.48	427.64	0.22	1.88	0.51	0.66	15.98	5.00
6	1996	MITSUBISHI	CANTER 2 tonne	2.10	362.70	0.28	2.63	0.35	0.51	13.56	6.00
7	1996	MITSUBISHI	CANTER 3 tonne	1.76	373.39	0.28	2.64	0.35	0.57	13.94	7.00
8	1986	DAIHATSU	DELTA	3.23	362.09	0.76	1.22	0.67	0.93	13.66	8.00
9	1998	ISUZU	MU	0.08	393.92	0.05	1.69	1.21	0.98	14.57	9.00
10	1997	MITSUBISHI	CHALLENGER	1.07	446.52	0.16	1.52	0.25	0.29	16.59	10.00
11	1994	TOYOTA	ESTIMA EMINA	8.20	394.61	0.15	0.78	1.16	1.63	15.08	11.00
12	1994	TOYOTA	ESTIMA EMINA	8.20	384.60	0.15	0.71		1.78	14.71	12.00
13	1994	TOYOTA	HILUX SWT	1.09	477.10	0.13	0.93	0.36		17.72	13.00
14	1994	TOYOTA	HILUX SWT	0.77	510.78	0.12	1.14	0.86	0.95	18.94	14.00
15	1987	ISUZU	BIGHORN	2.86	346.85	0.27	1.06	0.95	0.88	13.02	15.00
16	2004	MAZDA	BOUNTY	0.87	399.89	0.09	0.93	0.25	0.35	14.84	16.00
17	1999	FORD	ESCORT	0.32	240.14	0.06	0.69	0.09	0.09	8.90	17.00
18	1999	MERCEDES	VITO 108	0.88	293.87	0.10	0.95	0.20	0.21	10.93	18.00
19	1997	MITSUBISHI	L300	1.11	397.12	0.04	1.03	0.51	0.51	14.75	19.00
20	1995	TOYOTA	HIACE	0.76	360.84	0.06	0.98	0.26	0.24	13.39	20.00
21	1995	TOYOTA	HILUX	0.55	334.61	0.09	1.22	0.27	0.29	12.41	21.00
22	1995	TOYOTA	HILUX	0.93	350.12	0.11	1.10	0.27	0.34	13.01	22.00
		Max		8.20	477.10	0.28	2.64	1.21	1.78	17.72	
		Min		0.08	240.14	0.04	0.69	0.09	0.09	8.90	
		Average		1.97	374.74	0.13	1.27	0.44	0.59	13.98	

Table 19: New Zealand Light Duty Diesel Data –Smoke Density Data.

	Year	Manufacturer	Model	ECE Peak K m^-	SAEJ1667 Peak K m^-	Post Gov Peak K m^-1	DT80 peak 1	DT80 peak 2	DT80 peak 3	DT80 av	DT80 max	
1	1999	NISSAN	LAUREL	1.63	1.71	1.67	2.91	2.63	2.64	2.73	2.91	1.00
2	1994	NISSAN	PULSAR	0.27	0.33	0.30	0.53	0.40	0.40	0.44	0.53	2.00
3	1991	NISSAN	SERENA	2.91	2.94	3.19	4.53	5.57	5.08	5.06	5.57	3.00
4	1990	TOYOTA	CORONA	1.56	1.53	1.77	1.79	1.81	2.91	2.17	2.91	4.00
5	2004	DAIHATSU	DELTA	1.77	2.22	1.86	2.47	1.90	3.29	2.55	3.29	5.00
6	1996	MITSUBISHI	CANTER 2 tonne	4.04	4.11	4.03		3.06	2.04	2.55	3.06	6.00
7	1996	MITSUBISHI	CANTER 3 tonne	4.04	4.11	4.03	2.50	2.55	2.64	2.56	2.64	7.00
8	1986	DAIHATSU	DELTA	3.24	3.08	3.12	2.57	3.18	3.78	3.18	3.78	8.00
9	1998	ISUZU	MU	0.81	0.83	0.81	2.89	3.78	2.79	3.15	3.78	9.00
10	1997	MITSUBISHI	CHALLENGER	4.45	4.39	4.52	3.62	3.59	4.63	3.95	4.63	10.00
11	1994	TOYOTA	ESTIMA EMINA	5.25	4.98	5.36	10.87	11.18	10.41	10.82	11.18	11.00
12	1994	TOYOTA	ESTIMA EMINA	7.62	7.65	7.90	10.36	10.41	10.64	10.47	10.64	12.00
13	1994	TOYOTA	HILUX SWT	1.28	1.26	1.27	1.14	3.53	4.95	3.21	4.95	13.00
14	1994	TOYOTA	HILUX SWT				9.49	5.78	5.03	6.77	9.49	14.00
15	1987	ISUZU	BIGHORN	4.03	3.68	3.88	3.53	4.38	4.00	3.97	4.38	15.00
16	2004	MAZDA	BOUNTY	1.33	1.42	1.37	0.76	2.24	5.40	2.80	5.40	16.00
17	1999	FORD	ESCORT	0.27	0.33	0.30	0.35	0.25	0.22	0.27	0.35	17.00
18	1999	MERCEDES	VITO 108	1.27	1.08	1.19	1.29	1.33	1.31	1.31	1.33	18.00
19	1997	MITSUBISHI	L300	3.62	3.65	3.38	1.87	2.12	2.36	2.12	2.36	19.00
20	1995	TOYOTA	HIACE	1.75	1.69	1.72	1.50	1.36	1.91	1.59	1.91	20.00
21	1995	TOYOTA	HILUX	4.48	4.41	3.71	2.17	2.87	3.12	2.72	3.12	21.00
22	1995	TOYOTA	HILUX	2.95	2.90	2.96	2.01	3.15	3.06	2.74	3.15	22.00
		Max				5.36	10.87	11.18	10.64	10.82	11.18	
		Min				0.30	0.35	0.25	0.22	0.27	0.35	
		Average				2.64	3.11	3.50	3.84	3.47	3.98	

Table 20: Vehicle Details for Heavy Vehicles Tested at Gough Gough and Hamer Limited.

Vehicle Number	Year	Manufacturer	Model	NZ NEW	Technology	Odometer km	Engine size cc	Fuel system	Turbocharged	Smoke density snap K m-1
1	2004	MAN	17.233	Yes	2	45882.5	6871	Common rail DI	Yes	0.26
2	2004	Nissan	CW400EE	Yes	2	1709	12500	Common rail DI	Yes	1.36
3	1996	Nissan	SBR180	Yes	1	535442	6925	Inline DI	No	1.75
4	1985	MAN	SL200	Yes	1	NA	9853	Inline DI	No	2.35

Table 21: Detailed Dynamometer Results for Testing Heavy Vehicles at Gough Gough and Hamer Limited.

Vehicle Number	Year	Manufacturer	Model	g/km	DT80 CO2 g/km	DT80 HC g/km	DT80 NOx g/km	DT80 F.C. l/100 km	DT80 PM (LSP) g/km	DT80 PM (filter) g/km	DT80 PM (filter) mg/s	Smoke density max K m-1
1	2004	MAN	17.233	1.77	1786.24	0.32	7.60	66.08	0.26	0.26	2.03	3.82
2	2004	Nissan	CW400EE	2.67	1295.58	1.00	6.44	48.17	0.88	0.79	4.36	4.28
3	1996	Nissan	SBR180	20.03	1719.98	0.83	5.33	65.29	4.89	4.56	35.30	7.22
4	1985	Man	SL200	8.62	1627.95	1.28	24.56	60.87	1.58	1.26	11.17	4.39

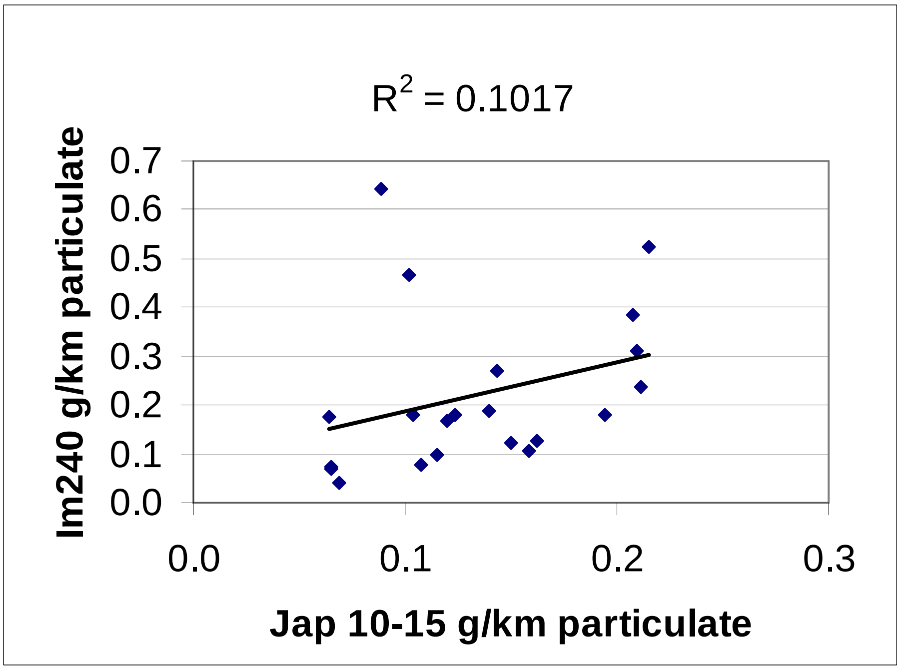


Figure 35: IM240 PM (g/km) Versus Jap10-15 PM (g/km) for EFRU Light Vehicle Tests.

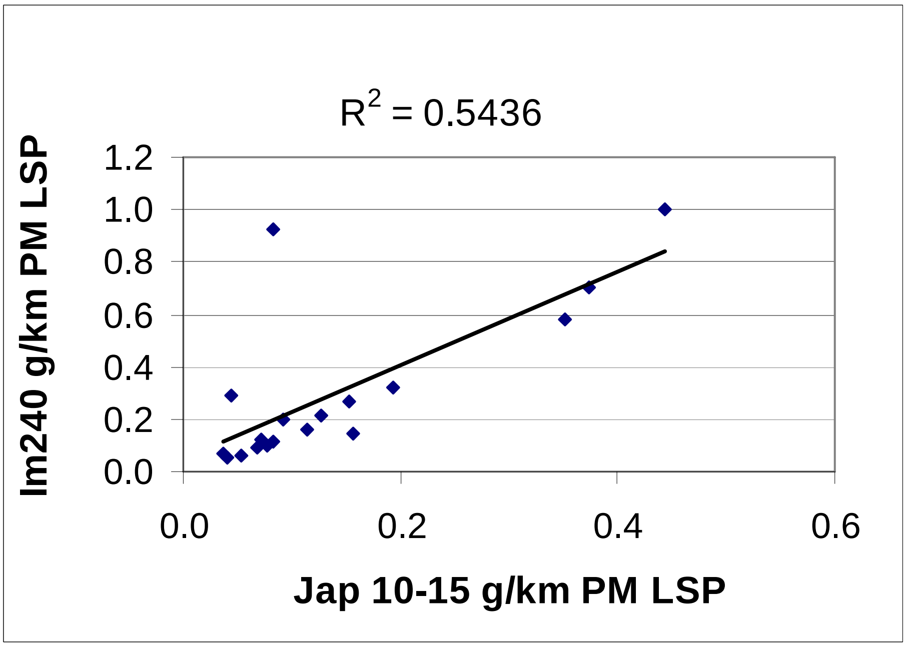


Figure 36: IM240 PM (g/km) LLSP Versus Jap10-15 PM (g/km) LSP for EFRU Light Vehicle Tests.

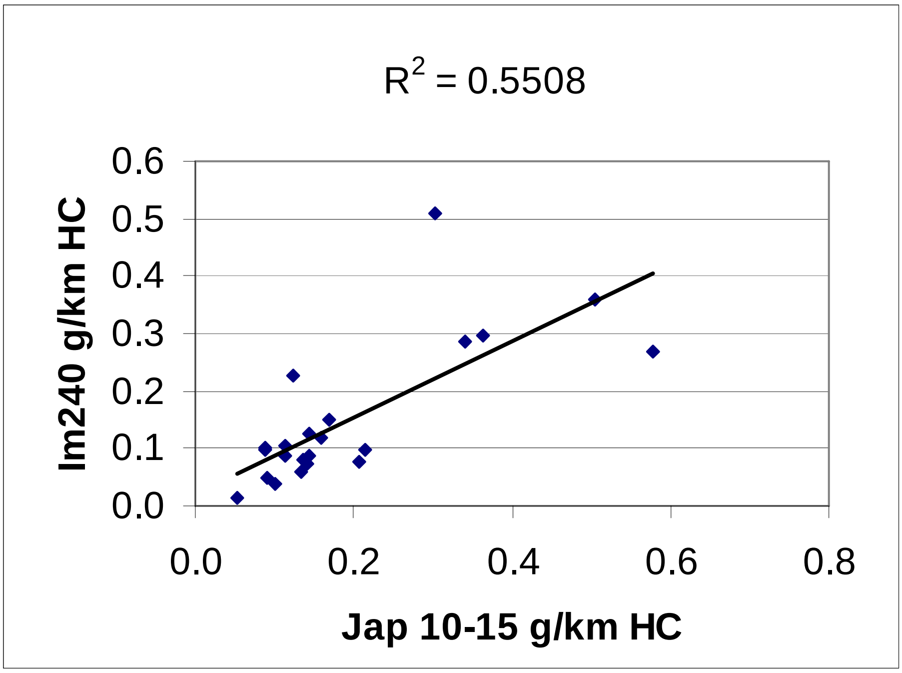


Figure 37: IM240 HC (g/km) Versus Jap10-15 HC (g/km) for EFRU Light Vehicle Tests.

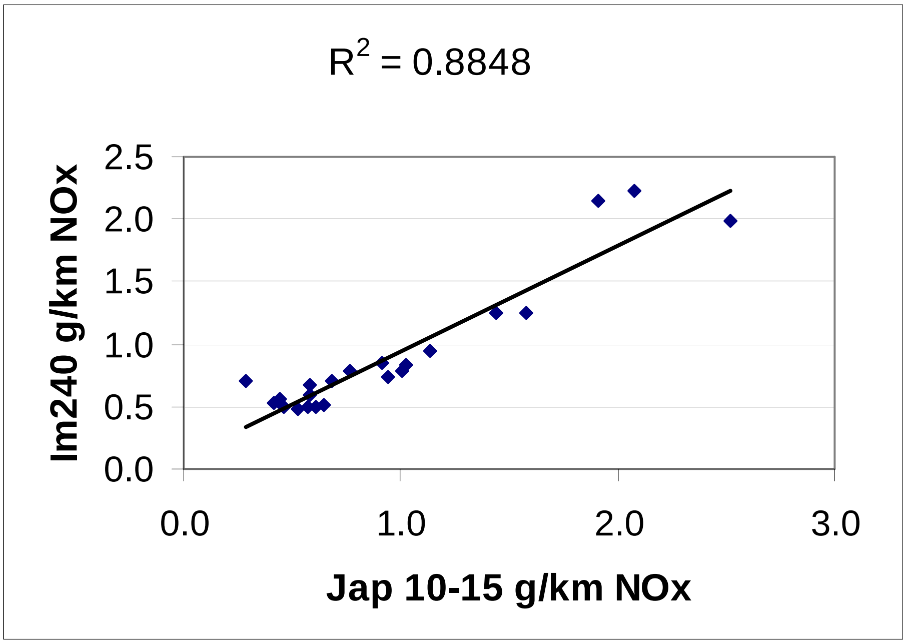


Figure 38: IM240 NOx (g/km) Versus Jap10-15 NOx (g/km) for EFRU Light Vehicle Tests.

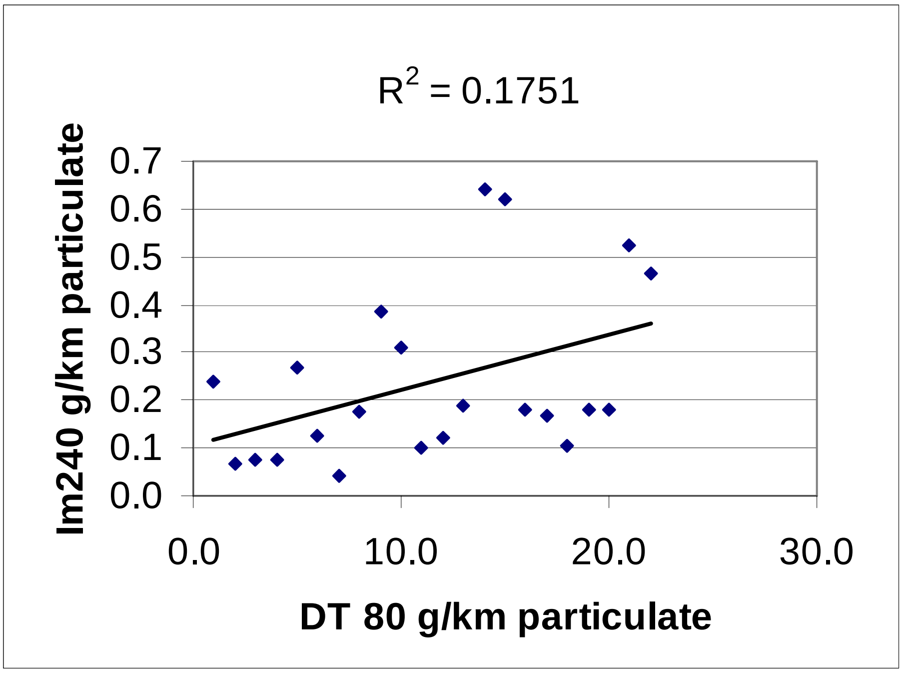


Figure 39: IM240 PM (g/km) Versus DT80 PM (g/km) for EFRU Light Vehicle Tests.

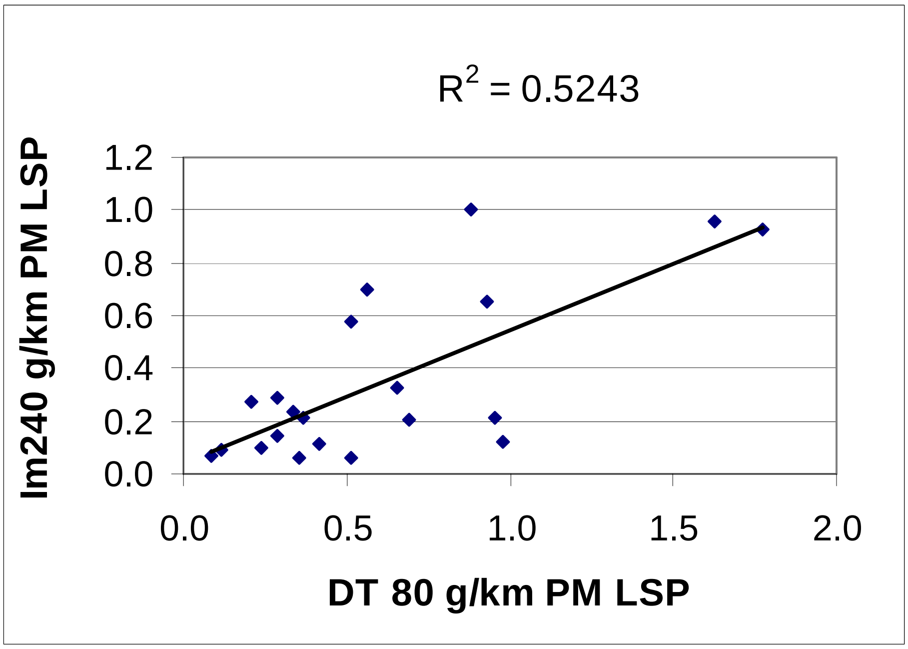


Figure 40: IM240 PM (g/km) LSP Versus DT80 PM (g/km) LSP for EFRU Light Vehicle Tests.

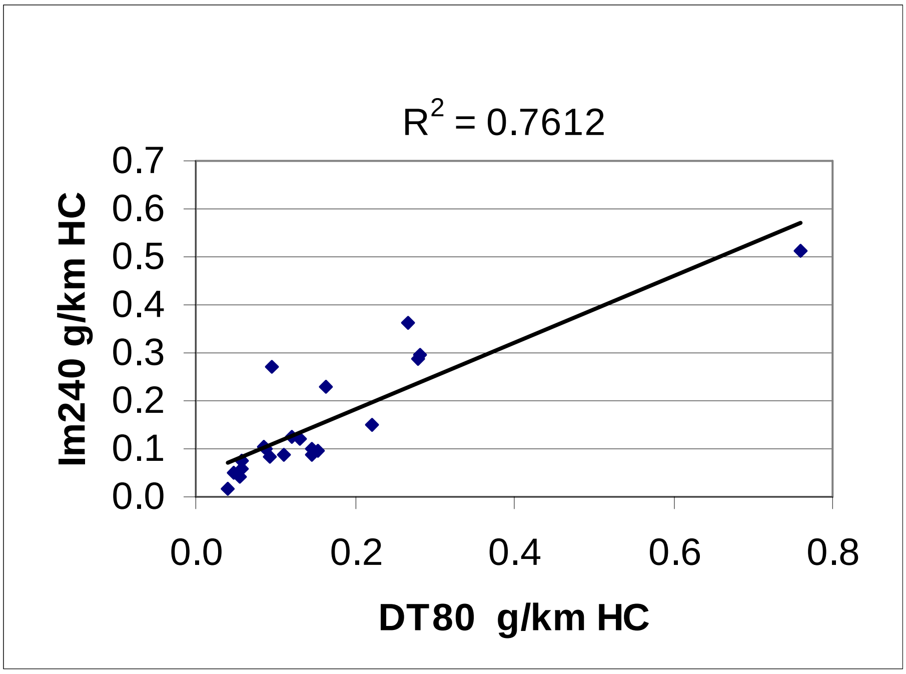


Figure 41: IM240 HC (g/km) Versus DT80 HC (g/km) for EFRU Light Vehicle Tests.

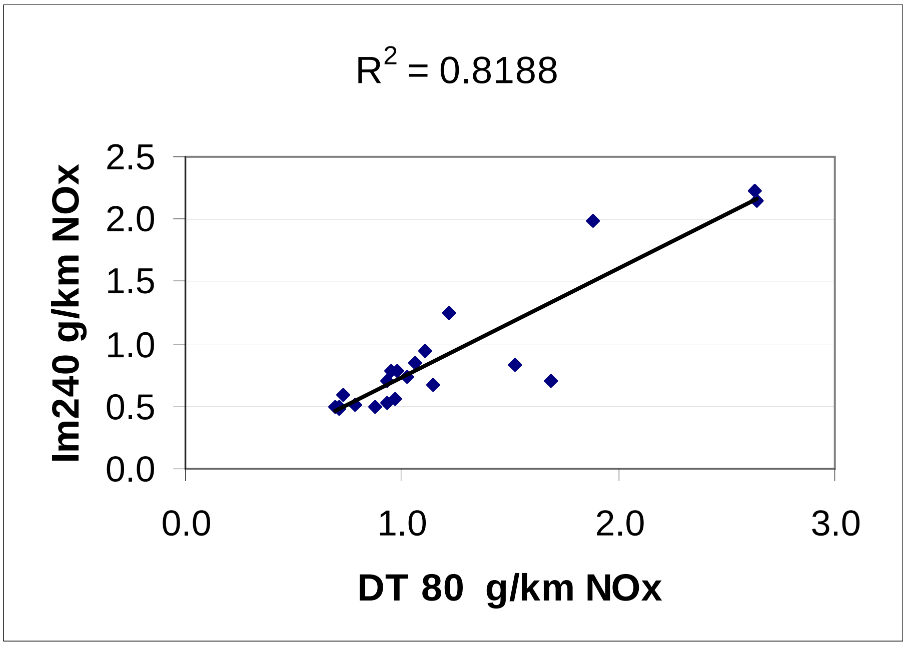


Figure 42: IM240 NOx (g/km) Versus DT80 NOx (g/km) for EFRU Light Vehicle Tests.

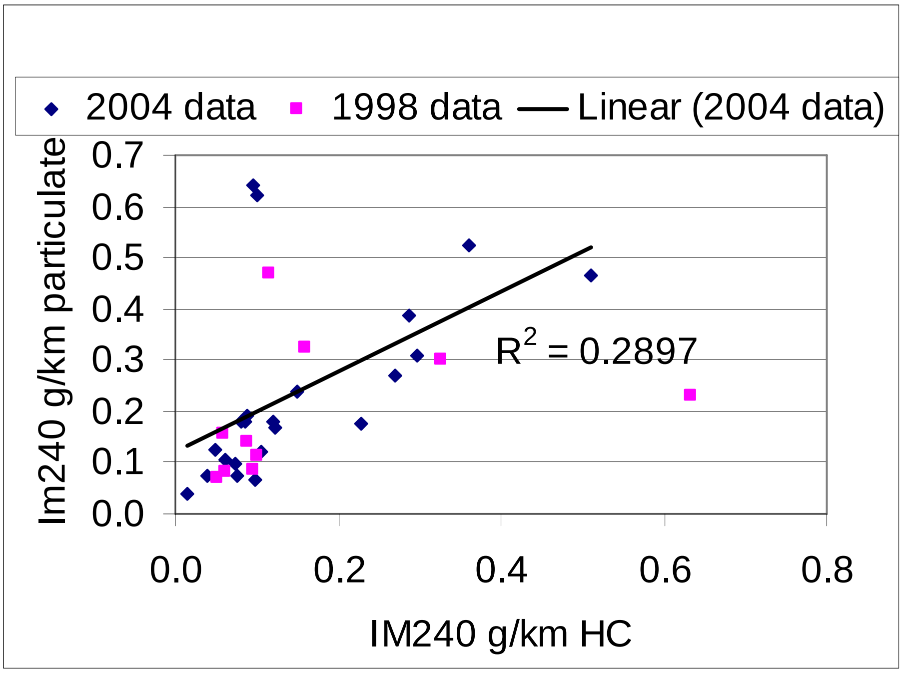


Figure 43: IM240 PM (g/km) Versus IM240 HC (g/km) for EFRU Light Vehicle Tests.

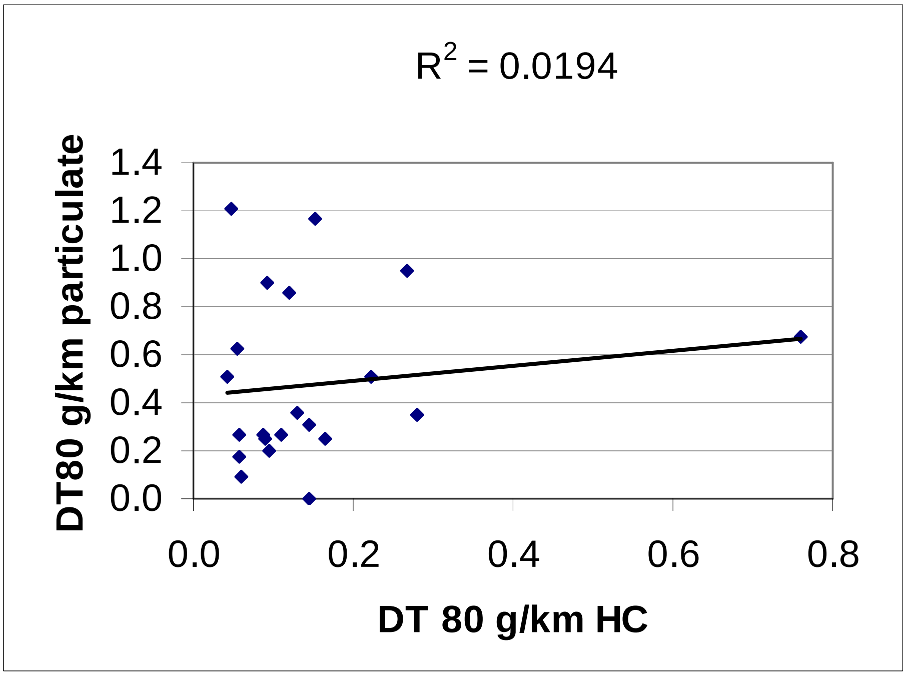


Figure 44: DT80 PM (g/km) Versus DT80 HC (g/km) for EFRU Light Vehicle Tests.

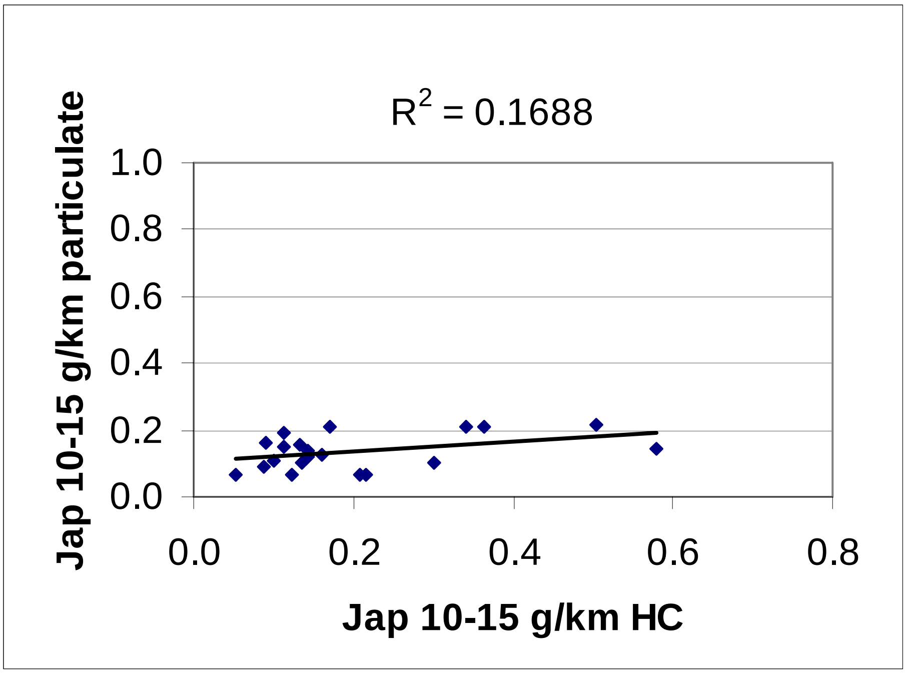


Figure 45: Jap10-15 PM (g/km) Versus Jap10-15 HC (g/km) for EFRU Light Vehicle Tests.

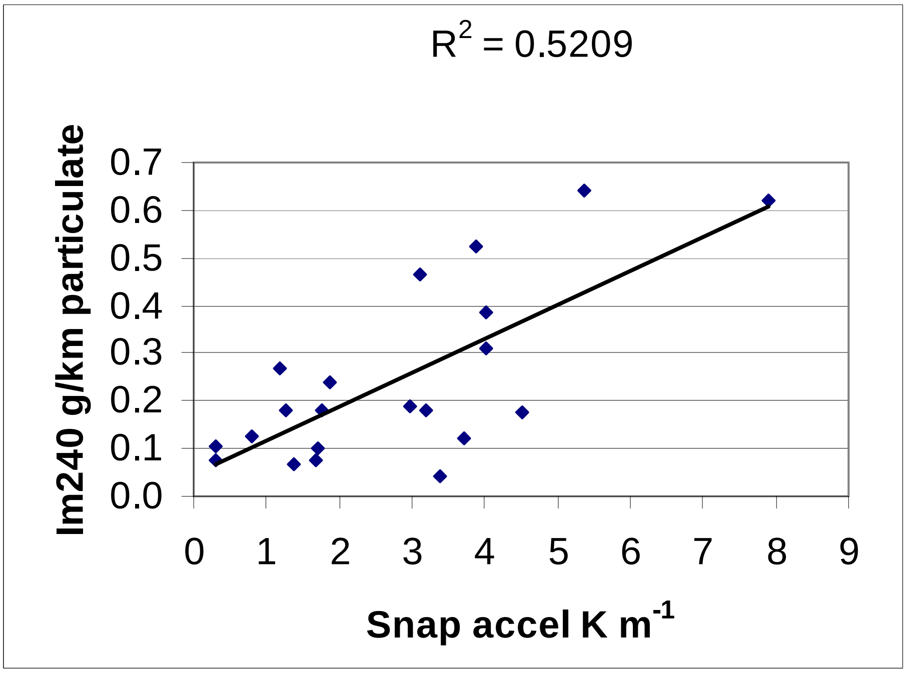


Figure 46: IM240 PM (g/km) Versus Snap Acceleration K for EFRU Light Vehicle Tests.

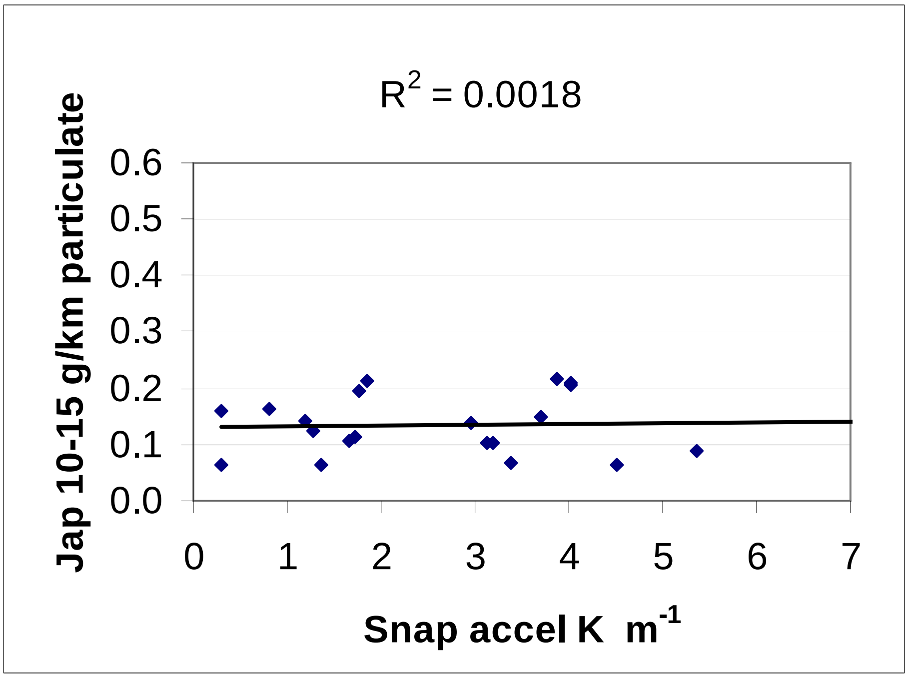


Figure 47: Jap10-15 PM (g/km) Versus Snap acceleration K for EFRU Light Vehicle Tests.

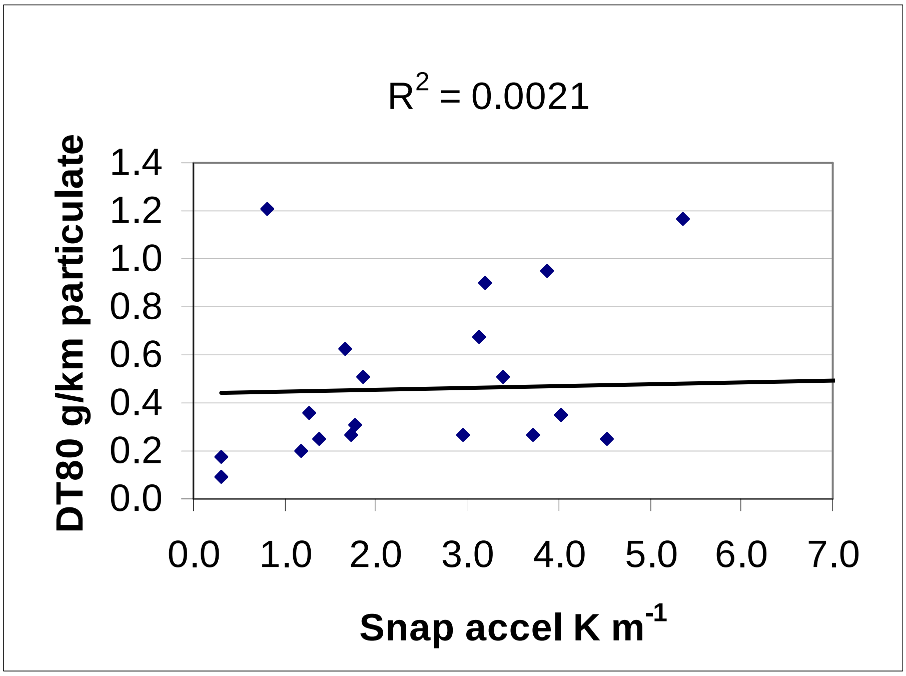


Figure 48: DT80 PM (g/km) Versus Snap Acceleration K for EFRU Light Vehicle Tests.

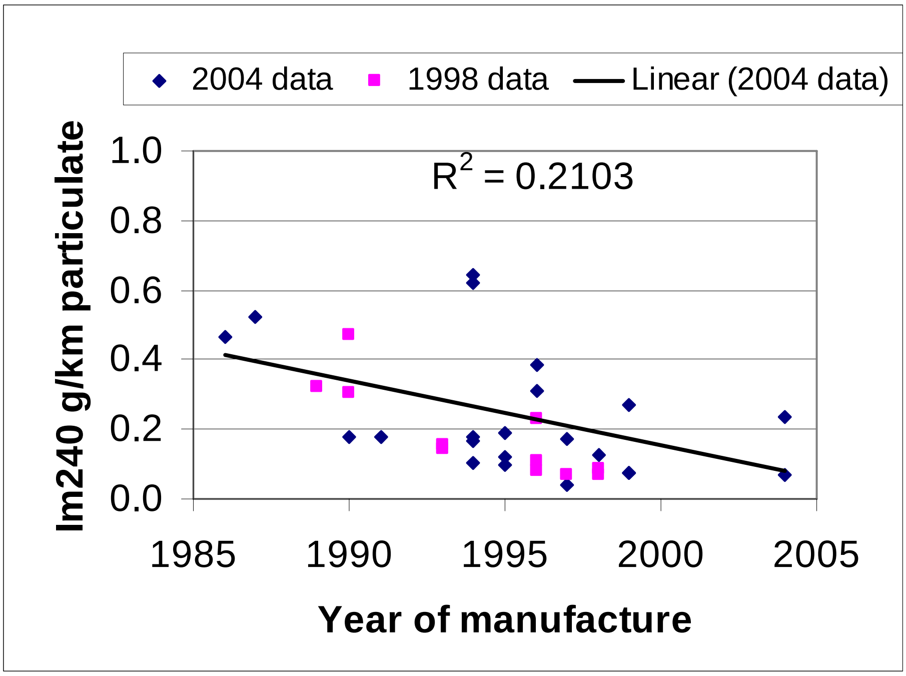


Figure 49: IM240 PM (g/km) Versus Year of Manufacture for EFRU Light Vehicle Tests.

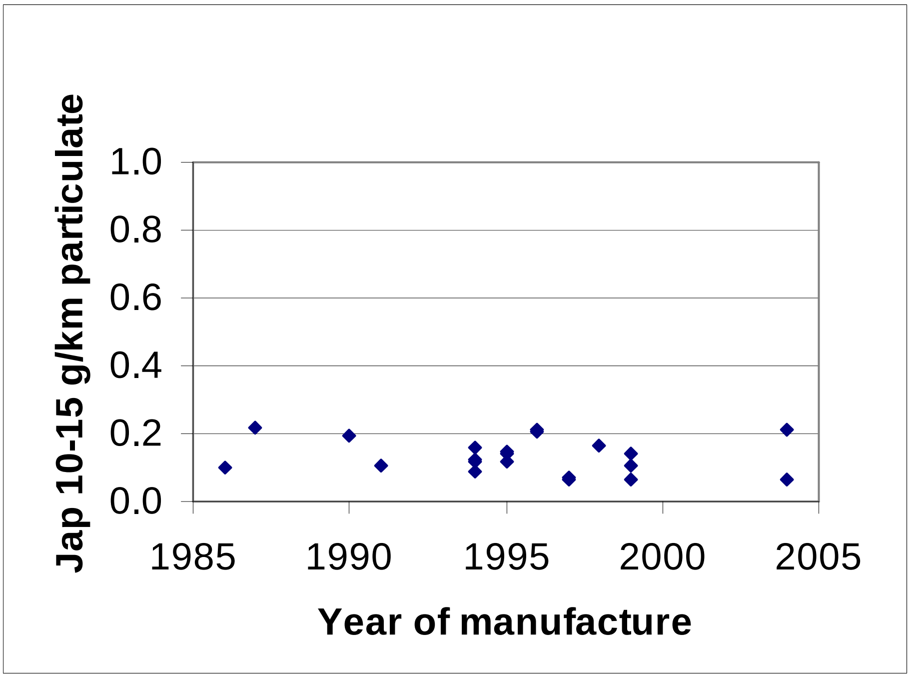


Figure 50: Jap10-15 PM (g/km) Versus Year of Manufacture for EFRU Light Vehicle Tests.

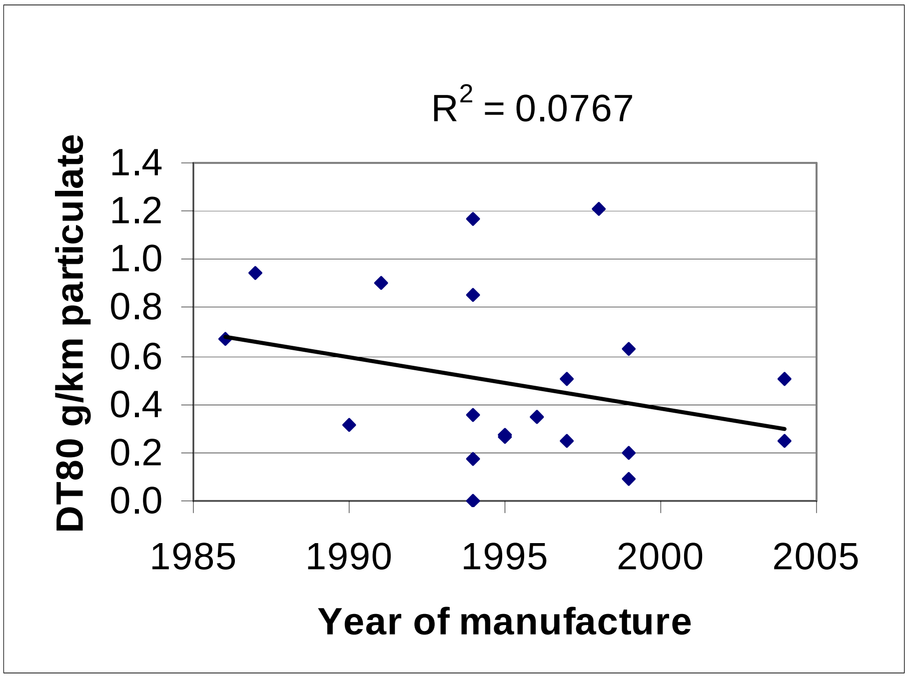


Figure 51: DT80 PM (g/km) Versus Year of Manufacture for EFRU Light Vehicle Tests.

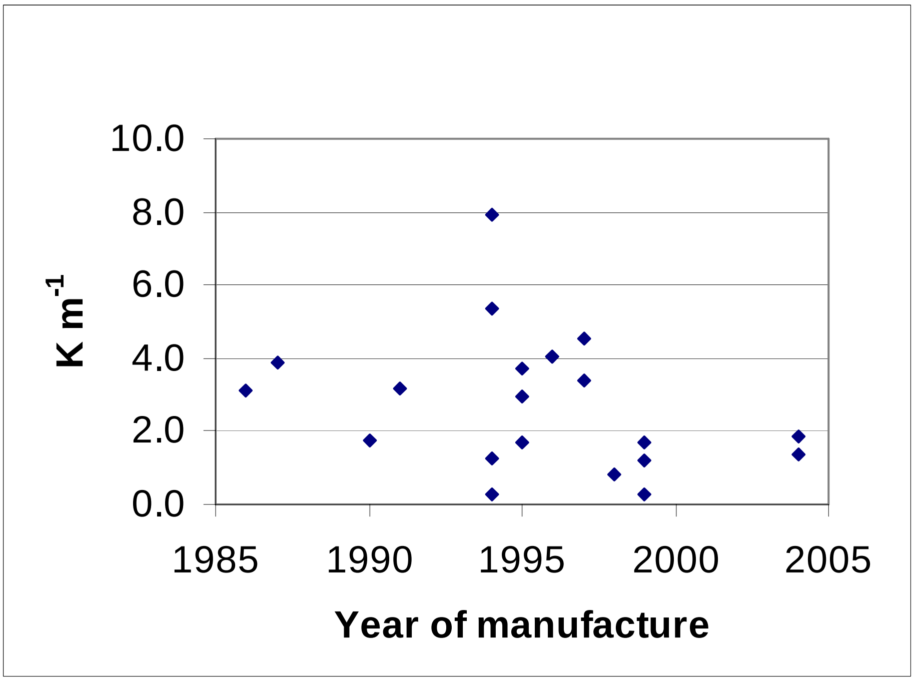


Figure 52: Snap Acceleration Results (K m-1) Versus Year of Manufacture for EFRU Light Vehicle Tests.

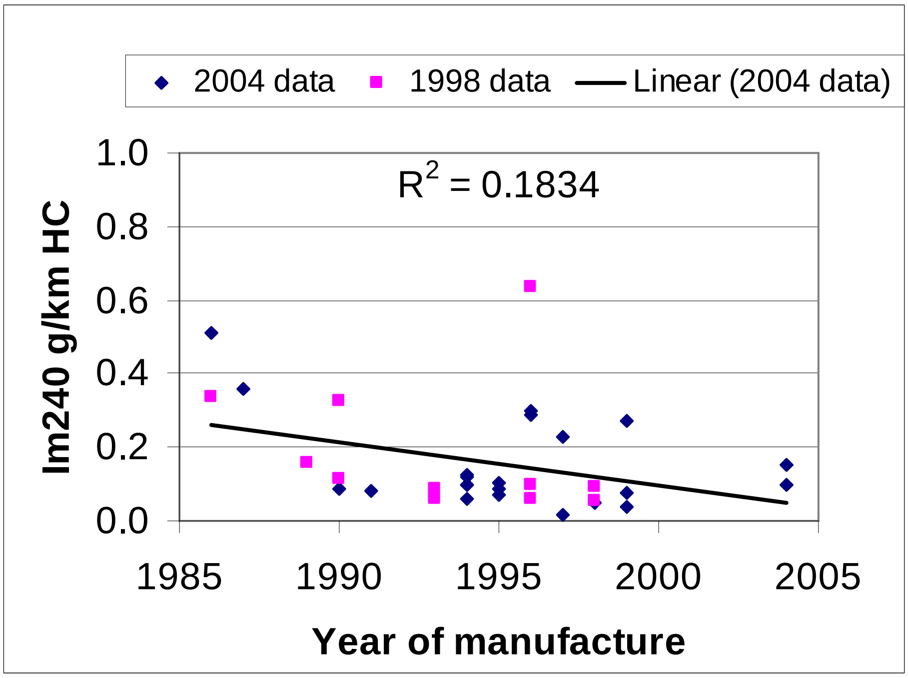


Figure 53: IM240 HC g/km Versus Year of Manufacture for EFRU Light Vehicle Tests.

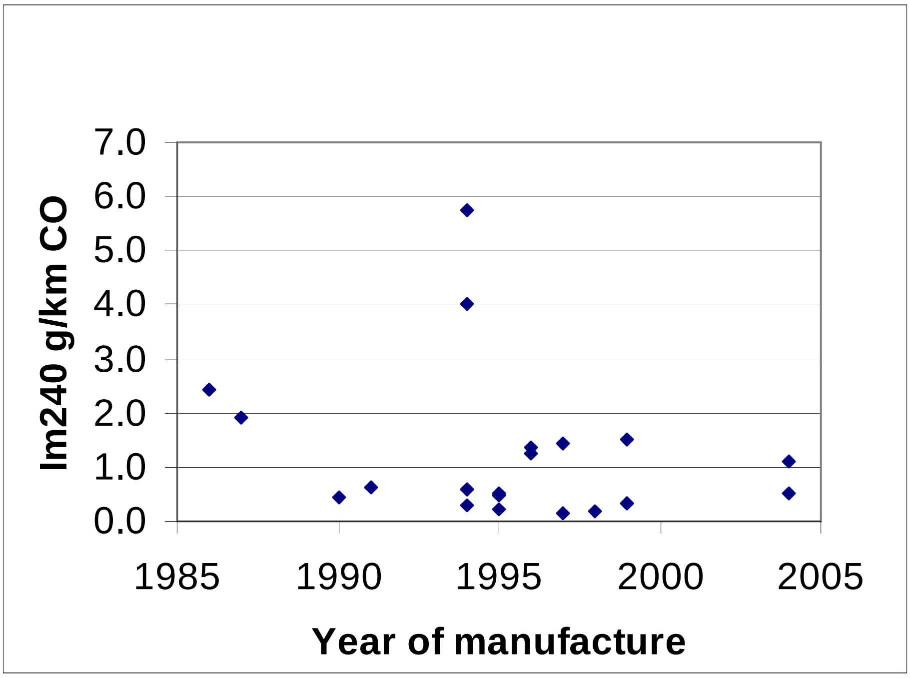


Figure 54: IM240 CO g/km Versus Year of Manufacture for EFRU Light Vehicle Tests.

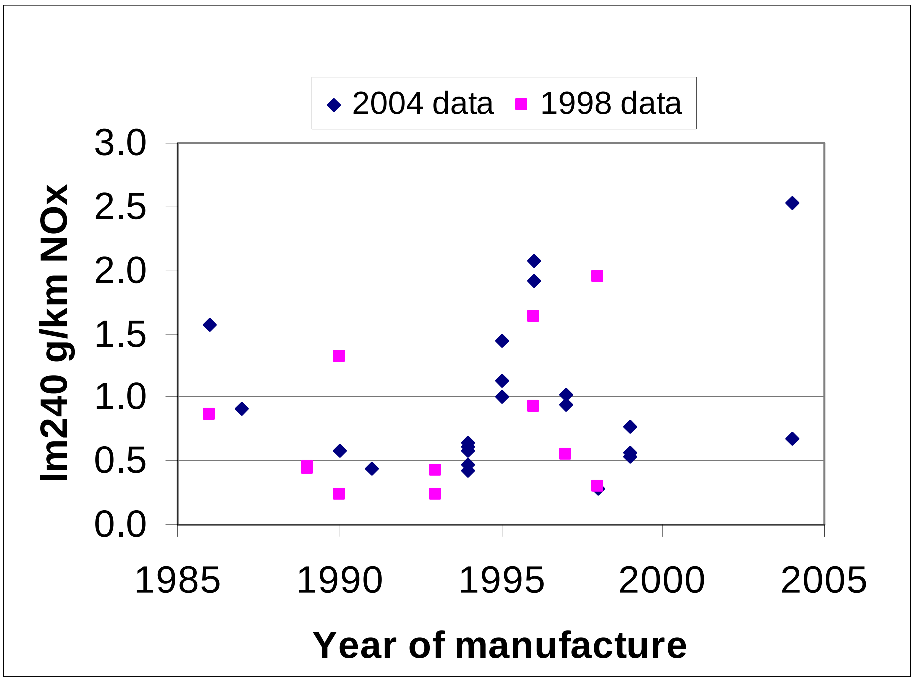


Figure 55: IM240 NOx g/km Versus Year of Manufacture for EFRU Light Vehicle Tests.

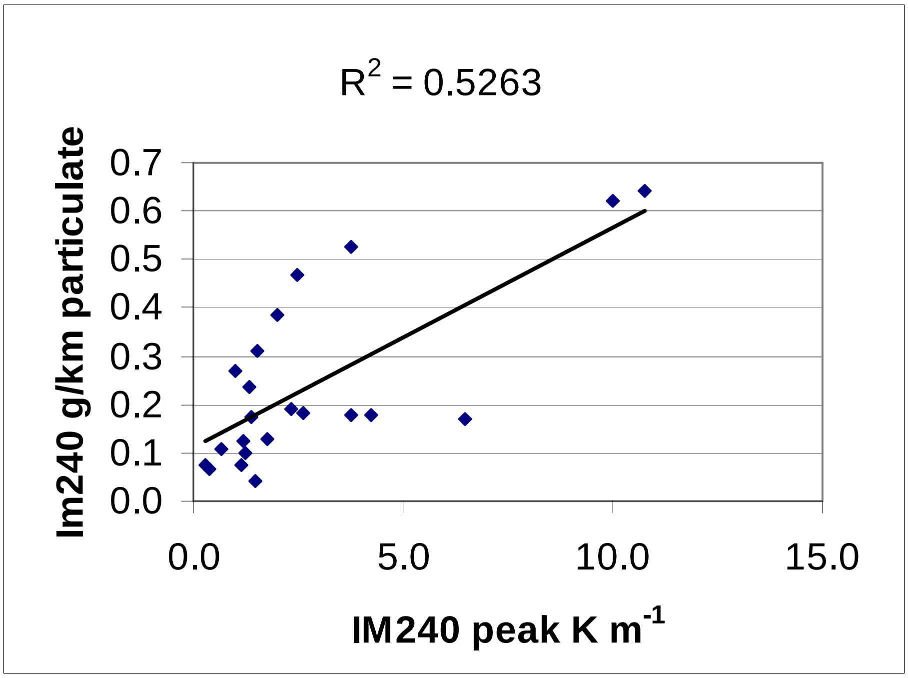


Figure 56: IM240 PM g/km Versus IM240 peak K for EFRU Light Vehicle Tests.

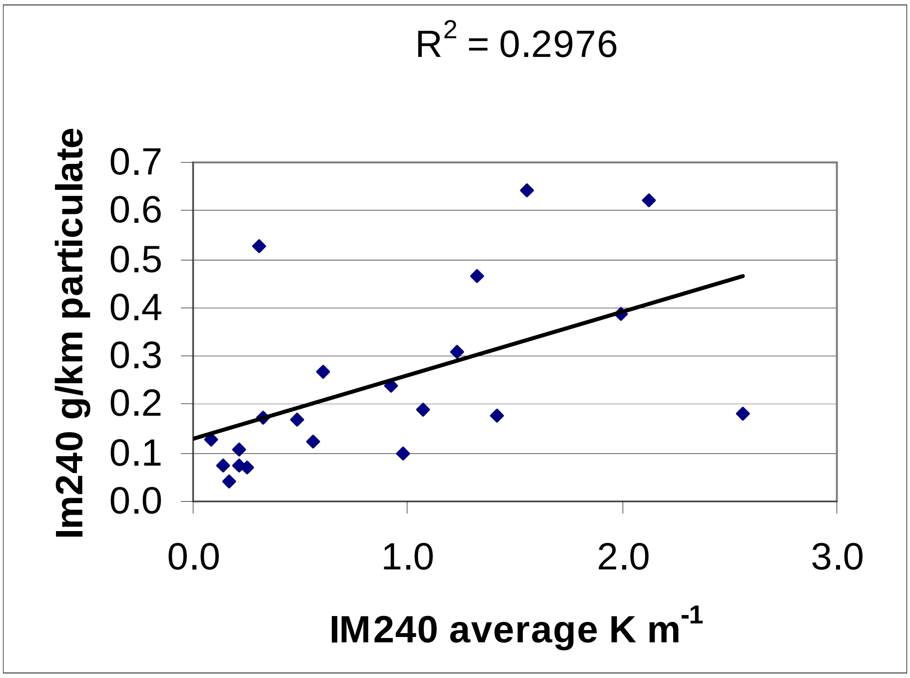


Figure 57: IM240 PM g/km Versus IM240 average K for EFRU Light Vehicle Tests.

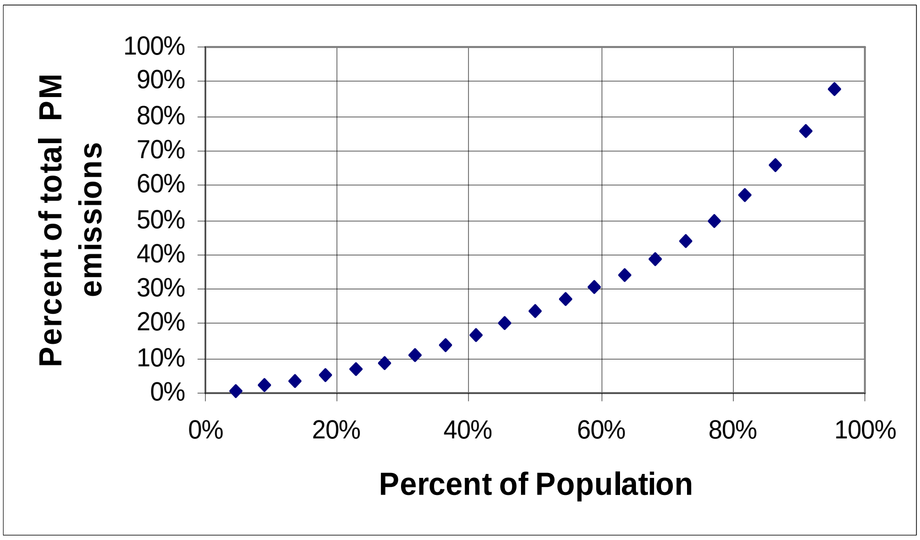


Figure 58: Percent of PM Emissions Versus Percent of Fleet Based on the IM240 Drive Cycle for EFRU Light Vehicle Tests.

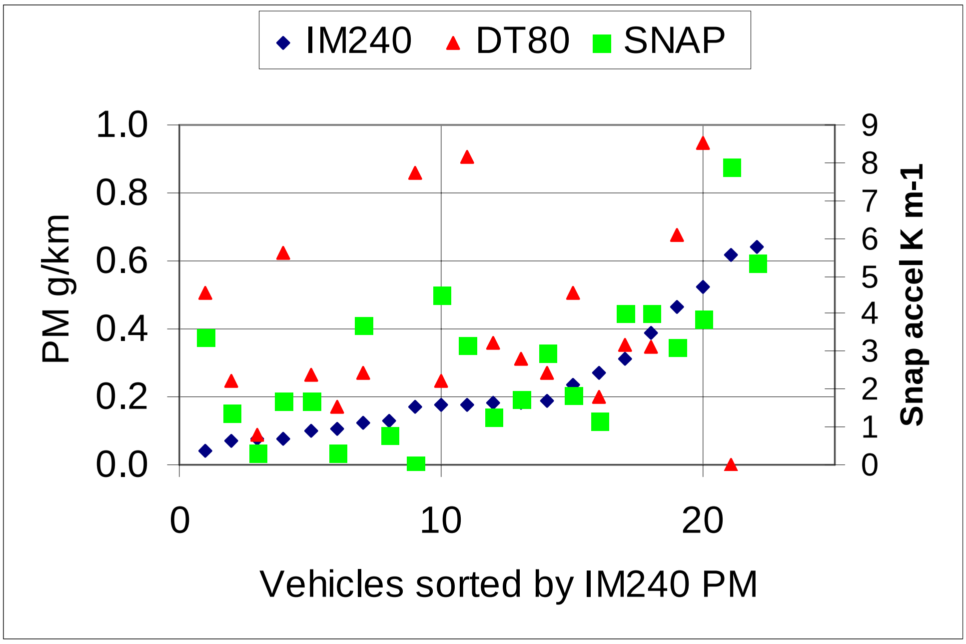


Figure 59: PM Emissions Sorted Lowest to Highest over the IM 240 Cycle, Data for the DT 80 Cycle and Snap Acceleration also Included, for EFRU Light Vehicle Tests.

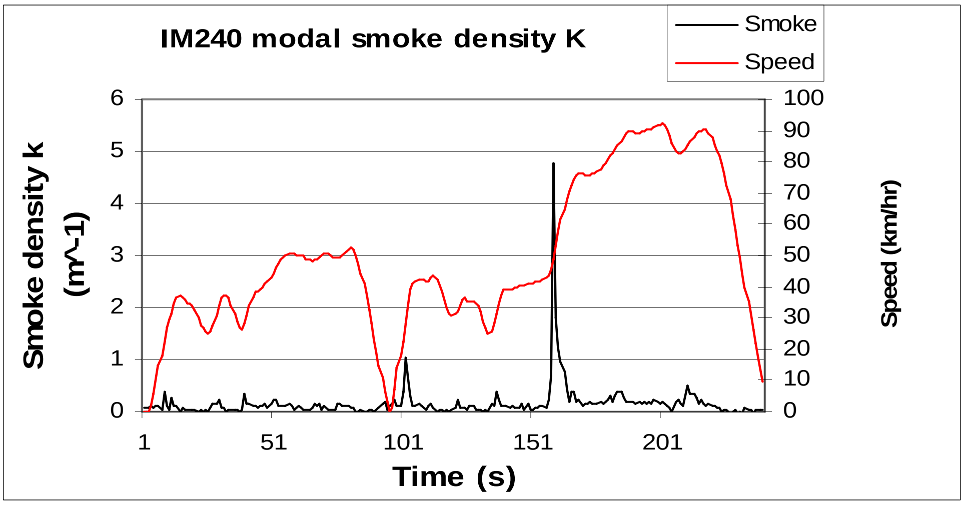


Figure 60: Smoke Emissions Measured Over the IM240 Driving Schedule for the Mitsubishi L300.

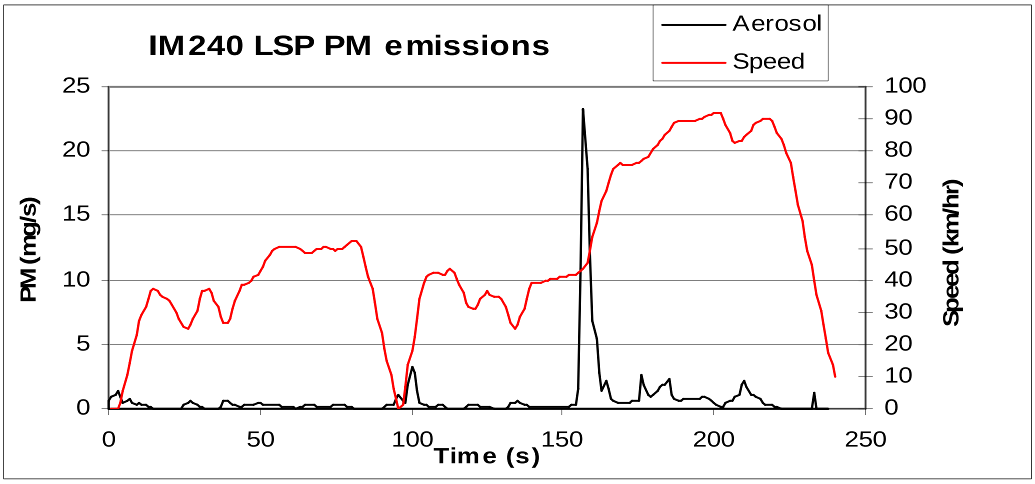


Figure 61: LSP Emissions Measured over the IM240 Driving Schedule for the Mitsubishi L300.

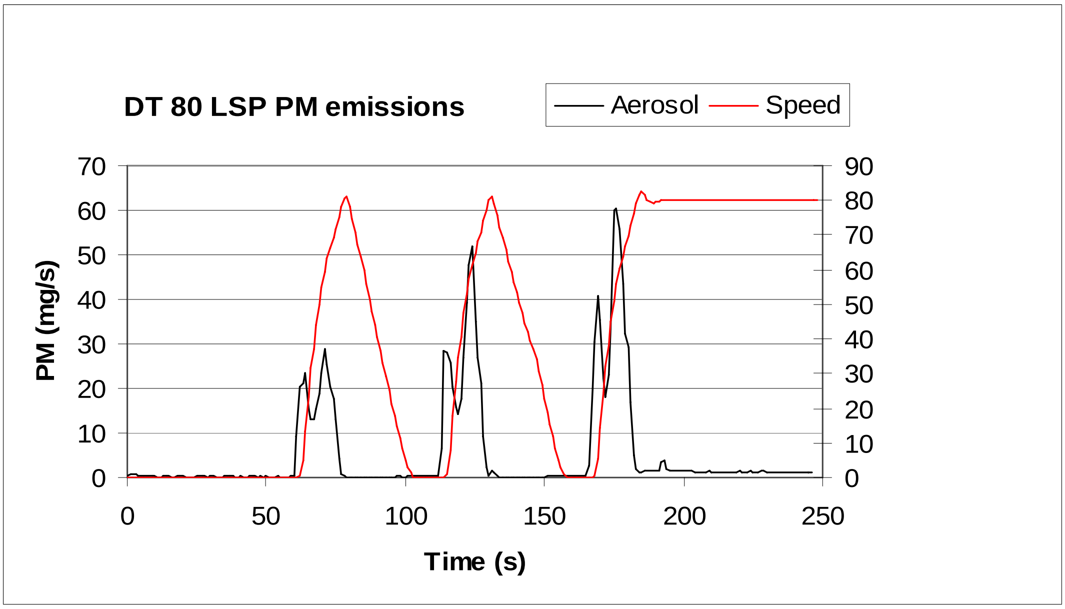


Figure 62: LSP Emissions Measured over the DT 80 Driving Schedule for the Mitsubishi L300.

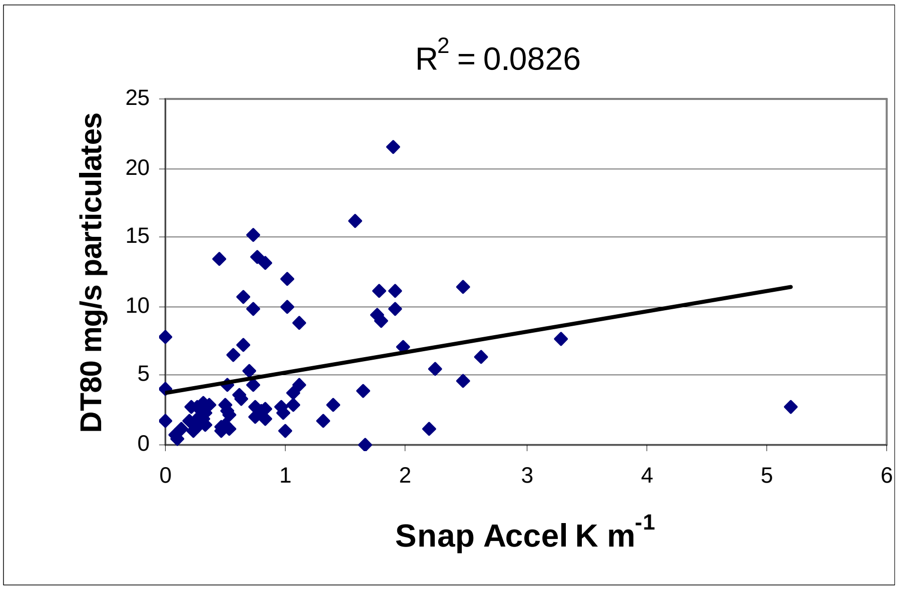


Figure 63: Australian DT 80 PM (g/s) (DustTraK) Versus Snap Acceleration K (m -1) for all Classes of Diesel Vehicles.

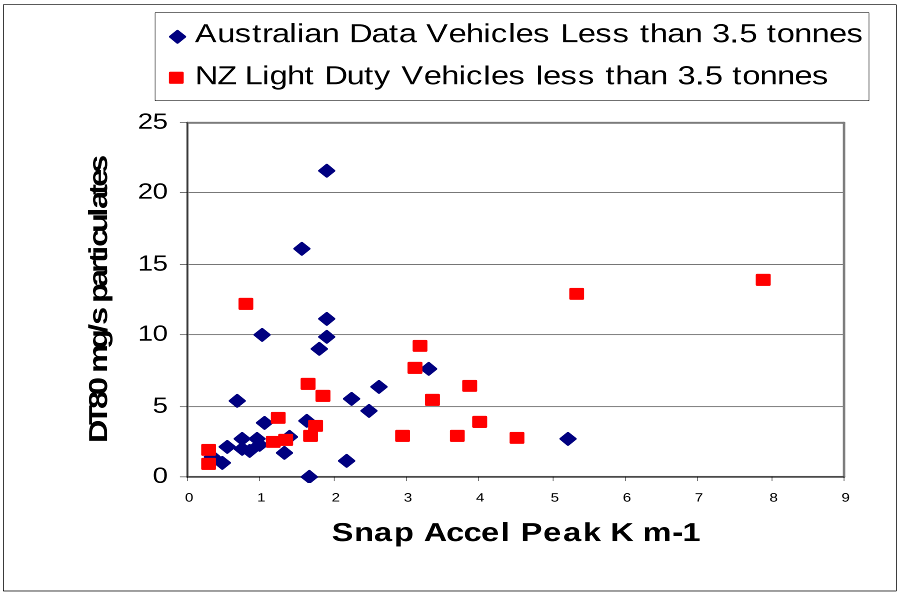


Figure 64: DT 80 PM (g/s) (DustTraK) Versus Snap Acceleration K (m -1) for Australian MC and NA Class Diesel Vehicles and all New Zealand Light Diesel Vehicles.

Appendix J: Industry Interview Process

The interview process for the vehicle repair industry regarding the repair of diesel vehicles comprised questioning on the following subjects, as appropriate:

- access to a smoke meter and believed usefulness;
- breakdown of staff numbers and their experience;
- description of facilities, including management of emissions;
- occurrence of faults:
    - what are the most common faults?
    - in general, what proportion of faults do they make?
    - how are the mentioned faults diagnosed?
    - what is the approximate cost for repair of mentioned faults?
    - what specific vehicle or models are involved?
- workshop competency in emissions-related repair;
- industry competency and capacity in emissions-related repair;
- value of snap acceleration testing;
- issues with snap acceleration testing;
- recommended approach the Government should be taking as far as vehicle emissions are concerned.

The interview process for the suppliers to repair workshops comprised questioning on the following subjects, as appropriate:

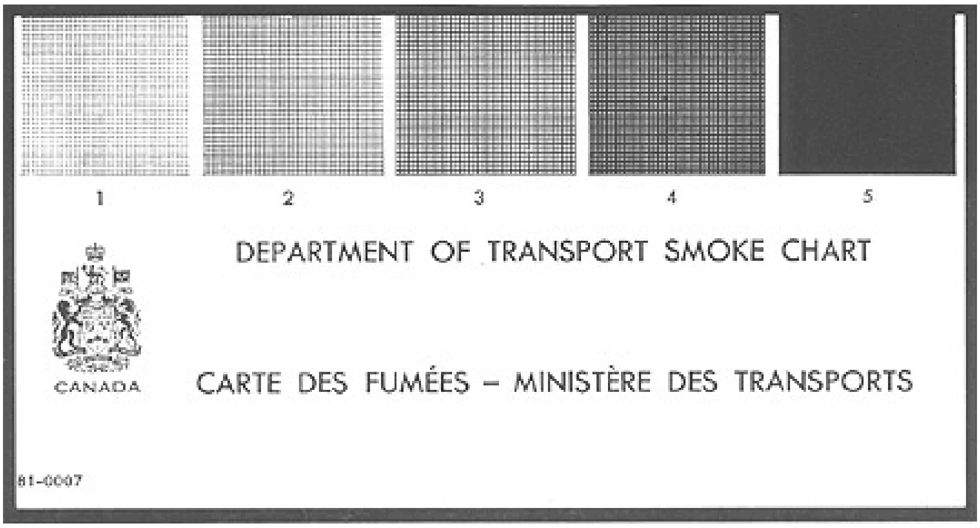
- equipment availability;
- training and support to clients;
- calibration procedures;
- experience to date;
- believed industry competency and capacity in emissions-related repair;
- believed value of snap acceleration testing;
- believed issues with snap acceleration testing;
- recommended approach the Government should be taking as far as vehicle emissions are concerned.

Those interviewed included:

- four principle suppliers of garage equipment in New Zealand (including suppliers of gas smoke meters of the type used for snap acceleration testing);
- seventeen snap acceleration test testers;
- twenty-one managers of vehicle inspection facilities;
- twelve Motor Trade Association (MTA) members, including Executives and Branch Presidents;
- fourteen managers of vehicle repair workshops or senior technicians (separate to the MTA members counted above) noting that all the managers involved were also skilled technicians themselves;
- two Motor Industry Training Organisation (MITO) Officers;

- John Fitch, Vehicle & Operator Services Agency (VOSA), UK — the officer involved in the original design and implementation of snap acceleration testing in the UK;
- Bernd Baumgar, Operations Engineer for SGS, the company contracted to manage the emissions testing of vehicles across Ireland;
- Chris Hunt, Crypton — a UK manufacturer of emissions test equipment. Answers to specific questions were also received from other overseas manufacturers through their New Zealand representatives.

Appendix K: Canadian Department of Transport Smoke Chart



INSTRUCTIONS FOR USE

1. Hold chart at arm's length.
2. View smoke at approximately right angles to line of travel of smoke.
3. Match shade of smoke with nearest shade on chart.

MÉTHODE D'UTILISATION

1. Tenir la carte au bout du bras.
2. Observer la fumée à peu près à angle droit avec la ligne de déplacement de la fumée.
3. Trouver la nuance de la fumée qui se rapproche le plus de l'une des nuances représentées sur la carte.

Figure 65: Smoke Chart from the Canada Shipping Act, Air Pollution Regulations, CRC, Vol. XV, c. 1404 as established buy the Consolidated Regulations of Canada, 1978.