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VEHICLE EMISSIONS PILOT PROJECT

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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

Emissions from motor vehicles have been attracting increasing attention in New Zealand. An option put forward by the Government for the control of vehicle emissions was to test the exhaust emissions of vehicles using simple test methods similar to those in use in some overseas countries. There are, however, peculiarities in the make-up of the New Zealand vehicle fleet making it necessary to check the application of these simple test methods to New Zealand vehicles. This was the basis of the Vehicle Emissions Pilot Project (the Pilot).

The Pilot comprised identifying the indicative current emissions performance of the vehicle fleet by testing a sample of vehicles using the simple emissions test methods, piloting simple emissions testing in order to gain the experience needed to aid the development of a simple emissions test régime for New Zealand, and understand the improvements in vehicle performance that may arise from the introduction of such a régime.

There are inherent differences between petrol and diesel engines and different simple emissions tests are involved. For this reason, reporting was divided into that concerning petrol vehicles and that concerning diesel vehicles. This report concerns petrol vehicles and the associated simple emissions test, the idle simple test.

1.2. Idle Emissions Performance of the Petrol Fleet

Idle simple testing was piloted at nine safety inspection and repair workshop sites around New Zealand over a four-month period beginning in September 2004. Around 1400 petrol vehicles were idle simple tested and visually inspected, 2100 petrol vehicles were visually inspected only, and a further 1400 were idle simple tested only as part of the Pilot. Quality assurance and analysis methods reduced the amount of data used in the main analysis to that from around 1100 vehicles for idle simple test analysis work and that from a further 1300 vehicles for visual inspection analysis work.

Much of the data was analysed using multiple variable statistical regression analysis in log-space, a particularly appropriate method of analysis given the high number of emissions-related variables involved, the high variability of the data and the severe skewedness in its distribution. This technique enabled the effects of individual variables to be isolated, their specific statistical significance to be gauged and the results to be modelled. This analysis found that:

- The technological make-up of the engine ('engine' including the exhaust system and hence any after-treatment system such as an exhaust catalyst if one is fitted) best described the high variability in idle simple test emissions results and found, at above a 90% confidence level (p-value <0.1), that vehicles fitted with exhaust catalysts exhibited on average 75% lower CO and HC idle simple test emissions than vehicles not fitted with catalysts.[1] Hence fewer catalyst-equipped vehicles failed to meet given pass-fail idle simple test 'cut-points'. Next most significant was a variable derived from a combination of the year of manufacture and the odometer reading, with a two- to three-fold increase in emissions expected in moving from vehicles of recent year of manufacture and low distance travelled to vehicles of less recent year of manufacture and most distance travelled, within an engine technology group;
- There are expected regional variations in the idle emissions performance of the petrol fleet, predominantly due to regional variation in fleet make-up with regard to engine technology;
- Whether a catalyst-equipped vehicle was registered before or after October 1996, when retail sale of leaded petrol was banned in New Zealand, was a statistically significant parameter but of small effect for (natural) idle[2] and fast idle[3] HC. The difference was to the order of 0.5% for fast idle CO for catalyst-equipped vehicles registered before October 1996. Around 5% of the Pilot's petrol sample were NZ-New vehicles that fitted into this category and around 5% were used imported vehicles that fitted into this category;
- Whether a petrol vehicle was NZ-New[4] or a used Japanese import was not consistently a statistically significant variable for describing idle simple test emissions results, where engine technology, year of manufacture and odometer were already considered. Engine power, engine size or whether a petrol engine was turbocharged were also not statistically significant indicators of expected idle simple test emissions performance;
- Around 60% of the visually inspected Pilot sample (around 2400 vehicles) were fitted with catalysts. It is expected the proportion of petrol vehicles fitted with catalysts in the New Zealand petrol fleet would currently be of similar order but it is expected that business-as-usual fleet turnover will increase this proportion substantially and average idle simple test emissions would be expected to decrease substantially as a result. Further, analysis of the Pilot results found around 60% of the catalyst-equipped vehicles to exhibit near-zero idle simple test emissions results, a proportion that is also expected to increase over time. It is believed this limits the usefulness of idle simple testing in the future;
- For a 3.5% (natural) idle CO, 1200 ppm (natural) idle HC cut-point, an idle simple test cut-point applied in the inspection of non-catalyst petrol vehicles in the UK, 35% of pre-1990 year of manufacture non-catalyst equipped

[1] Note care is required in the interpretation of this as vehicles fitted with exhaust catalysts tend also to be fitted with more sophisticated engine control systems and the average improvement in emissions is therefore not necessarily a function of the presence or absence of the exhaust catalyst alone.
[2] '(natural) idle' refers to the normal engine speed of a non-loaded engine without any depression of the accelerator.
[3] 'fast idle' refers to no-load operation at an engine speed of around 2500rpm.
[4] 'NZ-New' refers to vehicles that are not used Japanese imports.

vehicles did not meet this cut-point compared with 8% for pre-1990 catalyst-equipped vehicles. The proportion of vehicles not meeting this cut-point decreased as their year of manufacture became more recent with all catalyst and non-catalyst post-2000 year of manufacture vehicles meeting this cut-point. Emission profile curves were developed that allowed the proportion of vehicles not meeting other cut-points to be easily determined.

1.3. Value of Idle Simple Testing

Sixty-one variants[5] of petrol vehicles were tested to various drive cycle tests on a chassis dynamometer and the emissions results compared to the idle simple test results on an individual-vehicle basis. The vehicles were chosen to provide a broad range of variants. The drive cycles used were chosen so as to provide a representation of different on-road driving conditions. The idle simple test results were not found to provide a reliable indication of expected on-road emissions performance for this vehicle set. Some vehicles exhibited high idle simple test emissions and yet were expected to exhibit low on-road emissions, and vice versa. The coefficient of determination, R^2, for the comparison of various drive cycle emissions results to those from idle simple testing typically ranged from 0.1 to 0.6. An R^2 above 0.8 describes a reasonable correlation.

Analysis of test data from other studies also found there to be a poor relationship between idle simple test results and results from drive cycle testing.

1.4. Emissions-Related Repair

Seventy-two vehicles were idle simple tested before and after emissions-related repairs. Ten of these vehicles were subjected to detailed dynamometer testing to understand the effect of the repairs on on-road emissions and fuel consumption performance. Analysis found that:

- There was a high degree of variability in the response to repair for CO, HC, NOx and fuel consumption. Variations found in the repair of highest emitters ranged from a reduction in CO of 90% to an increase in CO of 60% and a reduction in fuel consumption of 18% to an increase in fuel consumption of 10%, based on the results from drive cycle testing (carried out to represent on-road performance);
- An average reduction in (natural) idle emission by 2.5% CO was achieved through repair for the repair-sample vehicles;
- A high proportion of repair costs were found in the range of $250-$500 and the average was around $350. For a fleet-wide programme a wide range of repair costs are expected and repair of older vehicles may be considered uneconomic at the upper end. A post-repair test (say, to test compliance to an idle simple test requirement) may add a further $60 to the cost of repair;

[5] That is, different vehicle models or different emissions-related configurations of the same vehicle, examples of the latter being a vehicle with and without an exhaust catalyst or before and after repair.

- In general the reduction in annual fuel costs achieved through repair is expected to be small compared to the cost of repair;
- Some vehicles in reasonable mechanical condition could not achieve low or even average idle simple test emissions even after repair;
- The majority of faults on modern engines were found to be the result of faulty sensors. A faulty oxygen sensor is a particularly common fault for the early vehicles fitted with such;
- Engine technology is becoming more sophisticated and requires more specialist equipment and skills to diagnose and repair faults. It is believed the industry will require a degree of re-tooling and up-skilling in order to provide an appropriate level of service. It is recommended high priority be given to encouraging this.

Applying the Pilot's repair results to various fleet scenarios suggests a régime that repairs the 10% worst emitters as identified by idle simple testing would be expected to reduce on-road[6] petrol fleet CO and HC emissions somewhere in the order of 10% and reduce NOx emissions much less than this. A reduction in fuel consumption of less than 0.5% would be expected.

1.5. Implementation of Idle Simple Testing

There are issues peculiar to New Zealand that would make it difficult to implement a fleet-wide régime based on idle simple testing:

- Around 50% of the fleet were not built to an emissions standard and it would therefore be difficult to require these vehicles retrospectively to meet a given emissions performance standard, unless it were a very lenient pass-fail cut-point;
- It is believed difficult retrospectively to require vehicles which were legitimately modified under the rules (or lack of them) prevailing at the time to then undergo re-engineering to meet a given emissions performance standard. A similar argument could be applied to those catalyst-equipped vehicles that have been 'modified' through poisoning of the catalyst on account of being fuelled with leaded petrol, the fuel that was made available at the time;
- The ability of the industry to provide sufficient capacity and capability to support such a régime is questioned;
- The poor relationship between idle simple test emissions and on-road emissions means that there is a risk the results of idle simple testing would be challenged;
- Implementation of idle simple testing would be a relatively expensive undertaking and would risk the industry over-investing in its formative years.

Furthermore, the usefulness of idle simple testing is expected to lessen as the fleet modernises, for example, due to the increasing proportion of vehicles that exhibit 'near-zero' idle simple test emissions (for although the idle simple test emissions are

[6] It is important to differentiate between 'idle emissions' as given in the second bullet point above, which are those from the idle test, and 'on-road fleet emissions', which are those from operation on the road. On-road fleet emissions are more important for emissions inventory purposes.

near-zero, the on-road emissions would not be expected to be near-zero, raising the question: how relevant is the test?). When all these aspects are considered, idle simple testing is not recommended for New Zealand as a mainstream vehicle emissions control programme. However, idle simple 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 control programme 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; identifying and monitoring the engine technology make-up of the fleet for emissions inventory purposes; emissions screening for potentially high-emitting vehicles using remote sensing supported by a more robust emissions assessment (such as interrogation of the onboard diagnostics system or cautious use of gas analysers); proof the emissions system on used imported vehicles is functioning correctly before they are permitted to enter the fleet, and simple testing exhaust O_2 as an awareness tool at the time of a safety inspection. It is recommended these options be further investigated.

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 an idle simple test régime or high emitter test and cut-point of some sort is not adopted. This weakens the authority upon which other emissions reduction programmes could be supported.

A recommended idle simple test procedure for New Zealand has been identified, should idle simple testing be introduced, as well as programmes required to support such.

Should idle simple testing be introduced as a fleet-wide requirement for petrol vehicles, it is expected the industry would require a further 1000 to 1200 personnel to support the testing involved and a further 600 full-time equivalents for personnel involved in the repair of vehicles. This is quite apart from personnel who may be involved in testing diesel vehicles, should there be such a programme. This being the case, the introduction of idle simple testing would require careful management, as this step increase in industry capacity would take several years to achieve, at best, and there is also a risk that the industry could over-invest in the earlier years. An over-optimistic introduction would also risk compromising the quality of the programme.

Once introduced, an idle simple test would be expected to take 5 to 20 minutes and cost around $35 on average, ranging from $20 to $60, depending upon the facility type and whether vehicles may be tested easily. The cost of idle simple testing may be higher still during any phase-in period.

1.6. Fleet On-Road Emissions Performance

The results from idle simple testing do not provide a good indication of expected on-road vehicle emissions performance, particularly on an individual-vehicle basis. As determined by multiple variable regression analysis applied to the results from detailed dynamometer testing of vehicles, a better assessment of expected on-road emissions performance could be achieved through modelling where the engine technology make-up, average year of manufacture and average odometer readings of a fleet of vehicles were known. This analysis found engine technology to be a statistically significant variable, at above the 90% significance level (p-value <0.1), with catalyst-equipped vehicles expected to exhibit, on average, 70-90% lower on-road emissions of CO, HC and NOx (emissions specie dependent) than vehicles not equipped with catalysts. The next most significant vehicle-related variable was a factor related to year of manufacture and odometer reading.

The drive cycle used for the basis of emissions determination was also found to be a significant variable, with emissions results from a drive cycle representing driving in congested driving conditions four to five times higher than those for a drive cycle representing more normal urban and inter-urban driving conditions. The combination of congestion and the absence of a catalyst could see, on average, 20 times higher emissions than driving in free-flow traffic in a vehicle fitted with a catalyst. Fuel consumption was two- to three-fold higher when testing vehicles to the drive cycle representing congested traffic conditions.

Through the use of the Pilot's emissions modelling and results from the Pilot's visual inspections on vehicles, it is expected to the order of 40% of the active petrol fleet in New Zealand are not fitted with catalysts and are responsible for around 80% of total on-road fleet emissions. Location-to-location variations are expected, predominantly due to differences in the local engine technology make-up of the fleet. Using the location-to-location variations found in the Pilot's visual inspection sample and applying Pilot-developed emissions prediction model to these produced ranges from 25% of an area's petrol fleet being non-catalyst and predicted to contribute to 65% of the total area's petrol fleet emissions, to 55% of the area's petrol fleet being non-catalyst and predicted to contribute to 90% of the total area's petrol fleet emissions.

Business-as-usual fleet turnover is expected to cause a substantial decrease in the proportion of non-catalyst-equipped vehicles, bringing about a substantial reduction in average vehicle on-road emissions.

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Acknowledgements

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Glossary

Blends	Mixtures of two fuels, for example petrol and ethanol or diesel and biodiesel.
Catalyst	For this report, referring 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 that represents congested city driving.
Chassis dynamometer	A dynamometer which allows vehicles to be operated and loaded, the vehicle wheels running on rollers.
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 statistics called upper and lower confidence limits, within which the value of a parameter is expected to be located.
Confidence limit	A number within a confidence interval at which statements about 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.
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.
EOBD	European OBD, the European version of OBD. See OBD.
Ethanol	An alcohol that, overseas, is sometimes blended with petrol as an automotive fuel.
Fast idle	Operation of an engine under no-load conditions at around 2500 rpm.
Global air quality pollutants	Those species with global warming potential, that is, 'greenhouse gases' included under the Framework Convention on Climate Change.
Heavy vehicle	A vehicle with mass greater than 3500 kg.
Heavy-light vehicle	A light vehicle with mass close to 3500 kg.
High Idle	As for fast idle in the case of petrol engines. Also refers to the upper governed speed in the case of diesel engines.
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.
JOBD	Japanese OBD, the Japanese version of OBD, see OBD.
Lambda	A measure of the air-fuel ratio relative to stoichiometric.

Light-off temperature	Temperature which an exhaust catalyst needs to reach in order for the conversion of exhaust emissions to be significant.
Light vehicle	A vehicle with mass 3500 kg or less.
Liquid petroleum gas	LPG. Petroleum-sourced gas that generally has a high proportion of propane and butane, stored under pressure as liquid.
Local air quality pollutants	Those species that can affect the local environment including carbon monoxide, hydrocarbons, oxides of nitrogen and particulate.
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.
MOBILE(x)	A vehicle emissions inventory model in use in the US with *x* denoting the version number.
Mode	Where there is a concentration of data around some value.
Multimodal	Where data is concentrated around more than one value.
Natural gas	Petroleum-sourced gas that has a high proportion of methane. May be dispensed in automotive applications as compressed natural gas (CNG) or as liquefied natural gas (LNG, requiring cooling of the gas to very low temperatures).
(Natural) idle	Idling without the engine in gear and without the accelerator being depressed.
O_2 Sensor	Oxygen sensor placed in the exhaust and used to provide a signal to the engine control system the better to meter the amount of fuel delivered.
OBD	Onboard diagnostics, an onboard vehicle system where an alert is given when expected operating conditions, with given allowance, are breached.
OBDII or OBD-2	A more recent version of OBD with more strict protocols and diagnostics requirements.
Oxygen sensor	See O_2 sensor.
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 hypotheses.
R^2	Coefficient of determination – statistical measure of the relationship between two result sets.
Remote sensing	Measuring exhaust gas concentration as a vehicle passes through a beam of light that crosses the road.
Simple test	Tail-pipe emissions test normally consisting of measuring exhaust species concentrations at (natural) idle and fast idle conditions by a simple emissions analyser.
Skew	The degree of asymmetry of a distribution around its mean.
Snap acceleration	A simple test for diesel vehicles in which the engine is rapidly accelerated and tail-pipe 'smoke' is measured.

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 both the year of manufacture and odometer reading of a vehicle.
Standard deviation	Describes the variability of 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.
Stoichiometric	The ratio of air and fuel that provides complete reaction of the compounds involved.
Tech (n)	Short form of Technology (*n*), defined as follows:
Technology 1	Vehicles that have simple carburetted fuel metering, no electronic engine management and no exhaust after-treatment (that is, no catalyst).
Technology 2	Vehicles that have fuel injection fuel metering systems and no exhaust after-treatment.
Technology 3	Vehicles that have an exhaust catalyst and 'open-loop' fuel metering (that is, no oxygen sensor is used to refine the metering of fuel).
Technology 4	Vehicles that employ an exhaust catalyst and 'closed-loop' electronic engine management systems (that is, with an oxygen sensor fitted, the signal from which is used to refine the metering of fuel).
Type approval standards	Standards provided by various jurisdictions to which vehicles are built.
Vehicle Variant	Describing vehicles of different emissions configuration whether by being a different vehicle or the same vehicle with a different emissions configuration (including after being repaired, before and after repair providing two vehicle variants).
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.
CNG	Compressed natural gas.
CVS	Constant volume sampling.
ECA	Environmental Capacity Analysis Model.
EFRU	Energy and Fuels Research Unit, University of Auckland.
EOBD	European onboard diagnostics.
FTP 75	Federal Test Procedure 75 (introduced 1975).
HC	Hydrocarbons.
IM240	Inspection and Maintenance test cycle – 240 seconds duration.
JOBD	Japanese onboard diagnostics.
LANDATA	Vehicle data held by the Transport Registry Centre.
LPG	Liquefied petroleum gas.
NES	Resource Management National Environment Standards Regulations 2004.
NO	Nitrogen oxide, sometimes also referred to as Nitric oxide.
NOx	Oxides of nitrogen.
NQA	Not quality assured.
NZTER	New Zealand Transport Emission Rates.
O_2	Oxygen.
O_3	Ozone.
OBD	Early onboard diagnostics systems in the US.
OBD-2	Second generation onboard diagnostics systems in the US.
OEM	Original Engine Manufacturer.
OMIL	International Organisation of Legal Metrology.
PM	Particulate matter.
$PM_{2.5}$	Particulate matter of size 2.5 microns or less.
PM_{10}	Particulate matter of size 10 microns or less.
ppm	Parts per million.
R^2	Coefficient of determination.
SAS	Statistical Analysis Software.
SMF	Sustainable Management Fund.
SO_2	Sulphur dioxide.
TWC	Three way catalyst.
US	United States.
VFEM	Vehicle Fleet Emissions Model.
VFECS	Vehicle Fleet Emissions Control Strategy.
VKT	Vehicle kilometres travelled.
VOC	Volatile Organic Compounds.
WoF	Warrant of fitness.
Y	Average year of manufacture.
YoM	Year of Manufacture.
4WD	Four wheel drive.

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. An Introduction to Vehicle Emissions

This report provides the findings of a pilot study on idle simple emissions testing of petrol vehicles in New Zealand (the Pilot). It is necessary to delve into quite complex and technical material when considering vehicle emissions and this forward section is intended to provide the reader with a base understanding of vehicle emissions. Those familiar with the science of vehicle emissions may wish to begin at Section 3.

2.1. Pollution in a Wider Context

The environment is a receptor of pollution from natural sources and human activity and can sustain a certain level of pollution without suffering irreparable damage. Sources of pollution from human activity include those associated with driving our cars, heating our homes, generating power and as the by-product of any number of industrial processes.

Efforts to improve local air quality have been underway in industrialised societies for many years. More recently, and separate to factors affecting air quality in the locality where emissions are generated, there has been a growing world-wide concern that certain atmospheric pollutants decrease the amount of the sun's radiant energy that is reflected back into space, contributing to the so-called 'greenhouse effect' and raising associated concerns over global warming.

Reducing pollution arising from human activity invariably involves a cost. Cleaner methods or technologies in every sector, whether in industry or in transport, tend to be more expensive, and the outlay on these must be traded off against commodities or services that might have been purchased with the same money. Health and environmental damage costs associated with pollution also come into the balance and, recognising there is capacity in the environment for some degree of pollution, this therefore poses the question: up to what level of pollution is acceptable?

In New Zealand, the believed safe limits for 'local air quality pollutants' are set by the Resource Management National Environment Standards Regulations 2004 (NES). According to the NES, 'local air quality pollutants' are gases and particles which are of concern in open air where people are affected. Included in this definition are PM_{10} particles — airborne particles which are less than ten microns in diameter, or between one fifth and one tenth of the diameter of a typical human hair — and the gases sulphur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO) and ozone (O_3), among others[7]. The consideration of pollutants with global warming potential, such as carbon dioxide (CO_2), is largely the job of the New Zealand Climate Change Office.

The use of motor vehicles is responsible for both kinds of pollution and in some circumstances can be the most significant source of these emissions.

[7] http://www.mfe.govt.nz/laws/ris/ris-air-quality.html.

When air quality is measured, no differentiation is made between pollution from industry, power generation, or transport. It is proposed that localities failing to meet air quality standards such as those stipulated by the NES will not be granted further resource consents to discharge air pollutants, so that a poor air quality result will have a direct and serious impact on industrial and commercial growth. Parts of Auckland are at particular risk in this regard and improvement in vehicle fleet emissions performance may be required to avert significant future restrictions to commercial activity.[8]

2.2. Vehicle Emissions and How to Test for Them

2.2.1. Operation of a Petrol Engine

Eighty-three percent[9] of self-propelled vehicles registered in New Zealand are powered by engines burning petrol (also sometimes called gasoline). Petrol is a wide-ranging mixture of chemicals named *hydrocarbons* which are predominantly made up of the elements carbon and hydrogen. Most of the hydrocarbons comprising petrol are highly volatile. Given the right conditions, they will readily combine with oxygen in an explosive reaction (*combustion*) which predominantly produces carbon dioxide and water and releases heat energy. There are many other compounds that may also form during the combustion of petrol in an engine, including products of the partial combustion of petrol and lubricating oil that has been entrained into the process, and reactions with nitrogen in the air that is the source of oxygen.

A basic petrol engine consists of an air intake system, a fuel metering system, a spark ignition system, a combustion chamber (often called a 'cylinder') containing a piston connected to an output shaft and an exhaust system.

For the necessary explosive reaction of petrol and air to occur, these must be mixed in close to correct (or *stoichiometric*) proportions. Petrol is normally metered into the intake air, the fuel and air mixture is then drawn into the engine's combustion chamber where it is compressed by a piston then ignited by a timed spark (the presence of the 'spark' is the reason petrol engines are sometimes referred to as *spark ignition engines*). Ignition begins combustion, which typically spreads out as a 'flame-front' through the unburned fuel and air mixture. Unless it is stopped prematurely by, for example, quenching, combustion will proceed throughout the unburned fuel and air mixture until there is no further unburned fuel or oxygen available. The heat generated by combustion causes the pressure of the gas in the cylinder to increase sharply. This pressure acts on the piston, the work associated with its travel transferred to the engine's output shaft. The engines used in modern motor vehicles usually have more than one — most commonly four or more — combustion chambers, or cylinders.

There are variations on the same basic process. An engine may be fitted with a *turbocharger*, for example, which acts to push a greater volume of fuel and air

[8] Councils with non-complying air quality will be expected to meet a 'deemed plan' for improvement, where they will show a linear path to compliance with no more than one instance of exceeding 50µg/m3 by 2013; http://www.mfe.govt.nz/laws/ris/ris-air-quality.html ruling that non-compliance in the future will prevent the granting of new discharge consents could have serious implications to the likes of industrial or commercial growth.
[9] Land Transport Safety Authority, *New Zealand Motor Vehicle Registration Statistics, 2003*, ISSN 0114-7234.

mixture into the combustion chamber, in turn making available more energy per *power stroke* (the movement of the piston in response to combustion).

Fuels such as *natural gas*[10], *liquid petroleum gas* (LPG) and alcohols such as *methanol* and *ethanol* have broadly similar properties to petrol, relative to the likes of diesel, and are also used in spark ignition engines. The properties of diesel fuel make this fuel better suited to use in so-called *compression ignition* engines, which rely upon a different combustion initiation process.

2.2.2. Emissions from Petrol-Engined Vehicles

There are many types of *emission* arising from the normal operation of motor vehicles, including (although we may ignore them for our purposes here) heat and noise. Most of the emissions under consideration are the gaseous by-products of the chemical reactions comprising combustion, and include *carbon monoxid*e (CO), *hydrocarbons* (HC sometimes also referred to as volatile organic hydrocarbons, VOC), *carbon dioxide* (CO_2), *oxides of nitrogen* (usually referred to as NOx, which includes both *nitrogen oxide* NO and *nitrogen dioxide* NO_2) and *sulphur dioxide* (SO_2). Some emissions have nothing to do with the engine's exhaust at all, such as those that are due to the evaporation of fuel from fuel tanks, lines and metering systems. This includes emissions when the vehicle is not in use, as in 'resting losses', where fuel evaporates and escapes through faulty connections, permeable hoses and other fuel system componentry; and 'hot soak' emissions, the increased resting losses suffered by a vehicle left warm at the end of a trip. An amount of petrol vapour escapes to the atmosphere when a vehicle is re-fuelled. Similarly, vehicles also emit *particulate matter* (PM) — referring to microscopic, airborne particles — both in their exhaust and from brake, clutch and tyre wear.

The pollutants *carbon monoxid*e (CO), *hydrocarbons* (HC), the *oxides of nitrogen* (NOx) and *sulphur dioxide* (SO_2) have been associated with a range of health problems. One significant component of gaseous vehicle emissions are the so-called 'toxics' — *aromatic hydrocarbons*[11] such as *benzene*, *toluene*, *formaldehyde*, *aldehyde* and *1,3-butadiene* — which are known carcinogens (cancer-causing agents). NOx and SO_2 have been associated with environmental damage due to their tendency to combine with water to form powerful acids. NOx and hydrocarbons have also been identified as the major components of photochemical 'smog', the visible haze of pollution familiar to modern city-dwellers. Most countries consider PM_{10} (particulate matter with a diameter of less than ten *microns*: a typical human hair is 50 to 100 microns in diameter) to be a health hazard, and the especially hazardous effect of $PM_{2.5}$ — particles with a diameter of less than 2.5 microns, small enough to be carried deep into the human lung — has been receiving increasing attention from health researchers. CO, HC, NOx, PM_{10} and SO_2 principally effect the local environment and are often referred to as *local air quality pollutants* (although they can travel considerable distances by wind). Carbon dioxide (CO_2) is a 'greenhouse gas', and is among the group of gases and particles considered to be *global air quality pollutants*.

[10] Natural gas for vehicles is typically made available in the form of compressed natural gas (CNG), the fuel being stored under high pressure in pressure vessels.
[11] An 'aromatic' hydrocarbon is one which contains one or more benzene rings — a ring of six carbon atoms. Aromatic hydrocarbons have been implicated in the development of human and animal health disorders, notably cancer.

Not all harmful exhaust emissions from vehicles are present in the tail-pipe. Emissions from vehicles can be significant *precursory* sources of air pollutants, which means that while they are not in themselves of concern, they readily convert to species of concern in the atmosphere. Vehicles emit nitrogen oxide (NO), for example, which relatively easily converts to NO_2 in the atmosphere. Further reaction with hydrocarbons in the presence of sunlight generates *ozone* (O_3), which is harmful in the lower atmosphere. This kind of downstream reaction must be considered when assessing the environmental impact of vehicle emissions: a locality may suffer from high levels of a pollutant that cannot be detected in the emissions of local vehicles, which are nonetheless responsible for them.

2.2.3. The Sources of Engine Exhaust Emissions

Carbon Monoxide

Carbon monoxide emission results from the incomplete combustion of the carbon component of hydrocarbons to carbon dioxide (CO_2). This occurs most commonly where insufficient oxygen is available for the amount of fuel delivered to the combustion chamber, such as when 'rich' (that is, fuel-rich) mixtures are used. Even a sophisticated modern engine will venture into rich operation during normal use, particularly when cold-started or under sudden changes in engine load, such as when overtaking.

Hydrocarbons

Due to the many hydrocarbon formation processes involved in a petrol engine, the cause and effect of hydrocarbon emission is more complicated than that of carbon monoxide. Simplistically, though, cold engine operation, older engine designs, higher engine speeds, low-load operation, use of fuels of inappropriately low volatility and the use of fuel-rich air-fuel mixtures (including during phases of the normal driving cycle, such as at engine start-up and when significant variations in engine load occurs) tend to increase hydrocarbon emission. Engine misfiring — where combustion initiation is poor or fails completely due to a faulty spark ignition system or because the air-fuel mixture is too fuel-lean (contains too much air) — will also cause the exhaust of unburned hydrocarbons.

The emission of hydrocarbons comes about through the incomplete combustion of the components of fuel or of lubricating oil (also a hydrocarbon) that has been pulled into the gases in the combustion chamber. There are many reasons why the combustion of fuel can be incomplete. Fuel may somehow escape exposure to combustion during the power stroke. The flame-front may be quenched as it approaches combustion chamber walls. The surfaces of the combustion chamber, including any deposits, may be 'wetted' with liquid fuel, especially during cold operation, where a higher proportion of fuel would be liquid (petrol must be vaporised before it will take part in the combustion reactions, and the proportion of the fuel vaporised before it reaches the combustion chamber depends on temperature). In any of these events, partially combusted hydrocarbons are often caught up in the swirl of gases in the combustion chamber and some further combustion may take place before the products are passed to the exhaust. Some degree of further oxidation will normally take place in the exhaust system, but an amount of unburned hydrocarbons, or their partially combusted derivatives, will be present in the exhaust gases.

For the above reasons, the hydrocarbons emitted from a petrol engine would be expected to contain some of the toxic hydrocarbon fractions which are present in the base fuel, or at least their partially combusted derivatives. Indeed, certain amounts (albeit small) of the toxics formaldehyde, acetaldehyde, benzene, 1,3-butadiene and *polyaromatic hydrocarbons* (PAH) are found in the exhaust gases of a petrol engine.

Oxides of Nitrogen

Nitrogen oxide (NO) is formed principally in the combination of nitrogen (N_2) and oxygen (O_2), both of which are present in air. This requires the disassociation of either nitrogen or oxygen, which occurs at high temperatures. There are many complex chemical associations and processes involved. However, simplistically, NO emission is expected to be highest under higher engine loads and where air-fuel mixtures are slightly fuel-lean of ideal.

The amount of nitrogen dioxide (NO_2) formed in petrol engines is normally very small. However, NO relatively quickly combines with oxygen in the atmosphere to form NO_2, an NES pollutant. Hence, the tendency of NO to produce NO_2 makes an engine's level of NO emission of concern. The combined NO and NO_2 emissions from engines are usually referred to as 'NOx emissions'.

Another oxide of nitrogen, N_2O, can also be formed during combustion or through the action of *exhaust catalysts* (see below: Engine Design and Emission Levels). The amounts produced are typically very small, but N_2O has a very high global warming potential compared with CO_2, and hence has received increasing attention in recent years.

Sulphur Dioxide

Sulphur dioxide (SO_2) is produced by the combustion of fuel-borne sulphur. Lowering the levels of sulphur in fuel will directly reduce the levels of SO_2 emitted.

Particulate Matter

Particulate matter, or PM, are superfine particles. The emission of PM_{10} (particles ten microns or less in diameter) from petrol engines is associated with the partial combustion of 'heavy-ends', or the longer-chain hydrocarbon components of fuel, and of lubricating oil that has been pulled into the combustion gases. SO_2, sulphates (which are formed by the further reaction of SO_2), and water (which is a normal by-product of the fuel's combustion) can add to the weight of the individual particles, and overall particulate emission.

Diesel engines are a far greater source of particulate emissions than petrol engines. The Auckland Regional Authority claims 91% of engine-sourced particulates are from diesel vehicles.[12] This suggests only 10% of engine-sourced particulate comes from light petrol vehicles, 10% from light diesel vehicles ('light vehicles' are defined in New Zealand as those weighing 3500 kg or less) and 80% from heavy vehicles — diesel-powered buses and trucks.[13]

Visible Emissions

Visible emissions from petrol vehicles include smoke and condensed water vapour.

Smoke is the visible component of particulate emission. For petrol engines, visible smoke is usually associated with lubricating oil which has been entrained into the combustion gases and is partially burned and emitted. Oil smoke has a blue tinge, and in a modern engine indicates poor engine condition.

It is usual for a car which has been cold-started and has yet to reach operating temperature to emit visible white vapour, as the water vapour which is a product of the combustion of hydrocarbons condenses in the cold exhaust pipe.

Secondary Emissions Species

Most people consider ozone (O_3) to be a 'good' or 'friendly' gas, due to its indelible association with 'the ozone layer', a layer of the gas in the upper atmosphere which reduces the amount of damaging ultraviolet light reaching the earth's surface. The same gas at ground-level, however, is an air pollutant with harmful effects on lung function[14] and is one of the target gases in the NES. O_3 is not emitted directly from a vehicle; rather it is a 'secondary' pollutant, derived from the combination of NOx and hydrocarbons in the presence of sunlight.

Similarly, secondary *sulphate* and *nitrate* particulates are formed by reactions of sulphur dioxide (SO_2) and NOx in the atmosphere. These are acidic in nature.

2.2.4. What Affects Engine Emissions

As indicated in the preceding section, the nature and volume of emissions generated by a petrol engine are functions of a complex set of variables. This may include, among other things, how complete the combustion of the fuel is, combustion temperatures, how much lubricating oil is entrained into the cylinder gases (and what combustion of that lubricating oil takes place) and what after-treatment of exhaust gas (if any) is carried out. The resultant emission from an engine is therefore largely determined by the base engine design, commonly referred to as the 'engine technology' (where 'engine' also includes the exhaust system and any exhaust after-treatment system that may be fitted).

[12] http://www.arc.govt.nz/arc/index.cfm?506F3920-F13F-4943-AA63-A1645BE69384. The accuracy of this is questioned although the order is as would be expected.

[13] Based on the average (light) petrol vehicle emitting an order of magnitude lower PM_{10} than the average light diesel vehicle - there being ten times more petrol vehicles than light diesel vehicles - and typical ratios of weight of particulate emitted by light and heavy diesel vehicles.

[14] http://en.wikipedia.org/wiki/Ozone.

Engine Design and Emission Levels

Over the years, the technology of motor vehicle engines has evolved as manufacturers have responded to various market demands. Some markets at some periods have demanded high-powered engines to the exclusion of all other considerations. During the 'oil shocks' of the 1970s, the market strongly preferred smaller engines which were more economical to run. Since the late 1990s, however, as the quality of the air in our cities has noticeably deteriorated, most markets have demanded technology that emits minimal local air quality pollutants. And more recently again, there has been a shift to the demand for the low emission of species associated with global warming.

The latter is the same as striving to achieve the best possible fuel economy, where the use of carbon-containing fuels (of which petrol is one) is concerned. It is important to note, though, that some measures that will decrease fuel consumption actually increase emission of local air quality pollutants[15]. Today's engine designers achieve both fuel economy and low emissions through a range of tools, including the use of sophisticated fuel metering systems and advanced combustion chamber design, *exhaust gas recirculation* and the use of *exhaust catalysts*.

Recirculation of exhaust gas dilutes the incoming air-fuel charge with largely inert gases, and has the affect of lowering temperatures during combustion, reducing the formation of NOx.

Exhaust catalysts have been shown to reduce emissions of concern by 95% or more. In general, catalysts used on spark ignition engines promote the oxidation of partially combusted fuel to CO_2 and water and, in some cases, also reduce NOx.[16] The performance of catalyst systems depends upon, among other things, the accurate metering of fuel, the quality of the initial combustion, the condition of the catalyst and operation above their *light-off temperature.*[17]

Other Factors

Due to the many emission species of concern and the varying and complex paths to their formation, there are many other variables besides engine technology that can also have significant effects on emission levels from vehicles. In the United States, statutory authorities charged with evaluating vehicle emissions are required to use an inventory process named MOBILE6[18] which, as the name suggests, is one in a series of versions which have been developed since the scheme's instigation. The factors used to describe emissions in MOBILE6 provide a good indication of the range and scope of the variables at work. The list of factors includes:[19]

- Engine technology, or more specifically the original emissions performance of the vehicle (that is, the 'build' performance);

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[15] For example, advancing the spark ignition timing will normally decrease fuel consumption but increase NOx emission.
[16] Exhaust catalysts first introduced for spark ignition engines oxidised CO and HC to CO_2 and water and were called 'two-way' catalysts, as they targeted two emissions species. A catalyst that also reduced NOx was required as overseas emissions standards became more stringent. These catalysts were termed 'three-way' catalysts (TWC), as they targeted three emissions species. TWC required reasonably precise control of fuel metering in order to function well.
[17] The temperature above which the catalyst begins to work effectively, which is typically around 300°C for a modern spark ignition engine catalyst.
[18] MOBILE6.2 is the current version used in the US, see http://www.epa.gov/otaq/m6.htm#m60.
[19] http://www.epa.gov/otaq/models/mobile6/420r03010.pdf

- the deterioration of vehicle emissions performance by age and distance travelled (for various vehicle types and engine build performance);
- the age and population distribution of various vehicle types (including by fuel type and build performance);
- road and driving factors including road type, average speed, number of starts and proportion of driving period after cold start, by various vehicle types and build performance;
- distance travelled by various vehicle types, with respect to build performance and road and driving conditions;
- fuel factors including fuel type, formulation (for example, oxygen content — oxygenates are added to a significant proportion of the petrol sold in the US) and the possible misfuelling (use of the wrong fuel) of vehicles;
- vehicle maintenance and the incidence of tampering (with engine management or exhaust emission control systems), including what inspection and maintenance (I/M) programmes exist and what anti-tampering checks are in place, if any;
- environmental factors including altitude, temperatures, humidity and solar load (duration and intensity of sunshine);
- modelling emissions output requirements (including the definition of emissions and their dimensions: for example, defining the cut-off size for particulates, such as $PM_{2.5}$ or PM_{10}.

It is not just the sheer number of variables that make the assessment of vehicle emissions performance difficult. There are complex links and associations between the different variables themselves. The ambient temperature, for example, can significantly affect emissions during and after cold start, and influence the duration of that effect. Similarly, the cold start effect differs markedly from vehicle to vehicle depending on the engine technology involved — the catalyst on a vehicle so equipped, for example, does not 'light up' until the vehicle has reached an appropriate temperature, and the vehicle's emissions will be many times greater during the cold running period compared with its base emissions performance. A vehicle which is not equipped with a catalyst will not exhibit the same dramatic difference in emissions performance during cold and normal running, although its base emissions performance will be expected to be poorer than a catalyst-equipped vehicle. As well, the ambient temperature significantly affects the reactions which take place between vehicle emissions and atmospheric gases.

A potential weakness of the MOBILE6 approach is the use of vehicle emissions factors based on average speeds by roadway type. It is widely understood that vehicle emissions are more closely associated with interruptions to the steady-speed operation of vehicles rather than to average speed. Hence a bottom-up approach would tend to describe road and driving conditions by their transient nature and not their average speed, an approach that is supported by the findings of the testing carried out by the Pilot. Here, a four- to five-fold increase in emissions was found when vehicles were tested across a drive cycle realistically representing the stop-start nature of driving in congested roadways, compared with the results of testing over a drive cycle representing smoother driving conditions.

For New Zealand, vehicles may also be imported new or used and this can be an influential emissions parameter, although a coarse one, when the likes of build performance are not known.

A modified list of variables affecting emission levels for use in New Zealand might look like this:

- build performance (which is closely associated with engine technology);
- deterioration due to age and vehicle history;
- the vehicle fleet profile;
- driving style and road-related factors;
- distance travelled;
- fuel factors;
- maintenance factors;
- environmental factors;
- vehicle origin.

2.2.5. Emissions Reduction Options

The above list describes variables affecting emissions from the fleet. It follows that management of these variables should lead to a reduction in the fleet's total emissions. What, then, are our options for reducing vehicle emissions by addressing these factors?

Build performance

An obvious measure for improving the emissions performance of the New Zealand vehicle fleet is to ensure that as the fleet undergoes business-as-usual renewal, new entrants are required to meet a minimum emissions performance standard. A step in this direction has already been taken: the Land Transport Rule – Vehicle Exhaust Emissions 2003 (the Emissions Rule) stipulates a minimum emissions build specification for new fleet entrants,[20] based on their year of manufacture (as given by reference to the exhaust emission component of vehicle emissions standards in use in the four jurisdictions from which New Zealand recognises vehicle standards). Note this rule does make allowance for fuel quality in New Zealand and vehicle production lead times, meaning the resulting standards referred to are less stringent than those current in overseas jurisdictions. This rule also omits to require vehicles to be fitted with vapour control systems or certain engine management systems that could have added emission benefits. New Zealand also permits the importation of used vehicles, which permits entry to vehicles built to older, less stringent, emissions standards.

Before the Emissions Rule for light vehicles was implemented in 2004, there was effectively no requirement at all for imported vehicles to meet any minimum emissions specification. The consequence is that many new vehicles which entered during this period employed cheaper and less advanced engine technology, compared to the engine technologies in mainstream use in other countries. Used imports, on the other hand, were normally built to an emissions standard requiring comparatively

[20] 'new fleet entrants' refers to both new vehicles and used imports new to the New Zealand fleet.

advanced engine technology and could exhibit lower emissions than their technologically-challenged New Zealand-new counterparts. This subject is discussed more fully later in the report.

Overseas emissions standards tend to place differing requirements on different classes of vehicle. Trends in emissions standards for petrol vehicles include:

- the main specification of regulatory emissions standards for light vehicles[21] is based on the weight of emission per distance travelled (European standards, for example, refer to grams per kilometre [g/km]) and includes a maximum specification for CO, HC, NOx and sometimes (depending upon jurisdiction and vehicle model year) PM. Additionally, there may be an idle simple test emissions standard based on a concentration of emission in the exhaust gas (vehicles built to the current Japanese vehicle emissions standards, for example, may emit exhaust gas containing no more than 1% CO and 300 parts per million HC at (natural) idle[22]) that can also be used for in-service inspection and maintenance purposes;
- for petrol vehicles in Japan, many small passenger vehicles and large 4WD passenger vehicles are built to meet the same emissions standard (even though the larger 4WD vehicle is expected to have a much larger engine and higher fuel consumption) and are expected to produce much the same emissions on a per kilometre basis, at least when in a state of reasonable condition. Similarly, for Europe, the vehicle categories are sufficiently broad that a high proportion of passenger vehicles are within a single emissions standard category;
- in the past, quite different standards have been applied to vehicles using different fuel types, but specified limits are now converging across all fuel options;
- emissions standards for heavy vehicles tend to rely predominantly on the results of testing the engine only and, due to the large variation in power output between different engines, emissions specifications are normally given in a weight per unit of output energy (in the case of European emissions standards for heavy vehicles, for example, the unit used is grams per kilowatt-hour [g/kWhr]) and stipulate maximum levels for CO, HC, NOx and PM;
- some emissions standards include distance-based performance requirements. In the United States, for example, some emissions build standards specify maximum emission limits at 50,000 and 100,000 or 120,000 miles. This US emissions régime is also supported by a sophisticated in-service vehicle testing programme.

Note that these different emissions standards prevailing overseas rely upon different test procedures. One consequence of the variety of testing procedures in use is that the limits set by one jurisdiction cannot be directly compared with those of another jurisdiction, unless they happen to stipulate exactly the same test procedure (as is the case with Australian Design Rules which refer to US or European standards, depending upon the period in question). Similarly, the result from testing a vehicle to one standard cannot be directly compared to the result from testing another vehicle to

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[21] In New Zealand, a 'light' vehicle is of gross mass of 3500 kg or less. Classifications in use in other countries may use other weight cut-points.

[22] Japan Automobile Standards Internationalisation Centre, *Automotive Type Approval Handbook for Japanese Certification, 2002*, Japan.

a different test standard. Nevertheless, specifying a minimum performance requirement at vehicle entry to the fleet is an effective means of intervention, as it 'sets the tone' for emissions performance from vehicles that are then expected to be in the fleet for some time.

Deterioration in Emissions Performance due to Age and Distance Travelled

In practice, the emissions performance of vehicles deteriorates with age and distance travelled. The rate and extent of this deterioration has been found to differ according to engine technology.[23] Further 'gross' deterioration may be caused by component failure (say, causing misfiring or over-fuelling, which has the potential to overheat the catalyst) or misfuelling. Given these findings, improvement in fleet emissions performance would be achieved through modernising the fleet and minimising the risk of 'gross deterioration' events.

Vehicle Age Population Profiles, by Vehicle Type

Generally speaking, an older vehicle will have been built to less stringent emissions performance requirements, will tend to have less durable engine components, will have travelled further and could be expected to exhibit higher on-road emissions levels (on a grams per kilometre basis) because of these factors. Generally speaking, then, the age population profile of the vehicle fleet is an important determinant of expected fleet emissions.[24]

Broad differences in emissions performance are also expected for differences in fuel (for example, the average petrol vehicle would be expected to emit greater CO, HC and NOx but far less PM than the average diesel vehicle, all else being equal) and vehicle type as defined by the basic vehicle and weight category into which the vehicle falls.

MOBILE6 divides light-duty petrol vehicles into five different weight categories, although the differences between the emissions performance of some classes is insignificant. It is difficult to make a similar differentiation in the New Zealand light petrol fleet, as the present vehicle classification system that divides the fleet has only become mandatory relatively recently[25] and is unreliable (permitting some vehicles to fall into different classifications). Weight, what's more, is not always recorded. In any case, as it has been found that there is little difference in emissions performance (with the exception of CO_2) for vehicles of widely ranging mass, dividing the fleet into anything other than very broad weight categories is becoming increasingly less relevant for emissions inventory purposes.[26] Nor, incidentally, is engine size a reliable indicator of expected on-road emissions performance. There are many reasons for this, including the wide range of engine sizes available for similar-sized vehicles,

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[23] http://www.epa.gov/otaq/models/mobile6/420r03010.pdf

[24] Note: care is required when applying this in the New Zealand context other than in general terms, as older used imported vehicles can be of more advanced engine technology than newer New Zealand-new vehicles, and the older used imports will exhibit lower emission as a result.

[25] The present classification system, introduced in November 1997 for used imports and October 1999 for New Zealand-new vehicles, divides the fleet by main function and weight into categories designated MA for light passenger cars, NA for light goods vehicles, NB for medium goods vehicles, etc.

[26] Note: a heavier vehicle would demand greater energy to carry out the same trip compared to a lighter vehicle and will therefore emit more CO_2, in the case of using a distillate fuel, all else being equal. In comparison, emissions of local air quality pollutants are a function of combustion management and exhaust after-treatment and can be managed so that quantities emitted from a light and a heavy-light vehicle (that is, a light vehicle near 3500 kg) are similar.

similar-sized engines develop varying levels of engine power and engine design being a far greater determinant of emissions performance than size. Using the example provided above, for petrol vehicles in Japan, large 4WD passenger vehicles are built to meet the same emissions standard (that is, same emissions limit on a grams per kilometre basis) as small passenger vehicles.[27]

As has also already been mentioned, there would be advantages from an emissions reduction perspective in modernising the fleet. There would also be benefits both in fuel economy and in CO_2 emissions in moving to a lighter fleet.

Road Type and Driving Conditions

Road type and driving conditions describe the *transient* nature of engine operation and, for road type, govern the engine load and pattern of power demand. Addressing the way we use our cars could greatly lower emissions. The stop-start motion of traffic in congested conditions, for example, causes sharp rises in vehicle emission rates, and hence good management of congestion would bring about a significant improvement in overall emission rates. 'Management' might include shifting the time of travel to avoid peak travel demand periods.

A 'driving condition' of particular importance is cold start and the time immediately afterward. During the period before a modern engine reaches its optimal operating temperature, the emission of air quality pollutants can be as much as twenty times higher than the base performance of the vehicle. A survey conducted by the (then) Land Transport Safety Authority (LTSA) in 1997/1998 reported that one third of the driving trips undertaken by New Zealanders covered distances of less than two kilometres and two thirds were under six kilometres.[28] Recent research by the Energy Efficiency and Conservation Authority (EECA) reports that the average trip to ferry children to and from school is 1.5 km.[29] This suggests a considerable proportion of the driving New Zealanders do is on a cold engine, when the vehicle's rates of emission are at their highest.

Distance Travelled by Vehicle Type, Road Type and Driving Condition

Simple logic suggests that reduction in vehicle-kilometres travelled will produce a reduction in emissions. With careful management, changing travel modes — say, from travelling in a private car to travelling on public transport — reductions in overall emissions may be achieved.[30] And as has been mentioned, avoiding peak travel demand periods and consolidating trips, both to reduce total kilometres travelled and the proportion of driving undertaken on a cold engine, would have a positive effect.

[27] However, it would be generally easier to achieve the same emissions performance for a lighter vehicle.
[28] Land Transport Safety Authority, *Travel Survey Highlights 1997/1998*, ISBN 0-478-20688-7
[29] 1.5 km is a figure used in industry for the average urban trip to primary schools across the country, based on a number of assumptions. Craig Richards, EECA, personal communication 2005.
[30] 'Careful management' is required as a shift from private car to public transport could also cause an increase in certain emissions.

Fuel Factors

Fuel quality must match the requirements of the engine technology to avoid compromising performance. These fuel requirements, along with environmental, safety and handling considerations, are managed in New Zealand by the Petroleum Products Specifications Regulations.

The most significant change in the local specification for petrol in recent times was the availability of unleaded petrol in New Zealand beginning 1986[31] and the total removal of lead from retail petrol in 1996.[32] Since the 1920s, lead compounds were added to petrol to suppress 'combustion knock' (otherwise known as 'detonation' or 'pinking'), which causes very high pressures and sharp rises in pressure in the combustion chamber capable of causing engine damage.[33] Lead was removed from petrol in response to mounting concerns about the public health effects of the high levels of environmental lead deposited by the vehicle fleet; but more relevant to present purposes, lead also 'poisons' exhaust catalysts, and an alternative fuel specification would eventually have been necessary to meet the demands of a modern, increasingly catalyst-equipped fleet.[34]

Potentially, catalyst-equipped vehicles in use in New Zealand before December 1995 suffered some degree of irrevocable lead poisoning of their catalysts, rendering them less functional. There is some chance that catalyst-equipped vehicles in use before as late as October 1996 may also have had their catalysts poisoned to some extent, although dispensers with larger diameter nozzles were used for the delivery of leaded fuel to make it difficult to get it into the small filling ports with which most catalyst-equipped vehicles are fitted.

Interpolating results provided by Milton,[35] one tank of leaded fuel (at the time, around 0.35 grams of lead per litre[36]) would reduce the efficiency of a catalyst by around 25%; since the effect is cumulative, four to five tanks-full would be expected to render the catalyst almost ineffective.

Alternative Fuels

The main fuel alternatives to petrol for spark ignition engines are *natural gas*, normally dispensed as *compressed natural gas* (CNG), *liquefied petroleum gas* (LPG), the alcohols *ethanol* and *methanol* and *blends* of these alcohols with petrol.

With the exception of low-percentage blends of ethanol and methanol with petrol, the available alternatives to petrol for use in spark ignition engines require modification of the base petrol engine design in order to function. As far as the main air quality species CO, HC and NOx are concerned, the resulting emission signatures largely depend upon the quality of those engine modifications. For example, the CNG and LPG conversions of petrol engines carried out in New Zealand up until the late 1980s

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[31] http://www.mfe.govt.nz/publications/ser/ser1997/html/chapter6.9.html#figure6.13
[32] Shipments of leaded petrol were not admitted after 1 January 1996 and it was illegal to retail leaded petrol from 1 October 1996. Paul Stannard, MED, personal communication.
[33] www.lead.org.au/lanv8n1/l8v1-5.html.
[34] Lead takes up the sites where emissions are converted, rendering them unavailable for the conversion of emissions gases.
[35] Milton, B.E., *Control Technologies in Spark Ignition Engines*, ISBN: 0-12-639855-0, 1998
[36] http://www.mfe.govt.nz/publications/ser/ser1997/html/chapter6.9.html

tended to use simple fuel metering systems that were a retrograde step in engine technology compared with the original, unmodified petrol engines. On average, poorer emissions performance would be expected compared to the same vehicle running on petrol in its unmodified state — an outcome not helped by the common practice of tuning the fuel metering systems to deliver fuel-rich mixtures, in an effort to compensate for the loss of engine power then commonly experienced on CNG and LPG.

Differing properties of fuels — such as the high heat of vaporisation, in the case of the alcohols — have implications for emissions performance if not appropriately managed. Overseas, the increasing application of stringent emissions regulations has limited the use of alcohols to low-percentage blends with petrol, and the use of alternative fuels in purpose-built vehicles or vehicles modified in a certified manner only.

Fuel grade CNG, LPG, ethanol and methanol have low amounts of toxics in the base fuel and hence little opportunity exists for significant base toxics to carry over into the exhaust. However, use of these fuels would be expected to exhibit an increase in *engine-out* aldehyde[37] emission, compared with a petrol engine, although the increased levels are expected to be small and insignificant for a warm engine coupled with a working catalyst. A low level of 1,3 butadiene and benzene emission would also be expected.

In common with an engine fuelled by petrol, some 'carry-over' of lubricating oil into the combustion gases would be expected when using alternative fuels, with associated emission from that lubricating oil carry-over. As in petrol engines, this emission is expected to increase with wear. Little difference in wear rates is expected when using the alternatives where the use of the fuel is well managed, although higher wear rates have been associated with the use of high-percentage petrol-alcohol blends in demonstrations in the 1980s.[38]

Maintenance Factors

The purpose of maintenance is to maintain performance at an acceptable level. In practice, maintenance régimes range from breakdown maintenance to sophisticated pre-emptive and preventative programmes. Where vehicle emissions are concerned, maintenance régimes may include:

- a method to select likely high-emitting vehicles, which may be:
    - a non-testing method such as selection by vehicle age, or inspection for the presence of a catalyst;
    - a testing method such as using a simple, instrumented emissions test.
- repair, or at least attempted repair;
- re-testing;
- repair alternatives;
- education;

[37] Aldehydes can be formed relatively easily by partial combustion of alcohol, so are expected to be more prevalent in the exhaust of vehicles fuelled with alcohol-containing fuels. They are irritants, toxins and possibly carcinogens (http://www.eia.doe.gov/cneaf/alternate/page/glossary.html).

[38] Campbell, A.R., 'Methanol in Otto-Cycle Engines', *Liquid Fuels Trust Board Project Report to Project 610/80/1*, 1986.

- incentives and/or enforcement;
- programme monitoring.

These elements may be more or less completely or rigorously applied. Testing methods, for example, could range from testing the exhaust for emissions whilst the vehicle was stationary and at (natural) idle or fast idle using simple analysers — the *idle simple test* considered by this Pilot — to the use of more expensive and time-consuming *loaded transient testing*, where a vehicle is driven on a set of rollers which are variably loaded to provide rolling resistance that simulates on-road operation. What's more, these elements could be applied at various stages through the life of a vehicle, whether occasionally and randomly, or regularly and linked to specific events, such as at the time of resale or warrant of fitness inspection.

2.2.6. Quantifying a Vehicle's Emissions

If we are to reduce the overall emissions of the New Zealand vehicle fleet, it is the emissions of vehicles in normal use which are the proper object of testing. Ideally, the result from an emissions test would provide a good indication of the on-road emissions performance of a vehicle — either a direct correlation with the on-road emissions performance, or a reliable indicator of the presence of an engine fault that is causing high on-road emissions.

Normal on-road driving comprises periods of acceleration, deceleration, steady speed and idling. Severe *transients* — sharp acceleration, deceleration and other sudden changes of load — are a significant determinant of a vehicle's emissions performance. Thus the best indication of a vehicle's on-road emissions performance would be gleaned from a test cycle that includes these components, matching the severity of the transient phases to those normally experienced on the road. Because everyday driving confronts us with an incalculably wide range of driving conditions, each with a different set of transients, even testing vehicles to a transient-loaded cycle is only an approximation of a vehicle's true on-road emissions performance. At best, results from testing to a number of different transient cycles can be generated, providing indications of a vehicle's emissions performance under as wide a variety of circumstances as possible.

In much the same way as a single test cycle cannot provide a precise indication of vehicle emissions in a range of driving conditions, particularly in cities where driving conditions differ significantly due to congestion, frequent cold starts and short trips, local air quality emissions inventories can be blunt instruments where based on the crude product of vehicle population profiles, distance travelled and single emissions factors. A more appropriate method of analysis is to consider a range of emission factors based on a range of driving conditions. This is the approach taken by the Ministry of Transport's Environmental Capacity Analysis (ECA) planning model.[39] The range of emissions factors employed in this model are calculated using the Ministry's Vehicle Emissions Fleet Model (VEFM), which in turn is used to calculate

[39] Irving, P. and Moncrieff, I., 'Managing the Environmental Impacts of Land Transport: A Measured Approach to Sustainability by Integrating Environmental Analysis with Urban Planning'. *Science of The Total Environment*, Volumes 334-335, 1 December 2004, Pages 47-59.

the New Zealand Traffic Emissions Rates (NZTER), the principal set of vehicle emissions rates used for vehicle emissions inventory work in New Zealand.

In-service testing of vehicles to a single transient cycle is expensive enough without testing them to a range of transient cycles. Practical and cost considerations usually demand a compromise, and relatively simple tests, or even visual inspections that eschew testing altogether, are often used. Testing and inspection options include:

- IM240. This approximates the first 240 seconds of Federal Test Procedure 75 (FTP 75), the procedure used for the emissions certification of light vehicles in the United States. This is a loaded transient test carried out on a *chassis dynamometer*, an apparatus where a vehicle's drive wheels are positioned on rotating drums which can be loaded to varying degrees, simulating different transients. Exhaust gas is continuously sampled throughout the test sequence and levels of CO, HC and NOx in the collected sample are measured at the conclusion of the test.
- Acceleration Simulation Mode (ASM). This is a test procedure in use in the United States where a vehicle is run on a chassis dynamometer at steady speed and increasing load (simulating steady acceleration, by contrast with the IM240 test cycle, which includes a number of different transients). Levels of CO, HC and NOx in exhaust gases are measured.
- Remote Sensing. This is where infrared and ultraviolet light of specific wavelength is beamed across the roadway between a source and a receptor, with vehicles passing through the beam. Exhaust pollutants — the species measured are CO, HC and NOx — absorb differing levels of light within certain wavelengths according to their concentration. Sensors in the receptor measure this absorption, providing an indication of the concentration of pollutants in the exhaust.
- Idle Simple Testing. This is where CO and HC exhaust emission levels are checked using a relatively simple *gas analyser* whilst the vehicle is stationary and the engine is at (natural) idle or fast idle.
- Idle Simple Testing in combination with *fumigation*[40] of a gaseous fuel or oxygen into the inlet air. This tests the function of the fuel metering system on modern vehicles.
- Interrogation of the engine's *onboard diagnostic* ('OBD'[41]) system. Late-model vehicles commonly employ a computerised engine management system, which scans various input data that can be retrieved to diagnose system faults. Examining this data may reveal an emissions performance-related fault.
- Visual Inspection. This is a simple, visual verification that the emission control system is intact and in working condition.
- Proof of Minimum Maintenance. This entails inspecting documentary evidence that a given minimum level of maintenance, targeting those items and settings that are likely to 'fall out of tune', has been carried out.

[40] Controlled release of gas at low pressure.
[41] There are various industry-standard 'OBD' systems in use. They are: OBD, the first onboard diagnostics system introduced in the US in the 1980s; OBD-2, the onboard diagnostics system introduced in the US in 1992; JOBD, the Japanese version introduced 2000-2001, and EOBD, the European version also introduced 2000-2001 (with the 'Euro 3' emissions build requirements). The OBD-2, EOBD and the more recent versions of JOBD are two-O_2 sensor onboard diagnostics systems, which can also check the function of the catalyst. Personal communication, New Zealand representative of an overseas original engine manufacturer.

Table 1 provides a summary of the relative advantages and shortcomings of the above-mentioned test and inspection options.

Table 1: Various Emissions Test Options and their Relative Advantages and Disadvantages

Test	Relative Advantages and Disadvantages.
IM240	• Based on the use of a transient test cycle and hence has potential to provide a reasonable indication of on-road emissions performance for some driving conditions (i.e. driving conditions that produce transients similar to those of the IM240). • Allows the engine to be loaded, which is essential for obtaining a meaningful NOx emissions result. • Is a relatively expensive test compared to simpler test options (expected to cost to the order of $80-$140 if introduced to New Zealand).
ASM	• Provides an emissions indication based on the simulation of smooth acceleration, which is a coarser indication of on-road emissions than the multi-transient IM240 test. • Still loads the engine, which allows a reasonably meaningful NOx emissions result to be obtained. • Generally less expensive than an IM240 test, all else being equal, due to the use of cheaper equipment and less time taken to test (expected to cost to the order of $60-120 if introduced to New Zealand).
Remote Sensing	• Can sample a large number of vehicles in a short time (7000 per day or more). • Emissions results are a 'snapshot' of engine emissions performance (immediately after the vehicle passes through the measuring beam) and will vary according to how the vehicle is being operated at the time. The operation of a vehicle passing through a remote testing site is managed to some degree, but it is not fully controlled. Hence results are a coarse assessment of an individual vehicle's expected on-road emissions performance. • Due to the high number of vehicles that can be sampled, remote sensing can provide a useful coarse screen for identifying potentially high-emitting vehicles. • In practice, requires the support of another test or inspection option to verify results and to carry out repairs to vehicles identified as high-emitters. • Low cost on a per-vehicle, per-test basis (to the order of $4).
Idle simple testing (including fast idle)	• Is a coarse indicator of on-road emissions performance. • Does not load the engine sufficiently to provide NOx emissions results. • Relatively low cost (expected to be the order of $20 to $60 if introduced to New Zealand).
Idle simple testing with gaseous fumigation	• Provides a reasonably simple check that a major component of the fuel metering system of modern vehicles is functioning. • Does not provide an indication of on-road emissions performance. • Relatively low cost (expected to add around $5 to $10 to the cost of an idle simple test).

Table 1 continued.

Visual inspection that emissions control system is intact	• Would be required to support any anti-tampering initiatives. • Checks physical presence only, not function. • Does not provide an indication of on-road emissions performance. • Low cost (expected to add around $5 to the cost of a warrant of fitness (WoF) or certificate of fitness (CoF)).
Interrogation of 'OBD'[42] system	• Identifies faults in the engine management system for later versions, with more accuracy than can be achieved using simple test options and visual inspection options. • Can only be applied to vehicles fitted with an 'OBD' system that allows easy and appropriate interrogation of engine management signals. • Depending upon system, may not provide an indication of on-road emissions performance. • Reasonably low cost to interrogate 'OBD' system (expected to be to the order of $20 to $50[43] if introduced into New Zealand).
Proof of Minimum Maintenance	• Careful design of régime is required to avoid excessive examination and cost, particularly considering the modern engine is designed for minimal maintenance. • Does not provide an indication of on-road emissions performance.

With the partial exception of the IM240 test, these procedures are all imperfect methods of assessing on-road emissions performance. However, even the least informative of them provides a means of identifying potential faults, and could be used as a coarse screen to identify potentially high-emitting vehicles and/or as a support tool in a public awareness campaign.

Instruments used to Measure Emissions

Garage-grade, gaseous emissions analysers use *non-dispersive infrared* (NDIR) techniques to measure the CO, CO_2 and HC components of exhaust, and an *electrochemical cell* to measure O_2 and NOx (as NO). NDIR methods are based on the tendency of different chemical bonds to absorb light of quite specific frequencies.[44] The higher the concentration of emission of a particular specie, the higher the absorption of light of the particular wavelength associated with that specie. Determining the amount of light absorbed provides an indication of concentration.

In the case of hydrocarbons, the signal is converted into a concentration of HC based on hexane.

For electrochemical cells, reactions on the surface of the electrochemical cell with a certain specie generates current. The higher the concentration of specie, the higher the current generated, providing an indication of emission concentration.

Apart from remote sensing, emissions measurement requires a means of sampling exhaust gas and delivering the sample to the analyser for measurement of emissions content. In the case of idle simple testing, the sample line usually consists of a non-

[42] 'OBD' (in inverted commas) refers to OBD, OBD-2, EOBD and JOBD, being different OBD systems in use in vehicles. There are some differences in their required function.
[43] $50 is based on work at garage-type operations, based on a $25 fee for time and $25 fee for scan tool charge. Note some garages are charging $70 per connection to a scan tool.
[44] http://www.dieselnet.com/tech/measure_gas.html

heated, flexible tube which cools the gases sufficiently to avoid damaging the analyser.

Laboratory emissions testing typically cools the sample by diluting exhaust gases with a measured quantity of air. NDIR is used to measure CO and CO_2, a *flame ionization detector* (FID) measures HC and a technique known as *chemiluminescence* measures NOx. Particulate matter is not normally measured for petrol vehicles (the emission of particulates from petrol engines being inherently small).

Laboratory equipment for testing gaseous emissions is many times more expensive than garage-type analysers. There are also some important differences in their comparative response. For example, FID returns reasonably consistent results for the main hydrocarbon emission species, whereas NDIR exhibits a far lower response to methane, the main component of natural gas.[45] This inherent inaccuracy with NDIR hydrocarbon measurement is especially apparent when measuring exhaust hydrocarbon emissions from CNG vehicles, where the HC result is unreliable unless it is converted using an appropriate conversion factor.

2.2.7. Comparability of Emissions Results

Vehicles will respond differently to different emissions tests and the results from one test cannot be directly correlated with the results obtained using another test. Differences in test responses may even rank the same set of vehicles differently with respect to their measured emissions levels. For example, three vehicles may be ranked 1,2,3 in order of their emissions performance as measured by idle simple testing, but may be ordered 3,1,2 by the results of a transient test. What's more, the order would likely change again depending on which emission specie was being considered.

There are other problems with comparing the results of different tests. The results of idle simple testing and remote sensing are expressed as *concentrations* of emission specie in the exhaust gases, whereas transient tests tend to provide the *weight* of emissions over the test cycle, say, on a per-kilometre-travelled basis. Conversion between these two dimensions is unreliable.

Due to these differences, care must be taken when quantifying the impact of the overall emissions rates of the worst offenders. Statements such as '10% of the worst offenders are responsible for 50% of emissions', while convenient from a public awareness and sloganeering perspective, are misleading unless derived from on-road emissions performance, which cannot be reliably predicted from the results of simple emissions testing such as idle simple testing or remote sensing. Even the prediction of on-road emissions performance based on testing a vehicle over a single drive cycle can only ever be approximate.

Statistical Analysis Methods Used to Consider Vehicle Emissions

If we were to test a random sample of vehicles built to meet a given emissions standard, we would expect the results, when graphed, to resemble Figure 1. The

[45] http://www.dieselnet.com/tech/measure_gas.html#gases

vertical dotted line represents an emissions standard limit, and vehicles whose test results placed them to the left of the line have met the standard. Curve 1 represents newer vehicles and exhibits a distribution skewed to the left, with most vehicles meeting the emissions standard. Curve 2 represents the same vehicles tested some years later and exhibits a 'stretching out' of the skewed distribution bell with more vehicles placed to the right, the result of the deterioration in average emissions performance due to vehicle age and distance travelled, which will cause many more vehicles to fall short of the standard.

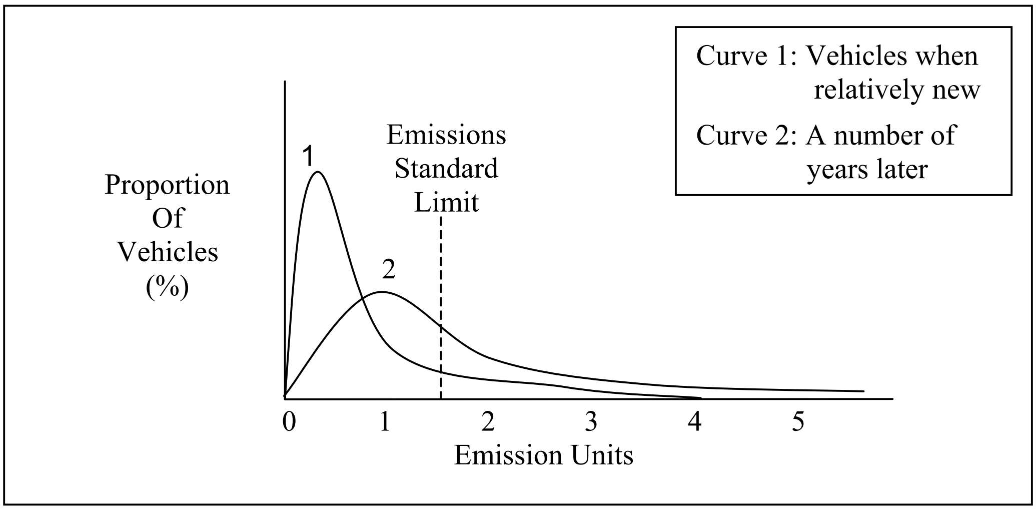

Figure 1: Expected Typical Emissions Response of Testing a Random Sample of Vehicles to the Original Build Standard Test.

It is difficult to statistically model such distributions of data as those above. It is more appropriate to use the (*natural*) *logarithms* of the data to attempt transformation of the distribution of data into a more classic, bell-shaped, normal distribution and to interrogate this distribution using classical statistical significance tests.[46] Results from statistical analysis in *log-space* can then be converted back into *real space* using a reverse of the logarithmic transformation process. Take, for example, the emissions data which generated the curves in Figure 1. When these are 'log-transformed' and plotted, they yield new curves as in Figure 2.

[46] Painter, L.J. and Rutherford, J.A. (1992) 'Statistical Design and Analysis Methods for the Auto/Oil Air Quality Research Program', SAE paper 920319, Society of Automotive Engineers, Warrendale.

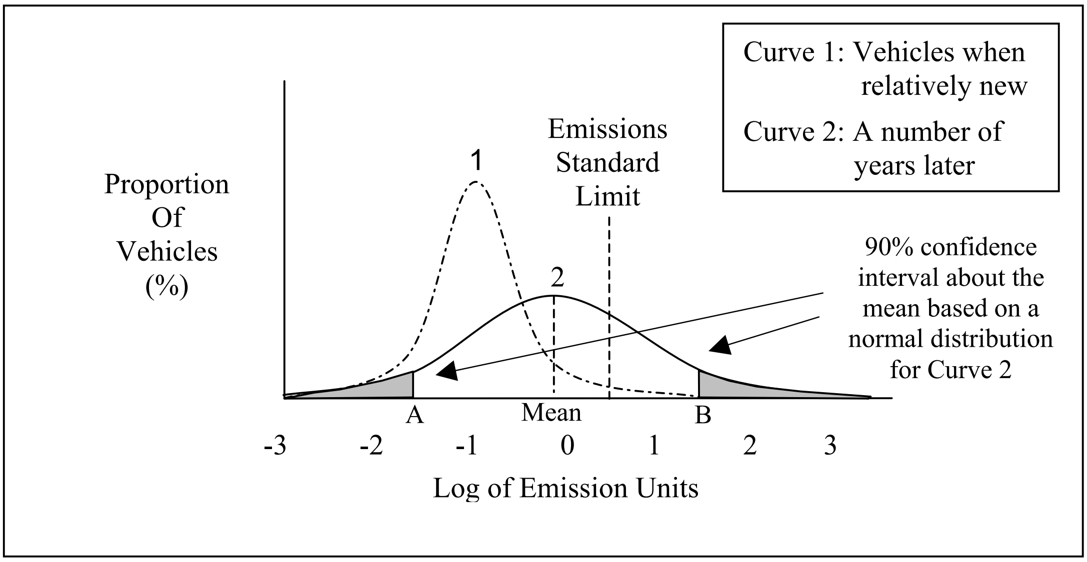

Figure 2: Emissions Data of Figure 1 Plotted in Log Space to 'Normalise' the Distribution Allowing Use of Standard Statistical Methods of Analysis

Distributions can be described by a number of terms which describe the *location* and *variability* of data, including:

- Mean. This is 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.
- Mode (and *multimodal*). The mode is where there is a concentration of data around some value, and 'multimodal' refers to a situation where data is concentrated around more than one value.
- Skew. This is the degree of asymmetry of a distribution around its mean. A normal distribution has a skewness of zero. A 'negative skewness' is a skew to the left; a 'positive skewness' is a skew to the right. Another indication of skewness is the difference between the mean and median values, a larger difference representing an increasing skew.
- Standard deviation. This describes the variability of 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. A small standard deviation indicates a tall distribution curve.
- Confidence interval. This is an estimate of the population parameter that consists of a range of values bounded by statistics called upper and lower *confidence limits*, within which the value of a parameter is expected to be located if the experiment was conducted again. For example, referring to Figure 2, the 90% confidence interval for Curve 2 is from the confidence limit A to the confidence limit B and the non-shaded area under Curve 2 shows where the true mean may be expected to fall with a 90% confidence. That is, if we were to conduct the experiment again, we could be 90% confident that the mean of the new set of data would lie somewhere between –1.7 (confidence limit A, the *lower 90% confidence limit*) and +1.3 (confidence limit B, the

upper 90% confidence limit). A *confidence coefficient* is sometimes also referred to, which in this case is 90%. Note:

- A narrow confidence interval indicates a small amount of variability in the data; a wide confidence interval, on the other hand, indicates a large amount of variability in the data. As depicted in Figure 2, the confidence interval for newer vehicles is narrower than for aged vehicles.
- While confidence intervals from a normal distribution in 'log-space' (that is, a graph on which log-transformed data are plotted) are symmetrical about the mean (the upper and lower confidence intervals will lie the same distance away from the mean in opposite directions), they will no longer be symmetrical around the mean in 'real space'. The distribution will be skewed, and the upper and lower confidence intervals will therefore lie at different distances from the mean.

A normal distribution is defined by the *mean* plus the *standard deviation*. This means that the amount of data required to define a distribution adequately is dependent on the characteristics of the results being considered rather than the sheer volume of results. Thus, simply collecting more data will not necessarily change the character of the distribution or the magnitude of the standard deviation.

It is common to attempt to explain results by their relationship to some chosen variable. A chosen variable may be more or less sufficient to explain the variation in results, and this sufficiency is expressed by the *coefficient of determination* (usually written R^2). The value of R^2 is always between 0 and 1. An R^2 value close to 1 means the variable being considered can account for the majority of the variation in results. The closer to zero the R^2 value, on the other hand, the less reliable the variable is in accounting for the variation in a set of results. If, for example, we take slices from a 500g block of butter, we find that when it is weighed, its weight in grams more or less exactly matches its thickness in millimetres multiplied by five. This proves to be the case whether we take thick or thin slices. If we were to choose 'thickness of slice' (t) as the variable in our butter-slicing experiment, the R^2 value (or coefficient of determination) of t for determining the variation in weight of different slices would be close to 1. Where an R^2 value is much below around 0.8, the chosen variable is normally considered to be a poor indicator of the result.

When considering variables describing vehicle emissions, R^2 values below 0.4 are common, indicating any individual factor affecting emissions performance, taken singly, is a very poor indicator of the total emissions result.

One way of overcoming this difficulty is to select data carefully so that the variable being considered is the only significant variable at play. This is difficult to achieve when considering vehicle emissions results, however, given the large number of variables involved. Care must be taken, too, to ensure that there are no unaccounted-for variables presenting 'wild card', significant effects, resulting in poor deductions being drawn from flawed analysis. One variable that has the potential to so affect emissions findings is engine technology, an often overlooked variable that can account for the majority of the variability in emissions test results.

A more appropriate analytical tool for considering vehicle emissions is so-called *multiple variable regression analysis*, where the emissions result is described by a number of variables at the same time. For example, variables x, y and z may be significant variables to the emissions result but, considered individually, each may have a low R^2 value with respect to the results — that is, each may determine only a small proportion of the variability in the emissions. Multiple variable regression analysis allows variables x, y and z to be considered at the same time, allowing the significance of each to be evaluated despite the variability caused by the others. This allows the significance of variables to be identified even in cases where the R^2 is very small (below 0.2, say).

Multiple variable regression analysis also allows a broad range of data to be analysed at the same time, and does not require data to be selected to minimise changes arising from causes other than the variable being considered. As a result, robust analysis can be achieved with smaller data sets and there is far less risk of missing significant variables.

A term often used in multiple variable regression analysis is statistical significance which for this report is defined as the estimated probability that the observed relationship (e.g, between variables) or a difference (e.g., between means) did not occur by chance. To say that a variable has an 90% statistical significance, say, in pure statistical terms means its relationship has a p-value[47] of 0.1. For this report a relationship is considered statistically significant if it is above 90% statistical significance (that is, has a p-value of less than 0.1).

[47] A p-value represents a decreasing index of the reliability of a result, that is, a measure of how much evidence is against the null hypotheses. http://www.cmh.edu/stats/definitions/pvalue.htm

3. Project Background

3.1. Beginnings

The study of vehicle emissions in New Zealand for modern-day policy purposes began in 1997, with a strategy named the Vehicle Fleet Emissions Control Strategy (VFECS) aimed at managing the impact of vehicle emissions on local air quality. This dealt with emissions in a series of stages, beginning with VFECS Stage 1 in 1997, which sought to achieve carbon monoxide (CO) mitigation, followed by stages which successively addressed oxides of nitrogen (NOx), particulate matter (PM_{10}) and hydrocarbons (HC) between 1997 and 2001. In that year, as a result of VFECS findings, New Zealand's first legally enforceable emissions test standard was introduced, with the so-called 'Ten Second Rule" — whereby the operators of vehicles that emit a continuous stream of clearly visible smoke or vapour for ten seconds or more may be prosecuted — introduced on 1 March 2001.[48] The Land Transport Rule – Vehicle Exhaust Emissions 2003 (the Emissions Rule) governing the minimum build performance standards for imported vehicles, introduced in 2003, was likewise an outcome of the VFECS process.

In 2003, an internal report prepared by the Ministry of Transport[49] presented the Government with a range of vehicle emissions intervention options. The Government, under the guise of the (then termed) Vehicle Emissions Policy (VEP), decided to introduce three of these: the emissions screening of imported used vehicles; public education, and in-service emissions screening.[50]

Up until this point, in-service emissions screening was intended to identify the gross emitters and to encourage vehicle owners to service their vehicles. It is notable that this régime:

- Commonly referred to 'something broken' when considering a 'gross emitter', where the vehicle was likely to be emitting many times more than its original design performance;
- Referred to 'screening' rather than 'testing', which permitted non-testing procedures to be used to identify vehicles (by age or engine technology,[51] for example) that would likely meet the required standard, and simple testing of the remaining target vehicles;
- Intended 'simple testing', if it were to be used, as a tool to encourage vehicle owners who were informed that their vehicles had 'failed' an emissions test to maintain their vehicles. The simple test in mind for petrol vehicles was the (natural) idle and fast idle test (see Section 4.1). This level of testing had two advantages: it avoided the high costs associated with rolling road/chassis dynamometer facilities, and it allowed standard procedures to be adopted from similar testing régimes in common use overseas.

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48 http://www.transport.govt.nz/downloads/03-tizard.pdf

49 Moncrieff, I. 'Assessment of Further Vehicle Emissions Control Interventions, Stage 1, Development of Possible Interventions'. MOT internal report, 2003.

50 http://www.beehive.govt.nz/ViewDocument.aspx?DocumentID=17975

51 Note 'engine technology' also refers to the exhaust system and any exhaust after-treatment system that may be fitted, not just the 'under-bonnet' section.

It was also widely believed that the New Zealand fleet had a number of unique characteristics, due to the fact that until very recently there were no build requirements for the emissions performance of new vehicles entering the fleet, and the high proportion of used imported vehicles present in the fleet. This meant there was no guarantee overseas simple testing régimes would be appropriate for the New Zealand fleet. Furthermore, work done as part of the VFECS identified a number of unknowns that made it difficult to account for the fleet's emissions performance. These included uncertainty about the engine technology make-up of the fleet and the condition of its member vehicles, including the condition of the used imported vehicles entering the fleet. It was therefore essential for the purposes of drafting effective policy that the applicability of overseas testing procedures be checked, and the extent and significance of the unique features of the New Zealand vehicle fleet be identified in detail.

The Pilot was charged with running a pilot simple testing programme in New Zealand and using this opportunity to investigate and better describe the fleet's emissions characteristics. To achieve both 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 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).

Since the emissions signatures and testing methods used for petrol and diesel engines are quite different, reporting on the objectives has been divided into a petrol volume and a diesel volume. This petrol volume considers the four main objectives, provided above, in Sections 4, 5, 6 and 8, respectively.

In addition to the work carried out to meet the Pilot Project's objectives, which was more focused on the results of idle simple testing, analysis was also carried out to characterise the expected on-road emissions performance of vehicles using data from testing vehicles to various drive cycles as its base. The findings of this analysis is reported in Section 7.

3.2. Project Scope and Boundaries

Simple emissions testing — and chassis dynamometer tests carried out under constant load, for that matter — are of limited use as far as understanding on-road emissions performance of vehicles is concerned. The best means of determining the emissions performance of test vehicles would have been to subject them to extensive drive cycle testing using a chassis dynamometer. While limited testing was carried out on chassis dynamometer equipment (as much as time and budgetary constraints allowed), the primary focus of the project was on simple testing and the results drawn there from.

The exhaust emissions considered for idle simple testing were carbon monoxide (CO), carbon dioxide (CO_2), hydrocarbons (HC) and oxygen (O_2). This combination also allows the determination of the factor known as *lambda*, which describes the air-fuel mixture.[52] Emission of oxides of nitrogen (NOx) was not measured during idle simple testing, as this test does not load the engine sufficiently for the NOx result to be meaningful.[53] However, NOx was measured during chassis dynamometer testing.

Figure 1 depicts the make-up of the self-propelled New Zealand vehicle fleet[54] by vehicle size and primary fuel. The main vehicle types are *light* (that is, of gross vehicle mass of 3500 kg or less) petrol vehicles, *light* diesel vehicles and *heavy* (that is, of gross vehicle mass of greater than 3,500 kg) diesel vehicles, the latter further divided into medium vehicles (greater than 3500 kg and 12000 kg or less) and large vehicles (greater than 12000 kg) for Figure 3.[55] The characteristics of engines in medium and large vehicles are relatively similar and can justifiably be considered together as "heavy" diesel vehicles. Excluding motorcycles and mopeds petrol light vehicles, diesel light vehicles and diesel 'heavy' vehicles make up 99.7% of the self-propelled fleet. Only 0.1% of the fleet use alternatives to petrol or diesel. Only 0.2% of the fleet was heavy petrol vehicles (these latter two being the make-up of 'Other').

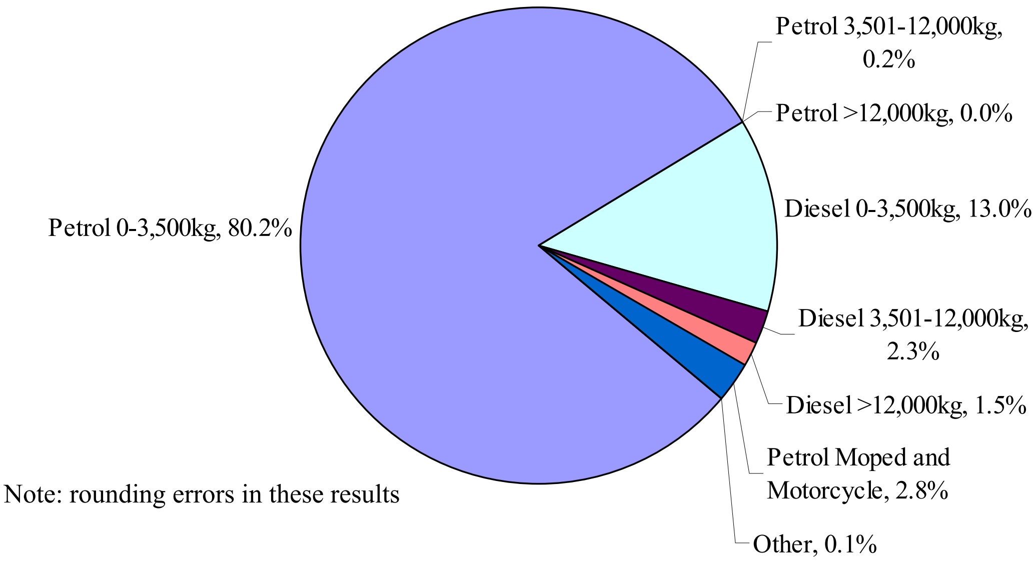

Figure 3: Make-Up of Self-Propelled Vehicles in New Zealand by Size and Fuel Type as given by LANDATA Data (active fleet as at December 2004).

[52] The air-fuel ratio is often defined in terms of the excess air factor, or lambda. Lambda of unity is a stoichiometric mixture, that is, where the proportions of fuel and air are chemically correct for complete combustion. Fuel-lean mixtures have excess air and lambda greater than unity. Fuel-rich mixtures have lambda less than unity.
[53] NOx formation requires high temperatures during combustion, which means that the engine must be loaded to obtain a meaningful NOx result.
[54] From LANDATA data for the active fleet as at December 2004. LANDATA is a database managed by the Transport Registry Centre and contains extensive records on fleet vehicles on an individual vehicle basis. 'Active' refers to vehicles that have had a current registration in the last 12 months from the date being considered.
[55] Note 'light' and 'heavy' are defined in various New Zealand regulations but 'medium' and 'large' are descriptors used for this report only, to help illustrate the make-up of the fleet.

Figure 4 provides the breakdown of the active light petrol fleet by New Zealand-new, scratchbuilt,[56] used Japanese-origin and used other-origin as at December 2004. At that time, there were roughly equal numbers of New Zealand-new vehicles and used Japanese imports.

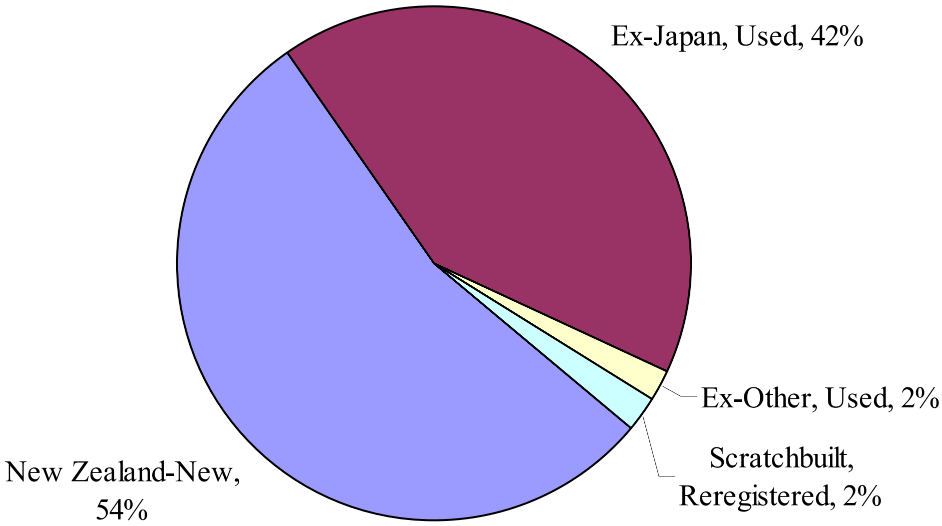

Figure 4: Make-Up of Active Light Petrol Fleet by Vehicle Origin as given by LANDATA Data (active fleet as at December 2004)

The active light petrol vehicle fleet was divided, for the purposes of analysis, into two divisions, 'Used Japanese Import' and 'NZ-New'. 'Used Japanese Import' refers to the proportion of used Japanese vehicles described in Figure 4, as the name would suggest. 'NZ-New' comprises the remaining vehicles and absorbs a very small proportion of vehicles, only 2%, imported used from countries other than Japan. This significantly simplified data handling requirements but, as the analysis found, its impact upon results was so slight as to be negligible.

Since relatively few New Zealand spark ignition vehicles use alternatives to petrol, the main discussion and focus of the report is on emissions from petrol vehicles. According to LANDATA data, 0.06% (1543 vehicles) of the active petrol fleet uses liquefied petroleum gas (LPG) as its primary fuel (that is, the vehicle has been specifically designed to use LPG as its main fuel) and 0.01% uses compressed natural gas (CNG) as primary fuel. The proportion of vehicles using these alternative fuels increases to 0.4% for LPG and 0.3% for CNG when vehicles equipped to use them as a secondary fuel (that is, 'multi-fuel vehicles') are taken into account. These figures should be treated with caution, as there is no mandatory mechanism for updating LANDATA when a vehicle is converted to use LPG or CNG, or when the alternative fuel system is removed. The LANDATA figure is believed of correct order for the number of vehicles actively using LPG[57] and a substantial over-estimation of the

[56] 'Scratchbuilt' vehicles are vehicles that are either assembled from previously unrelated components or a vehicle that has been significantly modified from its production version.

[57] LANDATA indicates there are 10,777 active vehicles that can use LPG in the fleet as at December 2004. The New Zealand LPG Association estimates there are between 10,000 and 15,000 vehicles using LPG in New Zealand, based on automotive fuel sales, which represents to the order of 0.8% of the active petrol fleet. LPG Association, personal communication.

number of active CNG vehicles, given there are expected few public CNG filling stations still operating in New Zealand.[58]

[58] No functional CNG stations could be found in a check with the industry.

4. 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 petrol fleet, using the results from idle simple testing.

4.1. Methodology

Emissions profiling and benchmarking of the active light petrol fleet comprised the following steps:

1. Set up test sites for idle simple testing;
2. Test vehicles using idle simple testing and visual inspection and retrieve data so generated;
3. Retrieve LANDATA records for the vehicles tested;
4. Screen and refine data;
5. Analyse data.

Nine sites around New Zealand were selected for idle simple 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 quality analysing equipment;[59]
- availability of suitable testing personnel;
- access to a believed representative sample of vehicles;
- cooperation of the chosen site's proprietor.

Table 2 lists the test site locations and their respective test sample sizes (after screening out data that did not meet data quality criteria), site types and analysers used.

[59] Equipment was required to be relatively new and maintained. Some garages could only offer the use of equipment that was 15 years old or more, and of dubious condition. Even though such equipment could be calibrated, it was not accepted.

Table 2: Idle Simple Testing Site Locations and Their Respective Site Type and Analyser Used.

Site No.	Location	Sub-location	Quality Tested Sample Size	Site Type	Analyser	Analyser Source
1	Whangarei		25	Workshop and repair(1)	Bosch BEA250	Own
2	Auckland	UniServices	81	Selected test vehicles	Various	Own and loan
3		VINZ, Mt Wellington	35	Safety inspection only	Motorscan 8020	Stocks
4		Carburettor Specialists	0[60]	Repair	Bosch BEA250	Own
5	Waitakere		241	Safety inspection only	OPUS 40B	Own
6	Hamilton		576	Safety inspection only	Autodiagnostics ADS500	EW
7	Palmerston North		25	Safety inspection only, workshop and repair2	Bosch BEA250	Own
8	Christchurch		100	Safety inspection only	Autodiagnostics ADS9000	Uni-Services
9	Dunedin		26	Workshop and repair	Bosch BEA350	Own
		Total Sample	1109			

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.
Note 2: The tester involved set up at various locations during the trial

The analysers used were of a type designed for idle simple testing. A description of this type of analyser and an assessment of various analysers available in New Zealand at the time is provided in Appendix B.

Analysers were either calibrated by Auckland UniServices personnel before use or, as in the case of the Bosch analysers, were new and had been recently calibrated by the supplier. Although a range of different analysers was used, this was not expected to introduce any significant errors, due to their calibration and the robust nature of the test procedures.[61]

Testers of varying competence were used across the test sites, as available staff were used at some sites whereas staff were hired specifically to carry out testing at others. Testers were trained in how to test to the project test protocol.

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[60] Data from repair vehicles was removed from this particular data set to avoid bias potentially arriving through including vehicles known to require repair.
[61] This compares to the likes of the 'snap acceleration test' used in simple emissions testing of diesel vehicles, where there can be considerable variation in results from two calibrated analysers when measuring the same vehicle at the same time.

The protocol for performing the idle simple test at the various sites consisted of the following steps:

- Vehicle selection:
  - For safety inspection-only test sites, this was the next vehicle to be presented after the emissions analyser became available and, for some sites, where consent from the driver 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;
- Carrying out a visual inspection of the vehicle and filling in the visual inspection form provided to testers (sample provided in Appendix C) in order to determine the engine technology (the engine technology divisions used are defined in Section 4.2.3 and refer to the exhaust system and not just the 'under-bonnet' section) of the test vehicle;
- Ensuring the engine was warm;
- Checking the emissions analyser's measurements for clean air were sensible before inserting the analyser's sample probe into the vehicle's exhaust pipe;
- Taking the engine speed up to 2500 revolutions per minute, maintaining this speed and measuring exhaust emissions of CO, HC, O_2 and CO_2 when the measurements became stable after 30 seconds or when 60 seconds had elapsed, whichever occurred first (providing the 'fast idle' test results);
- Checking fast idle test emissions measurements were sensible;
- Allowing the engine to return to natural idle speed, then measuring exhaust emissions of CO, HC, O_2 and CO_2 after 120 seconds (the '(natural) idle' test results);
- Checking idle simple test emissions measurements were sensible;
- Printing out results, and, for some test sites:
- Providing results to drivers.

This test protocol was similar to the procedure used in the United Kingdom for catalyst-equipped vehicles[62] and the test procedure used in the NISE 1 study.[63] Slight variations from the UK and NISE 1 procedures were not expected to affect the emissions result, such is the robustness of the procedure.[64] The test procedure notes provided to testers are provided in Appendix C.

At the Waitakere test site, some resistance on the part of vehicle owners to subjecting their vehicles to fast idle tests was initially encountered,[65] and for these initial tests only (natural) idle results were gathered. These were still meaningful and useful, notably for developing quality assurance test protocols that were then used for the test

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[62] Vehicle and Operator Services Agency (VOSA), *The MOT Inspection Manual - Car & Light Commercial Vehicle Testing*, Issue date: August 2004.

[63] Federal Office of Road Safety, *Motor Vehicle Pollution in Australia: Report on the National In-Service Vehicle Emissions Study*, Canberra, May 1996.

[64] As one example of the variations, the Project's procedure provided the option of up to 60 seconds for the vehicle/meter system to stabilise under the fast idle test rather than the specific 30-second period stipulated in the UK test. Also, the Project's idle simple test procedure was applied to catalyst- and non-catalyst-equipped vehicles alike, whereas in the UK the fast idle component is not applied to non-catalyst-equipped vehicles. In both cases, the Pilot-developed test procedure erred on the side of caution, even though this resulted in the test procedure taking a minute or two longer.

[65] Vehicle drivers were reportedly objecting to their vehicles being operated at fast idle. Fast idle does sound a harsh test to the uninitiated not cocooned within the passenger compartment of the vehicle. It is believed part of the issue was due to the tester not providing adequate advice to drivers.

procedure at other sites and for quality assurance testing of all data. This early Waitakere data was otherwise excluded from the analysis considered in this section.

The potential for variation in results between sites arising from the methodology was minimised by:

- Calibrating analysers, as above;
- Site visits, including validating the test procedure being used by testers;
- Data screening, including:
    - Removing engine repair vehicles from the data set, as such high-emitting vehicles risked bias of test results toward the higher end of the emissions range;
    - Removal of data that did not meet quality assurance criteria (see Appendix D for a full list of quality assurance criteria), such as where the sum of CO and CO_2 was outside practical limits (as given by basic combustion theory and practice) and where high exhaust O_2 was registered (indicating the possibility of an exhaust leak or that the sample tube was not sufficiently inserted into the tail-pipe);
    - Checking LANDATA data and field data matched;
    - Increasing odometer by 100,000 where a vehicle of year of manufacture earlier than 1980 showed less than 100,000 kilometres or miles (and may be presumed to have been 'around the clock' on the odometer);

Around 10% of data was removed by the data quality screening process, with this proportion being reasonably consistent between sites apart from Dunedin, which exhibited a 50% data rejection rate. No undue bias was thought to be at work in determining which vehicles were removed by this process. The resulting sample size, by location, is that given in Table 3.

Owners of newer vehicles are not required to present them for warrant of fitness inspections as frequently as those of older vehicles[66] and this presents a sampling bias. To take account of this, vehicles of less than six years of age were provided a double entry in the base data set. This increased the idle data set from 1109 entries from 1109 vehicles to 1244 entries from 1109 vehicles. This is the 'adjusted idle data set' used for emissions profiling analysis in this section. The adjusted sample size, by location, is provided in Table 3.

[66] This affects sampling at the time of WoF: '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 New Zealand website, http://www.ltsa.govt.nz/vehicle-ownership/warrant.html,

Table 3: Sample Size of Quality-Assured Data from Idle Simple Testing by Test Site and Resulting WoF-Adjusted Sample Size.

Site No.	Location	Sub-Location	Quality Tested Sample Size	Adjusted Sample Size
1	Whangarei		25	28
2	Auckland	UniServices	81	94
3		VINZ, Mt Wellington	35	47
4		Carburettor Specialists	0[67]	0
5	Waitakere		241	270
6	Hamilton		576	634
7	Palmerston North		25	27
8	Christchurch		100	117
9	Dunedin		26	27
		Total Sample	1109	1244

Data screening and emissions profiling and benchmarking analysis was carried out using multiple variable regression statistical analysis using Statistical Analysis Software (SAS Version 9.1).

Note: vehicles were presented for idle simple testing without the owners having been alerted that an emissions test was going to be carried out. Hence, vehicles were not pre-conditioned in any way for idle simple testing. It would be expected a small percentage of vehicle owners would carry out minor work or at least a simple visual check on a vehicle before presentation if simple emissions testing was mandatory, in much the same manner that some owners check lights and other components before a safety inspection.

4.2. Results and Analysis

4.2.1. Sampling Quality

The age distribution of the adjusted idle data set, by Used Japanese Imports and NZ-New vehicles, was checked for consistency against that of the active national light petrol fleet. As illustrated in Figure 5, the distributions of the adjusted idle data set (lower distributions) and from LANDATA (upper distributions) showed relatively good consistency. The worst discrepancy was a small deviation from 2002 for NZ-New vehicles. New Zealand-new vehicles for this period may not be accounted for as well in the field sample, perhaps because owners preferred to have the WoF inspection carried out at dealerships (a practical option whilst vehicles are under warranty). This difference was small when compared to the overall distribution, the median year for both the NZ-New and Used Japanese Import distributions of the LANDATA data being within the 95% confidence intervals of those from the adjusted

[67] Note data from Carburettor Specialists was excluded from this analysis data set as most of their sample vehicles were being repaired, and their inclusion risked introducing a bias in the sample towards vehicles of poor emissions performance.

idle data set. Hence the sample is believed to be a sufficiently representative sample of active petrol vehicles.

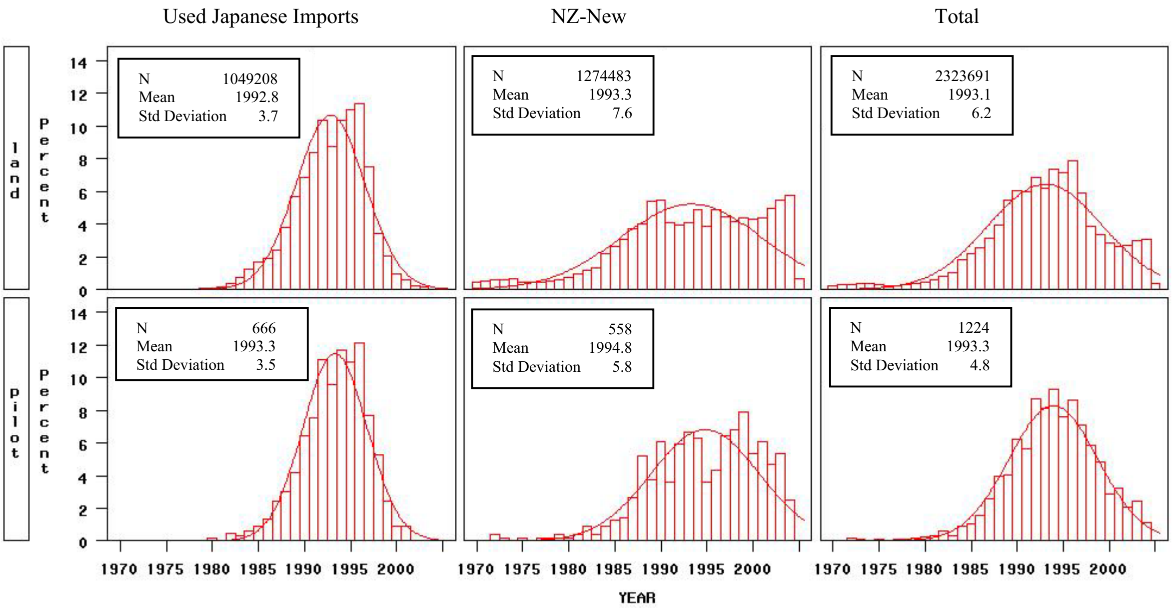

Figure 5: Distribution of Used Japanese Imports and NZ-New Vehicles by Year of Manufacture for the Active Petrol Fleet as Given by LANDATA and the Adjusted Idle Data Set.

A component of the Pilot also visually inspected a further 3500 petrol vehicles to determine the engine technology make-up of a greater number of vehicles from a wider range of locations. This data was also adjusted to take into account the less frequent safety inspection of vehicles of more recent year of manufacture. This data set is discussed further in Section 7. Table 4 compares base data for the adjusted idle data set, the adjusted visual inspection data set and data from LANDATA (which does not identify the engine technology of vehicles). Shown is the variability in the proportion of NZ-New vehicles to Used Japanese Imports; 54% of the adjusted idle data set being Used Japanese Imports compared to 49% for the adjusted visual inspection data set and a range from 45% to 54% for various locations from LANDATA data (lower figures in Table 4). This variability in fleet make-up partly explains the variation found in the proportion of catalyst- and non-catalyst-equipped vehicles, as is explained later in this section. This is not to say the data sets are not good samples; it is saying there is high variability in the make-up of the fleet between different sites and the distributions captured are believed suitably representative for the method of analysis used.

Further data for the adjusted idle data set is provided in Appendix E and for the adjusted visual inspection sample in Appendix F.

Table 4: Comparison of Base Data for Adjusted Idle Data Set, LANDATA and Adjusted Visual Inspection Data Set.

	Proportion of Vehicles in Given Sample		
	Non-Catalyst	Catalyst	Combined
Idle Data Set			
NZ-New	23%	24%	46%
Used Japan Import	8%	46%	54%
Total	31%	69%	100%
Visual Data Set			
NZ-New	30%	21%	51%
Used Japan Import	10%	38%	49%
Total	40%	60%	100%
LANDATA Waitakere			
NZ-New			46%
Used Japan Import			54%
Total			100%
Waikato			
NZ-New			56%
Used Japan Import			44%
Total			100%
Christchurch			
NZ-New			50%
Used Japan Import			50%
Total			100%
New Zealand			
NZ-New			55%
Used Japan Import			45%
Total			100%

LANDATA data based on 0-3500 kg, post 1970 YoM active fleet

4.2.2. Data Quality

The idle simple test procedure is relatively robust, and good testing repeatability is therefore expected. Nevertheless, a proportion of data was removed as it did not meet data quality criteria, as has been mentioned. It is possible, though, that other erroneous data escaped detection and is included in the idle data sample. This in no way discredits the results, however, as the data obtained is the result of the kind of testing procedures that would be used if idle simple testing were introduced in practice, or used to sample the fleet in the future, and hence the quality-assured data is considered fit for its intended use.

Note robustness of a test procedure is quite different to the sensitivity or resolution of the test. Many vehicles exhibited near-zero emissions and analysers of the type used for idle simple testing do not have good resolution when considering small changes within their far larger measuring scale. This is not to say that the test procedure is not robust.

The quality of visual inspection data, by contrast, cannot be considered quite so robust. However, the most important difference between engines detectable by visual inspection was whether or not it was catalyst-equipped, a relatively easy determination to make. But even where visual inspection errors occurred, these would have remained consistent throughout the analysis process, to a great extent cancelling out in the concluding results.[68]

4.2.3. Defining Variables for Emissions Profiling and Benchmarking

The initial analysis conducted was intended to determine how best to group vehicles so as to understand the emissions profile of the fleet. The adjusted idle data set was subjected to multiple variable regression analysis, testing for the statistical significance of the effects of a wide range of individual factors (despite the variability in emissions result resulting from variability in other parameters: see Section 2). The individual factors tested were year of manufacture ('YoM'), odometer reading ('odometer'), engine technology (the various divisions of engine technology used for this analysis are defined in the next paragraph), NZ-New or Used Japanese Import, vehicle under-bonnet appearance, turbocharger fitted or not, exhaust showing blue smoke, exhaust showing black smoke, engine size, tare weight,[69] engine power[70] and, for catalyst-equipped vehicles, whether they were imported before or after October 1996 (an indication of their potential to have lead-poisoned catalysts, leaded fuel not being banned from retail sale in New Zealand until October 1996[71]). Only the parameters YoM, odometer and engine technology were found to be consistent, statistically significant factors (above 90% significance, [72] i.e. p-factor < 0.1) in describing the idle simple test emissions results of vehicles in the adjusted idle data set. Engine size and, for catalyst-equipped vehicles, whether they were imported before or after October 1996 were found to be statistically significant parameters (at around the 87% level, i.e. a p-value of around 0.13, for engine size and above 90% for date of import, i.e. p-value < 0.1), but not with consistency. These results are discussed later in this section.

[68] Where an error occurs, that is, it is likely to have been of equal proportion on both sides of the extrapolation equation, such that it will cancel out in the process of extrapolating from an idle data set to a larger visual inspection data set used to derive fleet emissions of that larger data set.
[69] Tare weight is not a compulsory field on LANDATA source datasheets, reducing the sample size for this test to around 500 vehicles.
[70] Engine power is not a compulsory field on LANDATA source datasheets, reducing the sample size for this test to around 200 vehicles.
[71] Shipments of leaded fuel were no longer admitted from 1 January 1996, and leaded fuel was banned from retail sale from 31 October 1996. Paul Stannard, MED, personal communication.
[72] The 'statistical significance' of a parameter refers to the 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 (p-value <0.1) has a 'high confidence', does reduce the unknown variability of the data, and does represent a real correlation.

'Engine technology' refers to the technology of the combined engine and exhaust system, including any exhaust after-treatment system fitted. This was determined by visual inspection of the appropriate components in the Pilot's testing process. In the context of this report, engine technology has been divided into four broad categories:

- 'Technology 1' vehicles have simple carburetted fuel metering, no electronic engine management and no exhaust after-treatment (that is, no catalyst);
- 'Technology 2' vehicles have fuel injection fuel metering systems and no exhaust after-treatment;
- 'Technology 3' vehicles have an exhaust catalyst and 'open-loop' fuel metering (that is, no oxygen sensor is used to refine the metering of fuel);
- 'Technology 4' vehicles employ an exhaust catalyst and 'closed-loop' electronic engine management systems (that is, with an oxygen sensor fitted, the signal from which is used to refine the metering of fuel).

These broad categories effectively describe the evolution of engine design which has occurred in response to the increasingly stringent emissions requirements imposed in the countries where vehicles are manufactured. Technology 1 is the engine technology of the Minis and Holdens of the 1960s and before. Technology 2 and 3 are the transitional engine technologies found from the 1970s onward, where fuel injection and exhaust after-treatment were developed to improve vehicle economy and emissions performance. Technology 4 is the mainstream production engine technology of today. Technology 1 and 2 can also result from the retrograde of a Technology 3 or 4 vehicle brought about by the removal of the catalyst.

Naturally, there are many subdivisions that could be made within each of the four engine technology categories, due to design elements other than those described which nevertheless have an impact on the emissions performance of a vehicle. Analysis shows, however, that the four categories as outlined are an effective means of distinguishing between engine technologies.

The most significant indicator of idle simple test emissions performance was found to be engine technology, with more advanced engine technologies exhibiting substantially lower emissions. Since the vehicle's engine technology at the time of testing is to a large extent determined by its original emissions build specification, this suggests that it is important to set a minimum build specification standard for vehicles entering the fleet. This, of course, is the basis of the Land Transport Rule – Vehicle Exhaust Emissions 2003 (the Emissions Rule).

Less significant than engine technology, but significant nonetheless, were the year of manufacture and the odometer reading of vehicles, despite inaccuracies expected in the odometer value for some.[73] The statistical significance of odometer describes the deterioration in a vehicle's emissions performance with use. There are many possible reasons for this deterioration, from the tendency of vehicles to fall 'out of tune' with distance travelled to the reduced efficiency through prolonged use of the exhaust catalyst, supposing one is fitted.

[73] Due to the likes of re-wound or stopped odometers, 'clocked' odometers (i.e. past 100,000 km/miles on a five-digit odometer) and replacement of odometers during the life of a vehicle.

The significance of year of manufacture, on the other hand, is likely to be quite complex, due to its potential coupling with many other parameters. A New Zealand-new vehicle built in the 1990s to the (then) mainstream Technology 2 standards (fuel injection, no catalyst fitted), for example, would be expected to exhibit lower emissions than a Technology 2 vehicle produced in the 1960s (when fuel injection was first introduced on the production line). A similar base performance capability of the original vehicle would be expected for vehicles of more recent YoM among vehicles sharing the other engine technologies. It is impractical to de-couple these parameters; but using YoM tends, to some extent, to describe the variability in results owing to a YoM-coupled parameter, and YoM thus remains a useful parameter for consideration.

A vehicle's odometer is also a YoM-coupled parameter, and it was found that a parameter produced by arithmetically combining YoM and odometer[74] could better describe the variability in idle simple test emissions result than could either YoM or odometer individually considered. Still, by comparison with engine technology, the joint YoM-odometer parameter was very much a secondary indicator of emissions performance and was termed a 'secondary performance indicator' (SPI)[75] for the purpose of reporting. The additional goal of using SPI is that this parameter contains most of the time-based variability in one parameter. However, engine technology is also somewhat time-based. For statistically modelling expected emissions results, any interdependence of the modelled parameters was alleviated by adding an engine technology-by-SPI term. This compensated for the interdependence of the individual variables in the model.

Similarly, although engine size[76] was found to be statistically significant, it accounted for only a very small to negligible variability in idle simple test emissions results, when engine technology and SPI were also taken into consideration. This finding was verified using a number of methods, including the comparison of statistical models of idle simple test emissions results. Two models were used for this exercise, a two-variable model, incorporating engine technology and SPI, and a four-variable model, where the variables were engine technology, SPI, engine size and engine size by engine technology. This analysis found the engine size parameter was only significant for the Technology 4 group (negative, indicating a decrease in emissions with a larger engine) and its real effect could be associated with other related factors. The two-parameter model could account for 98% of the variability described by the four-parameter model, further indicating that engine size has only a slight effect on the emissions result. As the two-variable model based on engine technology and SPI was the far more efficient, it was the preferred model in this study.

Additionally engine size is coupled with YoM, as engine size was found to increase with year of manufacture. The average engine size of light petrol vehicles of 1995 YoM is around 2.0 litres, compared with around 2.5 litres for 2003 YoM vehicles.[77] It would, however, be difficult to de-couple this relationship for analysis purposes, a

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74 2004-YoM +odometer/10,000.

75 Note whilst the likes of 'age-distance factor' would have been a more intuitive name for this next-most significant emissions factor, it was felt important to describe the depth of this factor beyond a simple YoM and odometer relationship given how difficult it is to decouple many other factors from these two variables.

76 Engine size is generally described in terms of engine capacity, that is, the combined volume of the combustion chambers (and is usually expressed in terms of the 'cc-rating', in cubic centimetres, or litres, where one litre equals one thousand cubic centimetres).

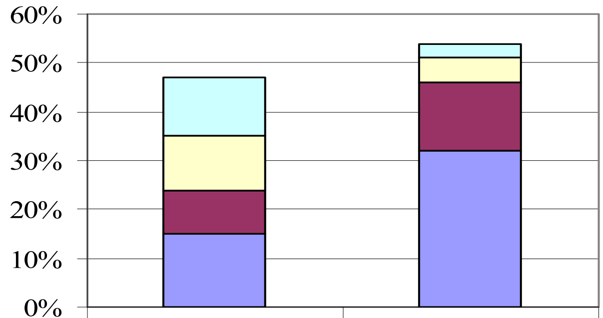
77 From LANDATA data, active petrol fleet at 31 December 2004.

further reason to exclude engine size in modelling so as to minimise interdependence of modelling parameters.

4.2.4. Field Data Distribution

As discussed, multiple variable regression analysis found engine technology to be the most significant parameter in describing vehicle idle simple test emissions performance. Much of the field data has therefore been grouped and reported by engine technology (as determined by the data gathered from a visual inspection of the test vehicle). This first analysis of data has also been divided by vehicle origin for demonstration purposes.

Figure 6 illustrates the proportions of engine technologies by vehicle origin (NZ-New or Used Japanese Import) for the adjusted idle data set and shows a significantly higher proportion of the more advanced engine technologies being used in Used Japanese Imports (a function of their respective emissions build requirement at the time, as is further discussed below).



	NZ-New	Used Japan Imp
Technology 1	12%	3%
Technology 2	11%	5%
Technology 3	9%	14%
Technology 4	15%	32%

Note: rounding error in these results

Figure 6: Make-up of the Adjusted Idle Data Set by Engine Technology and Origin.

The distribution of vehicles within divisions described by engine technology and NZ-New/Used Japanese Import is illustrated in Figure 7. These distributions show:

- A steady advance in mean YoM for NZ-New vehicles with advancing engine technology, from 1989.1 for Technology 1 to 1999.6 for Technology 4. This relatively wide spread in mean YoM is a function of many variables including the long history of this country's vehicle consumption and the delay in supply to the New Zealand market of more advanced engine technologies;
- In comparison, there is a small increase in mean YoM with advancing engine technology for Used Japanese Imports, from 1990.7 for Technology 1 to only 1994.0 for Technology 4 vehicles. For Used Japanese Imports, the majority are expected to have been fitted with exhaust catalysts originally; such were

the emissions standards to which they were built. One possibility, therefore, is that the advance in average YoM with advancing engine technology describes the likelihood that a catalyst has been removed from older vehicles in combination with an advance from Technology 3 to Technology 4.

- Apart from Technology 1, (from which New Zealand-new vehicles have been drawn for much of the vehicle fleet's long history), Used Japanese Imports are on average older than NZ-New vehicles of the same engine technology group;
- There is a marked increase in the supply of NZ-New Technology 4 vehicles from 1997. Leaded fuel was banned from retail sale in 1996 and on 1 January 1997 the local motor industry adopted a voluntary code that saw catalysts fitted to new vehicles. Note the actual code was not fully complied with for some vehicle models and some vehicles may have fallen short of the emissions performance targeted.[78]

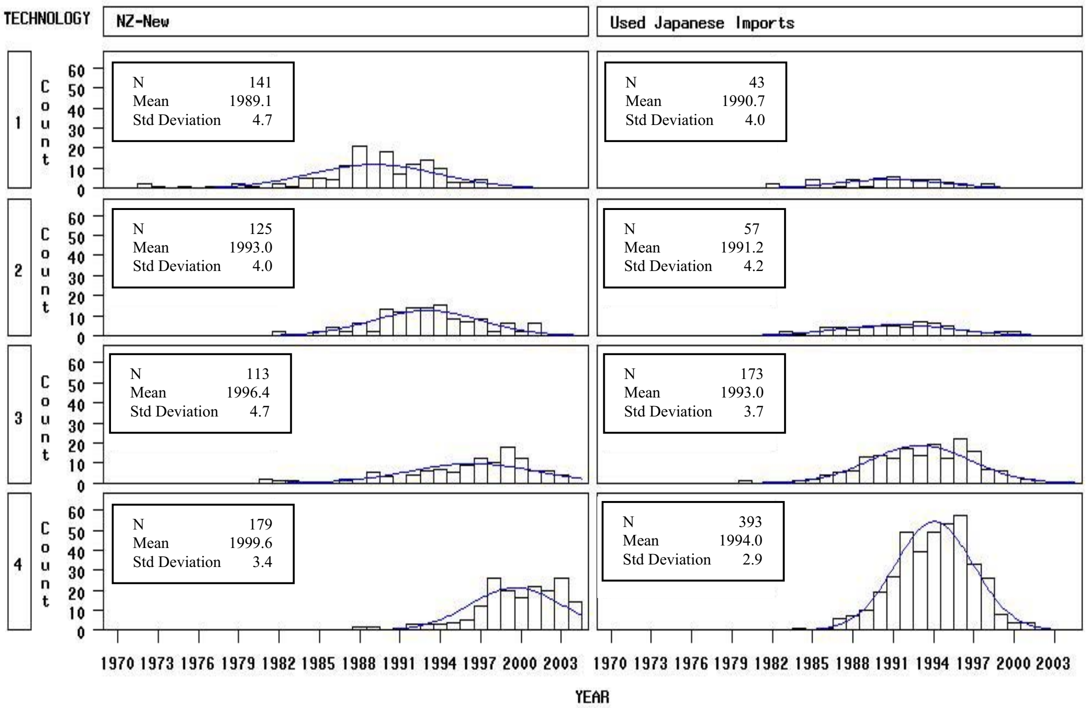


Figure 7: Year of Manufacture Distributions for the Adjusted Idle Data Set Divided by Engine Technology and Origin as given by NZ-New and Used Japanese Import.

Figure 8 provides the combined engine technology and vehicle origin distributions for the adjusted idle data set. For comparison's sake, the distribution for the active light petrol fleet as given by LANDATA[79] is shown. This corresponds satisfactorily with the adjusted idle data set except, for the reasons previously noted, in the case of vehicles of very recent YoM.

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[78] Note that it would have been difficult for some vehicles produced in high volume for the New Zealand market to meet the voluntary code precisely and fitting a catalyst was considered the next-best option. Personal communication from a New Zealand representative of overseas vehicle manufacturer.

[79] For active petrol fleet as at 31 December 2004.

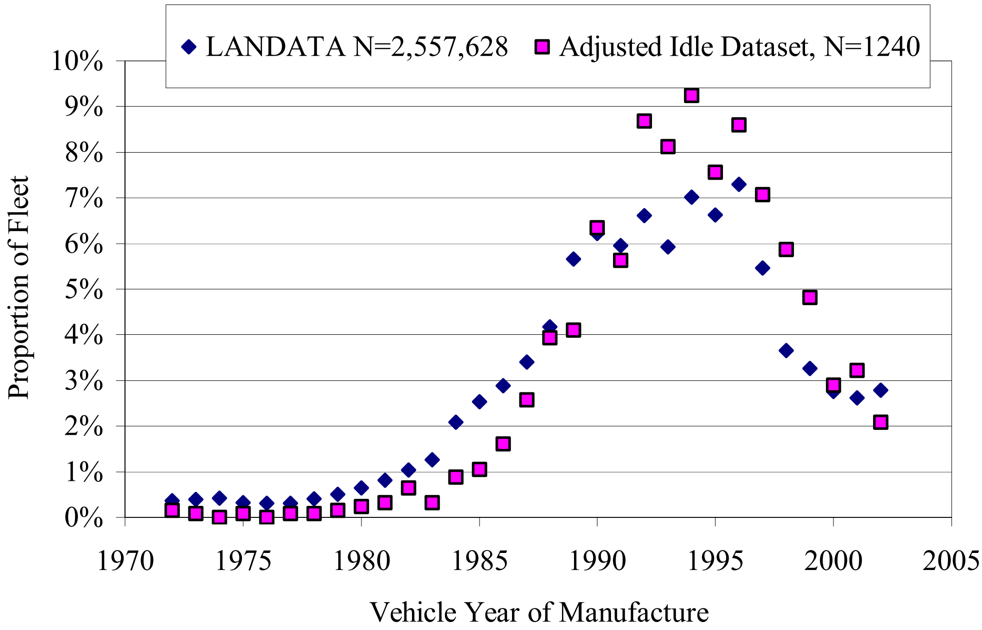


Figure 8: Distribution of Data by Year of Manufacture for the Adjusted Idle Data Set Plus Comparison with the Distribution as Given by LANDATA, Post 1970 Vehicles.

4.2.5. Emissions Result Analysis

Distributions of vehicle emissions results are usually highly skewed to the zero-emissions axis. In order to apply standard statistical analyses, the distribution of emissions results needed to be normalised. This was achieved by logarithmically transforming the raw data, as discussed in Section 2. Such analysis of emissions results in log-space is routinely carried out in the course of research undertaken overseas.

Figure 9 provides the vehicle count distributions of (natural) idle CO results of the adjusted idle data set grouped as before by engine technology and vehicle origin, in log-space. Note $\log_e$ -4 is around 0.02% CO and is at the normal resolution limits of the analysing equipment, and $\log_e$ 2 is around 7% CO, the upper limit of the high-emitters found. Two things are immediately obvious from these distributions: the wide variability in the data, from near zero to above 7% CO; and the bimodal character of the distributions for Technology 3 and 4, which have modes falling around near-zero and around $\log_e$ -0.5 (0.6% CO).

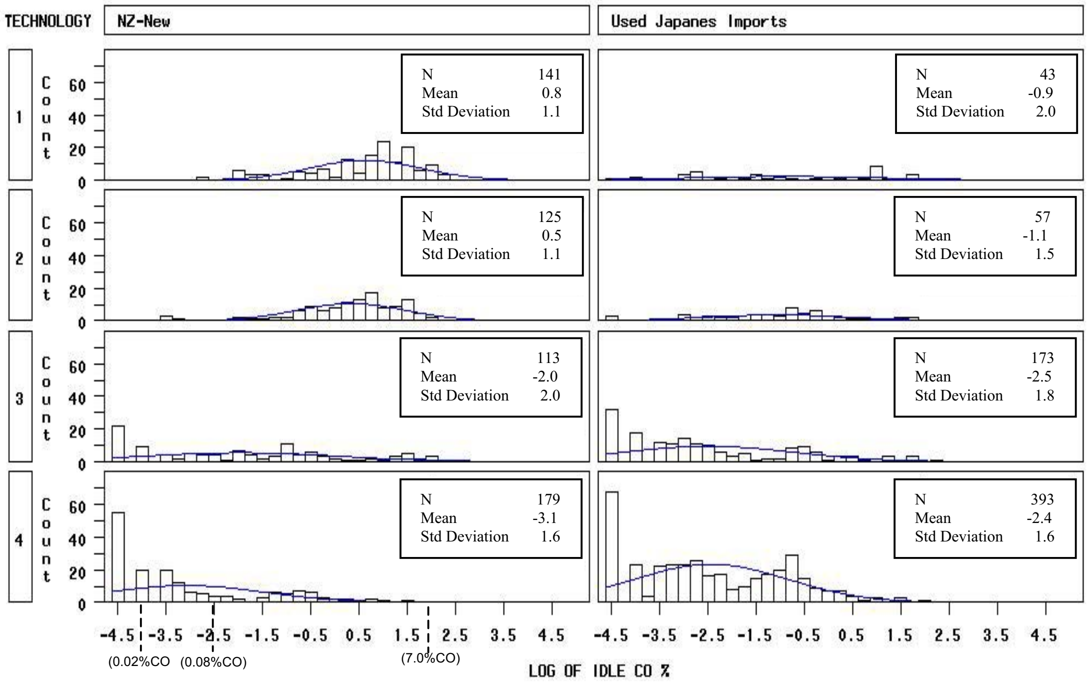


Figure 9: Vehicle Count Distribution of the Adjusted Idle Data Set Versus Log of (Natural) Idle CO by Engine Technology and Vehicle Origin

To eliminate one of the modes, vehicles which returned a near-zero result (vehicles with CO less than $\log_e$ -2.5 CO, or less than 0.08% CO — near the limits of resolution for the test) have been removed from the data set and placed at $\log_e$ -3.5. Figure 10 shows the resulting distributions for (natural) idle CO, in log-space, and shows:

- Extremely variable emissions performance, with the standard deviation ranging from similar to the mean to twice the mean;
- Similar mean (natural) idle CO emissions results for Technology 1 and 2 and for Technology 3 and 4 and a reasonable variation between these engine technology sets, from a mean (natural) idle CO of $\log_e$ 0.2 for Technology 1-2 (1.2% CO) to a mean (natural) idle CO of $\log_e$ -2.3 for Technology 3-4 (0.1% CO);
- Near-zero vehicles make up almost 60% of Technology 3 and 4 vehicles;
- The proportion of near-zero emission vehicles is highest for NZ-New, Technology 4 vehicles, at around 73%.

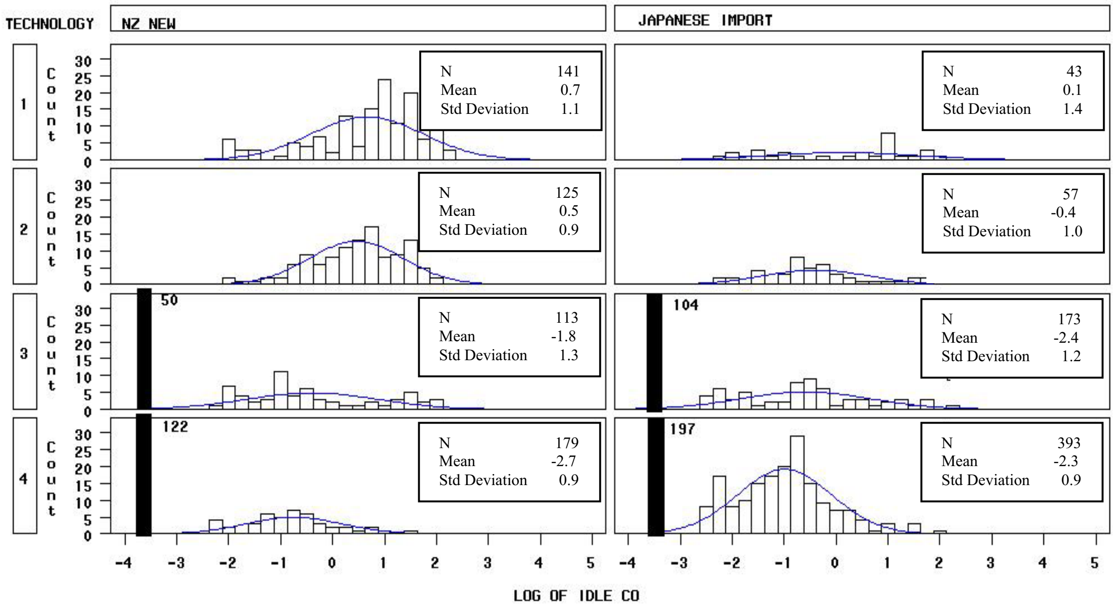


Figure 10: Vehicle Count Distribution of the Adjusted Idle Data Set Versus Log of (Natural) Idle CO by Engine Technology and Vehicle Origin Taking Near-Zero Emissions Vehicles into Consideration (means provided for Technology 3 and 4 being those inclusive of near-zero results)

Similar trends in distribution were found for (natural) idle HC and fast idle CO and HC, although a slightly lower standard deviation was found in the case of (natural) idle HC, ranging from 25% to 75% of the mean. Distributions for (natural) idle HC and fast idle CO and HC are provided in Appendix G.

The bimodal distributions produced by these results would have been extremely difficult to identify and analyse in real space, and vindicates the decision to conduct the analysis in log-space.

Figure 11 translates these results into real space, providing the median, the lower 10% and upper 90% percentiles for NZ-New and Used Japanese Imports combined (vehicle origin found to not be statistically consistently significant) and their respective 90% confidence intervals. Shown for all idle simple test results is the extremely wide range of the results (from the 10% percentile value to the 90% percentile value) and the relative similarities between Technology 1 and 2 and Technolog 3 and 4. The significant variation between these engine technology groups, Technology 3-4 exhibiting between 60%-90% lower emissions than for Technology 1-2, (natural) idle and fast idle and emissions specie-dependent, is largely attributable to the presence of a working catalyst. Note the effect reported here is based on mean emissions and takes into account a proportion of vehicles fitted with catalysts that may not be working or at least exhibit low emissions conversion efficiency.

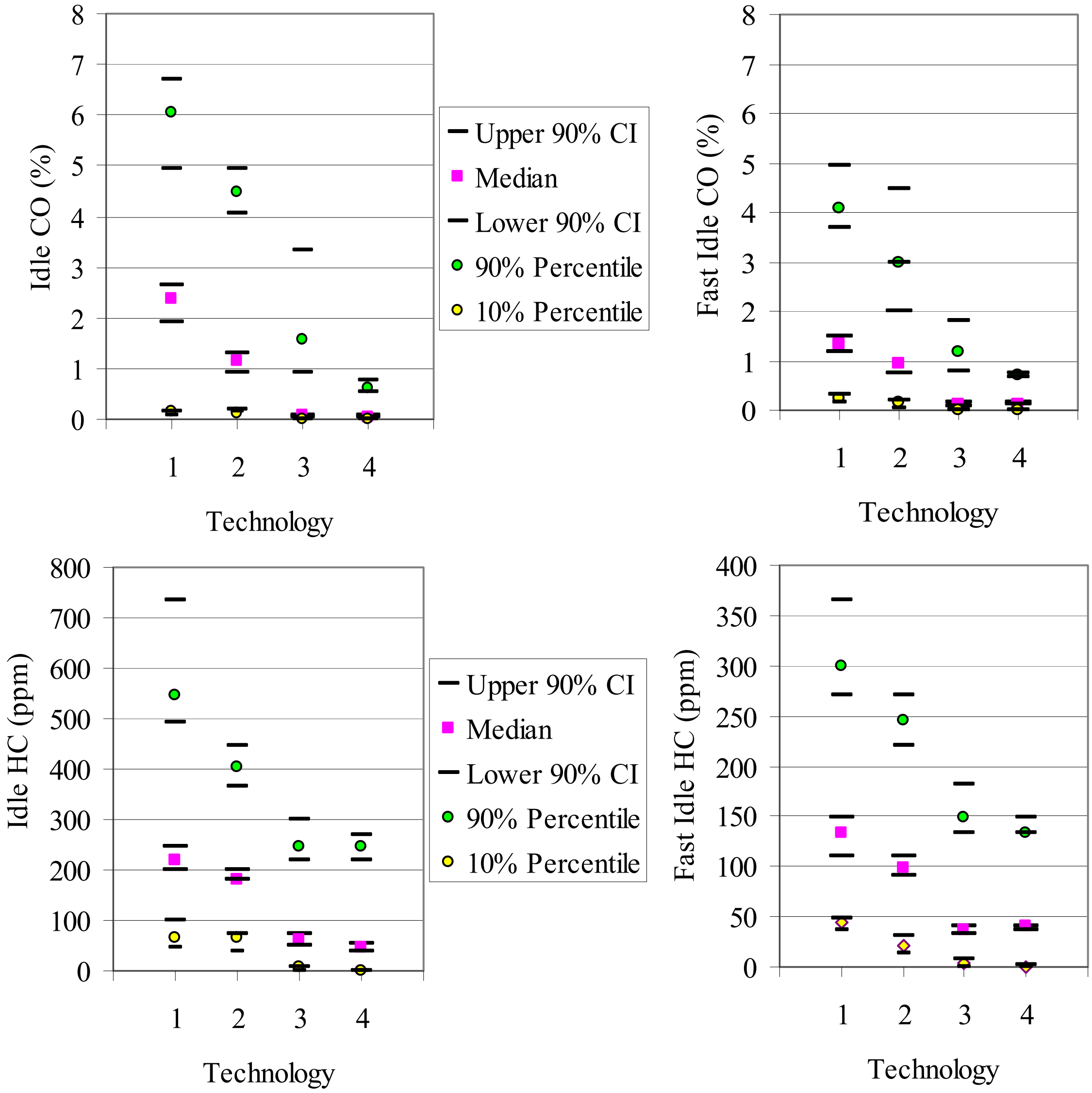


Figure 11: Median (Natural) Idle and Fast Idle CO and HC Emissions Plus the Lower and Upper 90% Confidence Intervals about the Mean.

On the latter point, whether a vehicle was imported before or after October 1996, when leaded fuel was banned from retail sale in New Zealand, was found statistically significant. This is discussed later in this section.

It should be noted that catalyst-equipped vehicles could be expected to have better management of fuel metering than original non-catalyst-equipped vehicles (due to design requirements), and a vehicle originally equipped with a catalyst that had had the catalyst removed would still exhibit lower emissions than an original non-catalyst-equipped vehicle. However, no evidence could be found to suggest this effect was anything but minor with the majority of the difference in emissions performance between catalyst- and non-catalyst-equipped vehicles being seemingly due to the presence and action of the catalyst. This is a good reason for ensuring catalysts are not removed from vehicles.

Figure 12 provides a balloon plot for the adjusted idle data set, for (natural) idle CO, with vehicles spatially distributed along their respective engine technology lines by

SPI, again merging vehicles of different origin. In the case of Technology 4 vehicles, NZ-New vehicles tend to be positioned at lower SPI (more recent YoM and lower kilometres travelled), and Used Japanese Imports tend to be positioned at higher SPI. Using this variable, vehicle origin is not significant and falls out.

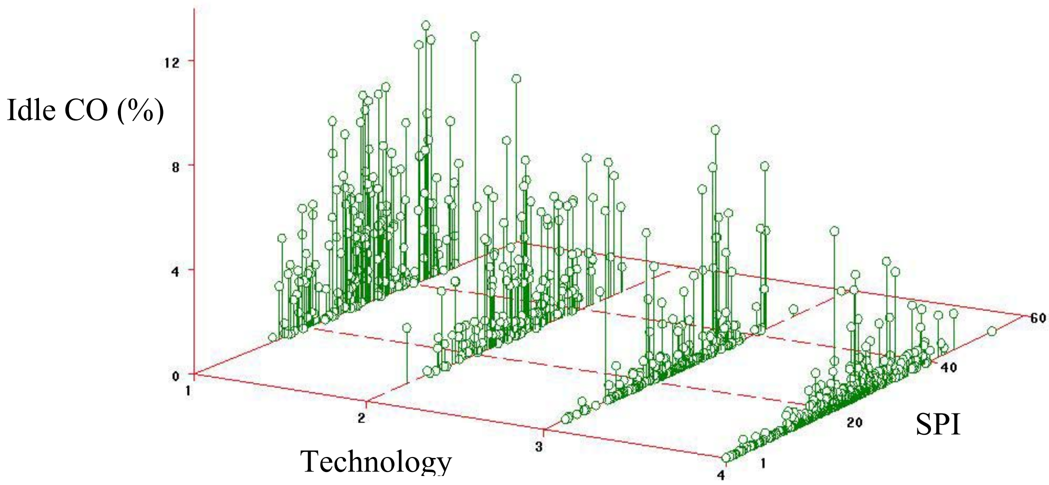
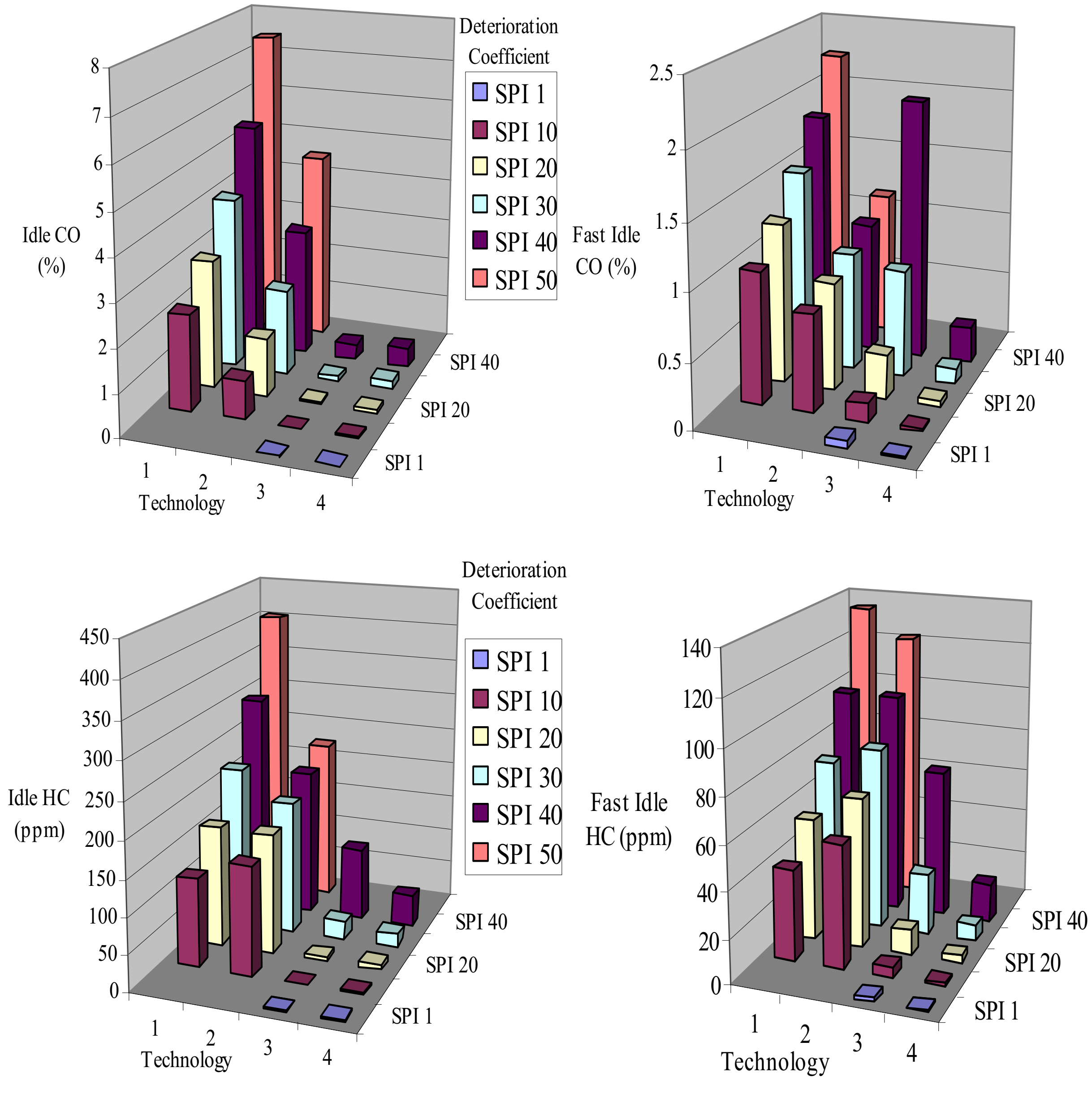


Figure 12: Balloon Plot of (Natural) Idle CO for the Adjusted Idle Data Set by Engine Technology and Secondary Performance Indicator.

Evident from Figure 12, once again, is the high variability in results. Trends can be seen beyond this and these were statistically modelled in log-space, using multiple variable regression analysis. Figure 13 provides the predicted (statistically modelled) profile for (natural) idle and fast idle CO and HC emissions, for the adjusted idle data set, with the results of this modelling then transformed back into real space. Modelled results have been used in this case, rather than real data, as this method can better account for vehicles placed at the fringes of the given SPI divisions.



Note: SPI 1 consists of vehicles typically of YoM between 2000 and 2005 and SPI 50 of typically pre-1980 YoM vehicles. Data points are not provided where there are few vehicles representing that cell.

Figure 13: Mean (Natural) Idle and Fast Idle CO and HC as Predicted by Statistical Modelling for Various Engine Technologies and Secondary Performance Indicators (SPI)

Figure 13 demonstrates the large reduction in mean (natural) idle and fast idle emissions for catalyst-equipped vehicles compared with non-catalyst-equipped vehicles, as before. Also shown is an increasing mean emission with increasing SPI:

that is, increasing mean emission for increasing YoM plus increasing distance travelled. For example, an older non-catalyst-equipped vehicle of higher odometer reading was expected to exhibit to the order of two- to three-fold higher idle simple test emissions than a recent YoM, less-travelled non-catalyst-equipped vehicle. A steeper 'deterioration' slope was exhibited for catalyst-equipped vehicles; that is, there was a higher relative increase in emissions compared to the first value, but the absolute values remained relatively low in comparison with those for non-catalyst-equipped vehicles.

Over time, it is expected that the population of non-catalyst-equipped vehicles and high SPI vehicles would substantially reduce through business-as-usual fleet turnover. This is essentially clearing the back area of Figure 13, effectively removing vehicle types of higher mean emissions, and would bring about a substantial reduction in mean fleet idle simple test emissions. It is recommended that forecasting analysis is carried out to quantify the effects of business-as-usual fleet turnover.

4.2.6. Idle Simple Test Emissions Profiles and Policy Considerations

The proportion of vehicles not meeting certain cut-points is important for policy concerning inspection and maintenance of vehicles. For this analysis, the Pilot sample fleet has been divided into two engine technology groups, non-catalyst and catalyst, and by the YoM groups pre-1990, 1990-1995 and post-1995. The engine technology split here reflects the ease with which vehicles can be divided into these groups in practice, say by visual inspection at the time of safety inspection. The use of YoM and not SPI is a compromise, but one which reflects the difficulty that would likely arise were policy to be based on odometer, which can be unreliable on an individual-vehicle basis. (Note, though, that using SPI is still recommended for modelling in considering the response to various policy options because it better describes emissions performance). Also, for this analysis, the distribution of idle simple test emissions has been provided in 'percentile plots', where vehicles are ordered with their level of emissions ranging from low to high, the horizontal axis showing the proportion of vehicles that have emissions lower than the given emission level.

Figure 14 provides the percentile plots for (natural) idle CO for the engine technology and year groupings identified. The curves that result show similar trend, namely a gradual increase in emissions levels as a higher proportion of vehicles is accounted for, followed by a steep increase in the 'tail' as this proportion of vehicles includes the higher emitters. Catalyst-equipped and more recent YoM vehicles initially exhibit flatter curves. The combination, catalyst-equipped vehicles of recent YoM, has a particularly flat curve (lower curve of Figure 14) and includes a high proportion of near-zero emitting vehicles, as measured by the idle simple test. In comparison, few vehicles would return near-zero results in on-road emissions testing (as evidenced by the results from testing vehicles under drive cycle conditions), which suggests that idle simple testing is not a good indicator of on-road emissions performance.

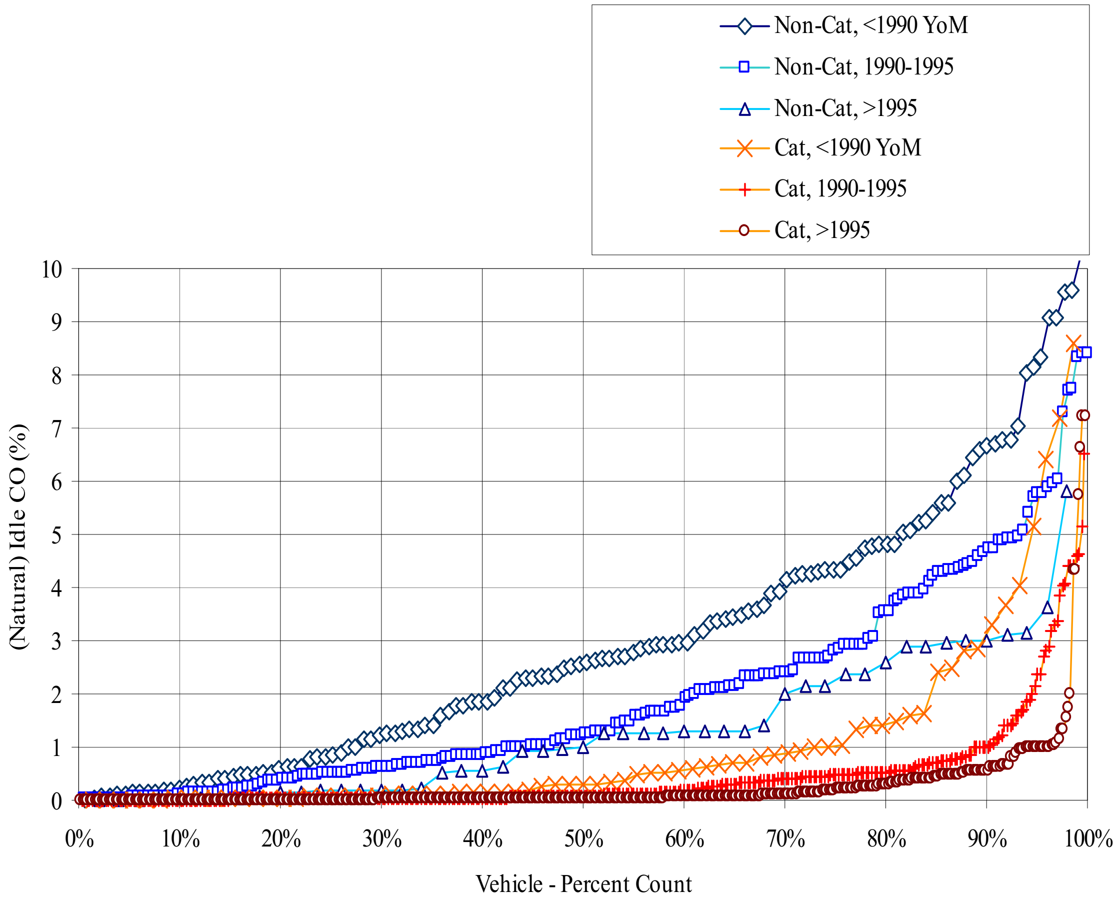


Figure 14: (Natural) Idle CO Percentile Plots With Vehicles Ranked Lowest to Highest Emitters For Catalyst- and Non-Catalyst-Equipped Vehicles and Different Year of Manufacture Ranges.

The plots in Figure 14 can be used to provide the proportion of vehicles not meeting a given cut-point or what cut-point would be required to fail a given percentage of vehicles. For example, for pre-1990 non-catalyst-equipped vehicles, around 35% would not meet a 3.5% (natural) idle CO cut-point (100%-65%) and a cut-point of around 6.5% (natural) idle CO would fail 10% of vehicles in this category. The latter compares with a cut-point of 0.6% failing 10% of post-1995 YoM catalyst-equipped vehicles.

Those vehicles in the higher emitting 'tails' of the percentile plots are more likely to have a fault. However, in general there is no set point above which an observer could be certain that a fault was present on a fleet-wide or even engine technology-wide basis unless that cut-point was made very high (identifying only vehicles with above 6% (natural) idle CO, say) or where the result for an individual vehicle could be identified as far above normal for that particular model. That is, in general there is no set cut-point that can be identified above which a result represents 'something broken'.

Similar trends were shown for (natural) idle HC and fast idle CO and HC. Percentile plots for these emission species are provided in Appendix G.

Idle simple test cut-point options in use overseas include:

- Visual only at (natural) idle (applied to vehicles first used before August 1975, UK);[80]
- 4.5% (natural) idle CO and 1200 ppm (natural) idle HC (applied to vehicles first used between August 1975 and July 1986, aimed at non-catalyst-equipped vehicles, UK);[80]
- 3.5% (natural) idle CO and 1200 ppm (natural) idle HC (applied to non-catalyst-equipped vehicles first used between August 1986 and July 1992 and remained as an option for vehicles where a manufacturer had not set their own testing limit until 1995, UK);[80 and 81]
- 1.0% (natural) idle CO and 300 ppm (natural) idle HC (being the in-service cut-point applied to petrol vehicles[82] in Japan);[83]
- 0.3% fast idle CO, 200 ppm fast idle HC and fast idle lambda between 0.97 and 1.03 plus 0.5% (natural) idle CO (normally applied to catalyst-equipped petrol vehicles in the UK).[80]

The UK cut-points are derived from European Union cut-points. The change shown over time for the UK (and the European Union, for that matter) reflects the advance in engine technology with progressively lower emissions cut-points required to identify vehicles that are 'off form' as they are built to meet ever more stringent emissions specifications. A summary of the evolution of idle simple testing and cut-points relative to that of the petrol engine is provided in Appendix H.

Figure 15 plots the (natural) idle CO result versus the (natural) idle HC result for the adjusted idle data set and shows the UK 3.5% (natural) idle CO and 1200 ppm (natural) idle HC cut-point. This plot shows the CO cut-point value to be the more stringent requirement with only a further three failed vehicles (one is off this plot) being added through the HC cut-point requirement. For the Japanese 1.0% (natural) idle CO and 300 ppm (natural) idle HC cut-point, 299 vehicles failed by the (natural) idle CO result and a further 33 vehicles failed when including the HC cut-point.

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[80] Vehicle and Operator Services Agency (VOSA), *The MOT Inspection Manual - Car & Light Commercial Vehicle Testing*, Issue date: August 2004.
[81] Lesley Emmett, MoT, Personal communication.
[82] All petrol vehicles are expected to be fitted with a catalyst in Japan, such are the emissions standards involved.
[83] Automobile Standards Internationalisation Centre, *Automotive Type Approval Handbook for Japanese Certification, 2002*, Japan.

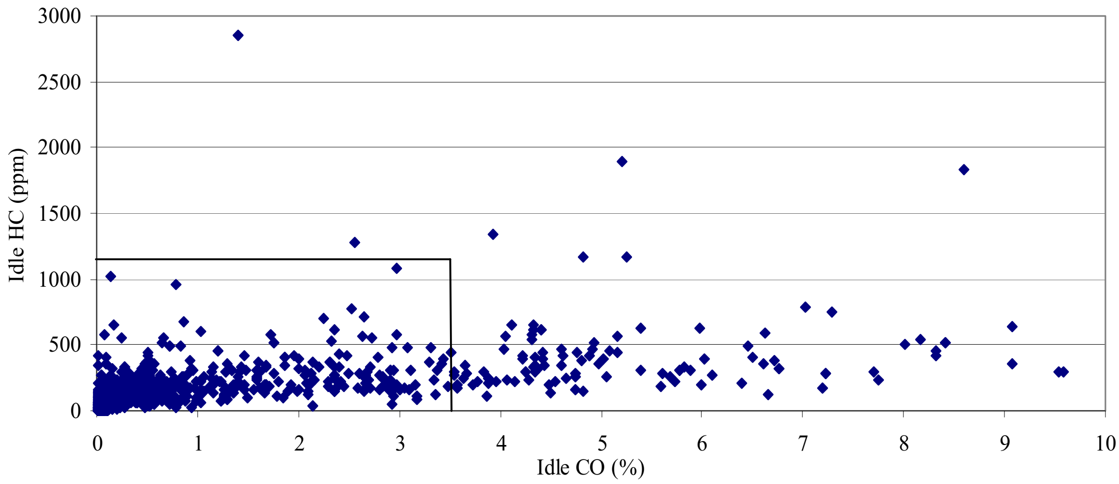


Figure 15: (Natural) Idle CO Versus (Natural) Idle HC for the Adjusted Idle Data Set

It would be difficult to apply a particular cut-point universally to New Zealand vehicles, as around half the fleet is New Zealand-new and the majority of these were not built to an emissions performance standard (and were never designed to meet an idle simple test cut-point). This is further discussed in Section 8. If idle simple testing were introduced, it is possible the most stringent cut-point for the existing fleet – catalyst- and non-catalyst-equipped vehicles alike – would be 3.5% or 4.5% CO plus 1200 ppm HC.

Table 5 provides the proportions of different vehicle groups not meeting a 3.5% (natural) idle CO, 1200 ppm (natural) idle HC cut-point and a 1.0% and 300 ppm HC cut-point. In general there is a steady reduction in the proportion of vehicles not meeting the given cut-points with more recent YoM, and a three- to four-fold increase in this proportion when moving to the more stringent cut-point. All post-2000 YoM catalyst-equipped vehicles meet the given cut-points.

Table 5: Proportion of Vehicles Not Meeting a 3.5% (Natural) Idle CO and 1200 ppm (Natural) Idle HC Cut-point and a 1.0% (Natural) Idle CO and 300 ppm (Natural) Idle HC Cut-point by Various Vehicle Groups.

	Vehicle Divisions							
	Non-Catalyst				Catalyst			
	Pre-1990	1990-95	96-2000	+2000	Pre-1990	1990-95	96-2000	+2000
3.5% (natural) idle CO and 1200ppm (natural) idle HC								
Failure (%)	35%	21%	5%	0%	8%	3%	2%	0%
Sample Size	130	202	43	6	73	362	320	104
1.0% (natural) idle CO and 300ppm (natural) idle HC								
Failure (%)	75%	57%	47%	100%	32%	13%	7%	0%
Sample Size	130	202	43	6	73	362	320	104

A notable exception to these generalisations is that all post-2000 YoM non-catalyst-equipped vehicles fail to meet the 1% (natural) idle CO, 300 ppm (natural) idle HC cut-point. The three vehicles in question (sample size doubled to 6 to correct for the extended safety inspection sampling period) were all New Zealand-new Hiace vans and appeared to be running fuel-rich. There were also three New Zealand-new Hiace vans in the 1996-2000 YoM group and these too exhibited noticeably higher emissions. A fourth Hiace van in this latter group was a used Japanese import and exhibited one-fortieth of the emissions. These higher (natural) idle CO emissions for the New Zealand-new model would have come about because this vehicle model was not required to meet an emissions standard for the New Zealand market and this would have influenced the design build for the engine involved (i.e. a 'general export' design build was likely to have been used rather than a design build aimed at meeting a particular emissions standard). This would have applied to other vehicle models as well but in this case the results from the Hiace stood out well beyond the others.

4.2.7. Sundry Effects

Regional Variations

There is potential for test site-to-test site variability due to such factors as differences in maintenance carried out on vehicles, differences in the practices or analysers used and the like. However, idle simple test results from the various test sites were found to be similar when compared on an engine technology-by-engine technology basis, indicating that any difference due to site-to-site variability in vehicle maintenance practices, analysers used, etc. is small. This is illustrated in Figure 16, which provides the log-space-derived mean (natural) idle CO results from various idle simple test sites, with mean emissions results being similar across the various engine technologies. The small site-to-site variations that were found could largely be explained by differences in site mean vehicle SPI.

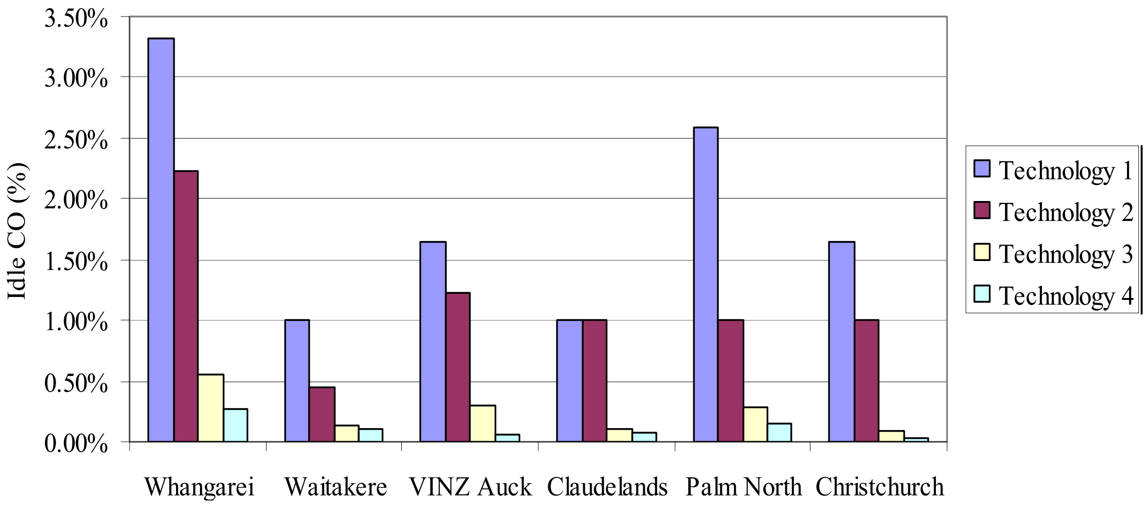


Figure 16: Mean (Natural) Idle CO for Various Idle Simple Test Sites by Engine Technology.

The notion that site was a small factor in determining mean idle simple test emissions, when engine technology and SPI were taken into account, was further explored by comparing the study data set with data from the NISE 1 vehicle emissions study carried out in Australia in 1996. This comparison found the two data sets on top of one another for Technology 1 (NISE 1 data within 11% of modeled Pilot/SMF[84] data for HC and 12% for CO) vehicles and the Pilot's Technology 4 vehicles to be lower emitters, on average, than NISE 1 Technology 4 vehicles.[85] The improvement in the Pilot's results for New Zealand Technology 4 vehicles could be explained by differences in SPI. This similarity, and considering vehicle origin was found to be insignificant, suggests the performance of vehicles is much the same when engine technology and SPI are taken into consideration regardless of where vehicles are.

Taking this to its logical conclusion, an understanding of the engine technology make-up and the SPI of the fleet is necessary for the extrapolation of the emissions results from the adjusted idle data set to the national fleet. SPI is available using LANDATA data. Engine technology is not.

To understand the engine technology profile of the national fleet better, visual inspections of vehicles were carried out at safety inspection-only sites in Whangarei, Tauranga, Gisborne, Palmerston North, Lower Hutt, Blenheim, Nelson, Greymouth, Timaru, Dunedin, Alexandra and Invercargill. These sites provided additional data to that drawn from the nine sites that conducted idle simple testing during which a visual inspection was also carried out. The visual inspection sheet used by those conducting idle simple testing was issued to these additional sites, and inspectors were provided with an inspection manual and given follow-up telephone calls for guidance. The visual inspection data received, plus the associated LANDATA data for the identified vehicles, were then screened by various data quality arguments (see Appendix D), then analysed.

Around 3500 petrol vehicles were so visually inspected as part of the Pilot. The quality assured data set, adjusted to take into consideration the less frequent safety inspections for vehicles of more recent YoM, had a sample size of 2607. A breakdown of this adjusted data set is provided in Appendix F. Note that due to concerns over data quality, data from Gisborne and Greymouth has been omitted completely from this analysis. Data screening detected an unusually high percentage of errors in the data from these sites.[86]

This analysis found:

- Engine technology make-up ranged significantly from site-to-site: for example, 25% of vehicles at VINZ Lower Hutt were Technology 4 vehicles, compared with 70% at VINZ, Mt Wellington, Auckland. The proportions of other engine technologies varied to a similar degree.
- The range of proportions of NZ-New to Used Japanese Imports also varied considerably from site to site, from a NZ-New proportion of 41% for

[84] Vehicle testing in 1996 under the Sustainable Management Fund (SMF) provided data that could be added to that of the Pilot. This if further discussed in Section 5.1.
[85] Note the NISE data set featured only Technology 1 and Technology 4 vehicles.
[86] For example, some petrol vehicles were shown to have diesel injection pumps and other incompatibilities.

Waitakere to 56% for Invercargill. As has been discussed a similar range in NZ-New/Used Japanese Imports was found using LANDATA data.

- The average YoM by site of the different engine technologies varied as much as 3.6 years. Similar differences were found in regional and local authority LANDATA data (for example, the mean YoM for petrol vehicles was 1990.7 for the West Coast and 1994.3 for the Waikato District Regions for LANDATA data).

The similarities in age profile and NZ-New/Used Japanese Import proportions with LANDATA provided confidence that the quality-assured visual inspection data provided a good sample of the petrol vehicle fleet operating in the regions where the various inspection sites were located.

Figure 17 shows the net results of applying visual inspection data to the statistical idle emissions prediction model (discussed above), giving expected mean (natural) idle CO result by inspection site. Interestingly, those sites in cities with significant ports where used imports were received — Auckland, Christchurch and Timaru — had a higher proportion of Used Japanese Import vehicles in the data samples, lower proportion of non-catalyst-equipped vehicles and correspondingly lower predicted mean (natural) idle emissions.

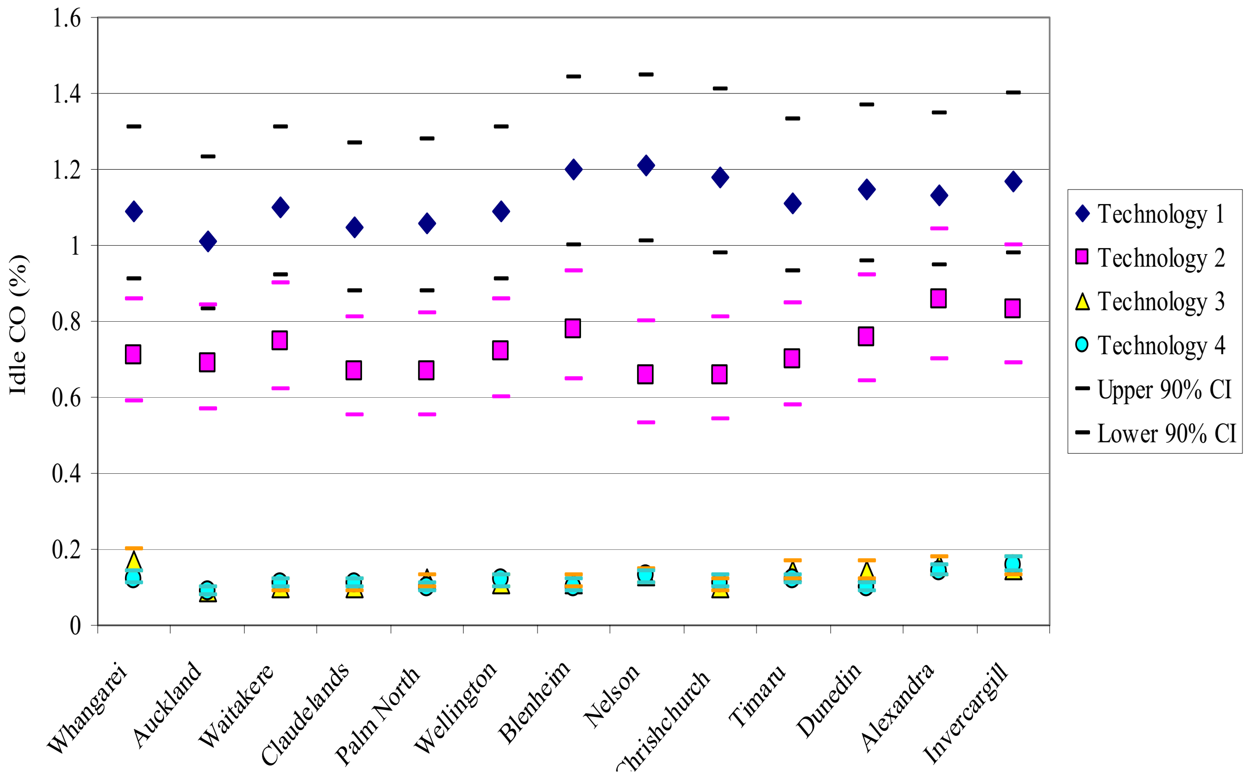


Figure 17: Predicted Mean (Natural) Idle CO Results by Inspection Site Location Plus Upper and Lower 90% Confidence Intervals Assuming Engine Technology and SPI are Known.

As shown by Figure 17 there is no significant difference in (natural) idle CO between sites, the test site-to-test site 90% confidence intervals overlapping.

Other Fuel Options

The small proportion of the fleet fuelled by CNG (believed insignificant, see Section 3) or LPG (estimated to be to the order of 0.6% of the spark ignition fleet, see Section 3) did not warrant specific targeted testing of these vehicles. Neither was any vehicle fuelled by CNG or LPG identified during idle simple testing. The idle simple test emissions response of vehicles fuelled by CNG or LPG can, however, be predicted from fundamentals.

As for petrol, a significant determinant of emissions during idle simple testing for CNG and LPG vehicles would be engine technology. What's more, since New Zealand CNG and LPG vehicles are predominantly retrofit (that is, after-market conversions rather than purpose-built), the quality of the conversion will also be a significant determinant of emissions performance at (natural) idle. For example, many of the conversions of the 1980s used simple fuel metering devices and due to the common practice of tuning the air-fuel mixture on the fuel-rich side of stoichiometric, higher emissions at (natural) idle would be expected compared to the original, pre-conversion petrol vehicle.

In order for the catalyst in modern vehicles so-equipped to be effective in reducing those emissions measured during an idle simple test, fuel metering must deliver a near-stoichiometric or fuel-lean air-fuel mixture to the engine. If the (natural) idle setting is set to fuel-rich, higher emissions at (natural) idle would be expected, there being insufficient oxygen for complete combustion rendering the catalyst ineffective. Since there is wide variation in the quality of conversion practices, some CNG and LPG vehicles will be operating at this less-than-ideal setting, and the mean emissions of CNG and LPG vehicles at (natural) idle is therefore expected to be higher than for petrol vehicles of similar engine technology.

Analysers used for idle simple testing do not respond well to the methane content of HC emissions, which is the most significant HC component for CNG vehicles. This will cause the analyser to provide an artificially low emissions reading for CNG vehicles, which would require correction.

Petrol-Alcohol Blends

It is possible low-proportion blends of ethanol in petrol could be used in New Zealand in the future. For less advanced engine technologies, the effect of adding alcohol would be to alter the air-fuel mixture to the fuel-lean side of the equation, if the engine was otherwise not altered, resulting in lower emissions of CO and HC at (natural) idle. Little difference in the simple idle test emissions of CO and HC would be expected for the use of low-proportion blends of ethanol in petrol in vehicles of more advanced engine technology, due to automatic compensation of fuel metering to the different fuel (for the low blends of ethanol expected in New Zealand).

Historic Petrol Vehicles

There is considerable variability in the design of engines through the ages. An issue for some historic vehicles is that fuel-rich air-fuel mixtures were sometimes used to achieve steady idling.[87] Such vehicles would be expected to exhibit high idle simple test emissions.

Modified Engines

One retrofit modification used to increase engine power on spark ignition engines is to use a 'hot cam'. This involves the use of an engine camshaft ('cam') modification that changes the manner in which gases flow through the engine and, among other effects, can significantly increase the amount of unburned fuel lost to the exhaust under natural or fast idle conditions, resulting in higher natural or fast idle emissions. It is expected a very small proportion of the fleet would be involved, although it would be difficult to confirm this. It has also been suggested by the Low Volume Vehicle Technical Association (LVVTA) that the vehicles in question are generally not used for day-to-day commuting.[88]

Re-chipping

Modern vehicles have sophisticated engine management systems controlled according to parameter maps often contained in processor 'memory chips'. 'Re-chipping' involves swapping a vehicle's control maps for others, generally with the intention of increasing engine power output. As the practice is uncontrolled, any control map configuration could be used and hence idle simple test emissions could well be higher for re-chipped vehicles.

Based on discussions with a number of suppliers of chips, it is believed the practice of re-chipping is not common, although it does appear both re-chipping and exhaust modification is commonly performed on one particular model range of new cars. The practice was not condoned by the importer of this particular model.

It would be difficult to determine from the testing and inspection carried out as part of the pilot whether a vehicle had been re-chipped.

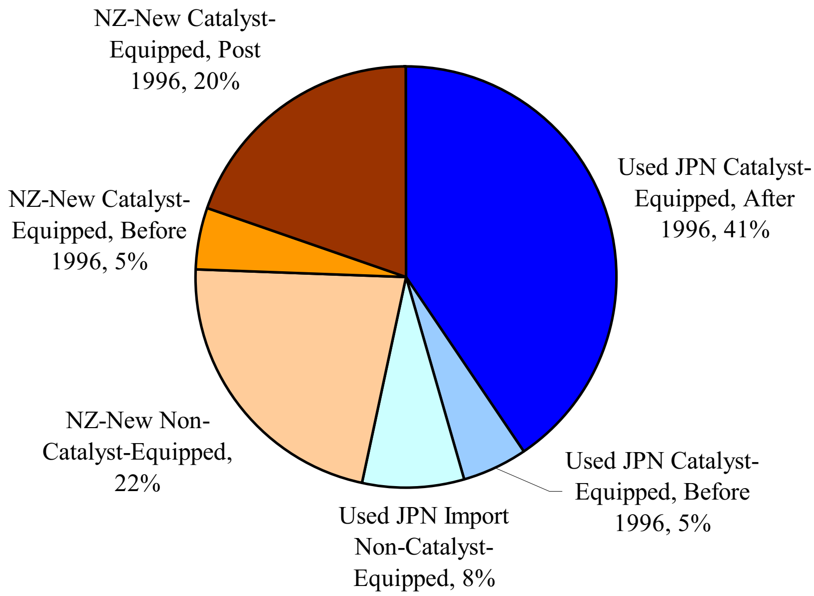
Catalyst Poisoning and Removal.

A vehicle originally fitted with a catalyst may, during the life of that vehicle, have the catalyst either poisoned to some extent or removed.

Catalyst-equipped vehicles in use in New Zealand before around mid-1996 risked having their catalysts poisoned through the use of leaded fuel.[89] The proportion of

[87] Fuel-rich mixtures were used at (natural) idle to counter mal-distribution of fuel to the cylinders. Operating fuel-rich satisfies the cylinders which would otherwise receive fuel-lean mixtures.
[88] Johnson, T., President LVVTA, personal communication.
[89] Lead takes up residence at the catalyst's conversion sites making them unavailable for the conversion of emission of concern.

vehicles at risk is shown in Figure 18, which divides the adjusted idle data set by vehicles with and without catalysts, NZ-New and Used Japanese Import and catalyst-equipped vehicles first registered in New Zealand before October 1996.[90] The number of Used Japanese Imports fitted with potentially poisoned catalysts made up 5% of the data set. Interestingly there were found to be New Zealand-new vehicles fitted with catalysts that were imported before October 1996, also making up around 5% of the data set. This is interesting because the new vehicle importers generally had more flexibility in specifying the vehicles being brought to New Zealand and having catalysts fitted to vehicles would not be expected to have been a priority when New Zealand still had leaded fuel. Checking the New Zealand-new vehicles in question, they were likely models drawn directly from overseas markets. For example, there were a number of Holden Commodores involved, the model exactly the same as the model in use in Australia, which at that time was fitted with a catalyst.



Note rounding error in these results.

Figure 18: The Adjusted Idle Data Set Divided by Vehicles Fitted and Not Fitted with Catalysts, NZ-New and Used Japanese Import and Catalyst-Equipped Vehicles First Registered Before October 1996.

Note the proportion of vehicles in the adjusted idle data set that were first registered in New Zealand before October 1996 showed very good agreement with the proportion as given by LANDATA data. For example, 9.0% of Used Japanese Imports of the adjusted idle data set were first registered in New Zealand before 1 October 1996 (being the 5% for catalyst Used Japanese Imports registered before October 1996 as

[90] The date when the sale of leaded petrol was banned in New Zealand. Unleaded fuel was introduced into the fuel supply chain well before this time so as to flush the leaded fuel product from the system before October 1996.

given in Figure 18 and one half of the non-catalyst Used Japanese Imports), which happens to be the exact value given by LANDATA data.[91]

The significance to idle simple test emissions of whether or not a vehicle was first registered in New Zealand before October 1996 was checked for statistical significance using a first order[92] of multiple variable regression statistical analysis. This import date parameter was found to be statistically significant for (natural) idle CO for NZ-New vehicles and for (natural) idle and fast idle CO and HC for Used Japanese Imports; on average, catalyst-equipped vehicles are expected to have around 0.5% lower (natural) idle CO on account of being imported after October 1996, than before, and used catalyst imports are expected to have around 30 ppm lower HC on account of being imported after October 1996.

Note that there was potential for some result bias due to the distribution of data, as vehicles imported before October 1996 were more likely to have higher SPI. Also, as the proportion of vehicles involved was relatively small, at 10%, and the effect could be at least partially accounted for by the SPI variable if an import date variable was not included, it was chosen to exclude the import date variable in the modelling discussed earlier in this section.

Metal-based oil additives also have the potential to poison catalysts and therefore another possible cause for the poisoning of catalysts is oil carry-over to the exhaust, such as in the case of an engine burning oil. It would be extremely difficult to acquire enough data to analyse this potential effect.

The proportion of non-catalyst Used Japanese Imports was 8% (yellow segment of Figure 18). It is suggested the majority of these vehicles were originally fitted with catalysts; such were the build emissions performance requirements in Japan for the models involved. This suggests the removal of catalysts from in-service vehicles would affect at least around 8% of the fleet. Noting that some of these vehicles were over 20 years of age, it is not surprising that the catalyst has been removed; exhaust systems do have limited life.

There would also be a proportion of catalysts removed from New Zealand-new vehicles, expected to be a smaller proportion of the New Zealand-new vehicle fleet, as catalysts are less likely to be fitted to older vehicles. This suggests the total proportion of vehicles that have had catalysts removed, for one reason or other, is around 10%.

Previous analysis suggested that around 20-25,000 catalysts are removed from in-service vehicles each year.[93] Simple modelling, using various vehicle retirement scenarios, equates this to 5% to 14% of the fleet having had their catalysts removed. The wide range stems from the difference in modelling between removing the catalyst shortly before a vehicle's retirement and removing it soon after fleet entry. The middle ground aligns reasonably well with the 10% value derived above.

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[91] For active light petrol fleet as at 31 December 2004.

[92] First-order analysis suggests there is potential for the result to be biased by the distribution of data by SPI, as vehicles imported before October 1996 are more likely to have higher SPI. A second level of analysis may better manage this potential bias. This analysis was not carried out as the percentage of vehicles involved, around 10% of the fleet, was considered a relatively small proportion of the fleet.

[93] Campbell, A. R., 'Assessment of Benefits of Prohibiting Removal of Catalytic Converters from Vehicles - A Short Report for the Ministry for the Environment', Fuel Technology Limited, 20 July 2003, plus follow-up interviews with precious metal recyclers, which are a destination point for most removed catalysts.

Removal of exhaust catalysts would be expected to significantly increase the average emissions of the vehicles concerned. Methods or régimes that would stop, or at least minimise, the removal of exhaust catalysts deserve investigation. This investigation would also need to consider options for replacement where catalysts are no longer fit to be on a vehicle.

Note: although it was a specific inspection item in the visual inspections carried out for the Pilot, the removal of catalysts was rarely identified, perhaps because it is difficult to determine whether or not a vehicle originally had a catalyst fitted.

Four importers of used vehicles were interviewed, and two of these said catalysts were removed from around 0.5-1.0% of used vehicles before first sale in New Zealand. The catalysts were reportedly removed where a vehicle's emissions "smelt of rotten eggs".

The Pilot specified visual inspection was to verify the presence of a catalyst unit only, and did not provide for verification that the internals of the catalyst box were present or working. The number of vehicles with empty catalyst boxes (that is, where the catalyst matrix has been removed or otherwise incapacitated), however, is expected to be small as it is just as easy to remove the catalyst all together.

Recent Imports

It was a contractual requirement of the Pilot to consider the idle simple test emissions of recently imported used vehicles and this was a focus of testing, for a time, at VINZ Mt Wellington, Auckland. However, only a small data set was obtained at this site. Instead, the profile of Used Japanese Imports first registered in New Zealand after 1 October 2003 (that is, within one year of when the Pilot was being conducted) was considered. There were 77 such vehicles in the adjusted idle data set and two did not meet a 1% (natural) idle CO and 300 ppm (natural) idle HC cut-point (the idle simple test cut-point current in Japan at the time of the respective vehicles' manufacture). One exhibited very high CO with (natural) idle and fast idle CO at above 5%. The other vehicle was only marginally over the 1.0% cut-point.

Extending this to vehicles first registered in New Zealand after 1 October 2002 (that is, within two years of the period over which the Pilot was conducted) captured 155 vehicles and one further vehicle that marginally failed the 1% (natural) idle CO was found. Hence for the sample of vehicles tested only a small proportion, the order of 2%, did not meet their country of origin idle simple test emissions requirements.

4.3. Conclusions

Profiling and benchmarking results from idle simple testing light petrol vehicles found:

- The idle simple test emissions performance of vehicles is extremely variable; based on a log-transformed emissions data set, the standard deviation for (natural) idle HC was from 25% to 75% of the mean and the standard deviation for (natural) idle CO was similar to the mean to twice the mean;
- Engine technology[94] is the most significant determinant of idle simple test emissions performance. On average, for the Pilot sample, catalyst-equipped vehicles exhibited around 75% lower idle simple test emissions than non-catalyst-equipped vehicles, the main reason expected to be the effect of a working catalyst. This lends weight to ensuring exhaust catalysts are not removed from vehicles;
- The next most significant determinant of idle simple test emissions performance was a parameter derived from YoM and odometer reading. This parameter takes into account distance- and time-related deterioration of vehicle emissions performance plus such factors as differences in original build performance arising over time (within the engine technology groupings used), due to the evolving requirements over time to build vehicles to more stringent emissions performance requirements in vehicle-origin countries. In general, comparing vehicles at the extremes of a particular engine technology grouping found vehicles of less recent YoM and higher odometer reading exhibited to the order of two- to three-fold higher idle simple test emissions than recent YoM, less-travelled, vehicles;
- Whether a catalyst-equipped vehicle was imported before or after October 1996, when leaded fuel was banned from retail sale in New Zealand, was found to be statistically significant for (natural) idle CO for NZ-New vehicles and for (natural) idle and fast idle CO and HC for Used Japanese Imports (ignoring a potential time bias, one set of vehicles normally being younger than the other due to the difference in date of import); on average, catalyst-equipped vehicles are expected to have around 0.5% lower (natural) idle CO on account of being imported after October 1996 than before and used catalyst-equipped imports are expected to have around 30 ppm lower HC on account of being imported after October 1996;
- Whether vehicles are Used Japanese Imports or not is an inconsistent determinant of emissions performance where engine technology, YoM and odometer are known. Also engine power, whether or not the engine is fitted with a turbocharger, and vehicle tare weight are not significant determinants of idle simple test emissions performance, where engine technology, YoM and odometer are known. Engine size was found to be a statistically significant emissions parameter for Technology 4 vehicles only, but the effect was small and could be caused by another factor correlated to engine size;
- There is a steady decrease in the proportion of vehicles failing to meet idle simple test cut-points as YoM becomes more recent, ranging from 35% for

[94] Note 'engine technology' refers also to the exhaust system and any exhaust after-treatment system that may be fitted, not just the 'under-bonnet' section of an engine.

pre-1990 non-catalyst-equipped vehicles to 0% for post-2000 non-catalyst-equipped vehicles and from 8% for pre-1990 catalyst-equipped vehicles to 0% for post-2000 catalyst-equipped vehicles for a 3.5% CO and 1200 ppm HC cut-point;

- Emission profile curves were developed that allow the proportion of vehicles not meeting given cut-points, or what cut-point would be required to fail a given percentage of vehicles, to be easily determined;
- A statistical emissions prediction model was developed and applied to data collected from various test sites around New Zealand. Site-by-site variations in predicted emissions were found not significant but they did show some differences;
- Business-as-usual fleet turnover is expected to bring about a substantial improvement in the idle simple test emissions performance of the fleet;
- Around 60% of the catalyst-equipped vehicles in the Pilot's sample exhibited near-zero idle simple test emissions performance. It is expected the proportion of vehicles in the New Zealand fleet that exhibit near-zero idle simple test emissions performance would increase substantially over time through business-as-usual fleet turnover;
- It is believed to the order of 10% of the fleet have had catalysts removed for one reason or other.

4.4. Recommendations for Further Work

It is recommended that:

- A programme to identify the engine technology make-up of the petrol fleet across an appropriate network of sampling sites be undertaken and this information be used to expand knowledge on the area-wise emissions performance of the fleet;
- A mechanism be considered for maintaining an engine technology profile of the fleet, including verifying LPG/CNG or other fuel option status;
- Options be considered for banning or at least managing tampering with a vehicle's emissions-related componentry. This work should include investigation into maintaining the function of the exhaust catalyst, where one is fitted, or managing the removal of exhaust catalysts from vehicles. It should also include further investigation into the incidence of catalyst removal, possible mechanisms to prevent catalysts being removed and the potential wider implications of such régimes;
- The expected improvements in idle simple test emissions performance of the fleet through business-as-usual fleet turnover be further investigated and quantified.

5. Evaluation of Idle Simple Testing

This section describes work carried out to evaluate idle simple testing against emissions results from detailed dynamometer testing of petrol vehicles — detailed dynamometer testing providing an indication of on-road emissions performance of vehicles.

5.1. Methodology

Evaluating idle simple testing against emissions results from detailed dynamometer testing comprised:

1. selection of appropriate dynamometer test cycles;
2. gaining access to and selection of appropriate test vehicles;
3. carrying out detailed dynamometer and idle simple testing on selected vehicles and recording the results;
4. data analysis.

In general, a vehicle's instantaneous emissions are expected to be higher during transients in engine load than for steady engine operation. Dynamometer testing allows vehicles to be subjected to repeatable, controlled, load transients similar to those expected during on-road driving. On-road driving conditions vary tremendously, however, as they are subject to such variables as congestion, road type, traffic control methods and the driver, making it difficult to designate any single drive cycle as representative of 'typical' driving conditions. For this reason, two quite different dynamometer drive cycles, the 'IM240' and the Central Business District Congested (CBDC) drive cycles, plus one steady speed test were chosen to represent a wide range of driving conditions.

The full set of tests carried out on each vehicle, in order, was:

1. The IM240 test cycle: a representation of mixed urban and inter-urban driving conditions and an internationally applied inspection and maintenance test procedure, which offered the opportunity for comparison of the data generated with international data sets such as that of NISE 1;
2. The constant volume sampling (CVS) idle test: the idle simple test modified to use the testing laboratory's CVS system and laboratory emissions instrumentation;
3. The steady speed 60km/h (SS60) test: this can be used as a representation of loaded cruise operation, and is comparable with the NISE 1 data set tests;
4. The CBDC test cycle: a representation of congested driving conditions based on real, on-road driving in congested traffic in Auckland;[95]
5. The fast idle simple test in accordance with the project's idle simple test procedure (detailed in Appendix C);

[95] Developed as a component of the MoT's VFECS work to provide a test cycle representing E and F 'level of service' (level of service, also referred to as LoS, is a standard measure used in traffic modelling to describe the flow of vehicles on a road compared with the road's design levels with an E and F LoS describing congested traffic conditions).

6. The idle simple test in accordance with the project's idle simple test procedure (detailed in Appendix C).

Details of the first four tests are provided in Table 6. Further detail on the IM240 and CBDC drive cycles are presented in Appendix I.

Table 6: Details of the Tests used on the Dynamometer-Tested Vehicles

	Test			
Details	IM240	CBDC	SS 60	CVS idle
Duration seconds	240	481	240	240
Distance travelled km	3.152	1		0
Average speed km/h	47.3	7.7	60	0
Max speed km/h	91.3	49.3	60	0
Idle time %	4.5	64.3	0	100
No of stops per km	.6	8.7	0	NA

For detailed dynamometer testing, vehicles were selected to provide a good cross-section of engine technology,[96] odometer, vehicle age and vehicle origin. As data was available from an earlier test programme that tested vehicles to the same drive cycles as given above, the Sustainable Management Fund (SMF) programme carried out for the MoT,[97] vehicle selection for the present testing also sought to facilitate comparability. The SMF programme had a high proportion of non-catalyst-equipped vehicles and hence a bias could be made in the Pilot toward the selection of more modern vehicles.

Vehicles were sourced by a variety of means. The main source was from University of Auckland staff. Email and car park notices invited staff to make their vehicles available for testing. Selections were then made from the pool of vehicles offered.

This process netted 51 vehicles, of which 10 had repairs carried out on them as part of the Pilot and which were retested. This yielded a set of 61 vehicle variants for which idle simple and detailed dynamometer test results could be compared. This process provided a broad spectrum of vehicle types, rather than a purely random selection of vehicles, the broad spectrum representing a far better sample of vehicle variants for the purposes of comparing the performance of idle simple testing to detailed dynamometer testing.[98]

Detailed dynamometer testing was carried out at the Energy Fuels Research Unit (EFRU), University of Auckland. The chassis dynamometer consisted of a set of two rollers in which the vehicle's drive wheels were placed. One roller allowed the vehicle to be loaded and was also weighted to represent the on-road inertia of the vehicle through the drive cycles. To follow the required test procedure test cycle, the test driver took the vehicle through a set of controlled accelerations, decelerations, periods of steady speed and associated gear changes, prompted by a visual display.

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[96] Note 'engine technology' refers also to the exhaust system and any exhaust after-treatment system that may be fitted, not just the 'under-bonnet' section of an engine.

[97] Energy and Fuels Research Unit, Department of Mechanical Engineering, 'Vehicle Exhaust Gas Emissions SMF Project 5034', a report prepared for the Ministry for the Environment by the University of Auckland. This project was managed by the MoT.

[98] Note detailed analysis then went on to show such 'convenience' sampling of test vehicles was unlikely to cause any significant bias of results, as is detailed later in this section.

A CVS system was used to sample drive cycle emissions. This is an internationally accepted method for sampling vehicle emissions for certification and inventory purposes. It provides emissions results in grams per kilometre (g/km) and grams per second (g/s), being the average emissions rate over the entire test cycle. Exhaust HC, NOx, CO and CO_2 were measured, using instrumental laboratory analysers (specification provided in Appendix I). Fuel consumption, expressed in litres per 100 kilometres (l/100km) and millilitres per second (ml/s), was calculated from CO and CO_2 emissions, as is normal practice for such testing.

Detailed dynamometer testing consisted of: checking and standardising the vehicles for testing;[99] adjusting the dynamometer settings for the vehicle being tested, then taking the vehicle through the set of tests. The vehicles were tested using the fuel with which they were presented.[100]

Analysis of results for this section consisted of simple analysis using comparative functions in Microsoft Excel, plus more sophisticated analysis using SAS. Data from the earlier SMF vehicle emissions test programme was also incorporated into some of the analysis. Where this was done, this is identified.

5.2. Results

5.2.1. Test Vehicle Selection

Table 7 provides the make-up of the 51 dynamometer test vehicles originally selected and the ten re-tested vehicles. As shown, a reasonable selection of different types of vehicle was achieved.

Table 7: Make-up of the Dynamometer-Tested Vehicles by Engine Technology and Origin.

Engine Technology[(1)]	Sample Number	New Zealand New	Average YoM	Re-tested Vehicles
1	7	7	1989	1
2	11	4	1991	4
3	5	3	1995	0
4	28	17	1996	5
Totals:	51	31		10

Note 1: Engine technology as defined in Section 2.1.

Emphasis was placed on obtaining a wide spectrum of vehicles in the dynamometer test sample. One check used was to compare the idle simple test results of the dynamometer test sample with the results obtained from the Pilot's first idle simple testing carried out at Waitakere.[101] Figure 19 provides this comparison for (natural) idle CO. The good dispersal of the dynamometer test sample through the distribution of YoM by emissions results yielded by the Waitakere sample suggests a broad

[99] Including checking fluid levels and tyre pressures were standard and the vehicle was fit for testing,

[100] Although fuel specification can have an effect on emissions it was considered the effect would be small in comparison to test-to-test variability and therefore was not considered an issue.

[101] 1430 vehicles, (natural) idle CO and HC results only.

selection of vehicles was achieved in practice. Detailed analysis also found there to be many similarities in the characteristics of these samples. For example, 31% of the Pilot's dynamometer test sample was near zero, 33% for Waitakere. (Natural) idle CO averaged 1.0% for the dynamometer sample, 0.8% for Waitakere.

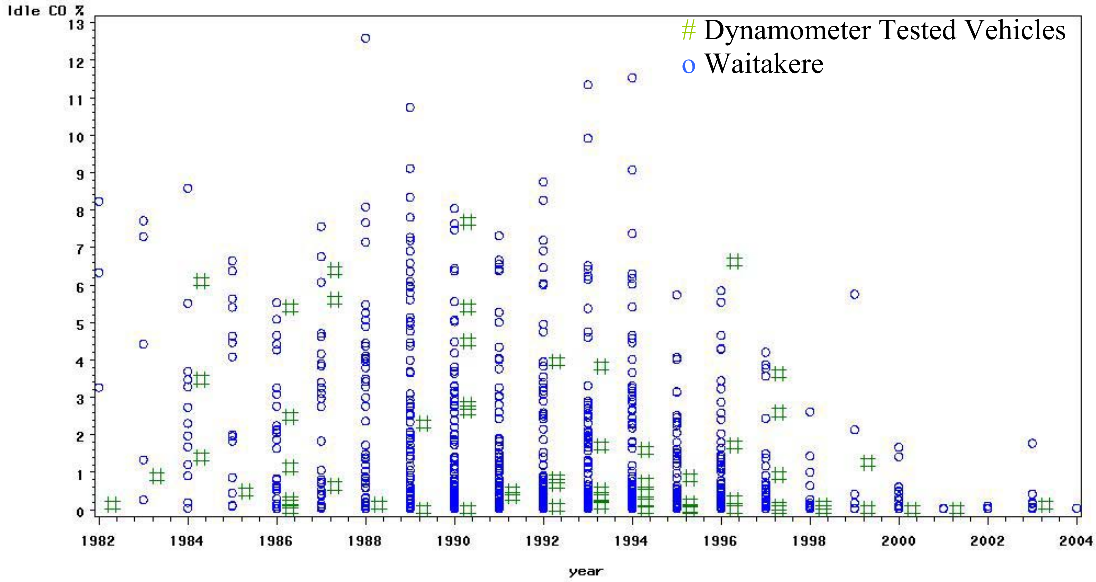

Figure 19: Comparison of (Natural) Idle CO Emissions, by YoM, for the Pilot's 61-Vehicle Variant Dynamometer-Tested Sample and an Early 1430-Vehicle Waitakere City Council Idle Simple Test Sample.

5.2.2. Data Quality

Data quality checks found some vehicles for which the IM240 CO emission result was close to or over the maximum scale of the CO emission instrument used at the time (an additional, higher-scale, CO analyser was introduced part-way through the test programme for this reason). Analysis using correlations with other emissions data suggested the results for three vehicles were not of correct order and the IM240 CO results for these three vehicles were adjusted 20% high in line with derived emissions correlations.

No other dynamometer test data was adjusted other than by the respective tests' standard methods.

5.2.3. Comparison of Results

Figure 20 provides comparison of the IM240 CO result with the (natural) idle CO result and Figure 21 provides comparison of the IM240 CO result with the fast idle CO result. A strong relationship between these result sets would have provided a consistent 'fog' of data along some line or curve. As shown, there is no such consistency, indicating there is no strong relationship between the transient test result and the (natural) idle test result. For example, an idle simple test result of 3.5% CO could be associated with an IM240 CO result of between 5 g/km and 45 g/km for different vehicles amongst those tested.

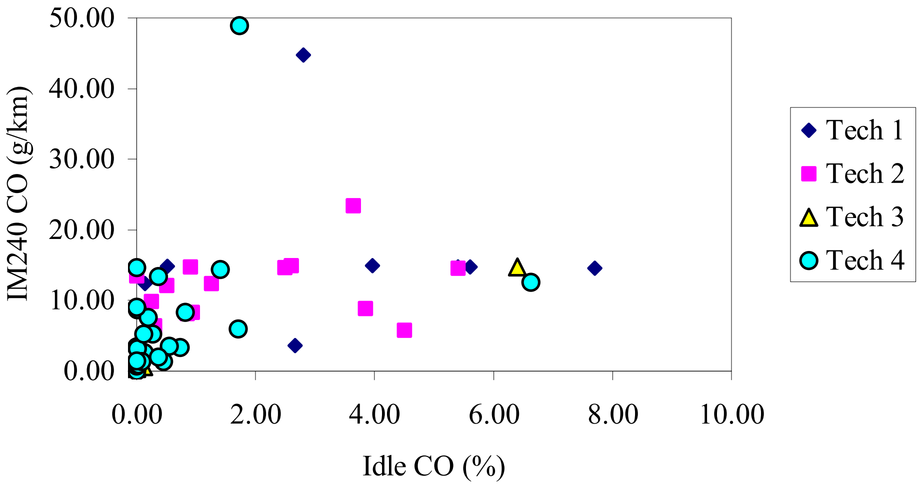

Figure 20: IM240 CO (g/km) Versus (Natural) Idle CO (%) for the 61-Dynamometer Vehicle Sample, by Engine Technology.

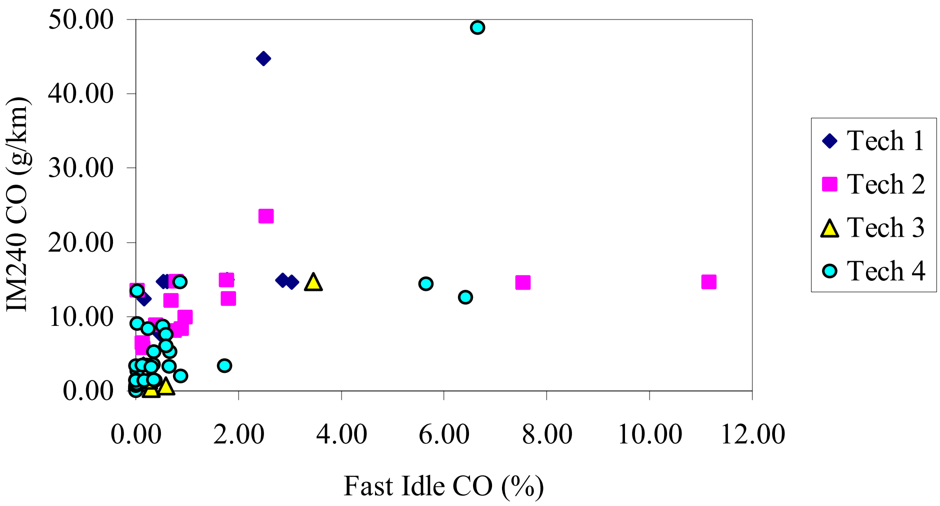

Figure 21: IM240 CO (g/km) Versus Fast Idle CO (%) for the 61-Dynamometer Vehicle Sample, by Engine Technology.

As a strong relationship was found between engine technology and emissions performance (Section 4.2), the results depicted by Figure 20 and Figure 21 have been grouped by engine technology. Even comparison on an engine technology-by-engine technology basis did not improve the relationship between (natural) idle and IM240 results for CO. Note that as vehicle origin was not found to be a consistent, statistically significant, indicator of emissions performance (see Section 4.2), no differentiation between New Zealand-new and Used Japanese Imported vehicles has been made here.

Figure 22 plots the IM240 CO versus fast idle CO results for the Pilot's 61-vehicle variant set (replotting Figure 21) and the SMF and NISE 1[102] data sets for comparison's sake. The results are scattered in all cases. Analysis on an engine technology basis was unable to find a statistically significant difference between the data sets and similar weakness in the relationship between the IM240 CO and fast idle CO result**.** Similar results were found for IM240 HC versus (natural) idle and fast idle HC (comparative plots are provided in Appendix J)

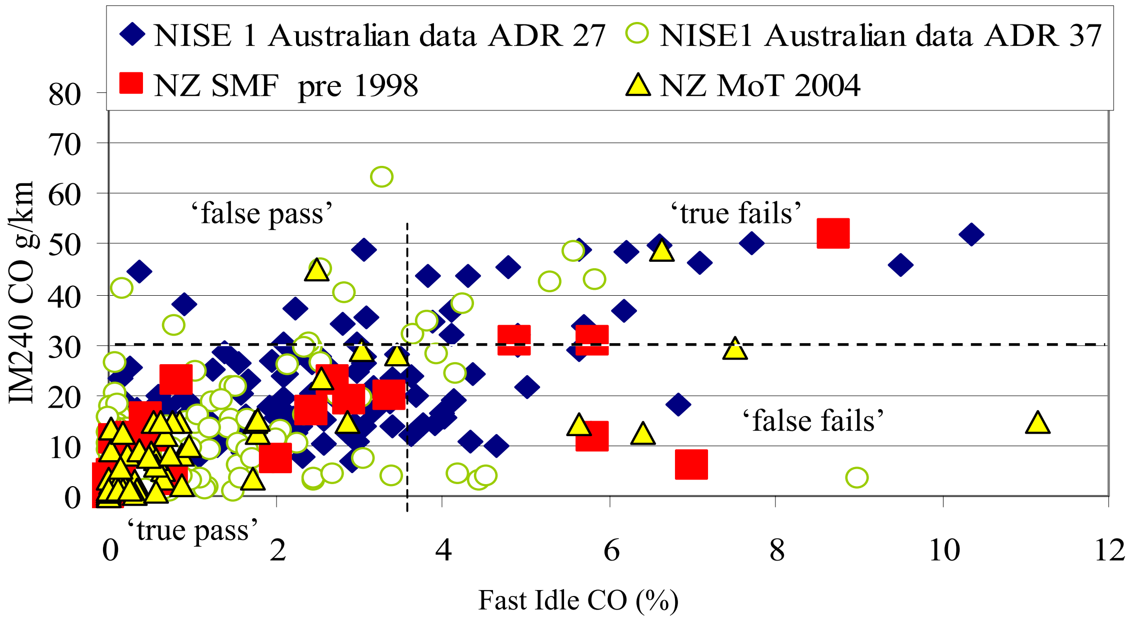

Figure 22: IM240 CO (g/km) Versus Fast Idle CO (%) for the Pilot's 61-Vehicle Variant Set, and NISE 1 and SMF Data Sets.

Also provided in Figure 22 are lines at 3.5% fast idle CO and 30 g/km IM240 CO, being nominal, respective, pass-fail cut-points for demonstration purposes. Those vehicles in the upper left quadrant have failed the IM240 test (close approximation to the original certification test in the US) but were not identified by the fast idle result and are therefore 'false pass' vehicles. Using a similar argument, the upper right quadrant are vehicles that are 'true fails', the lower right 'false fails' and the lower left 'true pass' vehicles. At risk, due to the scatter, is the high proportion of vehicles in the false pass and false fail quadrants. The latter group is likely to be of more concern, as these vehicles might be sent for repair based on the results from idle simple testing when in fact they are unlikely to be high on-road emitters. The number of false fails can be decreased by moving the fast idle cut-point to the right, but this increases the number of false passes, making the régime less effective.

[102] Note the NISE 1 data set is made up of Technology 1 (ADR 27) and Technology 4 (ADR 37) vehicles only.

Note that the number or proportion of false fails and false passes cannot be determined until pass-fail cut-points are determined for the idle simple test, a test is designated the representative test for indicating on-road emissions performance and a pass-fail cut-point is provided for that test. It is beyond the scope of this Pilot to offer suggestions for these. Also, adding complexity to the issue, the diversity of the make-up of the New Zealand fleet would make it extremely difficult to identify an appropriate, representative, on-road emissions performance test that would be accepted by the industry (vehicles being designed to meet different tests and some not designed to meet a test at all).

Instead, the statistical coefficient of determination (R^2) of the relationship between the results from idle simple testing on the one hand and the results from testing to a drive cycle on the other has been provided as an indication of the statistical significance of that relationship. Statistical R^2 values for various emissions data set comparisons, by engine technology, are provided in Table 8.[103] Data for Technology 1 and 2 and Technology 3 and 4 have been combined to lessen the potential effect that data distribution can play. This comparison also includes data from the SMF programme. As the low R^2 values — the majority in the range 0.1 to 0.6 — indicate, there was a poor relationship between all idle simple test results and the various indicators of on-road emissions performance, a positive slope to the relationship in all cases indicating at least some trend of higher simple test result with higher test cycle result. Similar analysis carried out on the NISE 1 data set for IM240 results provided R^2 values between 0.25 and 0.35, very similar to those shown here for the Pilot's results.

		Non-Catalyst-Equipped Vehicles (Technology 1 and 2) (Natural)		Catalyst-Equipped Vehicles (Technology 3 and 4) (Natural)	
	Specie	Idle	Fast Idle	Idle	Fast Idle
IM240	CO	0.21	0.18	0.14	0.57
	HC	0.13	0.22	0.21	0.47
CBDC	CO	0.37	0.14	0.64	0.78
	HC	0.11	0.11	0.3	0.54

Table 8: Coefficient of Determination (R^2) for Emissions Results from Detailed Dynamometer Testing Compared with Idle Simple Testing for the Combined Pilot (2004) and the SMF (1996) Data Sets.

The relationship exhibited between (natural) idle and fast idle CO and HC and drive cycle NOx was also tested and found particularly poor, as shown by R^2 values of less than 0.3. This is as predicted from fundamentals, there being little connection between NOx and (natural) idle or fast idle CO and HC.

Note at R^2 values of around 0.5, beneath which most of the comparative relationships lie, the relationship is such that for every high-emitter identified, two vehicles will be

[103] Note R^2 values have been calculated using SAS and have been tested and adjusted where the distribution of data caused falsely high R^2 values to be determined (say by a single outlying data point). Note also that this comparison of data was not forced through zero.

mis-identified. The risk, it is suggested, is that unless idle simple 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 idle simple testing may be challenged.

5.3. Conclusions

There is a poor relationship between an individual vehicle's on-road emissions, as indicated by various dynamometer drive cycle tests, and that vehicle's results from idle simple testing.

6. Characterising On-Road Emissions Performance of the Petrol Fleet.

This section describes analysis of the data collected in the Pilot to characterise the expected on-road emissions performance of the petrol fleet and the results of this analysis. This analysis was additional to the Pilot's contractual requirements, but it was anticipated that the results would be valuable in terms of understanding the on-road emissions performance of the fleet and in appraising the various methods of predicting it.

Since loaded dynamometer testing allows meaningful NOx results to be measured, emissions not only of CO and HC but also of NOx are considered in this section.

The results from remote sensing are sometimes used to characterise fleet emissions performance, and remote sensing has been considered in this context towards the end of this section.[104]

6.1. Methodology

Multiple variable regression statistical analysis, using SAS, was applied to a set of emissions and visual inspection data from 78 vehicle variants made up from the 61-vehicle variant data set (51 dynamometer-tested vehicles, plus re-tests after ten vehicles had been repaired as part of the Pilot: testing details were provided in Section 5.1), plus data from 17 vehicles from the SMF data set. The analysis carried out considered the emissions results from the IM240 and CBDC drive cycles (these drive cycles and the procedures of testing to them were also described in Section 5.1) and yielded a statistical model for describing and predicting these emissions results by certain vehicle parameters. The IM240 and CBDC drive cycles were chosen to represent quite different on-road conditions, with normal, on-road vehicle operation expected to fall largely between these two, depending on conditions at the time.

The statistical emissions prediction model that was developed was then applied to visual inspection data from a randomly selected sample of 2607 vehicles from 13 centres around New Zealand, providing a first-order analysis of the expected on-road emissions performance of the petrol fleet.

The multiple variable regression modelling used was based on the same philosophy and procedures used in the US Auto-Oil Program,[105] although the luxury of a completely independent parameter matrix such as was developed in the Auto-Oil Program was not developed here.[106] The multiple variable regression method used is a very powerful tool for extracting meaningful, tested, statistically significant results from data that is highly variable and which is the product of many parameters; hence

[104] There was a contractual requirement to consider the results from the Auckland Regional Council (ARC) – NIWA 2004 remote sensing programme, but data from this programme were not available by the Pilot's analysis cut-off date and are therefore not reported on.

[105] Painter, L.J. and Rutherford, J.A., 'Statistical Design and Analysis Methods for the Auto/Oil Air Quality Research Program', SAE paper 920319, Society of Automotive Engineers, 1992, Warrendale.

[106] The US Auto-Oil Program involved the testing of 20 new vehicles and 14 older vehicles on fuels of different specification and led to a formula for specifying fuel, a formula that is used by the vast majority of oil refiners in the US.

it is ideal for the analysis of vehicle emissions data. Of particular relevance, in this case, is the ability to do this with a relatively small sample size.

6.2. Results

6.2.1. Quality of the 78-Vehicle Variant Sample Set

Data from the combined Pilot and SMF data set of 78-vehicle variants was used to identify critical emissions-related relationships. Assessing the relationships involved required a broad spectrum of data rather than data from a completely random selection of vehicles.[107] This broad-spectrum requirement for vehicle selection was the same as the selection criterion for the 51 vehicles subjected to detailed dynamometer testing. Similarly, dynamometer-tested vehicles that were repaired represented real vehicles in the fleet offering further width in the spectrum of data, hence these were also included in the modelling data set. And since the SMF test sample tended to consist of less modern vehicles, 17 of these were used to gain a still wider diversity in the present sample.

It should be noted that the inclusion of repaired vehicles in the 78-vehicle modelling sample set would be expected to bias the sample somewhat toward lower emission vehicles, since the repaired vehicles exhibited slightly lower emissions than the base 51-vehicle data set (when compared on a like-for-like basis). However, since the change in predicted mean emissions was found to be marginal in terms of the methods used for this particular analysis, this effect was not considered to have compromised data or analysis quality. A similar argument exists for sampling from Auckland University staff and not a wider source of sampling.

6.2.2. Emissions Performance of the Pilot Tested Vehicles

Results are first provided here for the 61 vehicle variants tested by dynamometer as part of the Pilot. Vehicle-specific results for the SMF data have been previously reported.[108]

Figure 23 provides a cumulative emissions plot for CO as measured by the IM240, CBDC, SS60, fast idle and (natural) idle tests. For this, vehicles have been ordered from lowest to highest emitters by the test being considered. At the 80% of the fleet mark it can be seen that the worst 20% of the sample was responsible for 75% of the total fleet emissions by the fast idle results (100% less 25%) to 48% of total fleet emissions by the IM240 results. This is similar to the results of the NISE 1 programme, which showed the worst 20% emitters were responsible for 65% of the total fleet emissions by the fast idle results and 50% of the total fleet emissions by the IM240 results, providing confidence in the conclusions drawn from the Pilot, the 'emissions curves' describing relative performance being similar.

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[107] Where data is not well distributed according to any parameter being considered, a single out-lying data point can have substantial influence or 'torque' on the perceived relationship. This situation is less likely where data is well distributed.
[108] Energy and Fuels Research Unit, Department of Mechanical Engineering, 'Vehicle Exhaust Gas Emissions SMF Project 5034', a report prepared for Ministry of the Environment by the University of Auckland.

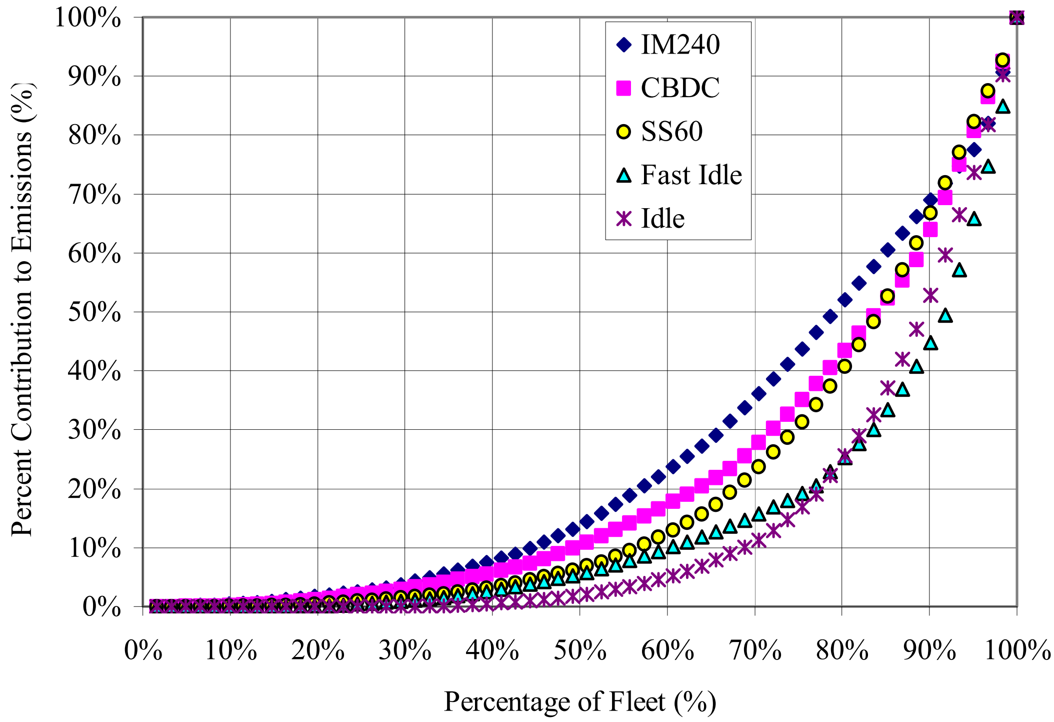

Figure 23: Cumulative CO Emissions for the 61-Vehicle Variant Data Set for Emissions as Measured by Various Methods.

The difference in the emissions result according to the test method illustrates the importance of knowing what test is being referred to in statements about the source of emissions, as the fast idle test over-predicts the contribution of high emitters to total emissions whereas the IM240 result is expected to be a better indicator of real on-road (warm vehicle) emissions performance.

6.2.3. Statistical Analysis of Detailed Dynamometer Test Results

Multiple variable regression analysis was carried out on the combined 78-vehicle variant sample, in log-space (see Section 2), to identify the statistically significant parameters that could describe the variability in IM240 and CBDC emissions results. This was the same process used to consider the data from idle simple testing in Section 4. The parameters so individually tested were YoM, odometer reading (‘odometer’, as defined in Section 4.2.3), engine technology (as defined in Section 4.2.3, noting that ‘engine’ also refers to the exhaust system and any exhaust after-treatment system that may be fitted), NZ-New (as defined in Section 4.2.3) or Used Japanese Import, vehicle under-bonnet appearance, turbocharger fitted or not, showing blue smoke, showing black smoke, engine size, tare weight and engine power. Whether a catalyst-equipped vehicle was imported before October 1996 or not (when leaded fuel was banned from retail sale) was not tested. Few catalyst-equipped vehicles in the sample were imported before October 1996 and therefore the result would not have been significant for this data sample.

Findings of this analysis were:

- Only the parameters YoM, odometer and engine technology were found to be consistently statistically significant (above 90% significance, that is, p-value <0.1) in describing drive cycle emissions results. Vehicle origin and engine size were found to be statistically significant but inconsistent parameters;
- Engine technology was the most significant parameter describing IM240 and CBDC emissions results, with vehicles fitted with catalysts on average exhibiting 70-90% lower drive cycle emissions for CO, HC and NOx than those vehicles without catalysts. There was statistically no significant difference between either Technology 1 and 2 or Technology 3 and 4;
- A factor made from the YoM and odometer parameters, termed the 'secondary performance indicator' (SPI),[109] was found to be the next most statistically significant parameter after engine technology, with vehicles of less recent YoM and higher odometer expected to exhibit higher IM240 and CBDC emissions. Mean predicted emissions increased 20% to two-fold across the full SPI range for Technology 1 vehicles and increased almost 30-fold across the full SPI range for Technology 4 vehicles (although from a much lower starting point), emissions specie dependent;
- SPI was a more significant parameter for Technology 4 vehicles compared with Technology 1 vehicles. That is, Technology 4 vehicles exhibited a faster rate of emissions deterioration than for Technology 1 vehicles. This finding agrees with a key finding from the NISE 1 programme;[110]
- Mean emissions factors for CO, HC and NOx were four- to five-fold higher for the CBDC drive cycle (representing congested driving conditions) than for the IM240 drive cycle, demonstrating the substantial difference in emissions that can result from operation in highly transient or congested conditions;
- Fuel consumption was also measured and fuel increased on average 2.5 times for the CBDC drive cycle over the IM240 drive cycle.

Figure 24 and Figure 25 describe the model predicted mean IM240 and CBDC CO emissions factors, respectively, for varying engine technology and SPI. Note whilst there appears a reasonable difference between Technology 1 and 2, the 90% confidence intervals are such that the difference in results between these engine technologies is not significant, as has been mentioned. Plots for HC and NOx are provided in Appendix K.

[109] The term 'SPI' has been used here rather than 'YoM-Odometer factor', say, to emphasis a greater depth for this factor than just YoM and odometer. For example, it is expected YoM or odometer would be coupled with many other variables including design build.
[110] Anyon, P. et al, *Motor Vehicle Pollution in Australia: Report on the National In-Service Vehicle Emissions Study*, Federal Office of Road Safety, Canberra, May 1996.

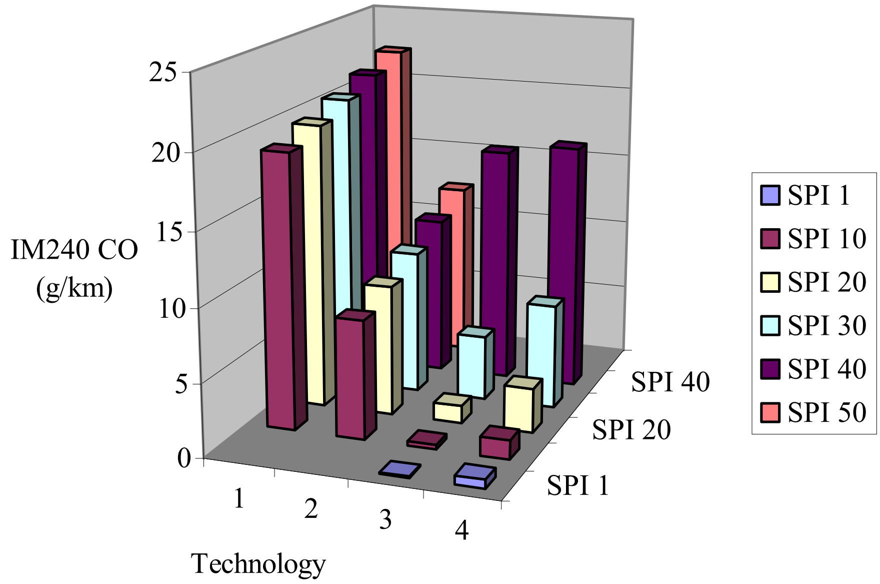

Figure 24: Predicted IM240 CO Emissions Factors Relative to Engine Technology and SPI.

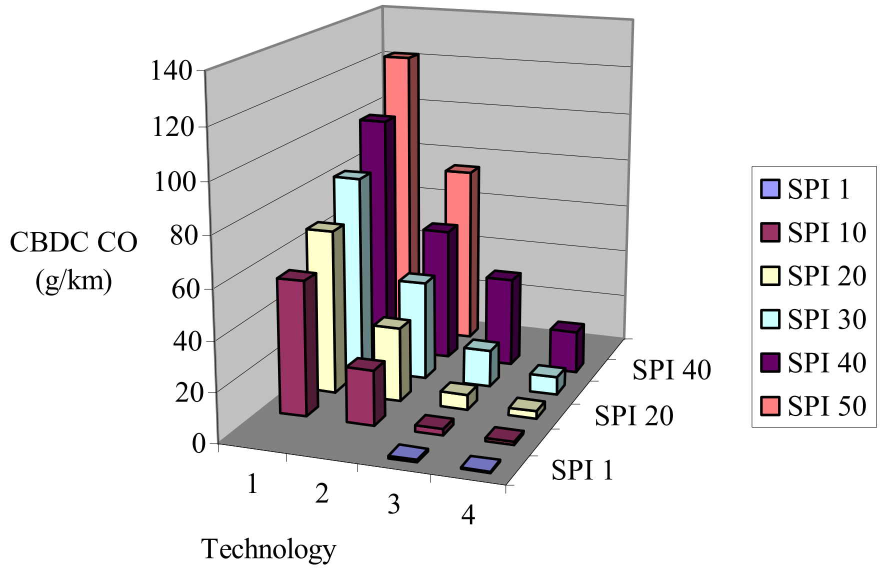

Figure 25: Predicted CBDC CO Emissions Factors Versus Engine Technology and SPI.

There are similarities between these findings and those findings from analysis of the idle simple test data. However, it is important these findings are considered separately, as drive cycle emissions are technically quite different to idle simple test emissions.[111]

[111] Drive cycle emissions include transients in engine load which tend to give rise to higher emissions than steady engine operation.

The statistical model that was developed for predicting drive cycle emissions took the form (in the case of IM240 HC):

$$Ln(IM240_{HC}) = (a_1, a_2, a_3 \text{ or } a_4) \times SPI + (c_1, c_2, c_3 \text{ or } c_4) \quad \text{- - - - - - - -} \quad (1)$$

Where:

SPI = (odometer reading (km)/10,000)+(2004-YoM),
a_1 to a_4 are determined by the engine technology categories 1 to 4, and
c_1 to c_4 are determined by the engine technology categories 1 to 4.

The derived coefficients of the statistical emissions prediction model for the emission species CO, HC and NOx are provided in Table 9.

Table 9: Derived Model Coefficients for Drive Cycle Emissions.

Predicted Emission	Coefficients as a Function of Engine Technology and SPI				Coefficients as a function of Engine Technology			
	a_1	a_2	a_3	a_4	c_1	c_2	c_3	c_4
IM240 CO	0.004	0.01	0.13	0.08	2.9	2	-2.4	-0.6
IM240 HC	0.01	0.03	0.09	0.07	0.7	-0.5	-3.8	-2.9
IM240 NOx	0.01	-0.01	0.07	0.9	0.1	1	-3.1	-3.5
CBDC CO	0.02	0.03	0.09	0.11	3.8	2.8	0	-0.06
CBDC HC	0.01	0.03	0.05	0.09	1.8	0.9	-0.9	-2
CBDC NOx	0.01	-0.01	0.02	0.1	0.2	1.3	-0.6	-3

The statistical emissions prediction model exhibited substantially higher R^2 values for predicting drive cycle emission factors than did predicting the same from the results of idle simple testing. For example, the prediction of IM240 HC by the model exhibited an R^2 of 0.76, more than twice that for the prediction of IM240 HC from idle simple test results. Following from this, it is expected that modelling using physical vehicle attributes as input parameters will provide a more meaningful assessment of mean on-road fleet emissions than derivation of the same from the results of idle simple testing.

A similar model was developed using a NISE 1 data set of 544 vehicles and derived comparable coefficients. Further, the Pilot's model predicted the NISE 1 mean IM240 HC for Technology 1 vehicles within 16% and mean IM240 CO for Technology 1 vehicles within 20%. This is considered a close match.

These findings support the philosophy underpinning the MoT's Vehicle Fleet Emissions Model, a model that predicts mean fleet emissions by assigning different emission factors to vehicles based on YoM, country of origin (used to estimate emissions build performance) and an estimated engine technology make-up for the fleet.

6.2.4. Application of the Statistical Emissions Prediction Model

First-order prediction of fleet emissions was carried out by applying the statistical emissions prediction model to data from visual inspections carried out at 13 sites around New Zealand (visual inspection work is described in Section 4.2.7). Emissions factors were calculated for each engine technology then weighted according to the relative proportion of each engine technology and expected mean annual vehicle kilometres travelled (VKT).

Annual VKT was based on odometer readings[112] provided by LANDATA for random samples of 5000 vehicles, each from 'New Zealand' and the Local Authority areas of Christchurch and Waitakere. This data was screened to remove non-sensible data, including removing data for vehicles exhibiting less than 100 km per six months and greater than 30,000 km per six months, resulting in sample sizes of around 2000 vehicles for each sample. The results for New Zealand, Christchurch City and Waitakere City are provided in Figure 26 and show reasonable consistency. Average annual VKT is around 8,000km for 1980 YoM vehicles and rises almost linearly to a peak at 14,000 km for 1995 YoM vehicles at which average VKT begins to decrease slightly.

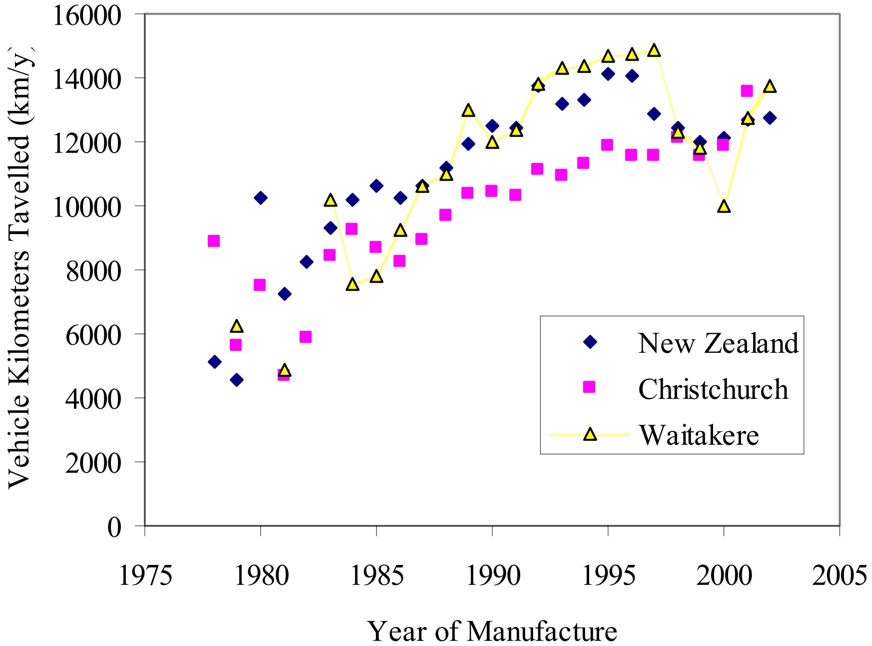

Figure 26: VKT by YoM as Estimated from LANDATA Odometer Data for New Zealand, Christchurch and Waitakere.

Figure 27 and Figure 28 plot the results of the first-order analysis predicting mean IM240 and CBDC CO emissions for the various sites considered, taking fleet engine technology make-up and VKT into consideration. The predicted mean IM240 CO ranged from 5.5g/km to 11 g/km, depending upon site, and the predicted mean CBDC CO ranged from 18 g/km to 38 g/km, with the CBDC results being almost a simple three- to four-fold scale-up of the IM240 results, such is the similarity in the plotted curves. The upper and lower 90% confidence intervals are also provided in Figure 27

[112] Namely the odometer readings recorded at the time of safety inspection for the two most recent years.

and Figure 28, based on the assumption that the VKT and engine technology make-up of the fleet are known. These indicate that although mean vehicle emissions were found two-fold higher for some areas compared to others, for the same drive cycle (that is, for similar driving conditions), the overlap at the 90% confidence interval means this variation is not statistically significant. Note that the relatively wide confidence limits are more a function of the high variability in data rather than of sample size.

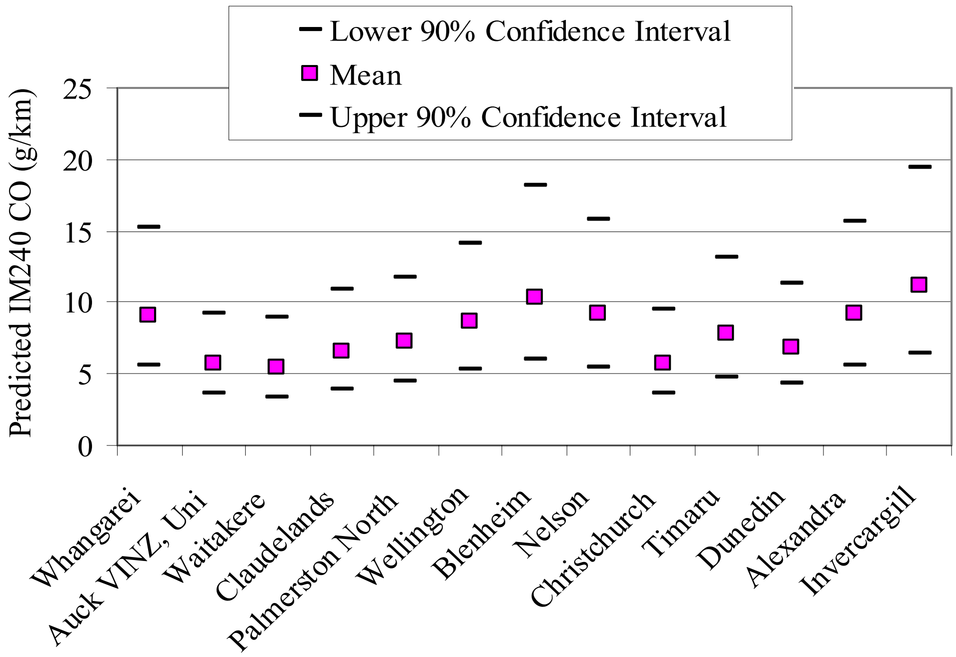

Figure 27: Mean IM240 CO Emissions as Predicted by Applying the Statistical Emissions Prediction Model to the Visual Inspection Data Set

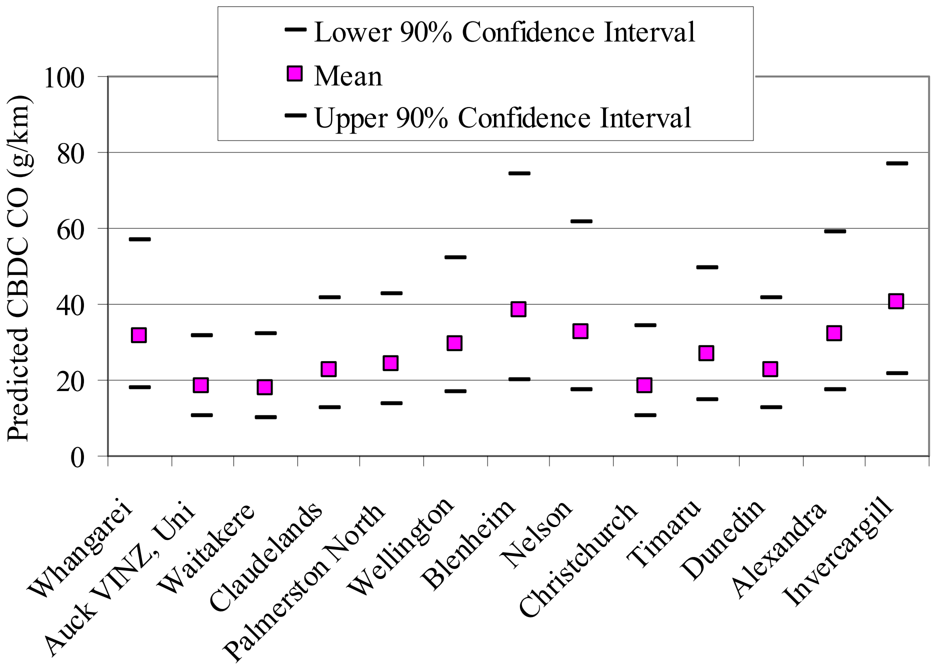

Figure 28: Mean CBDC CO Emissions as Predicted by Applying the Statistical Emissions Prediction Model to the Visual Inspection Data Set

The location-by-location variability was found to be predominantly due to the different engine technology make-up of the fleet at the various locations, SPI being a less variable parameter. This is further illustrated in Figure 29, which provides the proportion of non-catalyst-equipped vehicles at each site (diamonds, lower points) and their predicted contribution to total vehicle emissions (circles, upper points, based on the predicted mean IM240 result), the two sets of points trending similarly. On average, 40% of the Pilot sample were not fitted with catalysts and these vehicles are predicted to contribute 80% of the on-road emissions from the fleet. A similar order is expected for the New Zealand fleet.

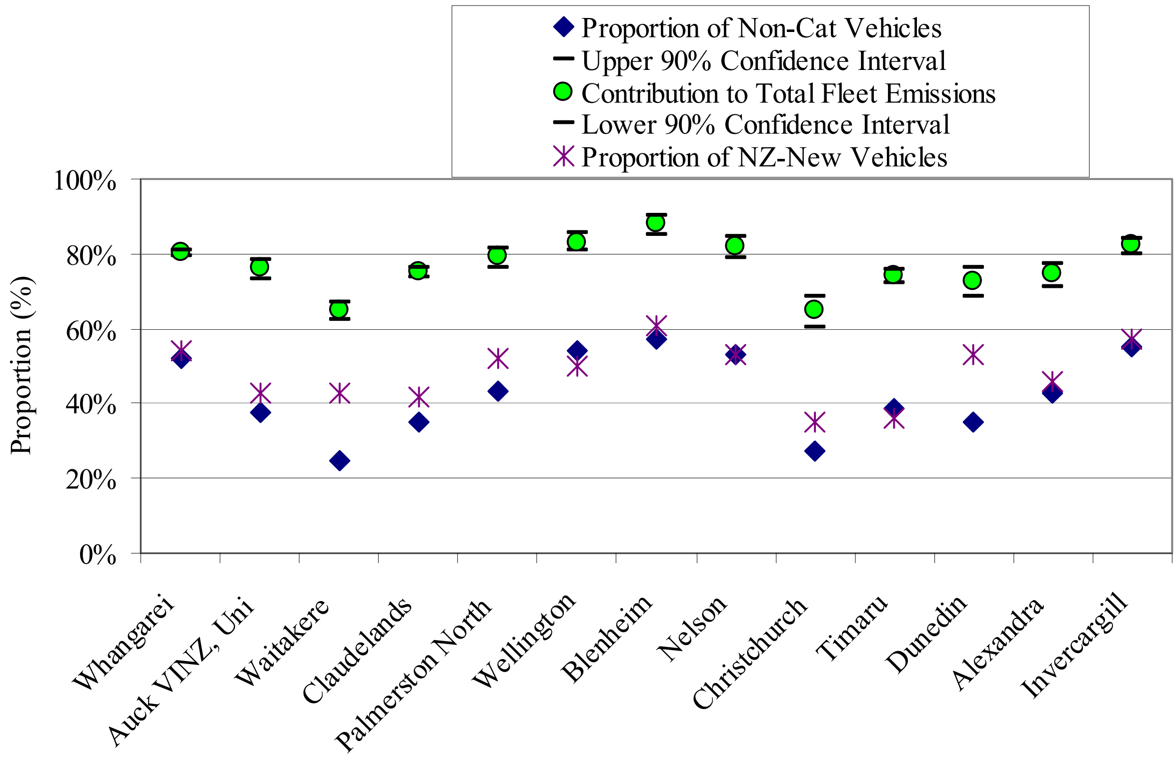

Figure 29: Proportion of Non-Catalyst-Equipped Vehicles at Each Site, Their Predicted Contribution to Fleet Emissions Based on their IM240 CO Result and the Proportion of NZ-New Vehicles in the Fleet.

Also provided in Figure 29 is the proportion of NZ-New vehicles which coarsely trends with the proportion of non-catalyst-equipped vehicles, a function of the tendency of NZ-New vehicles to be less likely to be fitted with catalysts. The differences between these two curves further illustrate that the NZ-New:Used Japanese Import ratio is a poor method of describing expected fleet emissions, as found in the earlier statistical analysis.

Analysis for HC and NOx exhibited similar trends.

Figures 27, 28 and 29 provide a good illustration of two significant issues involved in modelling vehicle emissions: the fleet's engine technology make-up is required to be known (on a local basis, if modelling local environmental impacts); and there can be significant differences in emission rates depending upon the driving conditions.

This further supports the use of modelling to predict mean on-road vehicle emissions, particularly for the likes of environmental capacity analysis for cities, where hour-to-hour and place-to-place driving and engine conditions can have substantial influence on resulting emissions from the fleet. Emissions results from such modelling certainly seem likely to provide a better understanding of fleet emissions than do ‘snapshot’ results from simple emissions testing of vehicles. It is thus recommended the MoT continue their efforts to develop an appropriate vehicle emissions model for use as a policy development and environmental capacity analysis tool. Due to the intricacies involved it is also recommended this work be carried out by those expert in this area.

Business-as-usual fleet turnover is expected to increase the proportion of catalyst-equipped vehicles substantially and hence, over time, mean fleet emissions are expected to decrease markedly. Further, it would naturally be expected that total emissions from petrol vehicles in a given area would decrease over time, even considering business-as-usual increases in traffic volume, except where levels of congestion increase substantially.[113]

6.2.5. Remote Sensing

Remote sensing is 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.

The advantage of remote sensing is that a considerable number of vehicles can be screened in a relatively short time; for example, the Auckland Regional Council/NIWA’s (ARC/NIWA) 2004 remote sensing programme screened up to 7000 vehicles per day. There are drawbacks with remote sensing: since, for example, the emissions result is a single snapshot of a vehicle’s emissions performance under one, partially unknown, mode of operation, it can only be a coarse assessment of a specific vehicle’s emissions performance.

An indication of the efficacy of remote sensing as an emissions performance indicator was obtained by considering the instantaneous exhaust emissions readings from a 4-gas analyser from a vehicle being driven through a known drive cycle. The 4-gas analyser, of the type normally used in idle simple testing, would be expected to measure exhaust emissions in a similar manner to remote sensing, although there is potential for the 4-gas analyser to filter off the peaks and troughs in emissions response.

Figure 30 depicts the results of such testing, which subjected a reasonably high-emitting Technology 2 (non-catalyst) vehicle to the IM240 test cycle, from hot starts, and took two successive CO result sets. As shown, at a coarse level there is reasonable consistency in the measured CO result across the drive cycle, despite the transients involved, and had remote sensing captured this vehicle the result would have been

[113] Based on emissions modelling detailed in Moncrieff and Campbell, ‘Procedures for Evaluation of Environmental Impacts’, 2005, internal report for Land Transport New Zealand.

expected to fall somewhere between roughly 2.5% CO and 4.0% CO,[114] indicating the vehicle had reasonably high emissions. At a more detailed level, this variation in CO emission is up to 30%, even during the periods of comparatively steady-speed vehicle operation, suggesting this assessment tool is relatively coarse.

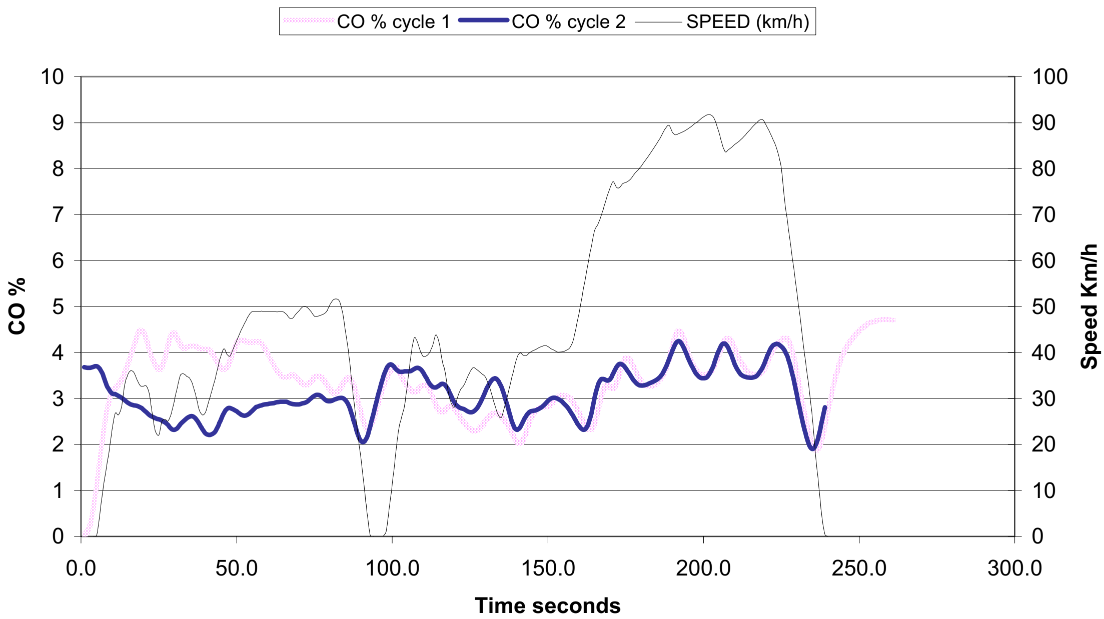

Figure 30: CO Emissions Measured Over the IM240 Cycle for Vehicle UZ9537 (1997 Year of Manufacture, Technology 2) from a Hot Start.

Figure 31 depicts the results for a Technology 4 (catalyst-equipped) vehicle of typical performance over three successive IM240 drive cycles with the initial cycle starting the engine from cold. As shown, there is a steady decrease in emissions as the engine and catalyst system warms, it taking something like 150 seconds for low emissions performance to be achieved (expected to correspond with the point when the catalyst 'lit up'). At a coarse level, once low emission operation had been attained, the emissions stayed relatively low and were the vehicle fully warmed when captured, remote sensing would be expected to indicate it as a low emitter. At a detailed level, even reasonably mild transients in load — for example, those at the 200-second mark — can increase relative emissions two-fold when emission levels are low, and there is some inconsistency in the response even for a relatively controlled test cycle.

[114] Note the period immediately after the 50-second mark is particularly pertinent as this driving condition is similar to that for vehicles passing through a remote sensing site.

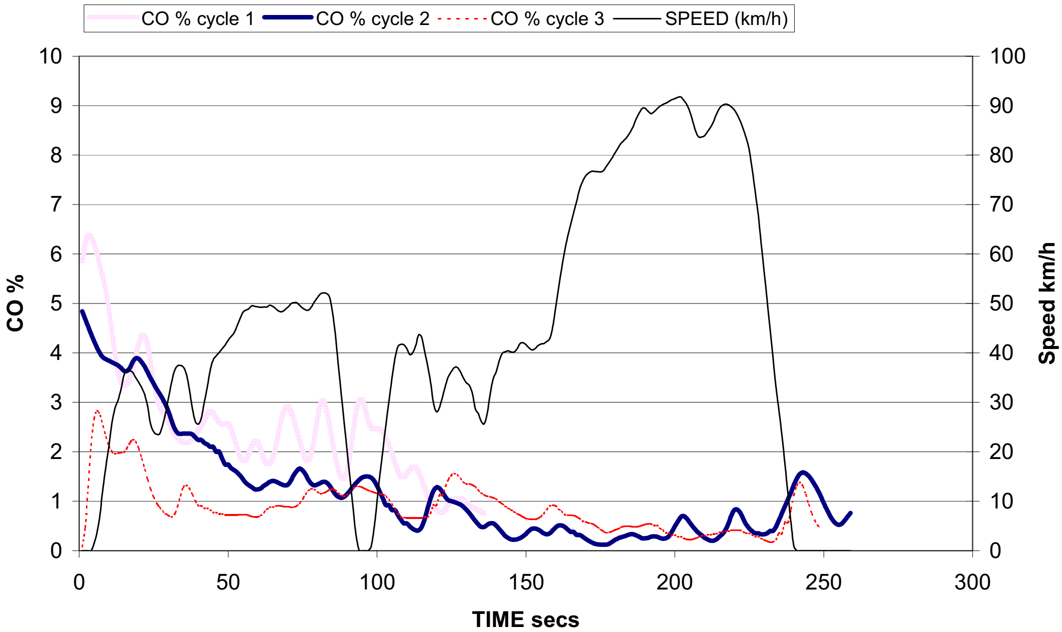

Figure 31: CO Emissions Measured Over the IM240 Cycle for Vehicle SJ1151 (1994 Year of Manufacture, Technology 4), First Cycle Cold Start

There are, what's more, potential errors involved in remote sensing associated with emissions measurement (comparison being made between the air before a vehicle passes and the air afterwards) and the manner in which the emissions results are calculated (based on a theoretical combustion equation from which some variance would be expected in reality).

The responses illustrated in Figure 30 and Figure 31 imply remote sensing is more of a coarse gauge for assessing a specific vehicle's emissions performance and hence would require the support of another screen or test if used to determine whether a vehicle needed work for emissions reduction purposes. Such a supporting screen or test could be idle simple testing (with careful use), loaded dynamometer testing or interrogation of the onboard diagnostics ('OBD'[115]) system. It would certainly be more practical to use these screens or tests for diagnosis and post-repair assessment than remote sensing.

The variability in response from remote sensing also indicates great care is required when comparing data from one site to another. There is a case for the use of control vehicles, of known in-service emissions production, the better to relate remote sensing data to true, on-road emissions performance. Care is also required to consider the limitations of the data from remote sensing if this data is used to approximate on-road vehicle emissions for emissions inventory purposes. The methodology described earlier in this section, applying known physical attributes of vehicles to an emissions

[115] 'OBD' here refers to OBD and OBD-2 (the US versions), EOBD (the European version) and JOBD (the Japanese version). There are differences in their respective functions that would need to be considered in developing policy based on the use of OBD.

prediction model, has the potential to provide a better assessment of the on-road emissions performance of a fleet of vehicles.

This is not to deny the main benefit of remote sensing, and that is its ability to screen a large number of vehicles in a relatively short time, permitting the identification of potential high-emitters, in order, say, to refer them for screening or testing using a more result-assured diagnostic tool. This high-volume screening will become more important over time as the population of higher emitting vehicles substantially decreases with business-as-usual fleet turnover, and for this reason remote sensing may be a more appropriate first screen for modern vehicles than idle simple testing.

Further, although there is considerable potential for variability in the results of remote sensing when applied to a single vehicle, it can return reasonably tight confidence intervals when used to gather high volumes of data. Remote sensing thus has the potential to provide a good current performance measure of fleet emissions, albeit expected to be poorly related to on-road emissions performance, which could then be used as a comparison for results from remote sensing carried out in exactly the same manner in the future.

6.3. Conclusions

This section considered the use of emissions results from testing vehicles to various drive cycles to predict mean fleet emissions. Other options to predict fleet emissions were also considered. The conclusions drawn from this work were:

- The most statistically significant vehicle parameter describing expected on-road emissions performance, as represented by the results from testing vehicles to the IM240 and CBDC drive cycles, is engine technology.[116] Catalyst-equipped vehicles are expected to exhibit, on average, 70-90% lower on-road emissions than non-catalyst-equipped vehicles, emission-specie dependent;
- A factor made from the YoM and odometer parameters, termed the 'secondary performance indicator' (SPI), was found to be the next most statistically significant parameter after engine technology, with vehicles of less recent YoM and higher odometer expected to exhibit higher IM240 and CBDC emissions. Mean predicted emissions increased 20% to two-fold across the full SPI range for Technology 1 vehicles and increased almost 30-fold across the full SPI range for Technology 4 vehicles (although from a much lower starting point);
- A significant parameter describing on-road emissions performance is driving conditions. A four- to five-fold increase in on-road emissions, on a per-kilometre basis, is expected for highly-congested road conditions, compared to more normal road conditions;
- A two- to three-fold increase in fuel consumption is also expected for highly-congested road conditions, compared to more normal road conditions;

[116] Note 'engine technology' refers also to the exhaust system and any exhaust after-treatment system that may be fitted, not just the 'under-bonnet' section of an engine.

- Predicting drive cycle emissions performance using a statistical emissions prediction model and applying it to certain known physical attributes of vehicles in a fleet can provide a better assessment of the on-road emissions performance of the fleet than using results from idle simple testing;
- Through such modelling, and using data from the visual inspection of vehicles, it is expected to the order of 40% of the active petrol fleet are non-catalyst-equipped vehicles and they are responsible for to the order of 80% of total on-road fleet emissions. Location-to-location variations are expected, predominantly due to differences in the engine technology make-up of the local fleet. Ranges found in the Pilot sample were from 25% of an area's petrol fleet being non-catalyst and predicted to contribute to 65% of the total area's petrol fleet emissions, to 55% of the area's petrol fleet being non-catalyst and predicted to contribute to 90% of the total area's petrol fleet emissions;
- Business-as-usual fleet turnover is expected to cause a substantial decrease in the proportion of non-catalyst-equipped vehicles in the fleet, bringing about a substantial reduction in average vehicle on-road emissions;
- Remote sensing is believed to be a useful tool as a coarse screen for identifying potentially high-emitting vehicles and would best be supported by other emissions screening or test options, such are the potential inaccuracies involved in the emissions result.

6.4. Recommendations for further work

It is recommended the Ministry of Transport expertly develops its Vehicle Fleet Emissions Model (VFEM), augmenting the design to take into consideration the findings of this Pilot. A component of this work is the further visual inspection of vehicles at other locations around New Zealand. Additional development of the VFEM may include further detailed dynamometer testing of selected vehicle types, in an effort to describe better the variability found in emissions results from petrol vehicles, and it is recommended this be considered in a VFEM development scoping study.

It is recommended remote sensing be investigated as a coarse screen for detecting potentially high-emitting vehicles, this investigation also to consider what emissions screening or test options should be used to support remote sensing.

It is recommended data from the ARC/NIWA 2003 and 2004 remote sensing programmes be analysed using multiple variable regression analysis to understand emissions-related relationships further.

7. 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 four main components:

1. Detailed dynamometer testing of ten vehicles before and after their repair and analysis of the results;
2. Analysing the effect of various fleet repair scenarios;
3. Evaluating repair effectiveness, based on the results of idle simple testing;
4. Obtaining information from the industry regarding repair of engines.

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

7.1. Detailed Dynamometer Testing of Repair Vehicles

7.1.1. Methodology

The methodology employed in the detailed dynamometer testing of vehicles has been provided in Section 5.1.

Eleven vehicles were selected for repair from the original 51 vehicles tested by dynamometer as part of the Pilot. These vehicles were selected for a variety of reasons:

- One vehicle had a catalyst that could be easily removed and put back on. Putting the catalyst back on was considered a repair;
- Owners of three vehicles elected to carry out repair work on their vehicles themselves. Post-work idle simple test results indicated reasonable differences were achieved in two cases and these two vehicles were re-tested;
- Eight other vehicles, exhibiting abnormal idle simple test results, were selected for repair at repair workshops. For one, idle simple testing after repair indicated there was no change in emissions performance and this vehicle was not re-tested (and therefore taken out of the selection of vehicles dynamometer tested).

This resulted in the selection of one Technology 1[117] vehicle, four Technology 2 vehicles and five Technology 4 vehicles.

The majority of repairs were carried out by a repairer who had specialised in fuel metering and spark ignition-related repairs for both older and more modern engine technologies. For some vehicles, intermediary repairs were also carried out by the vehicle owners. One vehicle was also sent to the New Zealand agent for that vehicle. Detailed dynamometer re-tests were only carried out where the results from idle simple testing indicated a change in performance had been achieved.

[117] Technology types are defined in the glossary and in Section 4.2.3.

7.1.2. Suitability of Repair Vehicle Sample

The 51-vehicle sample from which vehicles were selected for repair was not a randomly selected sample, since it was preferred to test a broad spectrum of vehicles (as discussed in Section 5.1). However, there was no reason to suggest the pre-repair maintenance carried out on these vehicles was any different to that found across New Zealand, with practices ranging from occasional oil changes only to regular, full servicing. Although only a limited number of detailed dynamometer tests could be carried out and this restricted the number of re-tests which could be performed, the sample of repair experiences is believed to provide a reasonable understanding of the range of issues involved and the expected range of emissions and fuel economy responses.

7.1.3. Results

All repairs carried out by the specialist repairer involved sensors or related connections. Repair of these eight repair vehicles involved the replacement of four oxygen sensors, two inlet manifold pressure sensors (plus the adjustment of the electrical plug fitting on another), two temperature sensors and one voltage regulator. For one vehicle, the throttle body and spark plugs were also replaced and the injectors serviced. Apart from the last, and the replacement of one of the oxygen sensors, the diagnosis and repairs carried out were of a specialist nature; that is, they required specialist knowledge and equipment. It is possible the faults found would not have been identified at a more generalised repair workshop and that the cost of repair would have been higher at a more generalised repair workshop due to the greater time needed to diagnose faults. Hence the repair results are believed to represent the upper bounds of quality of work and value of repair.

Results from testing repair vehicles are given in Table 10 and as shown there was considerable variability in the benefit realised through repair on an individual vehicle basis. For example, the change in NOx emissions ranged from a reduction to below the analyser significance to a 17-fold increase (although in this case, the original NOx was very low to begin with). There was also large variation in the change in emissions according to which drive cycle was being considered. The variability in emissions repair benefit could in part be explained in terms of the difference between results that were highly variable in themselves. Still greater variability would be expected had repair been carried out by mechanics of varying competency.

Table 10: Average Benefit and Range of Benefit in Emissions and Fuel Consumption Realised through Repair of the Ten Dynamometer Repair Vehicles.

Parameter	Benefit Realised Through Repair		
	Repair Fleet Average Benefit	Specific Vehicle Greatest Benefit	Specific Vehicle Least Benefit
ACCORDING TO CBDC			
CO	39%	93%	-30%
HC	33%	74%	-34%
NOx	-10%	100%	-1700%
Fuel Consumption	3%	18%	-10%
According to IM240			
CO	7%	84%	-58%
HC	42%	87%	1%
NOx	19%	100%	-17%
Fuel Consumption	1.6%	8%	-6%
Average CBDC/IM240			
CO	23%		
HC	38%		
NOx	5%		
Fuel Consumption	2.4%		

On average, fuel consumption reduced 2%, based on the weighed average of the IM240 and CBDC results. Although this average is derived from a small vehicle sample, and therefore cannot be taken as an accurate assessment of the New Zealand fleet, it happens to be very similar to the 1-2% improvement found in the NISE 1 study which involved the repair of almost 600 petrol vehicles. Of believed equal importance is the large range in fuel consumption responses when considered on an individual vehicle basis, the change in fuel consumption for these vehicles ranged from a reduction of 18% to an increase of 10%. There was no relationship found between the change in idle simple test results and the change in fuel consumption realised, that is, repair for idle simple test emissions improvement does not necessarily return an improvement in fuel economy.

The average 2% improvement in fuel economy correlates to an annual saving in the cost of fuel to the order of $35 for the typical motorist,[118] offering an insignificant return on the cost of repair. The best fuel economy benefit found, at 13% for the average of the CBDC and IM240 results (the 18% improvement provided above being for the CBDC test cycle only), correlates with an annual fuel saving of around $300. Compared to the $369 repair cost for this particular vehicle there is potential payback for this one vehicle.

[118] Based on an average annual VKT of 13,000km, an average fuel economy of 10 litres per 100 kilometres and fuel at $1.30 per litre.

The experiences found with the repair of dynamometer-tested vehicles included:

- Refitting the exhaust catalyst to a vehicle decreased idle simple test CO and HC around 80%. (Natural) idle CO reduced from 0.9% to 0.1%. Note that a (natural) idle cut-point of less than 0.9% CO would have been required to identify this vehicle as requiring repair through idle simple testing;
- A Technology 4 used imported vehicle that had recently been imported by the owner was found to have relatively high CO emissions according to results from idle simple testing and dynamometer testing. The owner elected to work on the vehicle himself first and returned lower (natural) idle CO but increased drive cycle emissions and slightly decreased fuel consumption. Specialist repair achieved a significant reduction in CO (83%, based on average of the CBDC and IM240 test cycles), HC (63%) and fuel consumption (13%). The NOx emission increased 8-fold;
- A New Zealand-new Technology 2 vehicle with high (natural) idle CO results was sent to the vehicle's New Zealand agent for a routine service and it was also explained the vehicle had high (natural) idle emissions and for this to be checked. The agent did not have emissions equipment. Post-service (natural) idle CO increased from 2.6% to 3.6%, drive cycle CO increased 18% and fuel consumption increased 3%. The vehicle was sent to a specialist repairer and no improvement could be made. The vehicle could not meet its factory setting for (natural) idle CO which was 1.0 ± 1.0% CO. The Pilot's idle simple test data set was checked for like model vehicles. Two out of the five like models found in this data set were found to have higher than the manufacturer's (natural) idle CO setting;
- A New Zealand-new Technology 4 vehicle found to have elevated (natural) idle CO yet low fast idle CO was given repair work. A lower (natural) idle CO resulted but CBDC drive cycle emissions increased.

The cost of repairs carried out by the specialist or vehicle agent ranged from the simple replacement of a faulty oxygen sensor, at $280, to a combination of simple parts replacement and injector service at $800. The average repair cost was $410. It is interesting to note the cost of the more complicated repairs — that is, those repairs requiring more sophisticated diagnosis — tended to be near the average cost of repair rather than at the upper bounds. The average cost of the adjustments and tune-ups carried out in the NISE 1 programme was AUD$200, which corresponds to around NZ$350 today, exhibiting reasonable agreement.

Note the above repair cost data includes one vehicle for which the catalyst was refitted. A nominal cost of $300 was assigned for this repair based on the cost of an aftermarket, low-end market catalyst. Catalysts are expected to range in cost from around $200 for a low-grade canister up to $3000 for fitting original twin catalysts on a modern vehicle such as a Mercedes. The repair costs also include one vehicle for which a used rather than a new throttle body was fitted. Interviews with the managers of a number of repair workshops established the use of used or reconditioned components to be normal practice outside vehicle agency workshops, where such parts were available and were permitted to be used.[119]

[119] Note: it is not permitted to replace certain safety-related components, including seatbelts and airbags, with used or reconditioned components.

In an emissions régime based on idle simple testing, a post-repair test would also likely be required and this could add a further $60 to the cost of repair.[120] Cost of idle simple testing is discussed more fully in Section 8.

Analysis of results found that identifying moderate to high (on-road) emitters required the interpretation of results from idle simple testing, rather than merely relying upon vehicles to exhibit higher levels than certain pre-determined cut-points. One criterion to look for was a moderate to large difference between the (natural) idle and fast idle CO result. In the majority of cases, only (natural) idle or fast idle CO was needed to detect a moderate to high emitter, and subsequently evaluate the effectiveness of the repairs. The fast idle HC result is also expected to be useful in a small number of cases.

Detailed descriptions and results of repairs and their effects are provided in Appendices L and J, respectively.

The variability in repair benefit shown by the ten dynamometer-tested vehicles makes it difficult to conclude what overall fleet benefit would be realised through repair. Instead analysis was carried out to evaluate various repair scenarios and this is reported in the next section.

7.2. Analysis of Fleet Repair Scenarios

Figure 32 presents the cumulative IM240 CO emissions results for the Pilot's dynamometer-tested vehicles, ordered from lowest to highest emitter, plus the associated fast idle and (natural) idle CO result. If one were to repair the highest 10% of emitters, ideally these would be the highest emitters based on on-road emissions performance. As shown by Figure 32 the expected highest on-road emitters, as given by vehicles with highest IM240 result, do not align with those vehicles with highest (natural) idle or fast idle result. Identifying the highest 10% emitters by the (natural) idle or fast idle result thus provides a compromise in identifying the highest on-road emitters and therefore a compromise in the emissions improvement that could be obtained.

[120] This is an upper cost for idle simple testing, reflecting the likelihood that the engine requires time to warm up. The cost of testing is further discussed in Section 8.

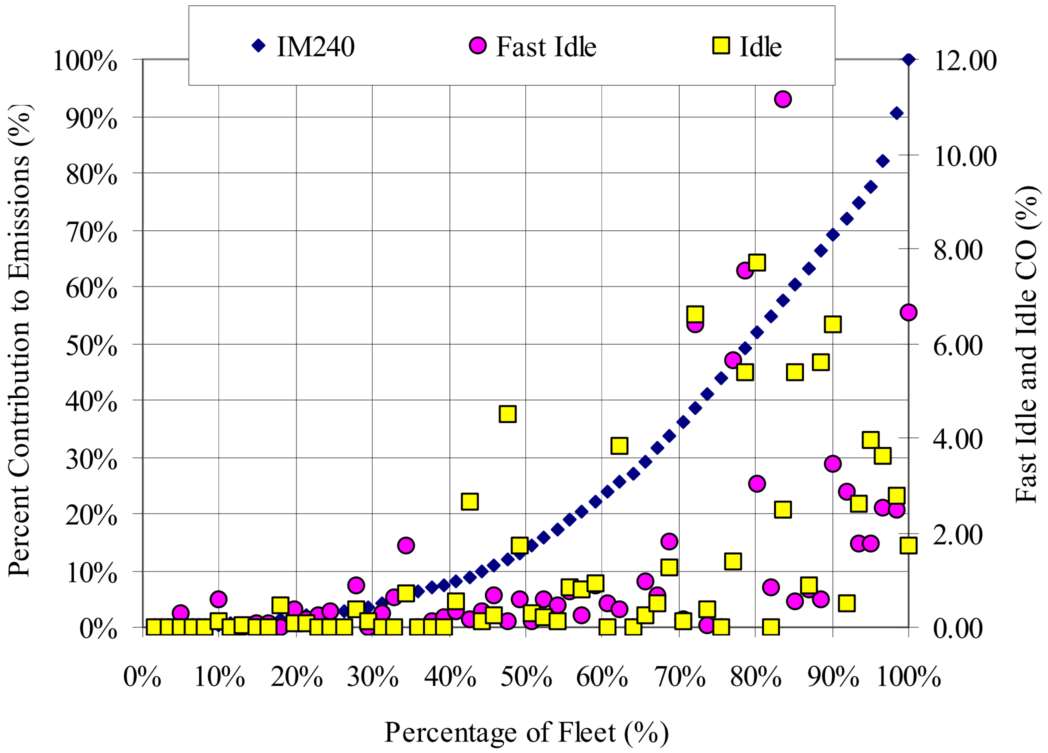

Figure 32: Cumulative IM240 CO Results Ordered from Lowest to Highest Emitter Plotted with Associated (Natural) Idle and Fast Idle CO Emissions for the Project's 61-Vehicle Variant Data Set.

This is further illustrated in Table 11 which provides the results of analysis on three scenarios, detecting the worst 10% emitters by the IM240 CO results, detecting the worst 10% emitters by the (natural) idle CO results and detecting the worst 10% emitters by the fast idle CO results and repairing them to the average on-road emissions performance of the remaining fleet. Detection of the worst 10% emitters by the (natural) idle result managed only a 17% improvement in overall fleet emissions compared to 25% for use of the IM240 results.

Table 11: Results of Emissions Repair Scenarios

Measurement Means to Identify Worst 10% CO Emitters	Emissions Measured by IM240 Test Cycle as a Proportion of Original Total (%)			
	Pre-Repair Fleet Total	Worst 10 % Total CO	Resulting CO for Repaired Worst 10 %	Percentage Reduction in Fleet Emissions (%)
1. IM240	100%	33%	7%	25%
2. (Natural) Idle	100%	25%	8%	17%
3. Fast Idle	100%	25%	8%	16%

Applying the same scenario to the 544-vehicle NISE 1 data set shows a 26% reduction in IM240 CO for high emitter detection by IM240 CO and 14% for high emitter detection by both (natural) idle and fast idle CO. These results and those using the Pilot's 61-vehicle variant data set are comparable.

Note that emphasis was placed on the detection of high emitters by the CO result, as this was expected to be the most likely reason for vehicles failing to meet idle simple test cut-points.

The analysis was extended to include the HC and NOx emissions benefit, as derived by consideration of the IM240 results for the Pilot's 61-vehicle variant data set. The results are provided in Table 12 along with the actual measured IM240 benefit realised through repairing the worst 10% emitters of the 544-vehicle NISE 1 data set (which has been shown to exhibit reasonably similar emissions characteristics to the various Pilot data sets and is of more appropriate size for this analysis). This suggests the scenario's repair to the average of the fleet may over estimate the repair benefit that would be realised in practice. Attempting to conclude an emissions benefit through repair it is suggested repair of the 10% worst emitters, as identified by the (natural) idle or fast idle CO result, would reduce CO and HC emissions somewhere in the order of 10% and reduce NOx much less than this.

Table 12: Modelled Fleet Average Emissions Benefit (Reduction), Based on the IM240 Result, for Repair of 10% Worst Emitters as Identified by (Natural) Idle and Fast Idle CO Plus Comparison to Real Data from the NISE 1 Data Set.

		Emissions Benefit		
Data Set	High Emitter Identifier	IM240 CO g/km	IM240 HC g/km	IM240 NOx g/km
Pilot (Scenario)	(Natural) Idle CO	17%	17%	6%
Pilot (Scenario)	Fast Idle CO	16%	18%	1%
NISE (Real)	(Natural) Idle CO	9%	6%	3%
NISE (Real)	Fast Idle CO	8%	5%	1%

The fleet average benefit to fuel consumption for repair of the 10% worst (natural) idle or fast idle CO emitters was less than 0.5% for both the Pilot and NISE 1 data sets.

The 2% saving in fuel consumption for the ten repair vehicles translates to an overall reduction in fuel consumption to the order of 1% for the original 51-vehicle sample. An overall fuel consumption reduction of 1.5% was found in the NISE 1 programme for tuning all vehicles, and it is felt these two results are in reasonable agreement, taking the differences in the repair scenarios into account.

Note that the NISE 1 programme carried out tuning, maintenance and re-test on all vehicles tested and found reductions in overall emissions of 25% for CO, 16% for HC and 9% for NOx and in fuel consumption of 1.5% based on the FTP75 result, a drive cycle result expected to correlate closely with that of the IM240.[121]

[121] The IM240 test cycle approximates the first 240 seconds of the FTP 75 test cycle.

7.3. Evaluating Repair Effectiveness Based on Idle Simple Test Results

7.3.1. Methodology

Four repair workshops were set up to carry out testing, repair and re-testing work according to the Pilot's idle simple test and reporting procedures (detailed in Appendix C). The selection of repair workshops was based on the perception of their abilities gained through a combination of recommendations from the industry and interviews with the managers of the workshops involved. Access to a suitable emissions analyser was also a prerequisite.

Repair workshops were asked to test and re-test post-repair every vehicle upon which repairs were being carried out where the repair might change the emissions of the vehicle. Although this sampling mechanism was biased towards vehicles whose owners had already elected to have repairs carried out — presumably due to deterioration of the vehicle's on-road performance or similar — it was believed a reasonably representative sample of emission-related repairs could be so derived, given the failure mechanisms involved.

In practice, workshops found it difficult to include the additional testing into their programme and few repair result sets were obtained.

This repair data sample was then screened for quality and appropriateness,[122] so that only data from those vehicles returning abnormal results from the pre-repair idle simple test were used.[123]

7.3.2. Results and Discussion

Of the four repair workshops, only one provided enough quality data to be of use to the Pilot. The low return in data was reportedly due to a variety of factors, including: a lower number of vehicles than expected requiring potentially emissions-related repairs; time constraints in the workshop, which prevented suitable vehicles being tested twice; physical constraints, such as where only one emissions analyser was available, restricting access and, in one case, where a high quality analyser failed twice, each failure taking more than a week to resolve.

The repairer who provided the main repair data was the specialist used for the repair of the dynamometer test vehicles, and thus the set of field repair data includes data for the vehicles that were also dynamometer-tested. Repairs were carried out using new, used and reconditioned components, as the repairer felt appropriate. It was established the use of used and reconditioned components is a typical practice in New Zealand, hence repair costs in this study are believed to be representative of this common practice.

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[122] For example, one vehicle was smoking heavily before repair and underwent a major engine overhaul at a cost of $3800. This was considered an outlying data point, bearing in mind the size of the field repair data set and the expected relative frequency of this type of work. The data from this vehicle was not included.

[123] That is, exhibiting higher than 1.0 % (natural) idle or fast idle, a difference of (natural) idle to fast idle of greater than 1.0% or, if fitted with an oxygen sensor, a lambda less than 0.9 or greater than 1.1.

The specialist repairer provided test, repair and re-test data for 71 vehicles. Data quality screening reduced this to a quality-assured data set of 52 vehicles. The average age of the 52-vehicle sample set was 1988, around 5 years older than the average age of petrol vehicles in the New Zealand fleet. It is believed this is reasonably consistent with older vehicles being more likely to require repair.

Analysis of the outcomes considered the emissions benefit, as measured by the (natural) idle CO result, realised through repair. The (natural) idle CO result was used for this comparison, as it had been shown earlier that of the idle simple test results, this was the most reliable indicator as to whether a vehicle required repair. It is also the result most often the cause of a vehicle not meeting idle simple test emissions cut-points in overseas programmes. Figure 33 compares the after-repair (natural) idle CO with the before-repair (natural) idle CO and shows a scatter of data. Line A-A represents the line where no change in emissions was achieved through repair and, as can be seen, the majority of the data is to the right of this line, indicating an overall improvement in (natural) idle CO emissions performance can be expected through repair. The mean vehicle improvement in (natural) idle CO emission through repair was 2.5% CO, absolute.

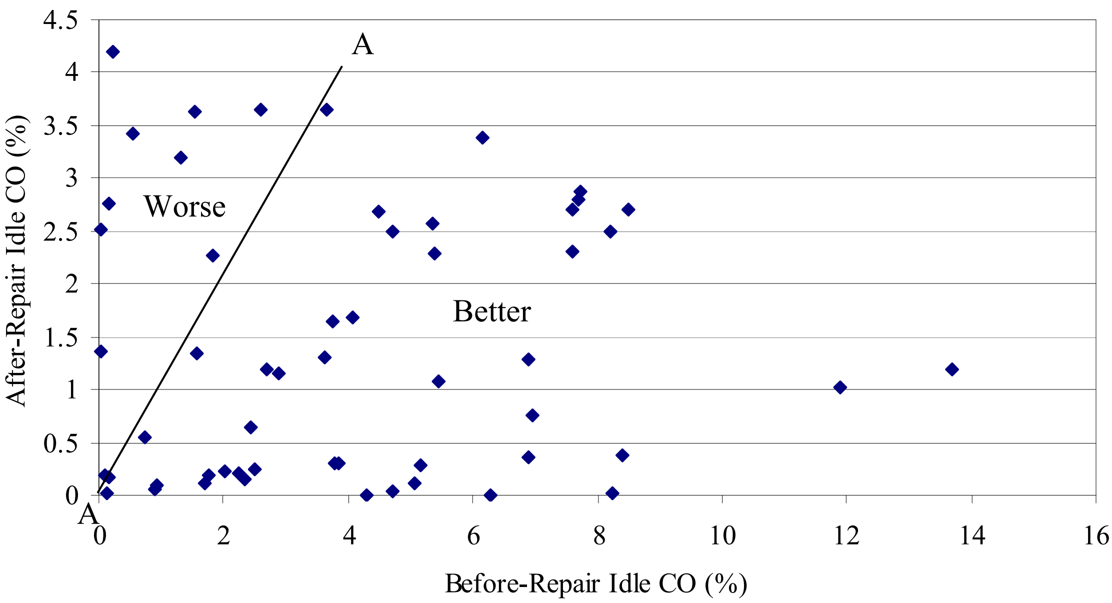

Figure 33: After-Repair (Natural) Idle CO Versus Before-Repair (Natural) Idle CO for the 52-Vehicle Test-Repair-Test Data Set

The nine points to the left of Line A-A are vehicles for which repair caused an increase in (natural) idle emissions. Six of these vehicles had faulty carburettors, two were early-model Technology 4 vehicles with faulty choke arrangements.

Of interest are the vehicles that exhibit moderate to high after-repair (natural) idle CO, say, above 2.0%. There are 19 vehicles in this subset and apart from a 1997 YoM Honda Civic with high (natural) idle CO (discussed in Section 7.1.3), they were 1990 YoM or earlier vehicles.

The range of repair costs by the change in (natural) idle CO emission achieved is given in Figure 34. The emissions improvement gained appeared to have no relationship to the cost of repair.

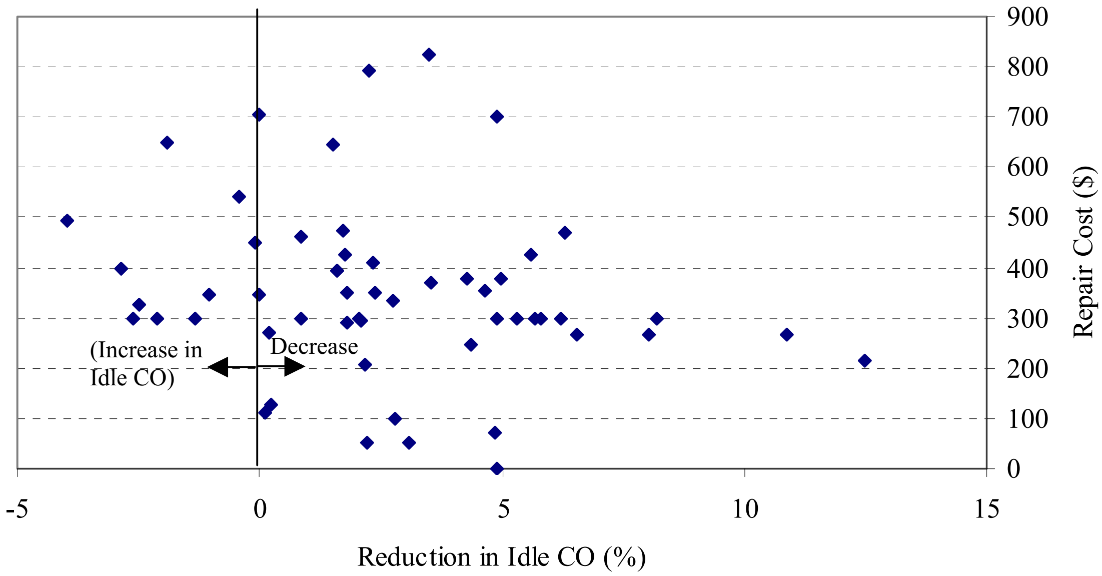

Figure 34: Reduction in (Natural) Idle CO Versus Cost of Repair for the 52-Vehicle Test-Repair-Test Data Set.

Repair costs range from $50 for cleaning spark ignition system components[124] to $825 for a multitude of repairs on one vehicle, including servicing the injectors. The average repair cost was $351 and, as shown by Figure 34, a cluster of repair costs was found in the $250 to $500 range. The difference between the average cost of repair for Technology 1 vehicles and Technology 4 vehicles was not significant. The sample size for Technology 2 and 3 vehicles was insufficient to allow comment on this.

Vehicles upon which repairs were carried out that cost above $600 appeared to have little in common with one another, these vehicles being of mixed YoM and engine technology. This being the case, it is likely an older vehicle of low residual value would occasionally fall into this area and the cost of repair may be considered uneconomic.

As has been mentioned, repair associated with an idle simple test régime would likely also incur an additional cost for a post-repair test and it is expected this cost would be to the order of $60.

In addition to the repair sample reported on here, there was one YoM 1992 Technology 2 vehicle that exhibited reasonably consistent misfire under cold or moderate- to high-load engine operation and would be expected to be a high on-road emitter of CO and HC as a result. However, the (natural) idle CO emission result for this vehicle was low (less than 0.2%). The spark plugs were found to be in poor condition and replacement eliminated the misfire. The opinion of several repairers was that many ignition system faults, including those that are obvious to the driver, may not manifest themselves under the light engine loading of idle simple testing.

[124] A nominal charge of $50 has been given for this, based on time taken. The customer in this case was not actually charged due to the particular circumstances involved.

Hence the idle simple test would not be expected to reliably fault vehicles in such condition.

Another component of Pilot work was targeted at diagnosing the reasons for the high idle simple test emissions results of some of the vehicles identified as high emitters by the Pilot's idle simple testing programme. Unfortunately, initiation work missed critical deadlines and this programme was abandoned. If idle simple testing is to be introduced as a mainstream emissions testing régime, then it is recommended this work be carried out in order to capture a greater diversity of vehicle types. For example, the current field repair data set features few late-model vehicles. Note, though, that despite this, the field repair data set is believed to be a good representation of vehicles requiring repair, especially since emission-related repairs and major engine overhauls on modern vehicles are expected to be rare.

7.4. 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 the different petrol engine technologies;
- the manner in which such faults could be diagnosed;
- how effective the gas analyser used for idle simple 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 M.

Generalising the views of those interviewed:

Common Faults:

- Faults are less likely to occur in more modern engine technologies. Some components of 1960s-era engines (at the time, when in regular use), by contrast, required six-monthly servicing to maintain acceptable performance. The implication is that it would be advisable to check vehicles of less-advanced engine technology more often than vehicles of more-advanced engine technology;
- One repairer believed up to 90% of faults on modern petrol engines were due to a faulty oxygen sensor. This view aligned with that of an expert in engine control systems who said oxygen sensors have a limited life of around 140,000km, after which they can adversely affect a vehicle's emissions performance;
- The common faults for earlier engine designs, on the other hand, were usually due to mechanical causes, including choke malfunction and breakdown of ignition system components;

- A dirty air filter for a petrol vehicle was not necessarily an emissions-related concern (the effect for many vehicles being more akin to throttling the air rather than disturbing the air-fuel ratio);[125]
- There were faults that were vehicle model-specific;
- A very small percentage of vehicles are expected to have badly worn engines to the point they are emitting visible smoke. Repair of a worn engine could cost $3,000 to $10,000, engine dependent. The cost of replacing an engine with a used engine, say from Japan, is expected to be in the range of $1,500-$4,000. This range is similar to the market price for a 1990-1995 YoM Japanese sedan, and such engine work may be considered uneconomic.

Use of the gas analyser to diagnose faults:

- Abnormal idle simple test results could be caused by many faults, the majority of which related to poor metering of fuel;
- The 4-gas analyser was a tool that could be used to diagnose the effects of faults but it was not believed to be essential (this was verified by a survey that found only a minority of repair garages actively use gas analysers) unless, say, an emissions specification were to be introduced.

Fault Diagnosis:

- More sophisticated equipment and more specialised understanding of engine systems were required for fault diagnosis on, and the repair of, modern vehicles;
- More modern vehicles were fitted with onboard diagnostics systems, allowing a certain degree of fault diagnostics using handheld ‘scan tools’. This method could not always be relied upon and in the event the scan tool was not successful in diagnosing a fault, yet another level of expertise was generally required to diagnose a fault. Further, a scan tool diagnosis may identify the effect of a fault and not necessarily the fault itself, a skilled technician still being required to identify the precise fault. At issue was that technicians skilled in the use of scan tools tended to be less skilled in fundamental diagnostics, and vice versa;
- For earlier model vehicles fitted with an oxygen sensor, a faulty oxygen sensor might not always be detected by a scan tool, including where the response of an oxygen sensor has become slow.

From the findings relating to common faults, it was believed both the dynamometer and field repair data sets provided a good spread of common faults that would result in the failure of a simple test by a vehicle or would have otherwise been identified by considering the results from idle simple testing.

Information concerning the capabilities of the industry has been deferred to Section 8.2.7, except that there are differing opinions within the industry of its capabilities and its understanding of requirements, such that the ability of the industry to support a régime based around idle simple testing must be questioned.

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[125] Note the opposite is generally true of diesel engines as a dirty air filter reduces the amount of air provided for combustion and the combustion is more likely to be less complete as a result.

Further detail of common faults associated with the petrol engine are given in Appendix N.

7.5. Conclusions

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

- There is a high degree of variability in the response to repair for CO, HC, NOx and fuel consumption. Even for the small sample of repair vehicles dynamometer tested, variations found in the repair of highest emitters ranged from a reduction in CO of 90% to an increase in CO of 60% and a reduction in fuel consumption of 18% to an increase in fuel consumption of 10%, based on the results from drive cycle testing (carried out to represent on-road performance);
- A régime that is associated with the repair of the 10% worst emitters as identified by idle simple testing would be expected to reduce petrol fleet CO and HC emissions somewhere in the vicinity of 10% and reduce NOx emissions much less than this;
- Repair of the worst 10% of emitters as measured by the (natural) idle CO or fast idle CO is expected to result in a fleet average fuel consumption benefit of less than 0.5%;
- Based on a repair sample of around fifty vehicles believed to be reasonably representative of the type of repairs likely to be required in an idle simple test programme, a high proportion of repair costs are expected to range to the order of $250-$500 and the average to the order of $350. A range of repair costs are expected and repair of older vehicles may be considered uneconomic at the upper end. In an idle simple test emissions régime, the cost of repair may also include the cost of a post-repair test which is expected to add a further $60 to the cost of repair;
- On average the annual reduction in fuel costs achieved through repair is expected to be small compared to the cost of repair;
- A repair may not return a particular vehicle to its original build emissions specification even when the repair is carried out by skilled technicians. Further, older vehicles, say of YoM before 1990, may not be able to attain an (natural) idle CO of less than 3.5% even after specialist repair;
- An average reduction in (natural) idle CO emission of 2.5%, absolute, was achieved through repair of the Pilot sample repair vehicles;
- The majority of faults on modern engines are the result of faulty sensors. A faulty oxygen sensor is a particularly common fault for early Technology 4 vehicles (early catalyst-equipped vehicles where the fuel control system incorporated an oxygen sensor);
- The more modern engine is more sophisticated and requires more specialist equipment and skills to diagnose and repair faults. The industry will require a certain amount of re-tooling and up-skilling in order to provide a quality level of service. There is a difference in opinion within the industry as to the scale of up-skilling that would be required.

8. Implementation Considerations

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

A section has also been provided on alternative options to idle simple testing. This discussion is additional to the contractual requirements of the Pilot, but it is believed to be important, given the alternative options presented may be more appropriate for New Zealand than idle simple testing.

8.1. Methodology

Consideration of the implementation of idle simple testing drew information from many sources including:

- Field idle simple testing – experiences from the Pilot's field idle simple testing, including discussions with vehicle drivers;
- Information for the industry including industry personnel, both in New Zealand and overseas;
- Overseas in-service testing standards;
- Laboratory assessment of the test protocol for the idle simple test;
- Laboratory assessment of analysers.

Field Idle Simple Testing:

As discussed in Section 4.1, nine sites were set up for idle simple testing of vehicles. Four were dedicated vehicle safety inspection sites; three were repair garages that could also issue WoFs, one was a repair garage only and one was the EFRU vehicle testing laboratory. This provided a range of test site types. Site specifics were such that testers of a range of competences were used and the time taken to carry out the test varied relative to other inspection, repair or test work underway at the same time. Also, as discussed in Section 4.1, testers were led through the project's test protocol (detailed in Appendix C), which included completing various test sheets supplied to them. One test sheet provided space for comments about the test or vehicle being tested and testers were encouraged to use this. Testers were also normally contacted every one or two weeks and asked to outline their experiences. Most sites were visited sometime during the Pilot, some on a daily basis, where there were found to be particular issues.

A number of managers at various test sites were also interviewed towards the end of the idle simple testing programme, with the aim of identifying which aspects of the programme went well and noting recommendations for potential improvements. By this stage, these managers had first-hand experience of the introduction of idle simple testing into their respective work programmes.

Information from the Industry

Many potential issues in implementing a régime based on idle simple testing were identified during the Pilot. These were investigated in discussions with various personnel from the motor-trade-related industry. Discussion forums 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 when discussing idle simple testing with overseas groups that had experience in its implementation. Those contacted in these forums included:

- The main suppliers of garage equipment in New Zealand (including suppliers of gas analysers of the type used for idle simple testing);
- Overseas manufacturers of exhaust gas analysers;
- Idle simple test testers;
- Managers of vehicle inspection facilities;
- Managers of vehicle repair workshops;
- Motor Trade Association (MTA) members including Executives and Branch Presidents;
- Motor Industry Training Organisation (MITO) Officers;
- John Fitch, Vehicle & Operator Services Agency (VOSA), UK, officer involved in the original design and implementation of idle simple testing in the UK;
- Bernd Baumgar, Operations Engineer for SGS, the company contracted to manage the emissions testing of vehicles across Ireland.

Overseas In-Service Testing Standards

Japan and many European countries have idle simple testing régimes in place. The test standards for Japan and the UK were considered: Japan, because this is the source country of a high proportion of the vehicles in use in New Zealand; and the UK, because similar test procedures have been adopted in other countries in Europe. In the case of the UK testing standard, the officer at VOSA also allowed the history of the development of idle simple testing to be explored.

Laboratory Assessment of the Test Protocol

The various elements making up the full idle simple test procedure were tested for robustness and efficiency 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. Various exhaust gas analysers were used, so that the dynamometer test programme was coordinated with the programme used to assess the performance of various analysers.

Laboratory Assessment of Analysers

Ten gas analysers of the type used for idle simple testing were assessed in testing carried out at the EFRU vehicle testing laboratory. This assessment included checking calibration, calibration method and stability, ease of analyser use (as appraised by the technician carrying out the test programme) and analyser functions. Detail of the methodology used is provided in Appendix B.

8.2. Results and Discussion

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

1. testing facilities and how idle simple testing could fit into existing processes;
2. testers;
3. analysers;
4. testing including test protocol, cut-points, test frequency and exemptions;
5. idle simple test costs.

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

8.2.1. 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. 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 the consideration of the centralised safety inspection findings.

There was no evidence to suggest the quality of idle simple 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 analysers. There would also be higher risks associated with smaller garage-type operations that were reliant on the operation of a single analyser.

It is suggested the range of vehicle 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. Interviews with garage owners in remote areas of New Zealand established that the convenience of WoF inspections in these areas was already a significant and growing concern.

Centralised, emissions-test-only facilities would be expected to exhibit similar test cost and analyser-quality benefits as for 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 Idle Simple Testing Within Existing Facilities

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

Experiences from the field trial pertinent to integrating idle simple testing with existing operations include:

Several disadvantages were found to idle simple testing at repair workshops. Physical workshop space tended to be at a premium and moving either the vehicle to the analyser or the analyser 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 an idle simple test took an additional five to ten minutes. 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 analyser capacity to deal with this. This also did not solve the warm-up issue for vehicles after they were repaired.

Test location and engine warm-up issues could add up to 20 minutes to an idle simple test. This compares to typical test durations of five to eight minutes,[126] five minutes being the time taken when a vehicle arrives warm and the analyser is immediately ready for the test. The time taken to emissions-test a vehicle would be further reduced to around three minutes if a 'fast test' option were allowed. A fast test is where a vehicle exhibits very low emissions on a first sample test and receives a pass on this result rather than being required to complete the full test cycle. This is a test option provided for in the UK and it is recommended this option be allowed in New Zealand, should idle simple testing be introduced.

It was found very difficult to integrate idle simple 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), five minutes being a comparatively long time for a vehicle to be in one place within a vehicle safety inspection process line. For example, at one site the emissions analyser was set to capture vehicles as they came off the brake tester. This soon

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

became a point of congestion and often required vehicles to be missed 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 analyser stations for each safety inspection line, but this would come at reasonable added cost due to the requirement of additional space and analysers. What's more, analysers 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 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 engine warm-up option of the prescribed idle simple test.

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 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, even if the technicalities of the engines were well beyond their comprehension. There also seemed to be an advantage where the tester had a good automotive background and could explain the results to the driver, providing remedial recommendations if the results from the test were poor. However, such consultations could add many minutes to a test.

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

Over 50 centralised or de-centralised facilities were visited during the Pilot and only a small proportion of these had vehicle exhaust extraction equipment available. The majority relied upon the doors to the facility being open and natural ventilation, which is of concern when it is considered how closed some workshop areas were.

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 idle simple testing.

Emissions extraction equipment is expected to cost to the order of $3,000 to $10,000 per emissions test bay.[127] 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 masks were not used much beyond the first week. The testers did not report any further issues after this.

Carbon masks were also sent to three other sites where potential problems existed. 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 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 idle simple test.

8.2.2. Testers

Sixteen different testers were involved in the Pilot's idle simple 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.

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.

As far as ability to carry out the test is concerned, as determined by occasional inspections of methodology, testers seemed sufficiently competent to follow the test

[127] Based on quotes provided by companies expert in dust and fume extraction.

protocol for idle simple testing. If testers were ranked from worst performers to best performers, based on assessment of their test methodology, 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. This same order would also result if rapport with drivers were considered.

In fact, analysis of the results of emissions testing and visual inspection found data quality to be roughly the same for all testers, as judged by the proportion of data which failed to meet quality control criteria which was reasonably consistently around 10% for the sites, apart from one. In the case of this single site, the proportion of data that failed to meet the quality control criteria was around 50%. This site was using a new, high-quality analyser and the tester was an experienced automotive technician who had been trained to carry out testing by the equipment supplier. The majority of the poor data in this case was due to high oxygen levels, and this should have been picked up during the test if the Pilot's test procedure was being followed correctly.

Data quality errors were identified during data analysis and it is recommended a data quality checking system be used that identifies potential problem sites and has a means of checking on those sites, in much the same manner as it is currently done for safety inspections. Additional data quality screening can be carried out if O_2 and CO_2 emissions are also reported,[128] rather than reporting only CO and HC, the normal cut-point emissions species. If data is captured automatically, as is possible with many analysers available, this additional data requirement would not add to the testing or processing time. It is therefore recommended that reporting of O_2 and CO_2 is required should idle simple testing be introduced.

Note that while testers were believed to have waited the prescribed period after setting an idle condition before taking results, the integrity of this component of the test could not be checked. Any variation to the prescribed method in this regard would, however, be expected to have small effect as the most significant change in emissions results occurs within 10 to 15 seconds after the reset of an engine condition.

The majority of testers were also involved in simple emissions testing of diesel vehicles using the 'snap acceleration' test. By comparison with idle simple testing of petrol engines, the snap acceleration test depended far more on the skill and honesty of the tester. For one tester, there was sufficient concern over the quality of the snap acceleration data that all data from that tester was discarded. There did not appear to be the same opportunity for the tester to influence the idle simple test result, especially if oxygen was also monitored as a quality check.

As has been mentioned, it is believed to be advantageous for the tester to have an automotive background and the ability to provide sound recommendations to drivers based on the results from idle simple testing. An emissions programme would also benefit from using testers of good aptitude. It is recommended that, at the very least, testers meet a minimum proficiency test and these qualities be considered therein.

[128] Among the checks that can be carried out, high O_2 indicates the sampling probe is possibly not sufficiently inserted, or there is possibly an exhaust leak, and CO_2 can be used to check whether the system is likely to be in calibration with regards to CO.

8.2.3. Analysers

The ten analysers assessed and tested at the EFRU laboratory constituted a wide range of analysers that could be made available for idle simple testing in New Zealand, ranging from low-end market analysers costing around $4,000 to high-end market analysers costing around $23,000. All analysers were 4-gas, measuring CO, HC, O_2 and CO_2. Analysers that measure CO and HC only are also available, but these were not tested as they are not appropriate for idle simple testing advanced-engine technology vehicles (i.e. modern catalyst-equipped vehicles).

The base component of the various analysers was the emissions 'analytical bench', which for the analysers assessed appeared to be either an Andros or Siemens bench. The differences between analysers were the 'ancillary' emissions sampling system, data handling and user interface. These differences, and whether the analyser had gone through verification testing, meant that the analysers also varied in the standards they met or were reported to be built to. This is further discussed in Appendix B.

Pertinent experiences from field idle simple testing and from the laboratory assessment of testing of analysers were:

- The two cheapest analysers did not provide accuracy to within the OMIL Class 1 specification (see Appendix B), as declared in their respective literature and there were also concerns over the quality of some components used in the cheaper analysers. Because of this, it is recommended a minimum specification of approval to BAR 90 (see Appendix B) or OMIL 1 be used for analysers. The process of approving an analyser to BAR 90 or OMIL 1 would also determine the frequency of calibration required by a particular analyser model;
- The higher-end analysers could be programmed to go through virtually any test sequence. A higher level of analyser again was available overseas that allowed wireless control, pre-programmed vehicle look-up tables and other advanced features;
- Two analysers failed during field testing. One was a reasonably new, quality analyser that failed twice for different reasons and held up testing at the site involved for some weeks while it was being fixed. This would have been an extreme inconvenience if emissions testing had been mandatory. Note that unlike brake testers and other safety inspection equipment, gas analysers are relatively fragile and there are no other options that can be used as stand-ins;
- Two cheaper analysers, provided new to the Pilot, could not be calibrated and could not be used for the Pilot;
- Analysers were found to exhibit similar response times, around 5-10 seconds, from when the probe was inserted into a vehicle's tail-pipe. This was an order of magnitude shorter than the time provided for the engine and analyser to stabilise during a test;
- Analysers provided similar results within their respective error bands;
- The current calibration procedure used by analyser suppliers in New Zealand, or their agents, was to use a single calibration gas. Tests using two different calibration gases found one analyser to be quite non-linear in the response to CO_2 and this, undetected, would have provided false results for lambda. It is

recommended the industry calibrate analysers using two different calibration gases. Further, due to concerns regarding the future capabilities of the industry in calibrating analysers, it is recommended a quality control programme be put in place to manage the calibration of analysers and accredit the laboratories and technicians performing calibrations.

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

Data processing within the inspection industry is becoming more automated and it is recommended the specification of analysers take this into consideration, at least by encouraging the purchase of analysers that can transfer data to a computer. However, it is suggested care be given to avoid over-specifying analysers, such that the entry cost rises to a point where it is difficult for small operators to remain involved or that prevents the use of multi-task analysers that can also be used for diagnosis.

8.2.4. Testing

Test Procedure

The specification for each component of the Pilot's idle simple test procedure is considered in this subsection, with recommendations provided for the idle simple test protocol, should idle simple testing be introduced into 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. taking the engine to and holding it at fast idle;
4. recording emissions results after providing time for the engine and analyser to stabilise;
5. allowing the engine to go to (natural) idle;
6. recording emissions results after allowing time for the engine and analyser to stabilise;
7. completion of a visual inspection form.

1. Pre-test Inspection

The pre-test inspection included checking for blue or black smoke from the exhaust at (natural) idle, a pass-fail check taken from the UK test procedure,[129] and checking for abnormal engine noise or other indication that the engine was not fit to test. No vehicle tested during the Pilot failed the pre-test inspection, although around 2% of the vehicles in the adjusted idle data set were found to have visible blue emissions at (natural) idle. Despite not 'failing' any vehicle at the pre-test inspection, it is believed this is an important component of the idle simple test, providing the tester an alternative method of failing a vehicle rather than risking damaging the vehicle or analyser. Furthermore, there is actually the potential for a smokey petrol vehicle to

[129] Vehicle & Operator Services Agency (VOSA), *The MoT Inspection Manual – Car and Light Commercial Vehicle Testing*. Issue date: August 2004.

exhibit low idle simple test emission results due to filters in the sample line taking out the measurable hydrocarbon component associated with the smoke. A pre-test inspection with the ability to fail a vehicle on the result is therefore recommended.

Note: one recommendation coming from the Pilot is for a visual inspection for visible emissions from the exhaust to be carried out at the time of a vehicle's safety inspection, and for this to follow the likes of the UK test procedure. The visual smoke check carried out as a pre-inspection check as part of the Pilot was not strictly controlled, emphasis being on the idle simple test. Hence results from the Pilot's visual smoke check would be unreliable for consideration of a visual smoke check régime in New Zealand.

2. *Warm-Up*

The Pilot's test protocol provided various options for testers to check the engine was sufficiently warm and, if it were not, required the engine to be operated at 2000 rpm for two minutes.

An engine is expected to exhibit higher emissions when cold than when at normal operating temperatures, hence the temperature of the engine when testing is important. Detailed dynamometer testing also indicated a cold engine could take several minutes of loaded engine operation to come up to sufficiently high temperatures that 'normal' emission levels were achieved. A longer period still would be expected if the engine were brought up to temperature by idling alone. Allowing the tester to determine if the engine is sufficiently warm appears the most practical option, and that is the option recommended for idle simple testing for New Zealand. The alternatives include: a minimum warm-up routine, which is not favoured because this would extend the duration of the test for all vehicles including those already sufficiently warm; and recording engine temperature, which is not favoured due to the added time involved in fitting sensors.[130] The recommended option, to leave the decision to the discretion of the tester, is believed to be sufficiently robust, as there is the opportunity during the fast idle component of the test to identify a vehicle that is still warming up, as indicated by decreasing emissions levels during the fast idle test.

Note the Bosch analysers used in the Pilot had been programmed to test to the UK idle simple test protocol and did not provide an 'OK' on the emissions result printout unless an oil dipstick temperature sensor was used and recorded temperature higher than 80°C.

To the advantage of carrying out idle simple testing at centralised facilities, vehicles generally had warm engines from the time of arrival to exit. A queue, if one developed, where the engine was turned off, offered the greatest risk of the engine cooling down.

3. *Fast Idling*

A reasonable proportion of vehicles did not have engine speed indicators ('rev counters'). Many newer vehicles were also fitted with spark ignition systems that

[130] The Bosch analysers had provision for input from an oil dipstick temperature sensor but this was not used beyond a small number of trials, as fitting it added up to five minutes to the duration of the test.

made it difficult to fit speed sensors and, where there was no engine speed indicator, engine pitch was used to determine an approximate fast idle speed. This was not considered a compromise, as engine tests indicated emissions results were relatively tolerant of the elevated engine speed chosen and even tolerant of slow changes in engine speed of up to 500 rpm.[131] The alternative, fitting a speed sensor, took over 15 minutes for a modern vehicle in one trial. Given the variability in engines on the market and the consequent difficulty in developing a ‘one size fits all’ fitting routine, and given the generally low emissions produced by modern vehicles and the relative stability of the emissions result with fast idle speed, the additional time necessary to fit an engine speed sensor could not be justified. It is recommended the manner in which the fast idle speed is set is left to the discretion of the tester.

4. Time for Stabilisation

The Pilot’s test protocol required operation at fast idle for 30 to 60 seconds, recording results as soon as the results became stable after 30 seconds or at 60 seconds, whichever was sooner.

Figure 35 and Figure 36 provide example plots of emissions results over time beginning from when the engine was taken from (natural) idle to fast idle, then taken back again to (natural) idle at around the 80-85-second mark. As shown by Figure 35, the Technology 1[132] engine in question took over 60 seconds for the emissions to stabilise. However, the change in emissions results after the 60-second mark was insignificant, being less than a 5% change for HC only. This compares with Figure 36 (note: using a different scale for both CO and HC) for a Technology 4 engine that exhibits a sufficiently stable result within 15 seconds. Plots for other vehicles tested in this manner exhibited much the same response times to one or other of the examples shown. It was concluded the Pilot’s 30-60 second stabilisation time was satisfactory.

[131] Four vehicles, one Technology 1 of average emissions, one Technology 2 vehicle and two Technology 4 vehicles of low emissions, were fast idle tested at engine speeds varying from 2000 rpm to 3000 rpm. There was no significant difference in emissions result shown.
[132] A description of the various Technology divisions is provided in the Glossary and in Section 4.2.3.

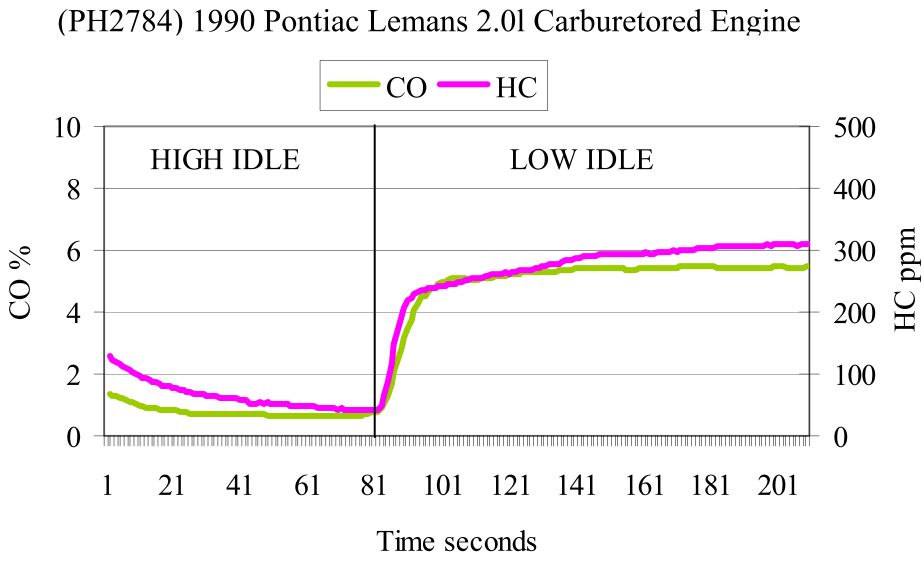

Figure 35: Emissions Response of a Non Catalyst-Equipped Vehicle During the Fast Idle and (Natural) Idle Components of an Idle Simple Test[133]

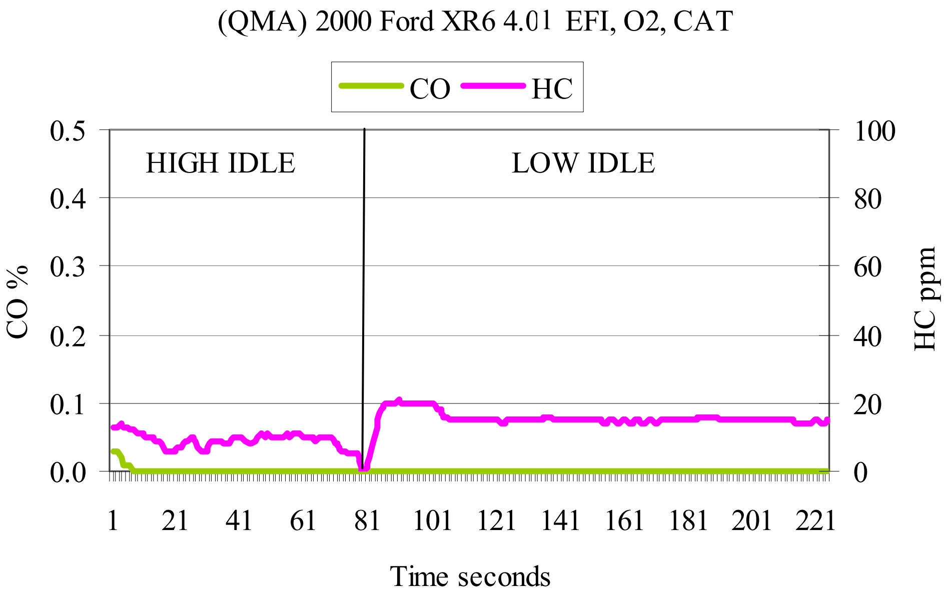

Figure 36: Emissions Response of a Catalyst-Equipped Vehicle During the Fast Idle and (Natural) Idle Components of an Idle Simple Test

Note: the discretion of the tester may determine that a continuing lowering of emissions result during the fast idle test is an indication the engine is still warming up and the tester may choose to re-test the engine beginning with raising the engine up to fast idle. This should also allow for those vehicles that seem initially slow in their emissions response to setting a fast idle speed.

[133] Note this figure has been provided to illustrate the time it can take for the results to stabilise. The results given should however not be taken as typical as they vary widely.

5. Idling

The Pilot's test protocol required the engine to be returned to the (natural) idle of the vehicle and no issue was found during this component of the test.

6. Time for Stabilisation

The Pilot's test protocol required operation at (natural) idle for 120 seconds before recording the emissions result. As shown by Figure 35, this happened to be around when the emissions result for vehicles exhibiting slow response to the change in idle speed stabilised. For some vehicles, it was obvious the emissions were going to remain low within the first ten seconds and it is recommended the option be provided for recording results after 30 seconds to allow the duration of the test to be shortened.

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.

8.2.5. Cut-points

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

Current Petrol Fleet

Around 50% of petrol 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 cut-point risks making the industry responsible where a vehicle in normal state of tune and condition does not meet the cut-point, a risk the industry need not assume. Further, some vehicles have been modified since production and it is believed it would be difficult to require vehicles to be restored to their original design when it was lawful, at the time, to make the modifications. A vehicle that has a poisoned catalyst due to use with leaded fuels may also fit into this latter category, the owner having done nothing out of the ordinary at the time although the vehicle is now more likely to exhibit elevated idle simple test CO emissions through the poisoning 'modification', which may be sufficient for the vehicle to fail to meet a given emissions cut-point.

Due to these considerations it is possible that at best a reasonably lenient 3.5 % (natural) idle CO or 4.5 % (natural) idle CO and 1200 ppm (natural) idle HC cut-point would be accepted by the industry for vehicles not built to an appropriate emissions standard. This would include catalyst-equipped vehicles not built to meet an emissions standard.[134] These cut-points have been based on the least stringent idle

[134] As a further illustration of the difficulty in applying overseas idle simple test régimes to the New Zealand fleet, a vehicle found fitted with a catalyst may not exhibit the performance expected of catalyst-equipped vehicles. For example, there was a period in New Zealand where some New Zealand-new vehicles were fitted with exhaust catalysts but the engine management system was not ideally suited for the catalysts used.

simple test requirements used in the UK[135] and represent a very basic, but normally achievable, emissions target. Even then, allowance may be requested beyond these cut-point values for vehicles shown to be in reasonable mechanical condition, providing for the likes of modified or classic cars that may have high emissions due to their design build. For classic cars, another option is to exempt vehicles older than a given age from the idle simple test.[136]

Used imports from the Japanese domestic market, which make up around 50% of the New Zealand vehicle fleet, would have been built to meet an emissions standard that included an idle simple emissions test. The same idle simple test and cut-point requirement, 1% (natural) idle CO and 300 ppm (natural) idle HC,[137] has been in place as a 'type approval standard'[138] since 1978 and is also used as an in-service emissions check in Japan. The majority of used Japanese imports should be able to meet this standard today, if they are still in reasonable condition.

For Europe, the emissions component of the type approval standard for petrol vehicles requires a model's representative tested vehicles to meet the given emissions limits when taken through that standard's drive cycle test. European Union member countries then set their own in-service requirements, it taken that the in-service test is less stringent than the type approval test and a vehicle built to the type approval test would also meet the in-service requirement.[139]

Note there is also another important differentiation to be made between the emissions component of a vehicle's type approval standard, to which it was built, and an in-service test such as the idle simple test component. The (drive cycle) emissions requirement of the type approval standard is expected to be met during the first years of vehicle operation, whereas the in-service requirement is expected to be met during the life of the vehicle, if the vehicle remains in reasonable condition.

The United States and various countries in Europe have, from around the mid 1990s, specified a more stringent idle simple test requirement than Japan. For example, the cut-points normally applied to a catalyst-equipped vehicle in the UK are 0.3 % CO, 200 ppm HC and lambda 0.97-1.03 for fast idle, and for 0.5 % CO for (natural) idle. Again, there is no reason why vehicles built to these standards would not meet their respective idle simple test cut-points today, if still in reasonable condition.

Vehicles that have been retrofit converted to alternative fuels such as LPG or CNG, may or may not meet original build emissions standards, depending upon the quality of their conversion.

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[135] The idle simple test cut-points in use in the UK for non catalyst-equipped vehicles are:

- Visual only for vehicles first used before 1 August 1975;
- (Natural) idle simple test cut-points of 4.5 % CO and 1200 ppm HC for vehicles first used between August 1975 and July 1986, aimed at non-catalyst-equipped vehicles;
- (Natural) idle simple test cut-points of 3.5 % CO and 1200 ppm HC for vehicles first used between August 1986 and July 1992 and remained as an option for vehicles where a manufacturer had not set their own testing limit until July 1995.

Vehicle & Operator Services Agency (VOSA), *The MoT Inspection Manual – Car and Light Commercial Vehicle Testing*. Issue date: August 2004.

[136] An extension of this would be to also refer to the annual distance travelled but it is suggested this would be fraught with issues regarding the quality of odometer readings among others.

[137] Automobile Standards Internationalisation Centre, *Automotive Type Approval Handbook for Japanese Certification, 2002*, Japan.

[138] A standard in a given jurisdiction to which the various vehicle models in that jurisdiction are built.

[139] Bernard Swierzy, Ford Motor Company (Germany), personnel communication.

Future Petrol Fleet Additions

Light vehicles now entering New Zealand[140] must have been built to minimum emissions standards, as far as exhaust emissions are concerned, as detailed in the Emissions Rule 2003. It is expected these vehicles would meet an idle simple test set (as detailed in the previous page). An option that therefore presents itself is introducing in-service idle simple testing for these vehicles, based on cut-points associated with their expected design performance. The problem is that there would be vehicle-specific cut-points involved, requiring an extensive vehicle information database to be developed and, in any case, the vehicles so targeted would be expected to be the lowest emitters in the fleet. The majority of these vehicles would also be expected to be fitted with onboard diagnostics systems in their various forms and interrogation of this is expected to provide a more accurate assessment of a vehicle's emissions-related condition.

For testing at the time of import, new vehicles would be expected to meet their respective emissions build specifications and no inspection of this beyond current practice[141] is believed necessary. On the other hand, used imported vehicles may have developed an emissions-related fault during use. The vehicle inspection carried out before a used imported vehicle can be registered for use on the road in New Zealand provides an opportunity to put in place an emissions check. If this were an idle simple test, one option would be to specify one cut-point across all used imported petrol vehicles, with that cut-point being based on the least stringent of the jurisdictions from which New Zealand receives vehicles, namely the 1.0% (natural) idle CO and 300 ppm (natural) idle HC of Japan. It is suggested the alternative of requiring vehicles to meet the idle simple test and cut-point of the emissions standard to which they were built risks disadvantaging imported vehicles built to more stringent emissions standards, and that the need to identify the correct cut-point could over-complicate the implementation of such a testing régime.

As shown in Section 6, requiring vehicles to meet a given cut-point will not necessarily identify vehicles with emissions-related faults (including removed catalysts) and hence it is recommended that vehicles be checked for correctly functioning emissions control systems rather than simply meeting an idle simple test cut-point. Idle simple testing may be a component of this, but other checks would be required if this were used. One alternative would be to interrogate a vehicle's 'OBD' system if a vehicle was fitted with an OBD-2, EOBD or a more recent JOBD version.[142] This is further discussed in Section 8.3.

Note the interrogation of onboard diagnostics systems may be an emissions screen option for the future. As with idle simple testing with its weakness with respect to applying it to New Zealand, where a proportion of vehicles were not built to meet an idle simple test, there would be a similar weakness in applying an emissions régime based on onboard diagnostics systems unless a time were specified after which fleet

[140]From 1 January 2004 for used light vehicles and new model light vehicles and from 1 January 2005 for all light vehicles.

[141] That is, checking that a vehicle was built to a given emissions standard as far as exhaust emissions are concerned.

[142] The listed 'OBD' systems have two oxygen sensors fitted, one either side of the catalyst, and also allow the function of the catalyst to be checked, providing a very good interrogation of the expected emission performance of a vehicle. New Zealand representative of an overseas OEM, personal communication.

entrants are required to be fitted with onboard diagnostics systems. A limitation of the Emissions Rule is that it concerns exhaust emissions only and does not require the often associated onboard diagnostics system, or vapour control equipment for that matter, to be fitted to vehicles. A mandatory requirement that petrol vehicles be fitted with certain onboard diagnostics systems would also in effect act as a minimum age barrier, similar to that created by the introduction of the Frontal Impact Rule, only cutting off at a more recent year of manufacture.

8.2.6. Frequency of Idle Simple Testing

There are many factors to be considered in determining the frequency of idle simple testing. The cost and inconvenience to vehicle owners and the limited capacity of the industry invite extended intervals between tests. 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 to six years old need not be tested. At the other end of the scale, the propensity for less advanced engine systems to move off calibration within 12 to 18 months suggests that a test interval of 12 months for these vehicles would be appropriate. A possible merger of these two frequencies would see catalyst-equipped vehicles tested every 24 months after a grace period for those less than six years of age, and non-catalyst-equipped vehicles tested every 12 months after a six years-of-age grace period. This mechanism is relatively simple, with the differentiation between catalyst and non-catalyst-equipped vehicles also sending a valuable awareness message and providing an incentive, in the absence of any other measure, to prevent catalyst removal.

When setting test frequency, the issues attending introducing idle simple testing should also be considered. The introduction of an idle simple test régime must take into account whether the industry possesses sufficient growth capacity to support the testing régime and the volume of repairs which it will occasion. Analysis of emissions results and questioning the industry on their capacity and capabilities found that:

- Those technicians skilled in emissions repair believe many years of experience were required to become proficient in the emissions repair of vehicles. Managers of more generalised repair workshops believed the required skills could be obtained through attendance of classes, the inference being that days of training were involved, not weeks or months;
- MTA Branch Presidents believe the industry would be capable of supporting a simple test-based emissions and repair régime within a 12-month lead-time if the emissions régime were carefully managed. This view was not supported by those skilled in emissions-repair work;
- Equipment suppliers believe they can provide the necessary equipment and training to support a country-wide, fleet-wide, idle simple testing régime within a 12 to 24-month period;
- MTA Branch Presidents and garage equipment suppliers believe around 10% of trade workshops have gas analysers. However, a telephone survey and

inspection of a number of garages with analysers suggested the percentage of garages owning operable exhaust analysers was nearer the 1 to 3% range.[143]

- The New Zealand representative of a certain make of vehicles in New Zealand was selling off their gas analysers as they were considered superfluous particularly since new vehicles had onboard diagnostics systems;
- One supplier of scan tools believes scan tools would be required for the majority of emissions-related repair on modern vehicles and that less than 10% of workshops have access to them;
- Some industry people were concerned at the potential for over-zealous or misguided repair that may result from the introduction of an emissions testing régime, there being many cases of this associated with safety inspections;
- It is estimated a régime that causes around 10% of petrol vehicles to require emissions repair would require to the order of 300 new, full-time-equivalent technician positions and 300 new, full-time equivalent support positions (that is, 600 full time equivalent positions in total based on 2.5 million vehicles and average of 3 hours per repair plus support staff on a 1:1 basis);
- Taking another approach it is estimated 1000 to 1500 technicians would require training to the point where they were competent in emissions-related repairs (the larger number than in the previous bullet point due to technicians not being engaged in emissions repair work on a full time basis, requiring 1 in 10 automotive technicians to be competent in emissions repair, an estimated 6000 workshops in New Zealand (MTA estimate), an average of 4-5 mechanics per workshop and beginning with a base of 1200-2500 competent technicians);
- It is estimated annual idle simple testing of petrol vehicles would require the addition of around 500-600 testers and around 500-600 support staff[144] (that is, 1000 to 1200 additional personnel in total). A proportion of the support staff would be personnel specialised in analyser servicing and calibration.

It is quite evident that the introduction of simple testing would require careful management over many years in order to allow demand to grow with capacity. The demands on the industry would be expected to be eased by the initially low proportion of vehicles of more advanced engine technology[145] requiring repair, in turn allowing the industry the opportunity to prepare itself better. The possibility that the number of vehicles requiring repair would peak then decrease as the fleet moves to more advanced engine technologies must also be considered. This creates a risk to the industry of over-investing in the programme.

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

- Providing idle simple testing initially for awareness purposes only, allowing vehicle owners to manage any non-compliance found over a longer term.

[143] The industry reports that it bought equipment in the late 1980s to prepare for the then expected introduction of emission testing, and has since generally taken the stance that it will wait until the government legislates the specification of equipment required before investing further. Much of the emissions equipment purchased in the late 1980s is unlikely still to be in an appropriate working condition for idle simple testing.

[144] Based on 2.5 million petrol vehicles, an average of 20 minutes per vehicle per test, including downtime and 200 days per year per tester.

[145] 'Engine technology' also refers to the exhaust system including any exhaust after-treatment, if fitted, and not just the under-bonnet section of the engine.

Such a programme could have a relatively short commissioning period for spot 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 earlier testing without financial incentive;
- Setting initially lenient cut-points so as to pick out the worst offenders while still creating valuable awareness;
- Progressively introducing vehicles to the idle simple test régime based on their year of manufacture or engine technology.

The last suggestion is based on the Pilot's finding that non-catalyst-equipped vehicles of less recent YoM were generally the higher-emitting vehicles of the fleet, and targeting these vehicles would provide the least cost per high emitter identified. These vehicle types are also of engine technologies with which the industry is familiar. The downside of a progressive implementation schedule is that initially there would be fewer sites offering emissions tests, making testing less convenient to the vehicle owner, and meaning lower utilisation of test equipment, making it less cost-effective for test facilities.

The suggested idle simple test régime requires the identification of a vehicle's engine technology and, ideally, retention of this information in a database that can be searched by testers. Such databases can take 18 months or more to develop. But there are also emissions inventory benefits in maintaining such a database, and it is therefore recommended that work begin on compiling this information.

8.2.7. Exemptions

It is suggested there is political and public awareness benefit in involving all petrol vehicles used on the road at least in an initial emissions screen, say, to see if a vehicle is then required to undergo an idle simple test. Possible emissions screen options include vehicle designation, vehicle age, whether the vehicle was fitted with a catalyst or not and visual emissions inspection. Note that there was no consistent significant difference found between the emissions of NZ-New vehicles and Used Japanese Imported vehicles when engine technology and YoM were taken into consideration, so whether a vehicle is New Zealand-new or a used import is not considered to be an appropriate emissions screen option. Nor was engine size found to be an accurate indicator on an individual-vehicle basis, and it is not considered an appropriate emissions screen option for this reason.

The exemption of vehicles that do not meet given cut-points even after repair is expected to be more at issue. The Pilot identified at least one model where the manufacturer's (natural) idle emissions setting could not be met even after repair. Options used overseas for such cases include providing exemption after a minimum amount has been spent on repair and designating the vehicle ineligible to be sold and to be retired within a certain timeframe.

Detailed dynamometer testing also indicated that some vehicles exhibit high idle simple test results 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 to alternatively quantify emissions for their vehicle 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.

8.2.8. Idle Simple Test Cost

Table 2.4.2 provides estimates of the cost of idle simple testing for various implementation scenarios, based on the Pilot's field experiences. These estimates have been based upon:

- Analyser cost of $30,000 for centralised testing, $15,000 for garage-type testing, financed at 20%;
- Emissions extraction cost of $5,000 financed at 20% plus 10% maintenance costs;
- Annual analyser calibration and maintenance costs of $3,000 and $2,000 for centralised and garage-type operations respectively (the lower cost for garage-type analysers is due to type of equipment used);
- Additional insurance of $2,000 and $1,000 for centralised and garage-type operations respectively, to cover for analyser loss and damage and added vehicle liability;[146]
- 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 facility-expected return on charged labour 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 times 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 a range of times found in field testing;
- Tester and analyser availability in centralised operations based on seven hours per day, 200 days per year;
- No cost has been provided for vehicle and driver downtime.

[146] 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 idle simple testing was a regular occurrence.

Table 13: Estimated Costs of Idle Simple Testing Under Various Scenarios.

	Centralised Costs ($)			De-centralised Costs ($)		
Total Emissions-Related Facility Costs ($/year)	19,500	19,500	19,500	10,500	10,500	10,500
Total Labour Charge ($/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	$30	$40	$59

The results of the simple analysis provided in Table 13 yield a potential range of costs for idle simple testing from $20 to $50 per test for testing at centralised facilities to $30 to $60 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,[147] is around $35. This cost does not take into consideration the time and associated costs involved in presenting a vehicle for idle simple 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 idle simple testing is similar to the current cost of a safety inspection test, and combined with the safety inspection would constitute a 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 analyser utilisation among things. The cost of testing during the Pilot was over $100 per vehicle for two sites and this was for a discounted rate on the hire of the analysers.

8.3. Other Implementation Options

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

[147] Based on LANDATA data.

- Visual inspection for visible emissions at the time of safety inspection. Benefits and potential drawbacks include:
    - It is expected to be relatively easily introduced;
    - It would identify oil-burning gross emitters;
    - It introduces vehicle owners to emissions testing;
    - It offers the opportunity to promote emissions awareness;
    - It is expected to aid the enforcement of the 10-Second Rule;
    - Against it, a visual test would be subjective. However the worst emitters would still be expected to fail and an option could be to require borderline vehicles to be tested by other means.
- A mechanism to forbid or at least discourage tampering with emissions-related equipment (including the removal of catalysts) supported by visual inspection carried out at the time of safety inspection and a related database of visual inspection results. Benefits and potential issues include:
    - Working catalysts provide significant emissions benefit and should not be removed;
    - A visual inspection and records database would allow monitoring of the fleet emissions build providing value input for predicting fleet emissions performance;
    - Set-up of an appropriate database may take several years and costs involved, including the inspection of vehicles, would be moderate.
- Emissions screening for potentially high-emitting vehicles using remote sensing supported by a more robust emissions assessment, such as interrogation of a vehicle's onboard diagnostics system or use of gas analysers. The benefits and potential issues include:
    - It could be focused on areas of greatest emissions concern;
    - With careful use, remote sensing could also be used as an indication of emissions status quo (but not for emissions inventory purposes);
    - Over time, the proportion of vehicles exhibiting near-zero emission is expected to increase substantially, resulting in the cost of idle simple testing being above $4,000 per high emitter identified.[148] Remote sensing offers a lower cost per potential high emitter identified.
    - The potential inaccuracy of a remote sensing result, on an individual vehicle basis, requires the use of devices that can provide a more accurate assessment of a vehicle's emissions condition. The use of other emissions assessment devices is also more practical for diagnosis and repair purposes.
- Proof the emissions system is functioning correctly on used imported vehicles before they are permitted to enter the fleet. The benefits and potential issues include:
    - It is expected to be a more accurate assessment of a vehicle's emissions capability than idle simple testing;
    - It 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 régime;
    - It ensures vehicles entering the fleet have functioning emissions systems;

[148] Based on Pilot results with fewer than 1% of Technology 4 vehicles failing to meet a 3.5% (natural) idle CO cut-point and $35 per idle simple test.

    - It would require careful design to ensure the pass-fail mechanisms were efficient and appropriate.
- Testing emissions for O_2 as an awareness tool at the time of a safety inspection. The benefits and potential issues are:
    - A relatively inexpensive O_2 sensor and analyser could be used;
    - The test is expected to take less than one minute if carried out at the correct time (when the engine is already warm);
    - The result is advisory only but could act as a valuable awareness tool;
    - Some owners may act on a poor result and have their vehicle checked.

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

Expanding on checking the function of the emissions control system of used vehicles at their time of import, one option would be to require vehicles to be fitted with a two-O_2 OBD system,[149] and no Diagnostic Trouble Codes (DTC) being indicated, or otherwise vehicles to meet a detailed check of the function of their emissions system. This should encourage the import of used vehicles with advanced onboard diagnostics systems which would be of more recent manufacture and built to more stringent emissions standards.

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 idle simple test régime or high emitter test and cut-point of some sort is not adopted. This weakens the authority that could be provided to support other emissions reduction programmes. This became apparent when one of the repairers involved in the Pilot was asked to check a vehicle that had returned a poor emissions result according to remote sensing in the Auckland Regional Authority/NIWA 2004 remote sensing campaign in Auckland. The vehicle was indeed found to be a high emitter, but the vehicle owner was not prepared to repair the vehicle due to the cost involved and was contemplating selling it instead.

8.4. Conclusions

There are problems peculiar to New Zealand that would make it difficult to implement a fleet-wide régime based on idle simple testing:

- Around 50% of the fleet were not built to an emissions standard and it would therefore be difficult to require these vehicles retrospectively to meet a given emissions performance standard, unless it were a very lenient pass-fail cut-point;
- It would be difficult retrospectively to require vehicles which were legitimately modified under the rules prevailing at the time (or lack of them) to then undergo re-engineering to meet a given emissions performance standard. A similar argument could be applied to those catalyst-equipped vehicles that have poisoned catalysts on account of being fuelled with leaded petrol, the fuel that was made available at the time;

[149] That is, OBD-2, EOBD or more recent JOBD.

- The ability of the industry to provide sufficient capacity and capability to support such a régime is questioned;
- The poor relationship between idle simple test emissions and on-road emissions means that there is a risk the results of idle simple testing would be challenged;
- Implementation of idle simple testing would be an expensive undertaking and would risk the industry over-investing in formative years.

As well the usefulness of idle simple testing is expected to lessen as the fleet modernises. When all these aspects are considered, idle simple testing is not recommended for New Zealand as a mainstream vehicle emissions control programme. However, idle simple 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; identifying and monitoring the engine technology[150] make-up of the fleet; emissions screening for potentially high-emitting vehicles using remote sensing supported by a more robust emissions assessment (such as interrogation of appropriate onboard diagnostics systems or use of gas analysers); proof the emissions system on used imported vehicles is functioning correctly before they are permitted to enter the fleet, and simple testing exhaust O_2 as an awareness tool at the time of a safety inspection. It is recommended these options be further investigated.

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 idle simple test régime or high emitter test and cut-point of some sort is adopted. This weakens the authority that could be provided to support other emissions reduction programmes.

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

- A Standard or Code of Practice for idle simple testing, including the specification of analysers;
- A minimum proficiency standard for testers;
- A quality control programme to manage the maintenance and calibration of analysers, 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;
- Training of automotive technicians in emissions repair.

[150] Note 'engine technology' refers also to the exhaust system and any exhaust after-treatment device, if one is fitted, and not just the 'under bonnet' section of the engine.

On the last point, regardless of whether idle simple testing is introduced, the industry is required to re-tool and up-skill itself the better to provide for emissions repair of the fleet and some means to encourage this must be introduced.

Should idle simple testing be introduced as a fleet-wide requirement, it is expected the industry would require a further 1000 to 1200 personnel to support the testing involved and a further 600 personnel for supporting the associated repairs. The introduction of idle simple testing would require careful management, as this step increase in industry capacity would take several years at best, and there is also a risk that the industry could over-invest in the earlier years. An over-optimistic introduction would also risk the quality of the programme being compromised.

Once introduced, an idle simple test would be expected to take 5 to 20 minutes and cost around $35 on average, ranging from $20 to $60 depending upon the facility type and whether vehicles may be tested easily. Higher costs would be expected during the régime startup period.

The idle simple 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.

9. Recommendations For Further Work

It is recommended that idle simple testing not be introduced as a mainstream vehicle emissions control programme in New Zealand. For this reason, recommendations provided below are based on the assumption that idle simple testing will not be so introduced in New Zealand.

It is recommended an integrated vehicle emissions control strategy be expertly devised.[151] Suggested options for consideration 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; identifying and monitoring the engine technology[152] make-up of the fleet for emissions inventory purposes; emissions screening for potentially high-emitting vehicles using remote sensing supported by a more robust emissions assessment (such as interrogation of the onboard diagnostics system or careful use of gas analysers); proof the emissions system on used imported vehicles is functioning correctly before they are permitted to enter the fleet, and simple testing exhaust O_2 as an awareness tool at the time of a safety inspection.

The Pilot has shown the advantages of use of emissions prediction models or inventories and it is recommended the Ministry of Transport's VFEM and the associated ECA model be further developed in an expert manner to provide a tool to aid the development of policy. A component of this is further surveying the fleet so as to better understand its engine technology make-up.

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

The vehicle repair industry does not appear to have the capability to support the fleet as it modernises and it is recommended high priority be given to re-tooling and up-skilling the vehicle repair industry.

Remote sensing programmes in New Zealand have provided very useful information. It is suggested this data could be further usefully mined using multiple variable regression analysis and it is recommended this be done.

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[151] It is understood there has been much investigative groundwork already carried out in this area in New Zealand, put into the New Zealand context, and hence it is not suggested the process begin from a standing start.
[152] Note 'engine technology' refers also to the exhaust system and any exhaust after-treatment device, if one is fitted, and not just the 'under bonnet' section of the engine.

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: Assessment of Gas Analysers

B.1 Emissions Analyser Specifications

The international standards specifying the performance of exhaust emissions analysers have been revised over time as improvements in vehicle engine technology have occurred, putting higher demands on measurement accuracy. For example, the California Bureau of Automotive Repair BAR 90 has been superseded with BAR 97, and OIML (International Organisation of Legal Metrology) R99 Class 1 with Class 0.

There is some level of equivalence between BAR 90 and OIML 1, as there is between BAR 97 and OIML 0, which is the higher specification, a principal requirement of which is a faster return to zero from HC measurement and an improvement in the response time of the nitrogen oxide cell.

These standards determine the complete requirements for the analyser with regard to its performance characteristics, which include:

- Indication of the measured result;
- Measuring range;
- Resolution of Indication;
- Scale, resolution and accuracy of ranges;
- Update rate and response time;
- Calibration, repeatability and stability;
- Self 'health' checking features for leak testing, HC residue, O_2 sensor error;
- Sample handling;
- Construction;
- Ability to withstand shock and vibration;
- Environmental conditions for operation.

The main component of the analysers is the 'analytical bench', which is a sub-assembly requiring a software interface and sample handling systems etc. to operate. Generally manufacturers of emissions analysers do not make their own analytical benches, instead using those made by others. The most commonly used benches appear to be either Andros or Siemens, although there are some others available.

The analytical benches from both these companies can perform to the OIML1 or BAR 90 specifications, providing the manufacturer includes the necessary control and instrumentation.

Manufacturers can describe an analyser as having accuracy to a given standard (or in some cases, exceeding it), or state conformity (approval) to the standard. To obtain approval, extensive testing has to be performed by an independent, certified laboratory to ensure all aspects of the standard are conformed to, which basically guarantees the performance of the instrument.

The benches use non-dispersive infra-red (NDIR) techniques to measure CO, CO_2 and HC. Measurement of oxygen (O_2) and nitrogen oxide (NO) is by electrochemical cell. Hydrocarbon measurement is based on hexane.

In addition to the measured gases, analysers display a value for lambda (an indication of the extent to which the air-fuel ratio is fuel-lean or rich) calculated using the simplified BrettSchneider formula (Bosch Technische Berichte, vol 6 (1979) No.4) (VOSA, 2004). This value is an approximation and requires input of fuel type.

Analysers sometimes include display of a 'Corrected CO' measurement, additional to the actual measured CO. This is a calculated value derived from the measurements of both CO and CO_2 and is useful in identifying if sample dilution is occurring.

Modern overseas procedures dictate the official test sequences to be followed, with measurement of oil temperature and engine rpm required for validation purposes – analysers are now mostly supplied with temperature probes and speed sensors to enable this.

B.2 Comparison of Analysers

Table 14 (at the end of this appendix) compares the basic details only of the analysers assessed during the programme and so does not represent a total list of equipment available in New Zealand. The information was sourced from manufacturers, information brochures and websites, where manufacturers have stated certain levels of accuracy in their specifications.

Some of the analysers were available to be used for testing for a significant period of the programme at the University of Auckland, while for others it was only possible to use them periodically and check their performance at the locations where they were in use.

Also, newer models that may have different specifications to those listed have superseded some of the analyser used in the project. In general, it would be expected that newer engine technology would result in improvements.

Assessing the analysers involved physically measuring their response to certified gas mixtures, appraising their ease of operation, verifying performance of functions and calibration requirements etc.

The more extensive testing, of the type required fully to assess performance of the analysers for standard approval, could not be conducted.

Two certified gas mixtures were prepared to check analyser accuracy. Gas 1 contained a blend of CO, CO_2 and HC (as propane, C_3H_8) in proportions suitable for checking and performing actual calibration, and Gas 2 contained a blend of CO, CO_2 and HC (as propane) but also with O_2 in concentrations designed to simulate the expected levels in vehicle exhaust (Table 14)

Table 14: Composition of Certified Gases

Component	Gas 1 (Calibration) *	Gas 2 (Verification) *
Carbon Monoxide (CO)	3.90%	1.01%
Carbon Dioxide (CO_2)	13.80%	14.20%
Hydrocarbons (C_3H_8)	2140 ppm	235 ppm
Oxygen (O_2)	0.00%	1.05%

* Note: The balance of the gas is nitrogen.

Using a bypass flow system, which enabled these gases to be sampled normally without dilution or pressurising of the cells, the analysers were checked for their accuracy of calibration and measurement at realistic levels. If necessary (and with approval) analysers that were not reading correctly were re-calibrated, provided the correct procedure was known.

The hydrocarbons measurements of the analysers is based on hexane; however it is standard procedure to perform the calibration using propane and correct the reading using a propane equivalence factor (PEF) which is specific for each individual analyser. The certified concentration (in ppm) of propane in the gas is multiplied by the PEF to obtain the correct value that should be indicated for hydrocarbons (PEF's vary typically between 0.490 to 0.540).

It should be noted that most of the analysers tested had the option of installing an electrochemical cell to enable NO measurement, although they were initially supplied without one.

B.3 Performance Assessment

Tables 15 and 16 (at the end of this appendix) summarise features of the analysers and include a simple rating system on certain aspects of these and their performance as described below:

- **Ease of Use**: covers user operation for all functions required for normal operation and system checks;
- **Accuracy Gas 1**: accuracy of measurement of the analyser sampling the certified calibration gas through its normal sample line;
- **Accuracy Gas 2**: accuracy of measurement of the analyser sampling the certified verification gas through its normal sample line;
- **Calibration Drift**: indication of the analyser's ability to maintain calibration over time;
- **Sample Line / probe**: indication of confidence in quality / durability of sample line and tail-pipe probe;
- **Pump**: indication of confidence in pump flow capacity and durability;
- **Filtration**: indication of quality and durability of filters, fittings and associated components. Greater star rating was given if the analysers had continuous water 'drain off';
- **Confidence**: indication of overall confidence in the finished product, its durability, ability to do the job, etc.

The more stars, the better the rating. It should be noted that the confidence ratings are not based on testing but are the opinions of qualified technical staff with considerable experience in emissions measurement.

B.4 Comments

The existence of BAR and OIML Standards (and others) should guarantee that an analyser is built to and performs to a certain minimum standard. However, using an analytical bench that is capable of meeting the requirements of e.g. OIML 1 but incorporating other components of lower quality to reduce costs results in a total package in which there is far less confidence in its ability to maintaining reliable and accurate operation.

One of the low-cost analysers assessed appeared to calibrate satisfactorily and also read the calibration gas values correctly; however, it had a severe non-linearity fault with CO_2 measurement that was only evident when checked with a gas of a different value. If this analyser had been used for testing it would have given falsely high CO_2 readings and correspondingly calculated incorrect values of lambda.

The measurement ranges of gas analysers are generally calibrated using ambient air for their zero setting and a span gas typically of a value approximately 80% to 90% of the full scale of the range to avoid extrapolation of errors.

Standards now specify the nominal mixture for calibration as;

- CO 3.5%
- CO_2 14%
- HC (propane) 2000 ppm
- N_2 balance

Ambient air is used for calibration of the O_2 cell.

While these values (particularly for CO and HC) do not correspond to the 80% to 90% of the measurement ranges, they do represent typical maximums for actual measurements expected from modern vehicles and therefore provide an accurate calibration for the range of use.

One company performing a calibration service for analysers was discovered to be using a gas mixture with only 7.5% CO_2 in the mixture, risking obtaining either high or low readings at the typical levels of 14% CO_2 in vehicle exhaust, as any calibration errors would be expanded.

Correct conducting of an emissions test is as vital for accurate results as having an accurately reading analyser.

In the UK, analysers must have full approval for use and be programmed with the official MOT emissions test procedure. Oil temperature and engine rpm are monitored and many analysers will only permit measurement when the correct operating conditions are met. In addition, only authorised personnel are permitted to perform the testing.

Warrant of Fitness testing stations have different needs for emissions analysers compared to auto repairers, who may additionally be licensed to issue WoFs. Auto repairers require to be able to diagnose faults with vehicles and so would have an interest in features of analysers that would be unnecessary for the simple execution of a WoF emissions test. Measurements of NO are only meaningful if conducted with the vehicle running under load and consequently are not of particular value for simple WoF tests.

Analysers with integral printers to record the results of the emissions tests could generally also provide a duplicate printout that could be given to the owner of the vehicle. Before vehicle registrations and other details could be included on the printout, by entering these via a keypad, either on the analyser itself or from a remote unit. Inputting this information via the keypads could be quite time-consuming and writing vehicle details onto the printout by hand was more common in the project. Processing and storage of this data requires retrieval and manual entry onto computer, which is time-consuming and also introduces the possibility for errors to occur.

Table 15: Comparison of Analysers

Gas		AVL DIGAS 4000	Autodiagnostics ADS9000	Autodiagnostics ADS500	AIRREX HG540	BOSCH BEA250	CODA 5 gas	KANE AUTO 4-2	Motorscan 8020	SPTC Autochek	OPUS 40B
HC	**Method**	NDIR	NDIR	NDIR	NDIR	NDIR	NDIR	NDIR	NDIR	NDIR	NDIR
	Range (ppm)	0 – 20,000	0 – 10,000	0 – 2,000	0 – 10,000	0 – 9,999	0 – 30,000	0 – 10,000	0 – 10,000	0 – 30,000	0 – 20,000
	Resolution (ppm)	1	1	1	1	1	1	1	1	1	1
	Accuracy		±11ppm - 3%	±11ppm - 3%			±4ppm (<2000)	±12ppm - 5%		±3%	±4ppm (<2000)
CO	**Method**	NDIR	NDIR	NDIR	NDIR	NDIR	NDIR	NDIR	NDIR	NDIR	NDIR
	Range (% vol)	0 - 10	0 - 10	0 - 10	0 – 9,999	0 - 10	0 - 15	0 - 20	0 - 14	0 - 10	0 - 10
	Resolution (% vol)	0.01	0.01	0.01	0.001	0.001	0.001	0.01	0.01	0.01	0.01
	Accuracy		± 0.06% (<2%)	± 0.06% (<2%)			±0.02 (<10%)	±0.06% - 5%		±3%	±0.02%
CO2	**Method**	NDIR	NDIR	NDIR	NDIR	NDIR	NDIR	NDIR	NDIR	NDIR	NDIR
	Range (% vol)	0 - 20	0 - 20	0 - 20	0 - 20	0 - 18	0 - 20	0 - 20	0 -18	0 - 20	0 - 20
	Resolution (% vol)	0.1	0.01	0.01	0.01	0.01	0.01	0.1	0.01	0.01	0.1
	Accuracy		± 0.4%	± 0.4%			±0.3% (<16%)	±0.5% - 5%		±3%	±0.3%
O2	**Method**	Cell	Cell	Cell	Cell	Cell	Cell	Cell	Cell	Cell	Cell
	Range (% vol)	0 - 25	0 - 25	0 - 23	0 - 25	0 - 22	0 - 25	0 - 25	0 - 25	0 - 25	0 - 21
	Resolution (% vol)	0.01	0.1	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.1
	Accuracy		± 0.2%	± 0.1%			±0.1%	±0.1% - 5%		±3%	±0.1%
NO	**Method**	Cell					Cell		Cell		
	Range (ppm)	0 – 5,000					0 – 5,000		0 – 4,000		
	Resolution (ppm)	1					1		1		
	Accuracy						±20 ppm				
OIML Class		1	1	1	?	0	1	1	0	1	1
Bar 90/97			90	90			97			97	
Country of Origin		Austria	Australia	Australia	Korea	Germany	Australia	UK	Italy	Korea	Sweden
Bench Manufacturer		?	Andros	Andros	?	Siemens	Andros	Kane	Siemens	?	Andros
Approximate Cost		$23,000	N/A	N/A	$3,500	?	$7,800	$8,000	$8,900	?	$6,200

Table 16: Analyser Features and Performance Assessment

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

Features	AVL DIGAS 4000	Autodiagnostics ADS9000	Autodiagnostics ADS500	AIRREX HG540	BOSCH BEA250	CODA 5 gas	KANE AUTO 4-2	Motorscan 8020	SPTC Autochek	OPUS 40B
HC Residue check	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Leak check	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Low flow indication	Yes	Yes	Yes	?	Yes	Yes	Yes	Yes	Yes	Yes
Size	Large	Medium	Medium	Small	Large	Medium	Miniature	Large	Small	Large
Display	Integral	Separate PC	Integral	Integral	Integral	Integral	Integral	Integral	Integral	Integral
Control	Integral	PC keyboard	Integral	Integral	Integral	Integral	Integral	Integral	Integral	Integral
Remote Control?			PC link				PC link	Yes		Capable
CO Corrected	Yes	Yes	Yes	No		Yes	No	Yes	?	Printed
NO capable?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Printer	Yes	Separate	Integral	Integral	Yes	Separate	IR beam	Integral	Integral	Integral
Recording	Yes	Yes	Via PC	?	?	Yes	Yes	?	?	Capable
Oil Temp/RPM	Yes	Yes	Capable		Yes	Yes	Yes	Yes	Yes	Capable
Official Procedure	Yes	No	No	No	Yes	No	Other model	Yes	No	Capable
Star Ratings										
Ease of Use	* * * * *	* * *	* * * *	* *	* * * * *	* * * * *	* * * * *	* * * *	* *	* * * *
Accuracy Gas 1	* * * * *	* * * * *	* * * *	*	* * * * *	* * * * *	* * *	* * * *	*	* * * * *
Accuracy Gas 2	* * * * *	* * * * *	* * * * *	*	* * * * *	* * * * *	* * * *	* * * *	*	* * * * *
Calibration Drift	* * * * *	* * * * *	* * *	*	* * * * *	* * * *	* * *	* * * *	*	* * * *
Sample line / probe	* * * * *	* * *	* * *	*	* * * *	* * * *	* * *	* * * * *	*	* * * * *
Pump	* * * *	* * *	* * *	*	* * * *	* * *	* * * *	* * * * *	*	* * * * *
Filtration	* * * * *	* * *	* * *	*	* * *	* * *	* *	* * * * *	*	* * *
Confidence	* * * * *	* * * *	* * * *		* * * * *	* * * *	*	* * * *		* * * * *

Appendix C: Test Sheets and Test Protocols

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.

PETROL 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:

% CO	ppm HC

And indicates the emissions performance of the engine was:

Good	Fair	Poor

The post-repair emissions test result was:

% CO	ppm HC

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 have been used as a guide to provide the emissions performance of your vehicle.

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 1: Indication of Emissions Performance of the 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 – Petrol

Start of Emissions Test

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
    - Blue or black smoke
    - Abnormal noise

    → if one of the above DO NOT PROCEED FURTHER. Still fill out a visual inspection sheet and put reason for not proceeding further on this sheet. Inform vehicle presenter
4. Zero analyzer where this does not automatically occur
5. Check engine 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 analyzer emissions results are sensible for ambient air:
    - CO less than 0.01%
    - CO_2 less than 0.1%
    - HC less than 20ppm
    - O_2 in range of 20.5%-21%

    → Note any problems and alert Andrew Campbell on acampbell@fueltechnology.net or (04)977 5795
7. Insert probe 250mm into exhaust pipe
8. Select 'sample mode' on analyzer
9. Check emissions results are sensible:
    - For older vehicles or non-catalyst vehicles:
        - CO less than 5.0%
        - CO_2 less than 13%-15.5%
        - HC less than 2000ppm
        - O_2 less than 3%

        → If not, check probe is correctly inserted and engine is warm
    - For newer vehicles
        - CO less than 0.5%
        - CO_2 less than 14%-15.5%
        - HC less than 200ppm
        - O_2 less than 1%

        → If not, check probe is correctly inserted and engine is warm
10. High idle test:
    - Operate the engine at 2250-2750rpm (ie at 2500rpm if possible) for 30-60 seconds, recording the emission results as soon as the analyzer is stable after the 30-second time, or at 60 seconds, whichever is sooner.
    - Press print
11. Low idle test:
    - Release the throttle and idle at normal low idle speed.
    - Note if idle is not at 500-1,100rpm
    - Record/print emission results after 120 seconds
12. Tear off print out, record the vehicle's data on the print out and attach to the vehicle's Inspection Form.

End of Emissions Test

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 D: Data Quality Assurance Criteria

Idle simple test data was excluded from analysis where the following quality assurance criteria were not met:

- Engine technology was not provided;
- Exhaust levels of (natural) idle or fast idle $CO + CO_2 > 16$;
- Exhaust levels of (natural) idle or fast idle $CO + CO_2 < 9$;
- Exhaust levels of (natural) idle or fast idle $O_2 > 2.5$;
- (Natural) idle or fast idle lambda > 1.3.

Visual inspection data was excluded from analysis where the following quality assurance criteria were not met:

- Fuel was diesel;
- Year of manufacture was not provided;
- Odometer reading was not provided;
- Odometer reading was greater than 500,000 km;
- A Technology 4 vehicle was manufactured before 1978;
- It could not be certainly determined whether a test vehicle was equipped with a catalyst.

Appendix E: Data From Idle Simple Testing Vehicles

Table 17: Data from the Idle Simple Test Data Set Adjusted to Take Account of the Less Frequent Safety Inspections for Newer Vehicles

			Engine Technology			
Test Location and Sample Size	Origin		T1	T2	T3	T4
WHANGAREI	NZ-New	N	3	7	1	3
Quality-tested sample 23		Y	1986.3	1989	1993	1999.7
Adjusted sample size 26		ODO	18.3	16.9	20.6	6.4
		percent	21	50	7	21
	Used	N	1	1	1	9
	Japanese	Y	1991	1990	1989	1996.6
	Imports	ODO	19.2	23.3	15.8	12.9
		percent	8	8	8	75
AUCKLAND	NZ-New	N	16	23	6	33
Quality-tested sample 116		Y	1987.4	1995.2	1998.7	2000
Adjusted sample size 141		ODO	16.7	12.6	8.6	6.6
		percent	21	29	8	42
	Used	N	1	10	8	44
	Japanese	Y	1982	1989	1990.3	1995
	Imports	ODO	24.4	17	17.4	11.4
		percent	2	16	13	70
WAITAKERE	NZ-New	N	27	16	32	49
Quality-tested sample 241		Y	1990.2	1993.8	1995.8	1998.6
Adjusted sample size 270		ODO	16.2	14.9	10.7	8.3
		percent	22	13	26	40
	Used	N	6	10	42	88
	Japanese	Y	1991	1993.9	1992.8	1993.8
	Imports	ODO	14.6	14	13.3	12.4
		percent	4	7	29	60
HAMILTON	NZ-New	N	76	67	68	78
Quality-tested sample 574		Y	1989.1	1992.1	1996.3	2000.1
Adjusted sample size 632		ODO	17.6	16.4	13.3	7.5
		percent	26	23	24	27
	Used	N	33	30	102	178
	Japanese	Y	1991	1991.6	1993.3	1993.8
	Imports	ODO	15.1	16.8	12.8	13
		percent	10	9	30	52

			Engine Technology			
			T1	T2	T3	T4
PALMERSTON NORTH	NZ-New	N	3	4	2	1
Quality-tested sample 25		Y	1989.3	1992.5	2000	1996
Adjusted sample size 28		ODO	17	20.5	9.5	10.4
		percent	30	40	20	10
	Used	N		3	2	13
	Japanese	Y		1990.7	1995.5	1994.5
	Imports	ODO		17.3	8.9	11.8
		percent		17	11	72
CHRISTCHURCH	NZ-New	N	15	12	4	14
Quality-tested sample 100		Y	1987.7	1995.3	1999.5	2000.2
Adjusted sample size 117		ODO	18.2	13.2	15	10.3
		percent	33	27	9	31
	Used	N	0	2	17	53
	Japanese	Y		1988.5	1993.2	1994.3
	Imports	ODO		14.1	12.6	12.5
		percent		3	24	74
DUNEDIN	NZ-New	N	8	2	0	4
Quality-tested sample 25		Y	1986.5	1991.5	0	1994.8
Adjusted sample size 26		ODO	18.5	19.3	0	13.3
		percent	57	14	0	29
	Used	N	2	1	1	8
	Japanese	Y	1989	1983	1984	1992
	Imports	ODO	13.3	17	20.1	14
		percent	17	8	8	67
Total Adjusted Sample 1240						

N: Number of data sets in sample after adjustment.
Y: Average year of manufacture.
ODO: Odometer reading.

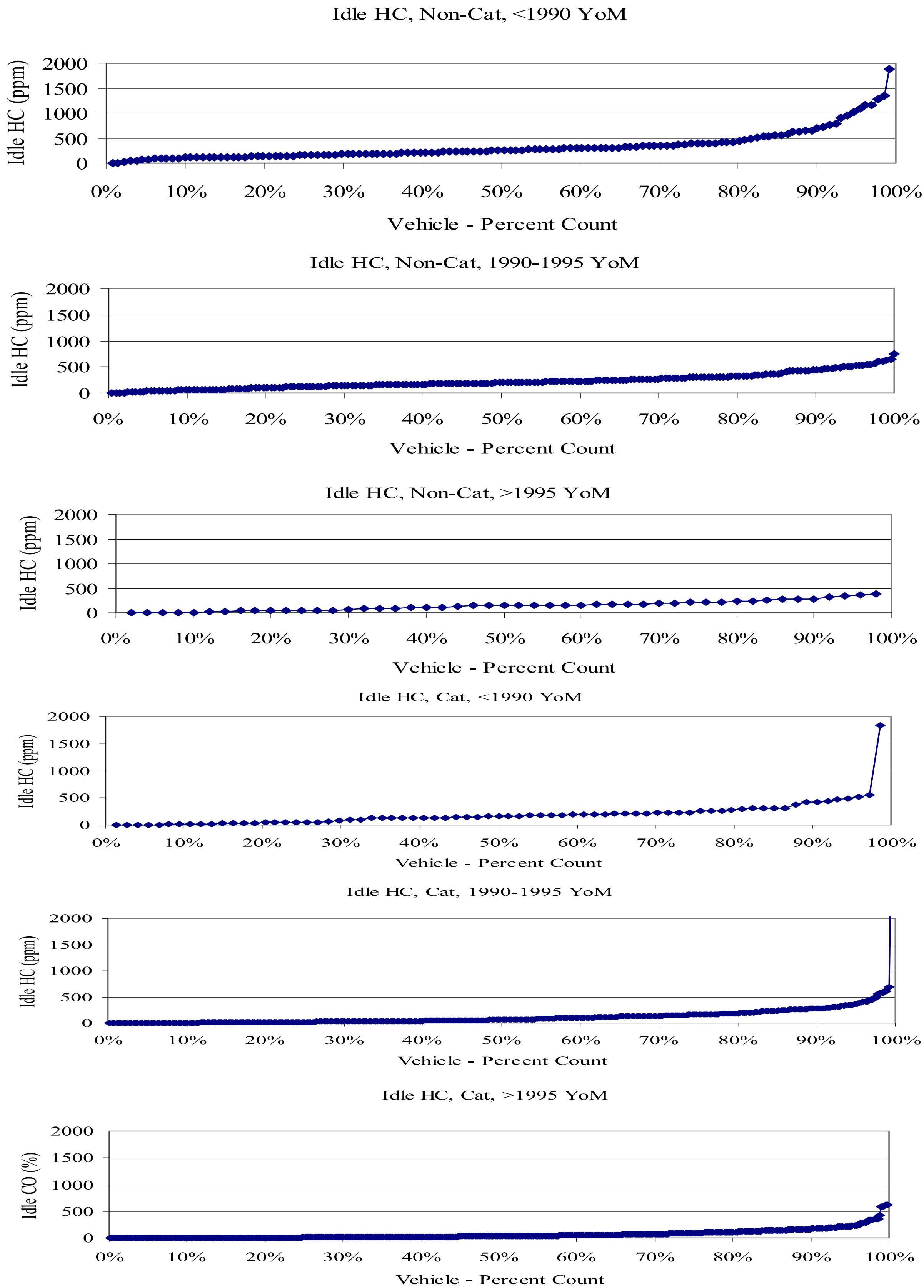

Figure 37: (Natural) Idle HC Percentile Plots With Vehicles Ranked Lowest to Highest Emitters For Catalyst- and Non-Catalyst-Equipped Vehicles and Different Year Ranges.

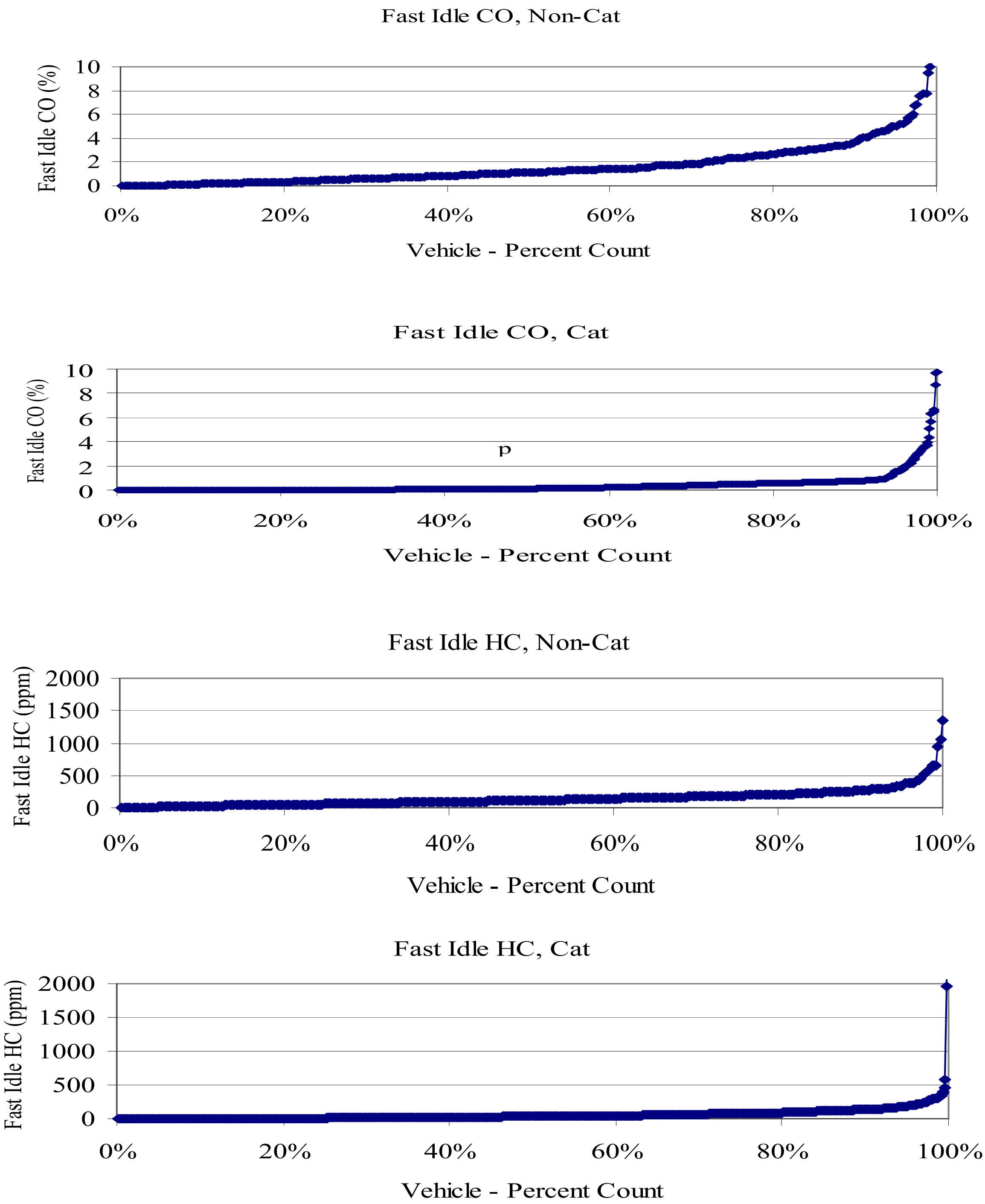

Figure 38: Fast Idle CO and HC Percentile Plots With Vehicles Ranked Lowest to Highest Emitters For Catalyst- and Non-Catalyst-Equipped Vehicles and Different Year Ranges.

Appendix F: Data From Visual Inspection of Vehicles

Table 18: Visual Inspection Data Adjusted for the Timing of Safety Inspections for Newer Vehicles.

			Engine Technology			
Test Site No. and Location	Origin		T1	T2	T3	T4
WHANGAREI	"NZ NEW"	N	38	39	10	17
Adjusted sample size: 191		Y	1988.9	1993.1	1989.6	1996.1
	JAPANESE	N	13	10	17	47
	IMPORTS	Y	1989.2	1992.1	1990.2	1993.7
AUCKLAND	"NZ NEW"	N	8	13	3	17
Adjusted sample size: 96		Y	1990.9	1995.1	1998.7	1999.6
	JAPANESE	N	0	9	6	40
	IMPORTS	Y	N/A	1989.1	1989.8	1994.6
WAITAKERE	"NZ NEW"	N	30	16	25	29
Adjusted sample size: 232		Y	1990	1993.8	1994.6	1997.8
	JAPANESE	N	6	9	37	80
	IMPORTS	Y	1991	1993.2	1992.4	1993.8
HAMILTON	"NZ NEW"	N	71	55	51	42
Adjusted sample size: 524		Y	1989.2	1991.9	1995.2	1999.6
	JAPANESE	N	31	25	97	152
	IMPORTS	Y	1990.8	1991.5	1993.2	1993.5
PALMERSTON NORTH	"NZ NEW"	N	31	21	6	23
Adjusted sample size: 156		Y	1986.7	1992.6	1993.3	1998.7
	JAPANESE	N	5	11	11	48
	IMPORTS	Y	1991	1992.3	1990.5	1993.7
LOWER HUTT	"NZ NEW"	N	31	33	1	17
Adjusted sample size: 163		Y	1988.8	1994.9	2002	1998.1
	JAPANESE	N	10	14	6	51
	IMPORTS	Y	1988.6	1992.7	1991.3	1994.1

			Engine Technology			
			T1	T2	T3	T4
BLENHEIM	"NZ NEW"	N	69	17	3	20
Adjusted sample size: 179		Y	1987	1990.4	1996.7	1998.2
	JAPANESE	N	9	7	8	46
	IMPORTS	Y	1988.3	1991	1989.3	1992.9
NELSON	"NZ NEW"	N	52	27	6	15
Adjusted sample size: 186		Y	1985.3	1992.1	1993	1996.9
	JAPANESE	N	7	13	10	56
	IMPORTS	Y	1987.9	1992.2	1989.3	1992.3
CHRISTCHURCH	"NZ NEW"	N	15	10	2	8
Adjusted sample size: 98		Y	1986.6	1992.4	1992.1	1997.6
	JAPANESE	N	0	2	14	47
	IMPORTS	Y	N/A	1988.5	1991.9	1993.8
TIMARU	"NZ NEW"	N	38	13	8	15
Adjusted sample size: 198		Y	1987.7	1994.3	1999.5	1999.6
	JAPANESE	N	14	12	28	70
	IMPORTS	Y	1990.6	1992.7	1990.9	1992.7
DUNEDIN	"NZ NEW"	N	41	18	4	47
Adjusted sample size: 208		Y	1988	1992.5	1994	1996.8
	JAPANESE	N	5	9	7	77
	IMPORT	Y	1988.2	1989.2	1990.3	1993.8
ALEXANDRA	"NZ NEW"	N	44	5	4	25
Adjusted sample size: 169		Y	1984.9	1991	1987.5	1995.2
	JAPANESE	N	17	6	9	59
	IMPORTS	Y	1990.7	1988.5	1991.6	1992.8
INVERCARGILL	"NZ NEW"	N	70	19	3	24
Adjusted sample size: 207		Y	1988.6	1991.8	1993.3	1993.9
	JAPANESE	N	16	9	15	51
	IMPORTS	Y	1988.6	1989.2	1989.9	1992
Total Adjusted sample: 2607						

N: Number of data sets after adjustment

Y: Average year of manufacture

T1 to T4: Engine technology categories 1 to 4

Appendix G: (Natural) Idle and Fast Idle Emissions Result Distributions and Percentile Plots For The Adjusted Idle Data Set

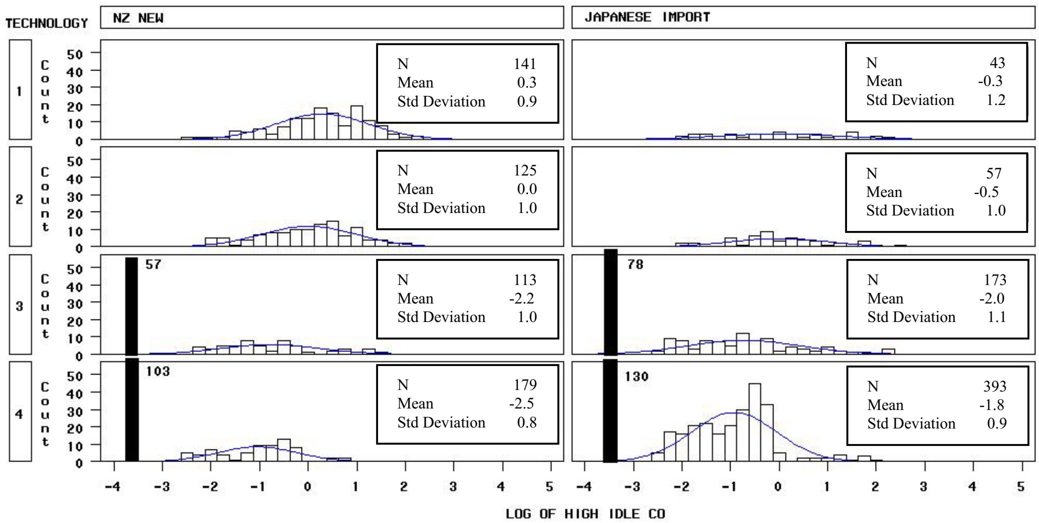

Figure 39: Vehicle Count Distribution of the Adjusted Idle Data Set Versus Log of Fast Idle CO by Engine Technology and Vehicle Origin Taking Near-Zero Emissions Vehicles into Consideration.

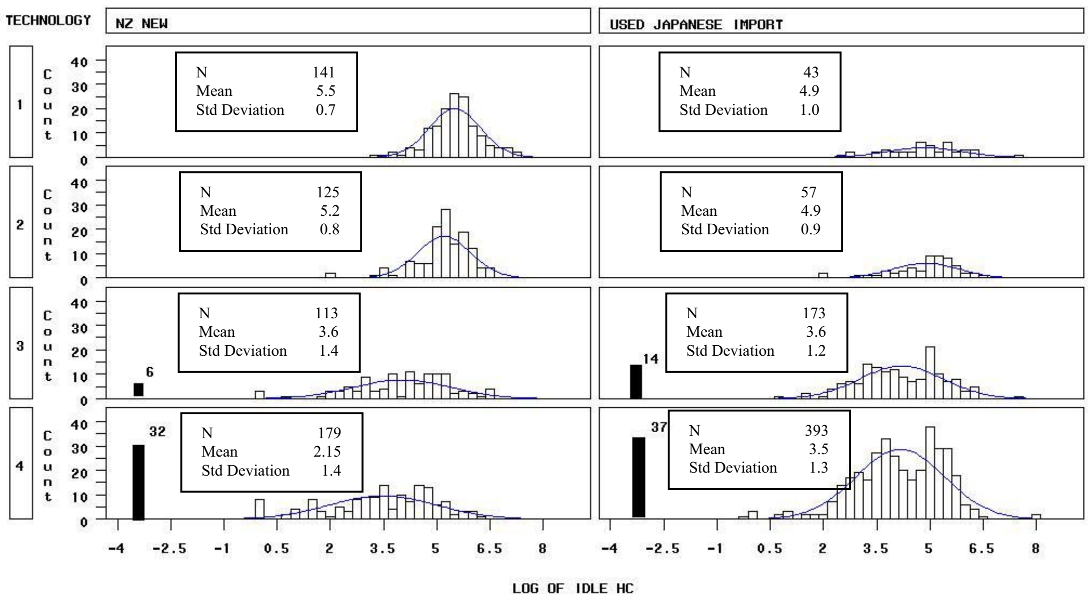

Figure 40: Vehicle Count Distribution of the Adjusted Idle Data Set Versus Log of (Natural) Idle HC by Engine Technology and Vehicle Origin Taking Near-Zero Emissions Vehicles into Consideration.

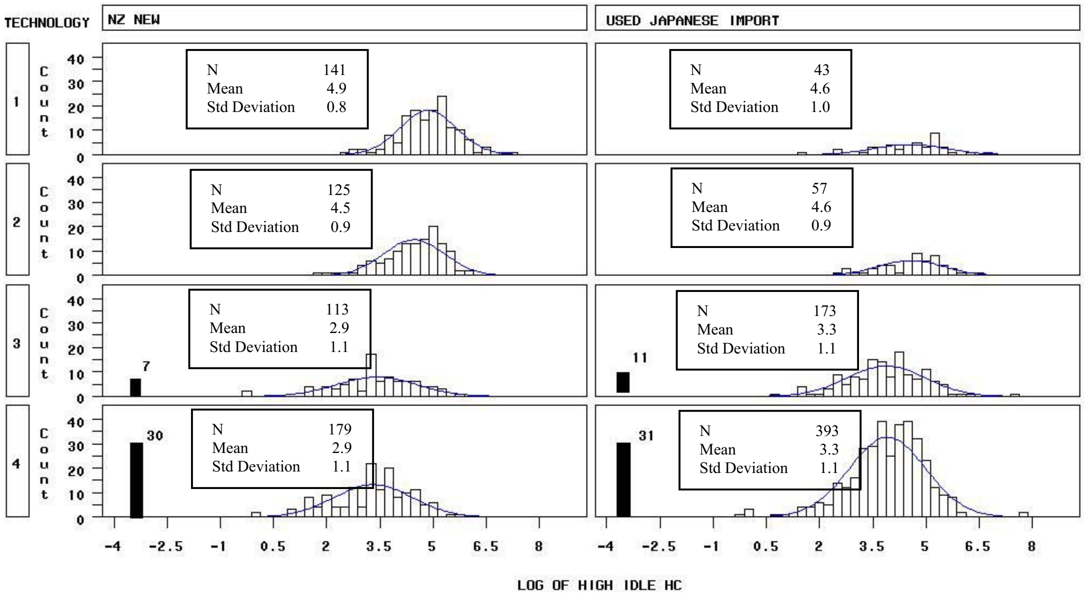

Figure 41: Vehicle Count Distribution of the Adjusted Idle Data Set Versus Log of Fast Idle HC by Engine Technology and Vehicle Origin Taking Near-Zero Emissions Vehicles into Consideration.

Appendix H: Evolution of Idle Simple Testing In The UK to Keep Pace With That of the Petrol Engine.

Simple emissions testing has evolved to keep pace with engine technology. Overseas, early, low-engine technology vehicles were simply visually checked for excessive blue or black emissions from the tail-pipe. The next generation of vehicles were tested with simple, two-gas (CO and HC) emissions analysers with emissions ranges being considered being well within the measurement range of the simple analysers used. A series of changes in vehicle emissions regulations then necessitated the use of exhaust catalysts on vehicles, then more sophisticated fuel metering coupled with the use of more sophisticated catalysts. The latter was best simple-tested using four-gas analysers and included a test at elevated engine speed. Petrol vehicles now entering the market generally have such low emissions that the amounts of the various emissions being measured are below the resolution of idle simple test analysers. Various countries are considering new emissions check options for these vehicles.

Table 19 summarizes this evolution of petrol vehicle engine technology and the changes in the simple emissions testing procedures in use in the UK (VOSA, 2004) and Ireland to match the engine technologies concerned.

Table 19: The Evolution of Petrol Engine Technology and the Idle Simple Testing used in the United Kingdom and Ireland to Match these Engine Technologies

Overseas Circa	Evolution of Petrol Vehicle Engine Technology	Simple Emissions Test Form and Function
Pre-mid-1970s	Vehicles with basic fuel metering.	Visual inspection for blue or black smoke indicating engine in poor mechanical condition (still current test in UK for pre-1975 vehicles)
Mid-1970s – Mid-1980s	Vehicles received more sophisticated fuel metering to improve stability and performance but still open-loop. No exhaust after-treatment.	Check of (natural) idle CO and HC to check fuel metering near to stoichiometric. UK cut-points: 4.5% CO and 1200 ppm HC, Ireland cut-points 4.5% CO and 1200 ppm HC.
Mid-1980s – Early 1990s	Vehicles with more sophisticated fuel metering but still open-loop (no feedback). No exhaust after-treatment.	Check of (natural) idle CO and HC to check fuel metering near to stoichiometric. UK cut-points: 3.5% CO and 1200 ppm HC. Ireland cut-points 3.5% CO and 750 ppm HC.
Mid-1980s - Present	Vehicles with sophisticated closed-loop fuel metering and catalyst exhaust gas after- treatment.	Check (natural) idle CO to check (possibly) open loop idle fuel metering setting. Check of fast idle CO, HC and lambda to check closed loop fuel metering appears to be working. UK and South Ireland cut-points based on engine manufacturer's design performance and typically around 0.5% CO at (natural) idle, 0.3% CO and 200 ppm HC at fast idle.
Future	Vehicles with sophisticated closed-loop fuel metering, exhaust gas after-treatment and onboard fault	Possibly check the onboard diagnostics status (currently being considered in the UK)

	diagnostics.	

Appendix I: Test Facility and Emissions Test Procedures

This appendix provides an overview of the techniques and equipment used to measure transient drive cycle emissions factors.

I.1 Transient Drive Cycle

Emission factors are generally measured by driving a vehicle on a chassis dynamometer under conditions of interest, such as in a transient drive cycle representing on-road driving conditions. A drive cycle will normally consist of periods of idle, acceleration, relatively steady speed, and deceleration. The drive cycles used to test petrol vehicles in the project were the IM240 drive cycle, illustrated in Figure 42, being the first 240 seconds of the FTP drive cycle (a cycle used for certification of new vehicles in the United States) and the CBDC drive cycle, illustrated in Figure 43.

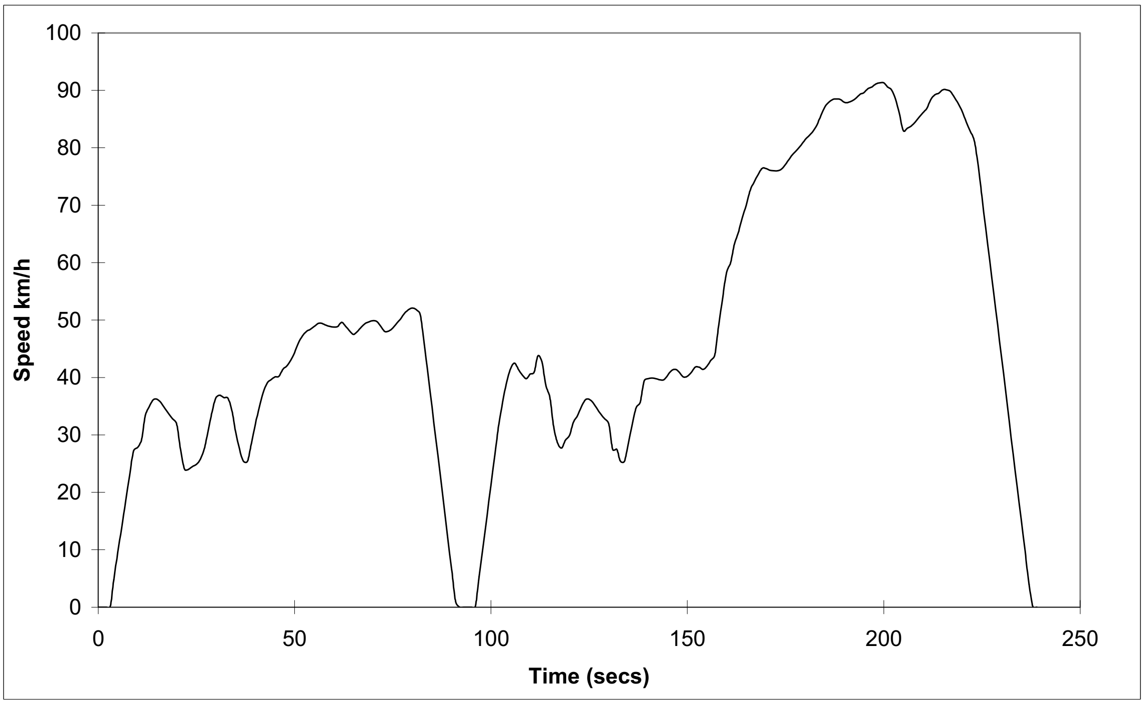

Figure 42: IM240 Drive Cycle.

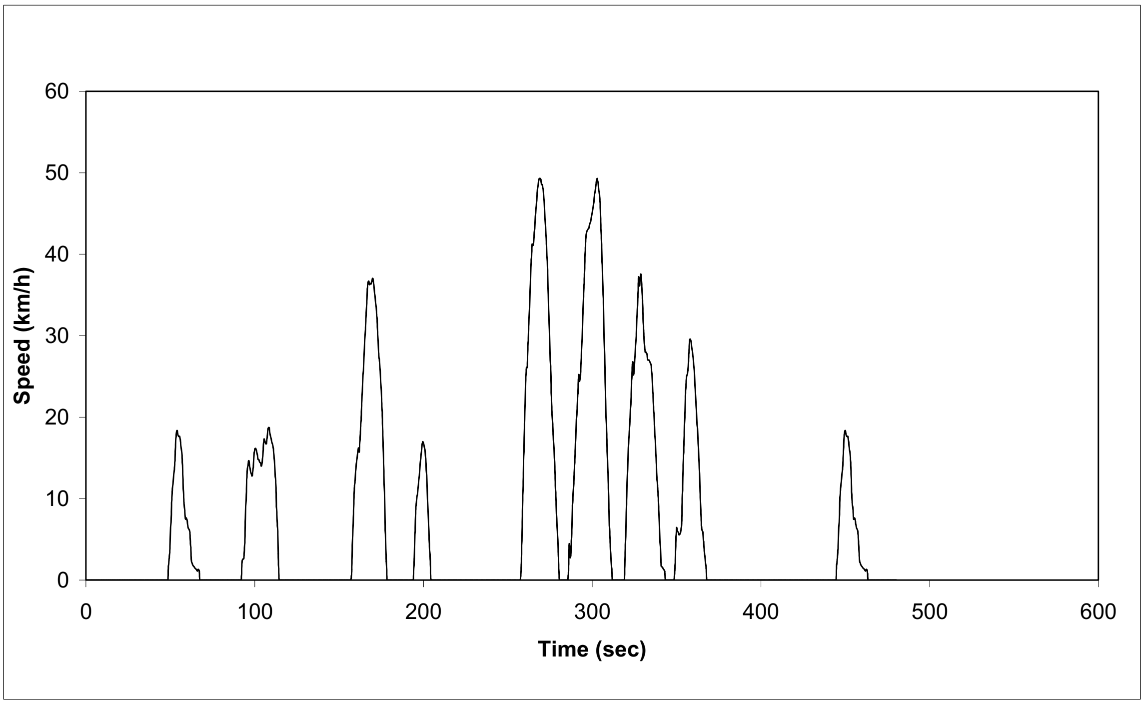

Figure 43: Central Business District Congested Cycle.

The University of Auckland's Energy Fuels Research Unit (EFRU) uses a computerised driver's aid to display drive cycles to guide the vehicle operator through a test cycle. The vehicle operator drives the vehicle in the same manner as normal on-road driving, to match the vehicle's actual speed on the chassis dynamometer to the desired drive cycle speed displayed on the screen. The system enables any driving sequence to be programmed to represent any type of driving that is desired.

I.2 Chassis Dynamometer Testing

The chassis dynamometer 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 here since testing to the IM240 drive cycle required following a similar procedure).

I.3 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.

A schematic of a CVS system is shown in Figure 45. 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.

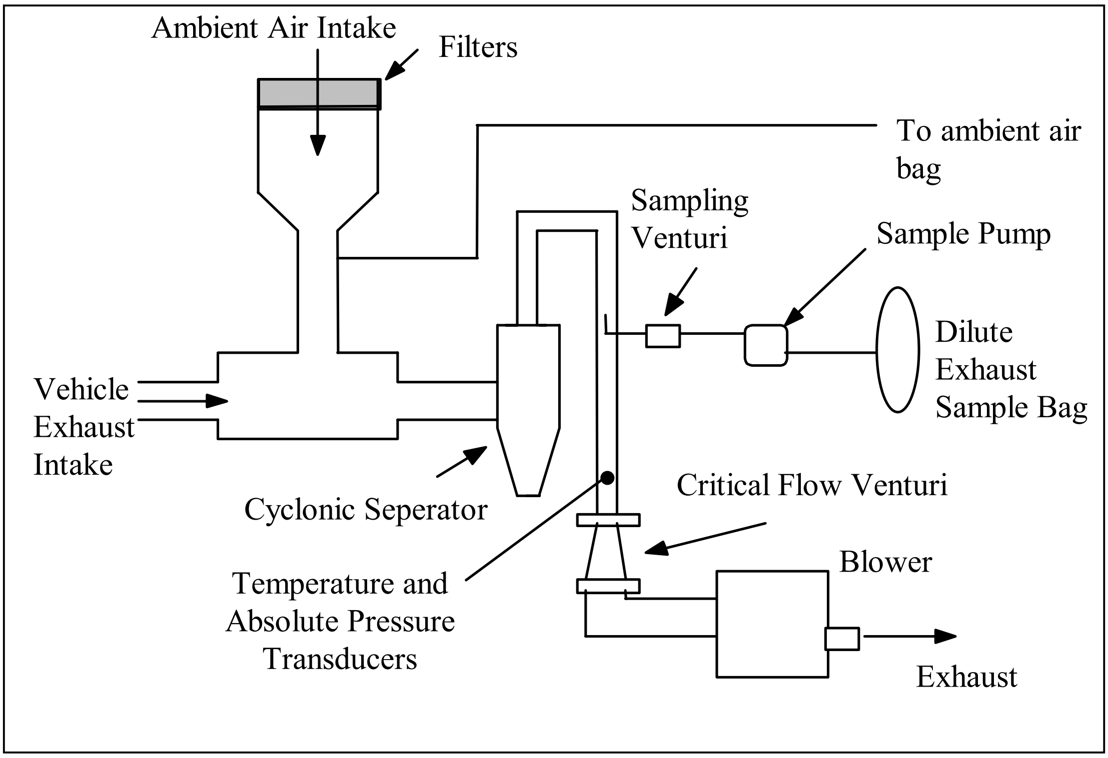

Figure 44: Schematic of CVS System.

I.4 CVS Unit

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.

I.5 Exhaust Gas Analysers

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%.

I.6 CVS System Propane Shot Verification

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.

Appendix J: Dynamometer Test Results and Analysis Plots

Table 20: Vehicle Details.

		Registration	Test date	Manufacturer	Model	NZ New?	Tech	ODO km	Year	Engine size litres	EFI	O2 sensor	Cat	
1		BWF605	29-Sep-04	Holden	Crewman S	Y	4	13099	2004	3.8	Y	y	CAT	1
2		HDLADY	01-Oct-04	Hyundai	Sonata	Y	4	9954	2004	2.4	Y	y	CAT	2
3		CR496	17-Sep-04	Ford	Fairlane	Y	4	22264	2003	4	Y	y	CAT	3
4		ABC188	29-Sep-04	Peugot	206XT	Y	4	31450	2001	1.6	Y	y	CAT	4
5		QMA	06-Oct-04	Ford	Falcon XR6	Y	4	108720	2000	4	Y	y	CAT	5
6		ZQ2376	12-Oct-04	Volkswagen	Golf	Y	4	47789	2000	1.6	Y	y	CAT	6
7		BFP661	30-Sep-04	Volkswagen	Passat	N	4	89099	1999	1.8	Y	y	CAT	7
8		XR9447	06-Oct-04	Mitsubishi	Diamante	Y	3	109065	1999	3	Y	n	Ocat	8
9		YH7922	22-Sep-04	Mitsubishi	L200	Y	4	145629	1999	2.4	Y	y	CAT	9
10		YN2857	12-Oct-04	Toyota	Hiace	Y	2	75301	1999	2.4	Y	n	0	10
11		YO1086	27-Sep-04	Toyota	Corolla	Y	3	72505	1999	1.6	Y	n	CAT	11
12		XC4378	21-Sep-04	Honda	Accord LX	Y	4	93397	1998	2.3	Y	y	0	12
13		XK2891	22-Sep-04	Toyota	Corolla	Y	3	75108	1998	1.6	Y	n	Ocat	13
14		SXSLESC	08-Oct-04	Toyota	Trueno S	N	4	122477	1997	1.6	Y	y	CAT	14
15		SXSLESn	08-Oct-04	Toyota	Trueno S	N	2	122477	1997	1.6	Y	y	0	15
16		UZ9537	17-Sep-04	Honda	Civic	Y	2	152552	1997	1.6	Y	n	0	16
17	S D	UZ9537 -	05-Nov-04	Honda	Civic	Y	2	156097	1997	1.6	Y	n	0	17
18		YJ7492	24-Sep-04	Nissan	Sunny	N	4	66427	1997	1.5	Y	y	CAT	18
19		BGB544	19-Oct-04	Mazda	Capella	N	4	100236	1996	1.8	Y	y	CAT	19
20		BSG 955	27-Sep-04	Toyota	Estima	N	4	129219	1996	2.4	Y	y	CAT	20
21		BSM765	01-Oct-04	Toyota	Starlet	N	4	120756	1996	1.3	Y	y	CAT	21
22	R CS	BSM765	22-Oct-04	Toyota	Starlet	N	4	121326	1996	1.3	Y	y	CAT	22
23	R 0	BSM765	10-Oct-04	Toyota	Starlet	N	4	121292	1996	1.3	Y	y	CAT	23
24		ABF398	11-Oct-04	BMW	316i	N	2	146266	1995	1.6	Y	n	0	24
25		BCH361	22-Sep-04	BMW	318Ti	N	4	58483	1995	1.8	Y	y	CAT	25
26		WZ4621	28-Sep-04	Nissan	Primera GT	N	4	128853	1995	2	Y	y	CAT	26
27	R CS	WZ4621	08-Nov-04	Nissan	Primera 2.0eGT	N	4	128853	1995	2	Y	y	CAT	27
28		AAT783	24-Sep-04	Nissan	Lucino	N	4	137930	1994	1.5	Y	y	CAT	28
29		AKT600	29-Sep-04	Mitsubishi	Chariot	N	4	144358	1994	2.4	Y	y	CAT	29
30		Dealer	10-Sep-04	Mitsubishi	Delicia	N	4	119485	1994	3	N	n	0	30
31		SJ1151	16-Sep-04	Holden	Commodore	Y	4	144025	1994	3.8	Y	y	CAT	31
32	R CS	SJ1151	21-Dec-04	Holden	Commodore	y	4	148913	1994	3.8	Y	y	CAT	32
33		YS9785	27-Sep-04	Toyota	Carina ED	N	4	114449	1994	2	Y	y	CAT	33
34		SH9621	28-Sep-04	Daihatsu	Charade	Y	1	44591	1993	1	N	n	0	34
35		SM7218	29-Sep-04	Toyota	Corona	Y	2	191206	1993	2	Y	n	0	35
36	R CS	SM7218	29-Oct-04	Toyota	Corona	Y	2	191206	1993	2	Y	n	0	36
37		UQ3084	21-Sep-04	Mitsubishi	Galant MX	N	4	119792	1993	2	Y	y	CAT	37
38		ZH2726	19-Oct-04	Subaru	Legacy GT	N	4	151934	1993	2	Y	y	CAT	38
39	R CS	ZH2726	04-Nov-04	Subaru	Legacy GT	N	4	152216	1993	2	Y	y	CAT	39
40		AJA952	24-Sep-04	Toyota	Mr2	N	4	89715	1992	2	Y	y	CAT	40
41		RO1648	29-Sep-04	Daihatsu	Charade	Y	1	118539	1992	1	N	n	0	41
42		WU3734	28-Sep-04	Suzuki	Swift Gti	Y	4	257068	1992	1.3	Y	y	CAT	42
43		AMZ597	30-Sep-04	Nissan	Primera	N	4	136157	1991	1.8	Y	y	CAT	43
44		TU5174	12-Oct-04	Mazda	MX5 Eunos	N	2	180589	1991	1.6	Y	y	0	44
45		BRU157	06-Oct-04	BMW	M325i	Y	2	204154	1990	2.5	Y	n	0	45
46	R D	BRU157	22-Nov-04	BMW	M325i - 2dr	Y	2	205955	1990	2.5	Y	n	0	46
47		GTA V6	11-Oct-04	Renault Alpine	GTA V6	Y	1	57799	1990	3	Y	n	0	47
48	R CS	GTA V6	22-Nov-04	Renault Alpine	GTA V6	Y	1	57913	1990	3	N	n	0	48
49		PH7284	08-Oct-04	Pontiac	LeMans	Y	1	118786	1990	2	N	n	0	49
50		Z16984	22-Sep-04	Audi	902.3E	N	3	111396	1990	2.3	Y	n	Ocat	50
51		OO8646	30-Sep-04	Toyota	Cressida	Y	4	210247	1989	3	Y	y	CAT	51
52		OA4560	01-Oct-04	Lada	2104	Y	1	31442	1988	1.5	N	y	CAT	52
53		NZ5684	11-Oct-04	Holden	Barina	Y	1	75939	1987	1.3	N	n	0	53
54		UF2331	12-Oct-04	Toyota	Hiace SC	N	3	238980	1987	2	N	y	CAT	54
55		DGNFLY	21-Sep-04	Toyota	Mr2	N	2	122580	1986	1.6	Y	y	0	55
56		RD664	08-Oct-04	Mazda	Luce 929	N	2	258223	1986	2	Y	y	0	56
57		SJ892	06-Oct-04	Toyota	Mr2	N	2	166333	1986	1.6	Y	y	0	57
58	R CS	SJ892	09-Nov-04	Toyota	Mr2	N	2	166333	1986	1.6	Y	y	0	58
59		SW2306	07-Oct-04	Toyota	Surf Tour	N	4	234820	1984	2	Y	y	CAT	59
60		AUC190	11-Oct-04	Nissan	280 ZX	N	2	64620	1983	2.8	Y	y	0	60
61		KT5777	16-Sep-04	Mitsubishi	SigmaGL	Y	1	243766	1982	1.6	Y	n	0	61

S service
R repair
D dealer
CS Carburettor Specialists
O owner

CAT 3 way exhaust catalyst
Ocat oxidation catalyst

Table 21: Light Duty Petrol Data IM240 Cycle in g/km and g/s

	Registration	Year	Tech	IM240 CO g/km	IM240 CO2 g/km	IM240 HC g/km	IM240 NOx g/km	IM240 FC l/100km	IM240 CO mg/s	IM240 CO2 mg/s	IM240 HC mg/s	IM240 NOx mg/s	IM240 FC ml/s	
1	BWF605	2004	4	0.18	317.69	0.06	0.00	13.16	2.42	4186.92	0.77	0.05	1.73	1
2	HDLADY	2004	4	0.38	260.07	0.09	0.05	10.79	4.97	3410.22	1.18	0.60	1.41	2
3	CR496	2003	4	2.63	297.16	0.12	0.01	12.47	34.50	3896.86	1.63	0.17	1.64	3
4	ABC188	2001	4	0.46	195.79	0.07	0.01	8.13	5.98	2562.42	0.88	0.16	1.06	4
5	QMA	2000	4	3.38	284.15	0.05	0.11	11.98	44.57	3741.26	0.72	1.43	1.58	5
6	ZQ2376	2000	4	0.00	220.48	0.10	0.30	9.13	0.00	2902.13	1.34	3.91	1.20	6
7	BFF661	1999	4	0.72	244.12	0.04	0.01	10.15	9.40	3194.67	0.57	0.16	1.33	7
8	XR9447	1999	3	1.12	298.28	0.11	0.09	12.42	14.85	3942.33	1.46	1.16	1.64	8
9	YH7922	1999	4	1.31	270.90	0.09	0.35	11.30	17.30	3584.40	1.19	4.63	1.49	9
10	YN2857	1999	2	12.39	283.93	1.20	3.89	12.70	166.76	3821.29	16.15	52.31	1.71	10
11	YO1086	1999	3	0.37	196.71	0.08	0.04	8.17	4.84	2583.40	1.10	0.48	1.07	11
12	XC4378	1998	4	1.48	264.80	0.06	0.07	11.05	19.39	3469.32	0.80	0.94	1.45	12
13	XK2891	1998	3	0.66	202.57	0.10	0.08	8.43	8.70	2671.85	1.29	1.01	1.11	13
14	SXSLESC	1997	4	1.36	218.03	0.23	.	9.13	17.75	2841.61	3.05	.	1.19	14
15	SXSLESh	1997	2	8.35	197.72	1.77	2.36	8.95	109.94	2602.43	23.31	31.04	1.18	15
16	UZ9537	1997	2	***14.89***	183.89	1.27	1.36	8.74	***195.75***	2417.96	16.68	17.92	1.15	16
17	UZ9537 -	1997	2	23.46	173.94	1.23	1.18	8.88	308.05	2284.39	16.11	15.56	1.17	17
18	YJ7492	1997	4	8.71	205.79	0.35	1.32	9.12	114.80	2711.52	4.62	17.36	1.20	18
19	BGB544	1996	4	5.25	223.67	0.26	0.55	9.62	68.83	2934.68	3.46	7.28	1.26	19
20	BSG955	1996	4	3.46	296.79	0.16	0.28	12.52	45.68	3919.31	2.12	3.65	1.65	20
21	BSM765	1996	4	12.59	176.89	0.74	0.20	8.23	166.19	2334.12	9.82	2.59	1.09	21
22	BSM765	1996	4	3.45	177.43	0.25	0.15	7.59	45.46	2341.38	3.33	1.94	1.00	22
23	BSM765	1996	4	48.90	138.85	1.96	0.14	9.18	643.43	1827.01	25.79	1.89	1.21	23
24	ABF398	1995	2	8.13	217.74	1.65	2.76	9.75	107.51	2878.66	21.78	36.46	1.29	24
25	BCH361	1995	4	0.91	279.05	0.05	0.69	11.60	12.00	3681.10	0.65	9.16	1.53	25
26	WZ4621	1995	4	***14.61***	226.12	0.70	0.24	10.39	***192.92***	2985.23	9.25	3.21	1.37	26
27	WZ4621	1995	4	7.57	228.05	0.26	0.23	9.96	100.11	3016.92	3.49	2.98	1.32	27
28	AAT783	1994	4	9.06	201.79	0.51	1.21	9.00	119.71	2666.31	6.79	15.95	1.19	28
29	AKT600	1994	4	3.29	254.69	0.28	0.63	10.78	43.44	3366.97	3.68	8.28	1.43	29
30	Dealer	1994	4	1.36	330.62	0.30	0.43	13.80	18.10	4394.93	3.93	5.68	1.83	30
31	SJ1151	1994	4	3.35	282.54	0.23	0.59	11.93	44.36	3742.65	3.07	7.80	1.58	31
32	SJ1151	1994	4	3.50	279.15	0.18	0.62	11.79	46.91	3738.26	2.37	8.24	1.58	32
33	YS9785	1994	4	3.18	219.60	0.13	0.04	9.30	41.93	2896.78	1.77	0.56	1.23	33
34	SH9621	1993	1	***14.86***	146.96	1.58	0.81	7.25	***195.18***	1930.08	20.77	10.60	0.95	34
35	SM7218	1993	2	8.90	206.36	1.19	2.15	9.27	116.76	2707.35	15.59	28.23	1.22	35
36	SM7218	1993	2	6.45	203.29	0.93	2.40	8.95	85.23	2687.70	12.29	31.79	1.18	36
37	UQ3084	1993	4	1.96	250.83	0.24	0.68	10.53	25.69	3287.60	3.18	8.97	1.38	37
38	ZH2726	1993	4	5.98	310.67	0.32	1.12	13.28	78.89	4095.63	4.17	14.74	1.75	38
39	ZH2726	1993	4	5.22	305.14	0.23	1.18	12.99	69.00	4034.24	3.09	15.58	1.72	39
40	AJA952	1992	4	1.38	225.69	0.10	0.07	9.43	18.18	2967.95	1.32	0.87	1.24	40
41	RO1648	1992	1	***14.93***	144.14	1.82	1.28	7.17	***197.12***	1902.56	24.06	16.86	0.95	41
42	WU3734	1992	4	8.31	167.59	1.41	1.79	7.66	109.32	2205.09	18.59	23.56	1.01	42
43	AMZ597	1991	4	13.42	230.15	0.31	0.65	10.43	176.55	3027.70	4.05	8.57	1.37	43
44	TU5174	1991	2	12.12	216.92	1.01	2.55	9.89	159.78	2859.41	13.33	33.58	1.30	44
45	BRU157	1990	2	5.76	255.94	1.20	2.49	11.12	75.78	3364.56	15.82	32.77	1.46	45
46	BRU157	1990	1	3.62	251.37	1.19	2.64	10.79	48.13	3339.06	15.78	35.11	1.43	46
47	GTA V6	1990	1	***28.80***	281.90	4.59	2.05	13.21	***377.21***	3692.92	60.09	26.79	1.73	47
48	GTA V6	1990	1	44.78	258.51	3.20	1.05	14.02	595.44	3437.09	42.49	14.02	1.86	48
49	PH7284	1990	1	***14.69***	229.09	1.42	1.84	10.61	***192.93***	3007.71	18.58	24.14	1.39	49
50	Z16984	1990	3	1.43	260.60	0.10	1.11	10.88	18.79	3412.17	1.33	14.48	1.42	50
51	OC8646	1989	4	1.46	255.70	0.10	0.23	10.68	19.19	3362.46	1.34	2.97	1.40	51
52	OA4560	1988	1	7.67	200.56	3.12	2.49	9.20	101.72	2658.37	41.31	32.95	1.22	52
53	NZ5684	1987	1	***14.72***	178.26	1.54	2.46	8.53	***193.84***	2347.89	20.26	32.43	1.12	53
54	UF2331	1987	3	***28.30***	246.60	1.25	2.64	11.32	***372.01***	3241.81	16.50	34.67	1.49	54
55	DGNFLY	1986	2	13.50	196.08	0.54	0.14	9.06	178.88	2597.97	7.13	1.80	1.20	55
56	RD664	1986	2	***29.30***	211.37	5.07	0.74	10.35	***374.41***	2796.24	67.10	9.76	1.37	56
57	SJ892	1986	2	***14.61***	178.06	3.47	2.13	8.77	***193.94***	2362.96	46.09	28.29	1.16	57
58	SJ892	1986	2	9.89	176.43	1.35	2.49	8.12	131.18	2339.22	17.95	32.99	1.08	58
59	SW2306	1984	4	***14.35***	217.85	2.86	0.83	10.32	***192.05***	2914.68	38.27	11.08	1.38	59
60	AUC190	1983	2	***14.70***	291.72	2.59	2.33	13.36	***192.60***	3821.50	33.87	30.47	1.75	60
61	KT5777	1982	1	12.43	189.22	0.35	0.03	8.68	165.44	2518.72	4.72	0.46	1.16	61

underlined bold italic results maximum reading from CO analyser reached

bold italic results corrected based on correlation to CBD drive cycle

Table 22: Light Duty Petrol Data 60 km/h Steady Speed in g/km and g/s

	Registration	Year	Tech	60 km/h SS CO g/km	60 km/h SS CO2 g/km	60 km/h SS HC g/km	60 km/h SS NOx g/km	60 km/h SS FC l/100km	60 km/h CO mg/s	60 km/h CO2 mg/s	60 km/h HC mg/s	60 km/h NOx mg/s	60 km/h FC ml/s	
1	BWF605	2004	4	0.03	200.83	0.02	0.00	8.31	0.56	3366.94	0.38	0.02	1.39	1
2	HDLADY	2004	4	0.28	174.16	0.02	0.00	7.22	4.59	2896.25	0.30	0.07	1.20	2
3	CR496	2003	4	1.31	196.49	0.06	0.00	8.22	21.93	3282.72	1.03	0.01	1.37	3
4	ABC188	2001	4	0.02	132.93	0.01	0.06	5.50	0.37	2231.83	0.18	1.00	0.92	4
5	QMA	2000	4	0.01	191.09	0.01	0.00	7.90	0.20	3221.44	0.09	0.03	1.33	5
6	ZQ2376	2000	4	0.00	156.83	0.02	0.77	6.49	0.00	2630.82	0.28	12.92	1.09	6
7	BFP661	1999	4	0.51	165.36	0.02	0.00	6.87	8.49	2777.99	0.32	0.02	1.15	7
8	XR9447	1999	3	0.46	192.51	0.05	0.00	8.00	7.68	3216.49	0.83	0.02	1.34	8
9	YH7922	1999	4	0.31	177.31	0.04	0.17	7.36	5.17	2969.78	0.70	2.87	1.23	9
10	YN2857	1999	2	10.07	187.38	0.66	2.32	8.49	169.01	3144.88	11.00	39.01	1.42	10
11	YO1086	1999	3	0.14	134.76	0.02	0.00	5.58	2.42	2259.33	0.34	0.00	0.94	11
12	XC4378	1998	4	0.15	167.62	0.01	0.02	6.94	2.58	2803.10	0.24	0.27	1.16	12
13	XK2891	1998	3	0.09	141.22	0.01	0.00	5.85	1.48	2363.66	0.21	0.00	0.98	13
14	SXSLESC	1997	4	0.67	154.28	0.07	.	6.43	11.31	2602.82	1.11	.	1.09	14
15	SXSLESn	1997	2	5.75	141.87	0.87	1.06	6.35	96.56	2381.72	14.67	17.84	1.07	15
16	UZ9537	1997	2	11.73	123.62	0.75	0.86	5.97	196.20	2067.50	12.62	14.36	1.00	16
17	UZ9537 -	1997	2	16.24	118.51	0.73	0.78	6.05	271.13	1978.05	12.24	13.02	1.01	17
18	YJ7492	1997	4	2.42	131.99	0.13	0.84	5.63	40.69	2220.05	2.12	14.10	0.95	18
19	BGB544	1996	4	2.62	153.95	0.08	0.19	6.55	44.08	2592.07	1.29	3.16	1.10	19
20	BSG 955	1996	4	0.73	174.50	0.02	0.00	7.26	12.19	2924.96	0.29	0.05	1.22	20
21	BSM765	1996	4	6.87	119.10	0.83	0.03	5.48	114.70	1989.71	13.87	0.57	0.92	21
22	BSM765	1996	4	2.53	122.94	0.17	0.03	5.27	42.59	2072.03	2.82	0.43	0.89	22
23	BSM765	1996	4	5.45	118.29	0.65	0.02	5.33	90.95	1973.51	10.92	0.39	0.89	23
24	ABF398	1995	2	5.70	159.67	0.84	1.67	7.08	95.50	2675.20	14.16	28.05	1.19	24
25	BCH361	1995	4	0.41	178.44	0.02	0.01	7.41	6.84	2989.84	0.40	0.18	1.24	25
26	WZ4621	1995	4	8.43	142.33	0.65	0.06	6.52	141.32	2385.28	10.95	0.94	1.09	26
27	WZ4621	1995	4	1.13	147.20	0.14	0.07	6.18	18.85	2462.00	2.35	1.17	1.03	27
28	AAT783	1994	4	1.62	119.76	0.10	0.32	5.07	27.14	2010.00	1.61	5.34	0.85	28
29	AKT600	1994	4	1.01	153.84	0.12	0.16	6.44	17.06	2587.26	2.05	2.64	1.08	29
30	Dealer	1994	4	0.41	197.49	0.14	0.04	8.21	6.91	3311.56	2.27	0.61	1.38	30
31	SJ1151	1994	4	0.05	185.96	0.04	0.80	7.70	0.92	3131.60	0.71	13.39	1.30	31
32	SJ1151	1994	4	0.04	181.05	0.03	0.28	7.49	0.74	3029.02	0.47	4.69	1.25	32
33	YS9785	1994	4	0.74	143.91	0.08	0.00	6.01	12.38	2402.44	1.36	0.02	1.00	33
34	SH9621	1993	1	11.65	96.76	0.80	0.48	4.86	195.56	1624.92	13.43	8.10	0.82	34
35	SM7218	1993	2	6.62	147.63	0.62	1.23	6.62	110.86	2473.98	10.40	20.62	1.11	35
36	SM7218	1993	2	3.32	144.23	0.38	1.27	6.23	55.67	2419.42	6.37	21.31	1.04	36
37	UQ3084	1993	4	0.54	183.67	0.08	0.11	7.64	9.07	3064.38	1.31	1.89	1.27	37
38	ZH2726	1993	4	0.52	197.59	0.09	0.12	8.22	8.79	3329.33	1.47	2.05	1.38	38
39	ZH2726	1993	4	0.33	187.87	0.07	0.54	7.80	5.60	3164.09	1.18	9.04	1.31	39
40	AJA952	1992	4	0.43	168.61	0.03	0.01	7.00	7.18	2820.14	0.57	0.09	1.17	40
41	RO1648	1992	1	7.51	103.16	0.75	0.78	4.85	125.69	1727.00	12.63	13.01	0.81	41
42	WU3734	1992	4	3.65	114.23	0.65	0.86	5.05	61.34	1917.15	10.89	14.37	0.85	42
43	AMZ597	1991	4	2.28	98.08	0.12	0.28	4.22	38.17	1643.73	2.01	4.62	0.71	43
44	TU5174	1991	2	4.70	156.20	0.70	1.97	6.86	78.37	2604.00	11.63	32.81	1.14	44
45	BRU157	1990	2	1.23	179.68	0.48	0.83	7.57	20.65	3008.86	7.96	13.83	1.27	45
46	BRU157	1990	1	1.23	175.16	0.46	0.77	7.38	20.60	2925.82	7.62	12.87	1.23	46
47	GTA V6	1990	1	9.49	218.40	2.16	1.29	9.93	158.89	3657.35	36.11	21.57	1.66	47
48	GTA V6	1990	1	10.24	202.26	1.30	0.84	9.20	173.31	3421.50	21.93	14.13	1.56	48
49	PH7284	1990	1	11.49	170.10	1.08	1.47	7.92	192.60	2852.05	18.16	24.62	1.33	49
50	Z16984	1990	3	0.01	180.99	0.01	0.69	7.49	0.20	3027.78	0.23	11.47	1.25	50
51	OO8646	1989	4	0.82	204.48	0.06	0.12	8.52	13.68	3419.11	1.01	1.96	1.42	51
52	OA4560	1988	1	2.10	135.51	0.84	1.12	5.85	35.35	2285.93	14.10	18.92	0.99	52
53	NZ5684	1987	1	2.92	144.86	0.89	2.66	6.30	48.82	2425.87	14.89	44.61	1.05	53
54	UF2331	1987	3	11.68	160.82	0.69	2.36	7.50	194.99	2685.62	11.52	39.42	1.25	54
55	DGNFLY	1986	2	0.21	150.15	0.05	0.03	6.23	3.51	2523.19	0.91	0.45	1.05	55
56	RD664	1986	2	11.29	140.41	2.95	0.30	6.93	190.93	2375.34	49.89	5.02	1.17	56
57	SJ892	1986	2	4.51	127.06	0.66	1.28	5.63	76.07	2141.02	11.15	21.62	0.95	57
58	SJ892	1986	2	5.10	127.39	0.70	0.18	5.69	85.37	2133.21	11.66	3.04	0.95	58
59	SW2306	1984	4	11.48	142.62	1.42	0.38	6.83	193.66	2406.63	23.95	6.34	1.15	59
60	AUC190	1983	2	8.75	216.79	0.98	1.08	9.66	146.64	3631.18	16.46	18.02	1.62	60
61	KT5777	1982	1	1.59	137.44	0.69	1.38	5.88	26.64	2304.70	11.49	23.19	0.99	61

Table 23: Light Duty Petrol Data CBDC Cycle in g/km and g/s.

	Registration	Year	Tech	CBD CO g/km	CBD CO2 g/km	CBD HC g/km	CBD NOx g/km	CBD FC l/100km	CBD CO mg/s	CBD CO2 mg/s	CBD HC mg/s	CBD NOx mg/s	CBD FC ml/s	
1	BWF605	2004	4	0.38	837.19	0.13	0.02	34.66	0.75	1665.76	0.26	0.05	0.69	1
2	HDLADY	2004	4	0.56	682.51	0.25	0.10	28.29	1.11	1357.39	0.49	0.20	0.56	2
3	CR496	2003	4	4.78	789.96	0.52	0.04	33.04	9.56	1581.87	1.04	0.07	0.66	3
4	ABC188	2001	4	0.10	480.50	0.13	0.00	19.89	0.19	939.23	0.26	0.00	0.39	4
5	QMA	2000	4	3.94	901.27	0.15	0.38	37.54	8.00	1828.78	0.31	0.77	0.76	5
6	ZQ2376	2000	4	0.47	516.04	0.35	0.33	21.41	0.93	1016.00	0.70	0.66	0.42	6
7	BFP661	1999	4	1.22	719.48	0.10	0.00	29.84	2.42	1421.99	0.20	0.00	0.59	7
8	XR9447	1999	3	7.74	682.63	0.85	0.46	28.84	15.54	1370.93	1.71	0.93	0.58	8
9	YH7922	1999	4	1.22	612.19	0.37	0.43	25.44	2.42	1219.20	0.73	0.86	0.51	9
10	YN2857	1999	2	46.48	646.69	4.84	4.14	30.40	92.57	1288.00	9.63	8.25	0.61	10
11	YO1086	1999	3	2.02	454.70	0.85	0.57	19.04	3.94	885.43	1.65	1.12	0.37	11
12	XC4378	1998	4	0.94	704.69	0.12	0.26	29.21	1.86	1392.97	0.23	0.52	0.58	12
13	XK2891	1998	3	4.53	431.06	1.39	1.35	18.30	8.95	852.20	2.75	2.68	0.36	13
14	SXSLESC	1997	4	3.79	485.34	1.29	.	20.48	7.37	944.44	2.50	.	0.40	14
15	SXSLESn	1997	2	17.72	443.44	5.03	2.68	20.15	34.89	873.05	9.91	5.28	0.40	15
16	UZ9537	1997	2	42.20	400.01	4.51	2.42	19.87	82.63	783.32	8.84	4.74	0.39	16
17	UZ9537 -	1997	2	49.85	401.03	4.52	2.05	20.42	97.94	787.89	8.88	4.03	0.40	17
18	YJ7492	1997	4	11.89	497.60	0.81	1.31	21.45	24.49	1024.40	1.67	2.69	0.44	18
19	BGB544	1996	4	9.60	526.27	1.08	1.19	22.53	19.23	1054.72	2.16	2.38	0.45	19
20	BSG 955	1996	4	9.95	753.72	1.02	0.61	31.94	19.66	1490.09	2.01	1.21	0.63	20
21	BSM765	1996	4	89.90	327.47	5.53	0.08	20.11	178.54	650.32	10.98	0.16	0.40	21
22	BSM765	1996	4	6.28	382.67	2.21	1.42	16.52	12.52	762.96	4.40	2.84	0.33	22
23	BSM765	1996	4	95.30	309.18	5.57	0.19	19.71	192.98	626.08	11.27	0.39	0.40	23
24	ABF398	1995	2	21.23	499.44	5.28	2.60	22.72	42.50	999.92	10.56	5.22	0.45	24
25	BCH361	1995	4	2.33	677.33	0.31	0.16	28.20	4.67	1355.23	0.62	0.32	0.56	25
26	WZ4621	1995	4	21.68	646.60	1.77	0.84	28.38	42.57	1269.88	3.48	1.65	0.56	26
27	WZ4621	1995	4	7.52	659.68	1.13	1.87	27.91	14.95	1311.13	2.26	3.71	0.55	27
28	AAT783	1994	4	8.28	466.76	0.69	1.09	19.93	16.81	947.26	1.39	2.20	0.40	28
29	AKT600	1994	4	6.01	668.75	1.18	1.72	28.20	11.88	1322.58	2.33	3.40	0.56	29
30	Dealer	1994	4	7.86	884.82	1.63	2.71	37.31	15.96	1796.34	3.32	5.50	0.76	30
31	SJ1151	1994	4	19.99	786.93	2.32	2.56	34.14	40.55	1596.27	4.71	5.18	0.69	31
32	SJ1151	1994	4	23.63	771.87	3.10	2.92	33.86	48.34	1578.72	6.35	5.98	0.69	32
33	YS9785	1994	4	5.53	488.12	0.64	0.32	20.63	10.79	953.62	1.25	0.63	0.40	33
34	SH9621	1993	1	39.83	455.45	4.65	0.95	22.03	77.25	883.46	9.02	1.84	0.43	34
35	SM7218	1993	2	39.78	475.28	5.93	3.19	23.02	76.91	918.94	11.47	6.17	0.45	35
36	SM7218	1993	2	10.81	470.93	4.04	3.53	20.71	21.12	920.32	7.89	6.91	0.40	36
37	UQ3084	1993	4	4.79	596.37	1.37	2.52	25.15	9.42	1173.65	2.70	4.95	0.49	37
38	ZH2726	1993	4	22.65	634.69	1.70	1.48	27.94	45.71	1281.25	3.43	2.99	0.56	38
39	ZH2726	1993	4	15.13	633.31	1.63	2.23	27.38	30.69	1285.06	3.30	4.52	0.56	39
40	AJA952	1992	4	2.62	554.35	0.79	0.73	23.19	5.18	1093.60	1.55	1.44	0.46	40
41	RO1648	1992	1	44.08	340.15	6.14	1.52	17.74	86.94	670.81	12.11	3.00	0.35	41
42	WU3734	1992	4	16.87	369.68	4.53	1.60	16.98	33.23	728.12	8.92	3.15	0.33	42
43	AMZ597	1991	4	25.85	581.39	1.14	0.84	25.87	50.62	1138.29	2.24	1.64	0.51	43
44	TU5174	1991	2	15.99	507.20	3.01	3.16	22.41	32.37	1027.06	6.10	6.40	0.45	44
45	BRU157	1990	2	85.82	628.30	8.64	2.03	32.69	165.22	1209.57	16.62	3.92	0.63	45
46	BRU157	1990	1	37.69	653.79	6.82	2.92	30.38	74.76	1296.71	13.52	5.80	0.60	46
47	GTA V6	1990	1	96.50	665.19	19.19	2.20	36.30	196.20	1352.51	39.03	4.48	0.74	47
48	GTA V6	1990	1	125.63	730.51	10.79	1.31	39.79	258.04	1500.50	22.16	2.69	0.82	48
49	PH7284	1990	1	48.13	575.43	4.08	2.69	27.46	96.66	1155.64	8.19	5.40	0.55	49
50	Z16984	1990	3	5.53	712.73	0.51	1.26	29.90	11.07	1425.46	1.02	2.52	0.60	50
51	OO8646	1989	4	4.70	637.58	0.69	0.85	26.76	9.48	1285.47	1.39	1.71	0.54	51
52	OA4560	1988	1	17.37	546.39	17.75	2.86	26.06	35.25	1109.02	36.02	5.80	0.53	52
53	NZ5684	1987	1	50.66	373.56	4.38	2.64	19.31	101.43	747.89	8.76	5.29	0.39	53
54	UF2331	1987	3	94.81	569.22	4.30	3.64	30.26	197.11	1183.40	8.93	7.57	0.63	54
55	DGNFLY	1986	2	19.36	416.09	2.14	0.50	18.74	37.98	816.18	4.20	0.98	0.37	55
56	RD664	1986	2	98.52	480.25	15.44	1.37	28.29	195.61	953.51	30.65	2.71	0.56	56
57	SJ892	1986	2	49.94	398.22	9.05	2.06	20.90	101.64	810.52	18.41	4.20	0.43	57
58	SJ892	1986	2	18.90	380.33	7.21	3.32	17.90	38.35	771.74	14.62	6.73	0.36	58
59	SW2306	1984	4	57.83	515.16	8.85	0.80	26.22	116.51	1037.82	17.82	1.60	0.53	59
60	AUC190	1983	2	49.14	736.15	8.68	2.34	34.77	96.03	1438.63	16.96	4.57	0.68	60
61	KT5777	1982	1	35.80	474.42	5.90	2.66	22.72	73.25	970.58	12.06	5.44	0.46	61

Table 24: Light Duty Petrol Data Idle g/s and Concentration.

	Registration	Year	Tech	Hi Idle CO %	Hi Idle CO2 %	Hi Idle HC ppm	Hi Idle O2 %	Idle CO %	Idle CO2 %	Idle HC ppm	Idle O2 %	Idle CO mg/s	Idle CO2 mg/s	Idle HC mg/s	Idle NOx mg/s	Idle FC ml/s	
1	BWF605	2004	4	0.00	14.24	0.00	0.00	0.00	14.27	0.00	0.06	0.19	1023.25	0.26	0.02	0.42	1
2	HDLADY	2004	4	0.00	14.04	0.00	0.02	0.00	14.02	0.00	0.01	0.37	643.08	0.37	0.29	0.27	2
3	CR496	2003	4	0.02	15.50	8.00	0.02	0.13	15.50	30.00	0.03	4.12	929.09	1.75	0.00	0.39	3
4	ABC188	2001	4	0.00	14.21	0.00	0.03	0.00	14.31	0.00	0.03	0.19	535.47	0.12	0.00	0.22	4
5	QMA	2000	4	0.00	14.20	0.00	0.29	0.00	14.06	0.00	0.58	0.19	1233.75	0.12	0.23	0.51	5
6	ZQ2376	2000	4	0.00	14.53	14.00	0.04	0.00	14.33	61.00	0.03	1.50	560.69	0.20	0.00	0.23	6
7	BFP661	1999	4	0.00	14.21	0.00	0.00	0.00	14.20	0.00	0.00	0.74	645.10	0.09	0.00	0.27	7
8	XR9447	1999	3	0.10	14.46	18.00	0.05	0.00	14.48	23.00	0.06	0.37	801.61	0.25	0.00	0.33	8
9	YH7922	1999	4	0.09	15.40	16.00	0.07	0.02	15.50	21.00	0.13	0.37	630.61	0.14	0.05	0.26	9
10	YN2857	1999	2	1.80	13.23	71.00	0.33	1.26	13.56	99.00	0.35	41.65	618.60	4.33	0.39	0.29	10
11	YO1086	1999	3	0.30	14.68	0.72	0.41	0.00	15.27	0.00	0.12	0.00	413.43	0.11	0.05	0.17	11
12	XC4378	1998	4	0.00	15.50	8.00	0.03	0.00	15.50	9.00	0.17	0.19	689.60	0.09	0.05	0.29	12
13	XK2891	1998	3	0.58	14.80	25.00	0.48	0.12	15.20	78.00	0.31	0.00	411.53	0.06	0.00	0.17	13
14	SXSLESC	1997	4	0.37	13.67	40.00	0.69	0.09	13.55	43.00	1.07	0.18	566.17	0.36	.	0.23	14
15	SXSLESn	1997	2	0.88	13.29	74.00	1.06	0.93	12.01	380.00	2.59	19.56	509.04	4.34	0.36	0.23	15
16	UZ9537	1997	2	1.77	14.30	57.00	0.19	2.60	13.70	283.00	0.39	45.37	399.45	4.60	0.30	0.20	16
17	UZ9537 -	1997	2	2.54	12.40	79.00	0.31	3.64	11.11	250.00	1.25	64.33	371.80	5.06	0.14	0.20	17
18	YJ7492	1997	4	0.52	13.36	64.97	0.14	0.01	13.66	24.99	0.81	0.38	539.30	0.22	0.36	0.22	18
19	BGB544	1996	4	0.66	13.34	70.00	0.67	0.27	13.59	146.00	0.60	0.56	578.71	0.20	0.00	0.24	19
20	BSG 955	1996	4	0.21	13.92	40.11	0.66	0.01	14.11	11.88	0.84	0.93	749.82	0.14	0.12	0.31	20
21	BSM765	1996	4	6.42	10.30	316.00	0.35	6.63	10.14	586.00	0.32	26.67	323.84	6.21	0.02	0.16	21
22	BSM765	1996	4	0.13	14.30	106.00	0.02	0.00	13.98	420.00	0.05	1.89	358.39	2.42	0.00	0.15	22
23	BSM765	1996	4	6.65	11.30	325.00	0.22	1.73	12.57	580.00	0.14	99.14	267.47	8.60	0.00	0.19	23
24	ABF398	1995	2	0.74	13.15	50.00	0.88	0.85	12.76	155.00	1.34	18.86	598.31	4.93	0.29	0.27	24
25	BCH361	1995	4	0.01	15.70	14.00	0.16	0.03	15.60	78.00	0.11	0.56	793.47	0.25	0.11	0.33	25
26	WZ4621	1995	4	0.86	13.20	74.00	0.61	0.00	13.04	10.00	1.71	0.37	772.70	0.42	0.16	0.32	26
27	WZ4621	1995	4	0.58	13.52	115.00	0.73	0.19	13.92	133.00	0.50	0.19	735.72	0.20	0.14	0.30	27
28	AAT783	1994	4	0.02	14.40	0.71	0.08	0.00	14.49	0.71	0.21	0.18	480.78	0.02	0.38	0.20	28
29	AKT600	1994	4	0.65	13.55	18.00	0.66	0.01	14.09	6.00	0.27	0.75	698.77	0.65	0.30	0.29	29
30	Dealer	1994	4	0.00	14.84	10.00	0.00	0.45	13.83	176.00	0.95	0.19	1088.27	0.60	0.24	0.45	30
31	SJ1151	1994	4	1.73	13.70	127.00	0.74	0.73	14.70	496.00	0.32	67.24	747.09	8.34	0.02	0.36	31
32	SJ1151	1994	4	0.34	13.85	24.00	1.18	0.55	14.39	467.00	1.20	19.05	823.08	5.15	0.07	0.36	32
33	YS9785	1994	4	0.30	14.26	67.50	0.12	0.01	14.65	80.73	0.06	0.37	513.09	0.61	0.00	0.21	33
34	SH9621	1993	1	2.86	12.21	79.00	0.36	0.52	12.94	38.00	1.20	13.96	675.54	1.75	0.34	0.29	34
35	SM7218	1993	2	0.38	13.38	18.00	0.75	3.84	11.53	289.00	0.57	79.01	393.83	7.39	0.16	0.22	35
36	SM7218	1993	2	0.12	12.78	20.00	1.48	0.30	12.58	177.00	1.64	9.23	466.18	2.89	0.32	0.20	36
37	UQ3084	1993	4	0.87	14.10	119.00	1.06	0.37	14.80	177.00	0.74	0.00	591.70	0.23	0.21	0.24	37
38	ZH2726	1993	4	0.58	13.85	68.00	0.43	1.71	13.34	189.00	0.08	19.83	565.87	2.22	0.00	0.25	38
39	ZH2726	1993	4	0.35	13.80	35.00	0.48	0.12	13.84	124.00	0.23	9.99	595.40	1.46	0.02	0.25	39
40	AJA952	1992	4	0.16	14.34	7.72	0.31	0.08	14.44	63.87	0.44	0.01	655.44	0.12	0.16	0.27	40
41	RO1648	1992	1	1.78	12.94	74.00	0.34	3.96	11.10	225.00	1.08	80.09	312.41	5.84	0.09	0.19	41
42	WU3734	1992	4	0.24	13.30	35.00	1.23	0.82	12.74	172.00	1.56	12.38	422.51	4.15	0.22	0.19	42
43	AMZ597	1991	4	0.03	14.22	0.00	0.02	0.36	13.50	92.00	0.61	14.61	626.38	1.12	0.09	0.27	43
44	TU5174	1991	2	0.68	13.77	56.00	0.66	0.50	13.68	131.00	0.92	13.52	540.35	3.36	0.50	0.24	44
45	BRU157	1990	2	0.14	12.55	0.00	1.52	4.50	10.73	133.00	0.52	189.94	688.75	12.46	0.34	0.42	45
46	BRU157	1990	1	0.15	12.53	159.00	3.00	2.66	12.49	211.00	0.86	107.91	795.33	9.08	0.23	0.41	46
47	GTA V6	1990	1	3.03	12.42	67.00	0.24	7.70	9.34	299.00	0.50	194.92	686.68	22.59	0.25	0.44	47
48	GTA V6	1990	1	2.49	12.62	74.00	0.30	2.80	12.59	160.00	0.61	220.13	956.71	14.23	0.41	0.56	48
49	PH7284	1990	1	0.54	13.37	47.00	0.75	5.40	10.63	309.00	0.58	121.52	526.83	8.34	0.18	0.31	49
50	Z16984	1990	3	0.25	15.20	42.00	0.45	0.00	15.00	12.00	0.80	1.85	874.90	0.22	0.36	0.36	50
51	OO8646	1989	4	0.35	14.57	16.00	0.41	0.00	13.96	0.00	0.18	0.19	820.99	0.41	0.32	0.34	51
52	OA4560	1988	1	0.47	10.69	1357.00	4.65	0.14	9.28	1025.00	6.98	8.40	736.38	25.56	0.75	0.34	52
53	NZ5684	1987	1	0.61	13.50	62.00	0.47	5.61	10.70	279.00	0.28	101.12	322.79	7.59	0.14	0.21	53
54	UF2331	1987	3	3.46	11.45	83.00	1.16	6.40	9.94	203.00	1.07	169.80	603.27	7.87	0.32	0.37	54
55	DGNFLY	1986	2	0.02	15.40	22.00	0.42	0.00	6.40	72.00	12.32	0.94	369.57	0.76	0.00	0.15	55
56	RD664	1986	2	7.53	9.70	285.00	0.32	5.40	10.78	623.00	0.56	50.75	380.35	9.39	0.05	0.20	56
57	SJ892	1986	2	11.15	6.80	589.00	1.26	2.49	11.29	288.00	2.32	17.17	397.62	4.54	0.07	0.18	57
58	SJ892	1986	2	0.96	11.81	251.00	2.26	0.25	8.11	559.00	8.00	4.11	384.03	16.54	0.05	0.18	58
59	SW2306	1984	4	5.65	10.71	181.00	0.13	1.41	13.30	204.00	0.04	66.82	569.87	6.36	0.11	0.29	59
60	AUC190	1983	2	0.78	13.51	35.00	0.56	0.90	13.17	110.00	0.93	37.03	890.24	6.58	0.50	0.40	60
61	KT5777	1982	1	0.16	13.60	45.00	2.82	0.14	13.80	101.00	2.41	25.81	629.97	4.67	0.45	0.28	61

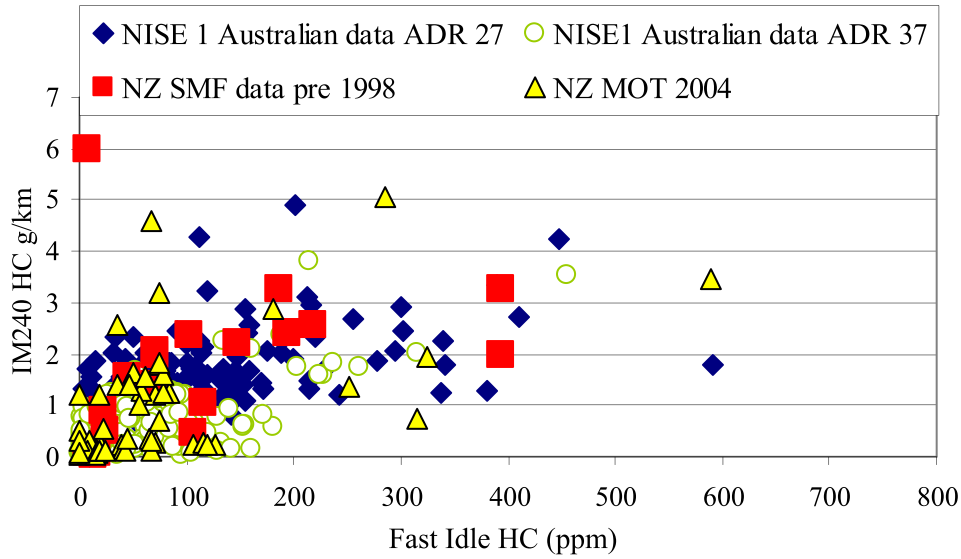

Figure 45: IM240 HC (g/km) Versus Fast Idle HC (%) for the Pilot's 61-Vehicle Variant Set, and NISE 1 and SMF Data Sets.

Following are various figures based on the 61-vehicle variant detailed dynamometer data set.

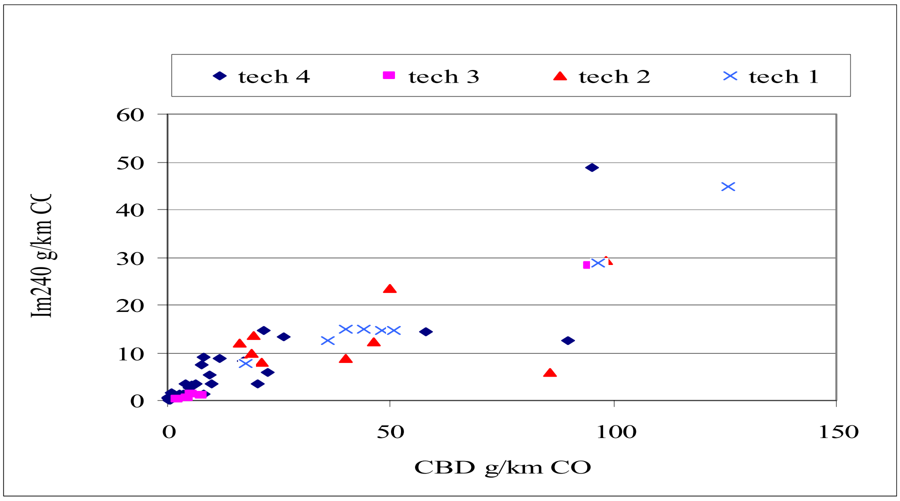

Figure 46: IM240 CO (g/km) Versus CBDC CO (g/km).

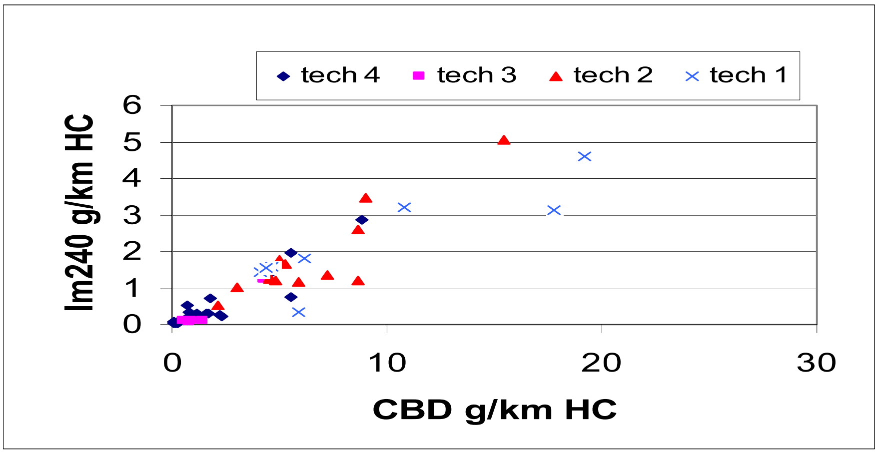

Figure 47: IM240 HC (g/km) Versus CBDC HC (g/km).

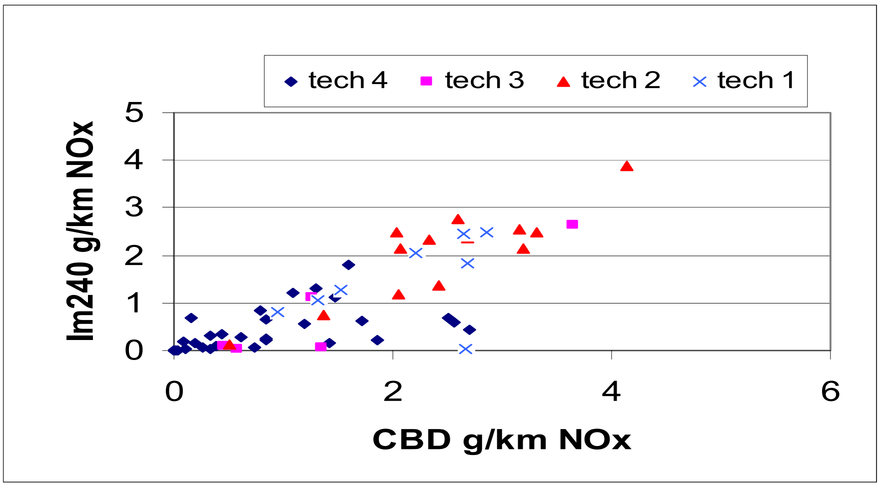

Figure 48: IM240 NOx (g/km) Versus CBDC NOx (g/km).

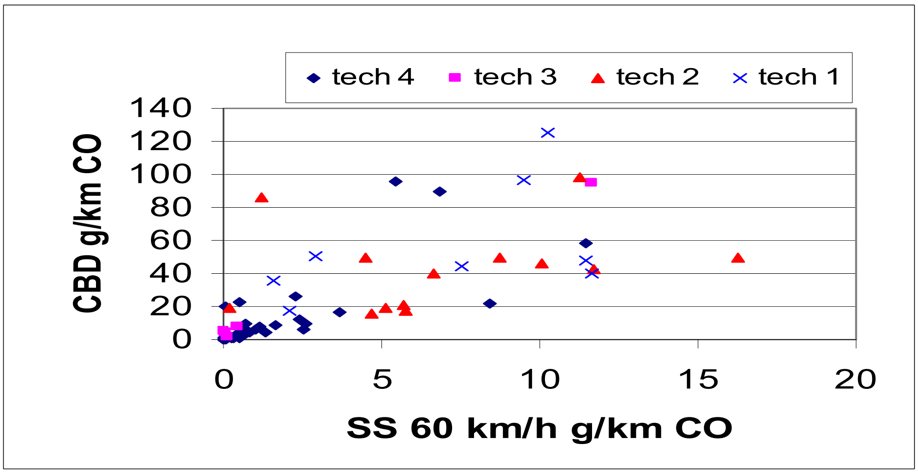

Figure 49: CBDC CO (g/km) Versus 60 km/h Steady Speed CO (g/km).

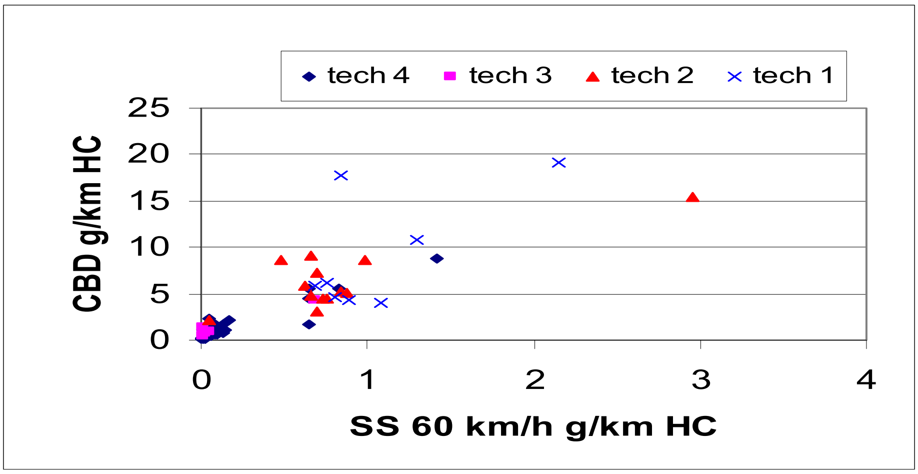

Figure 50: CBDC HC (g/km) Versus 60 km/h Steady Speed HC (g/km).

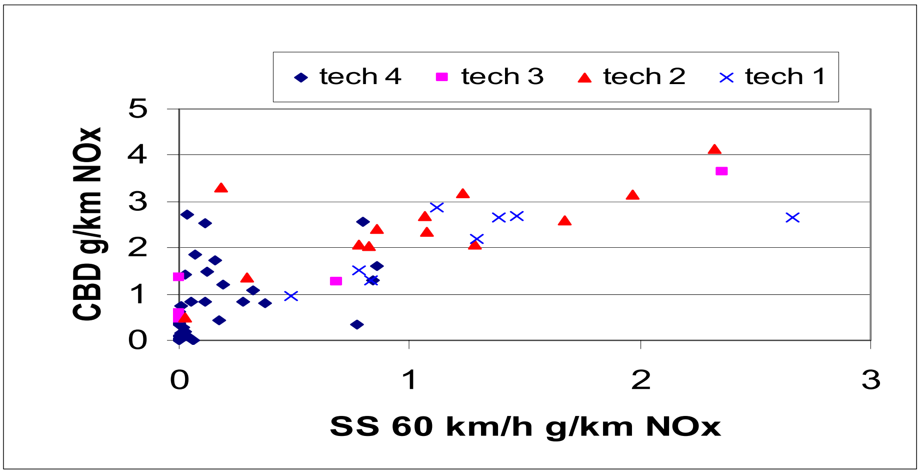

Figure 51: CBDC NOx (g/km) Versus 60 km/h Steady Speed NOx (g/km).

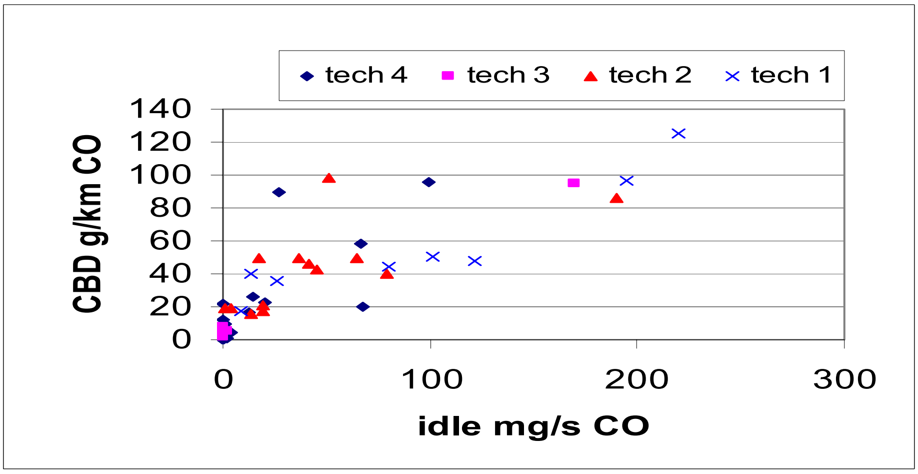

Figure 52: CBDC CO (g/km) Versus (Natural) Idle CO (mg/s).

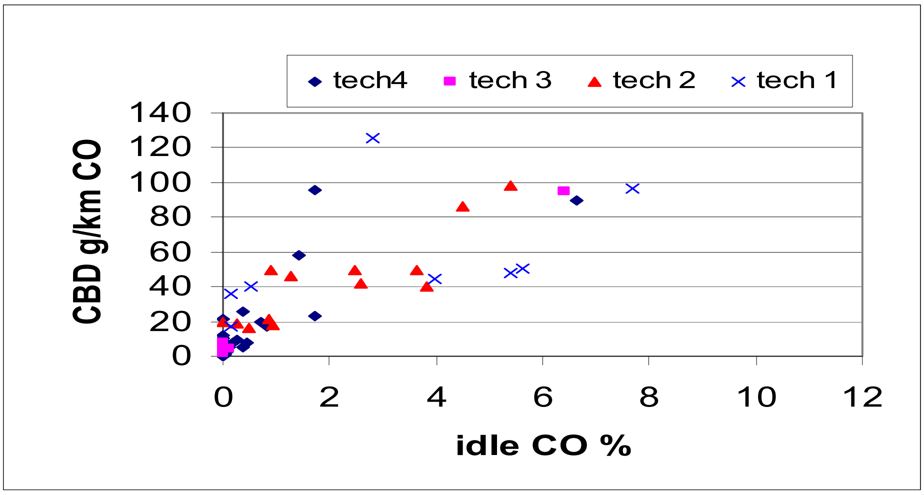

Figure 53: CBDC CO (g/km) Versus (Natural) Idle CO (%).

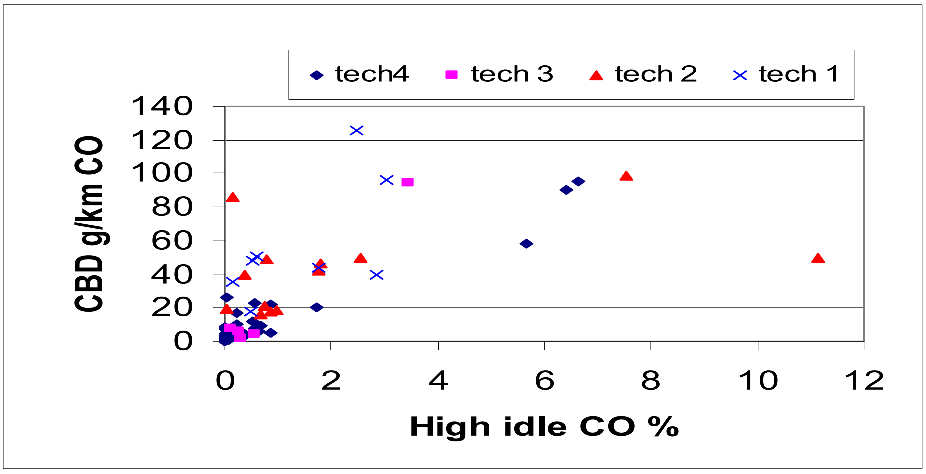

Figure 54: CBDC CO (g/km) Versus Fast Idle CO (%).

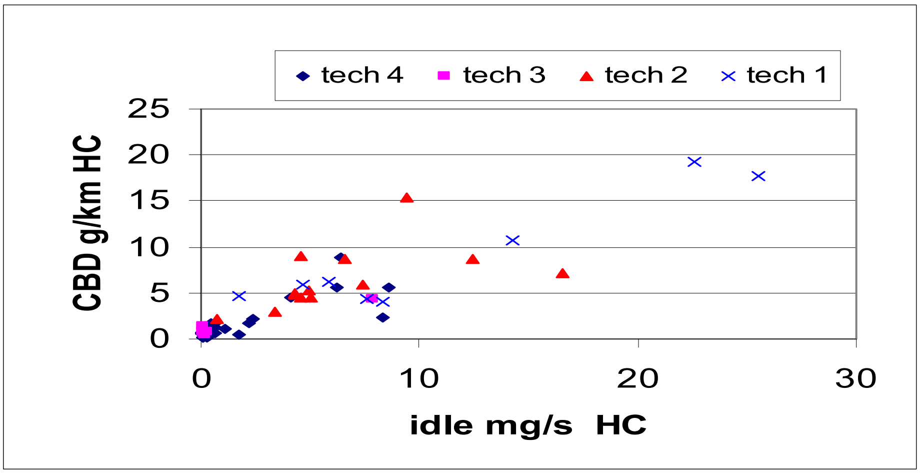

Figure 55: CBDC HC (g/km) Versus (Natural) Idle HC (mg/s).

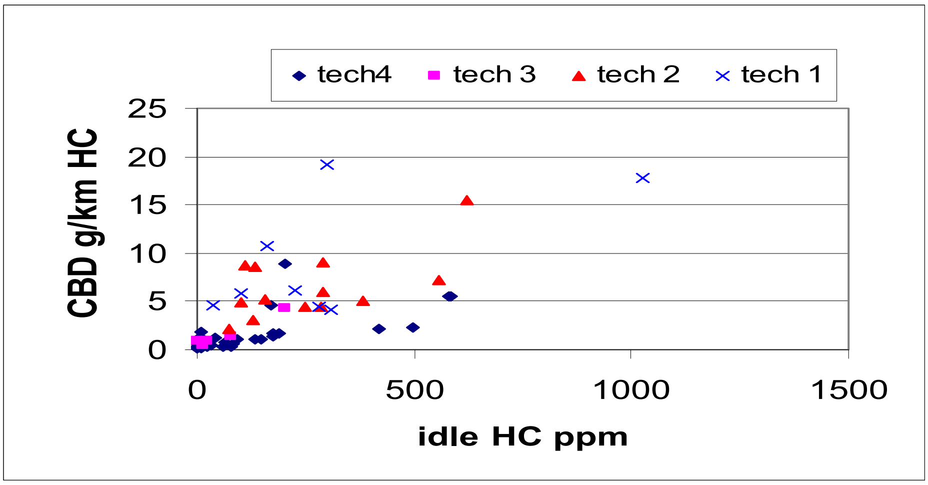

Figure 56: CBDC HC (g/km) Versus (Natural) Idle HC (ppm).

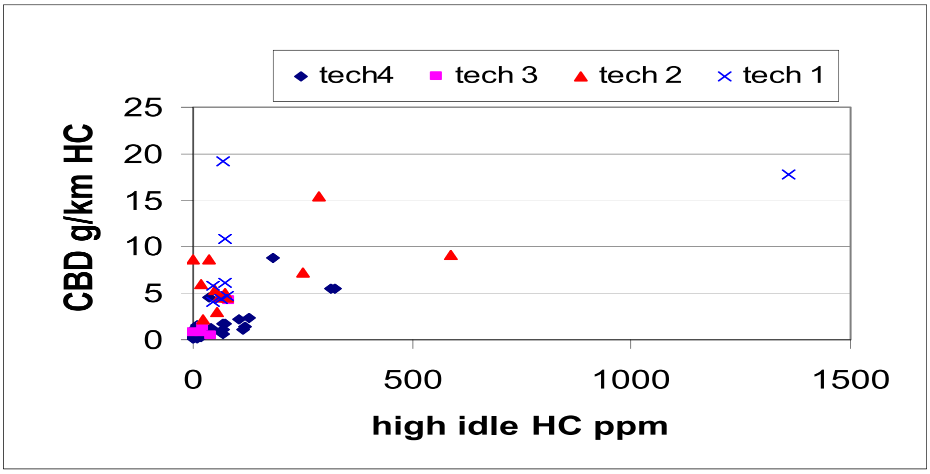

Figure 57: CBDC HC (g/km) Versus Fast Idle HC (ppm).

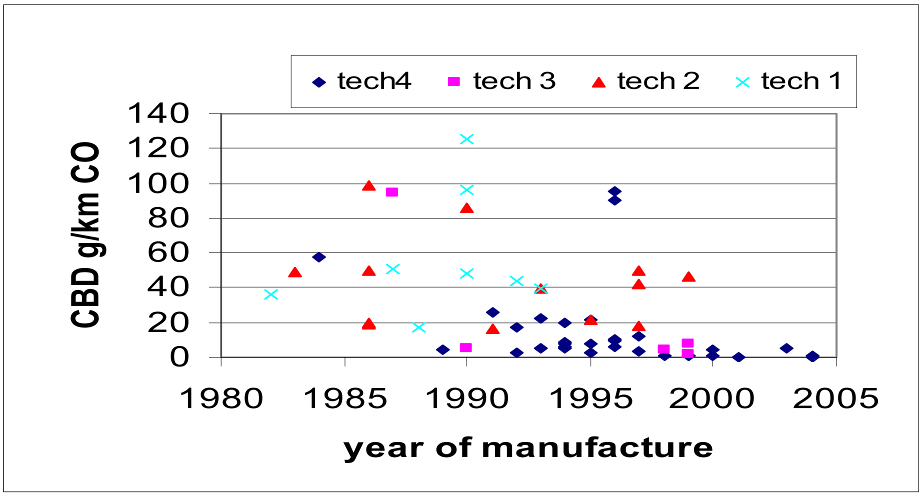

Figure 58: CBDC CO (g/km) Versus Year of Manufacture.

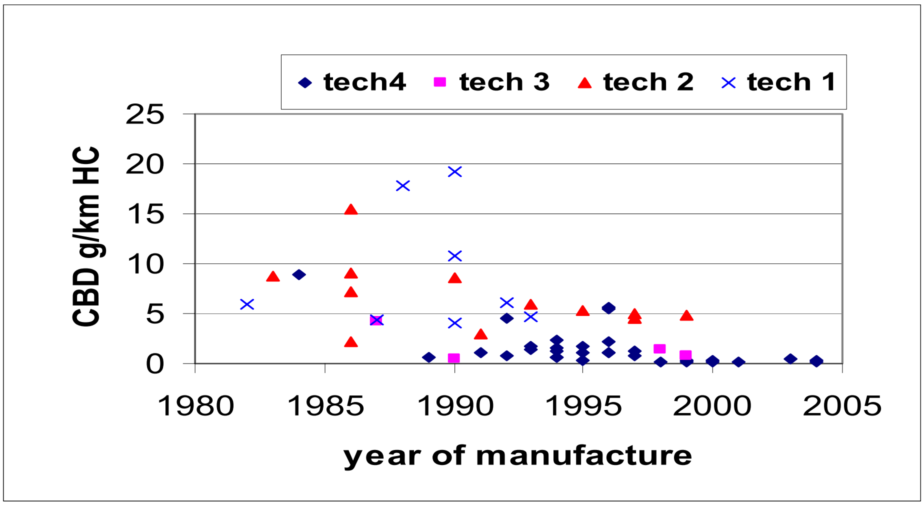

Figure 59: CBDC HC (g/km) Versus Year of Manufacture.

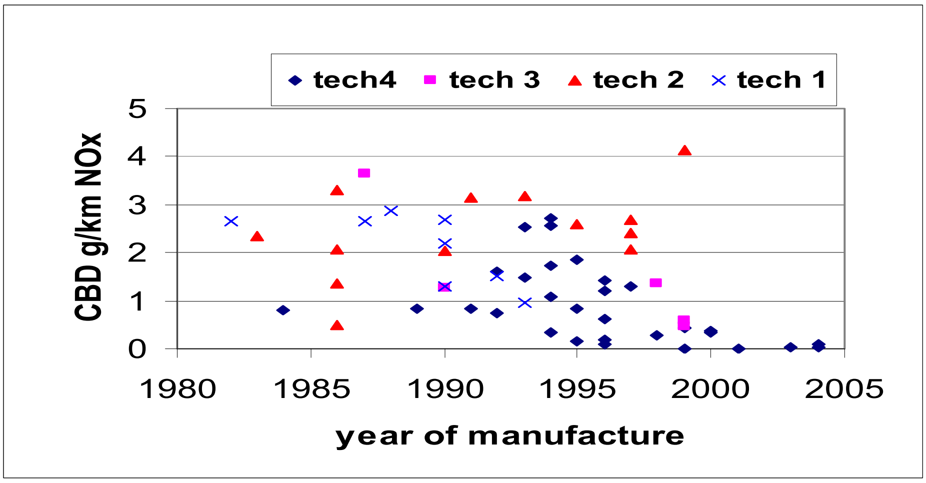

Figure 60: CBDC NOx (g/km) Versus Year of Manufacture.

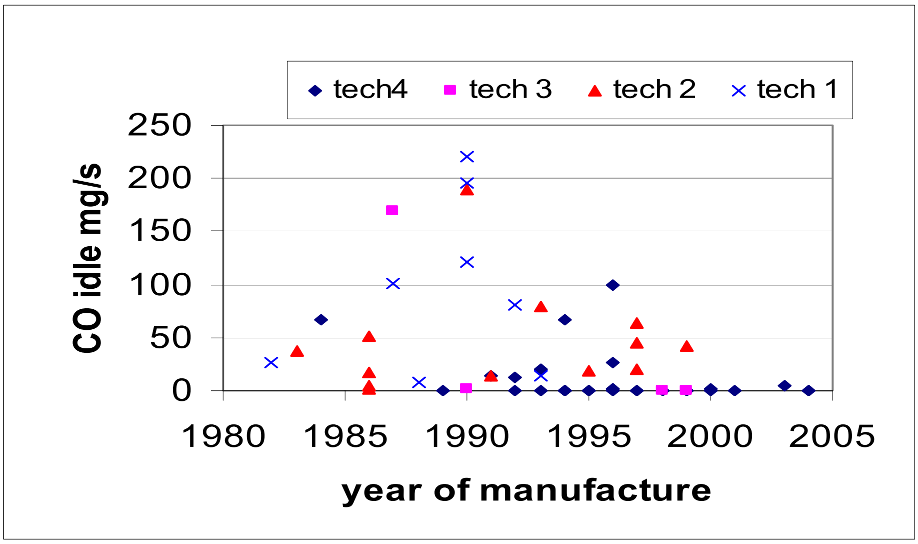

Figure 61: (Natural) Idle CO (mg/s) Versus Year of Manufacture.

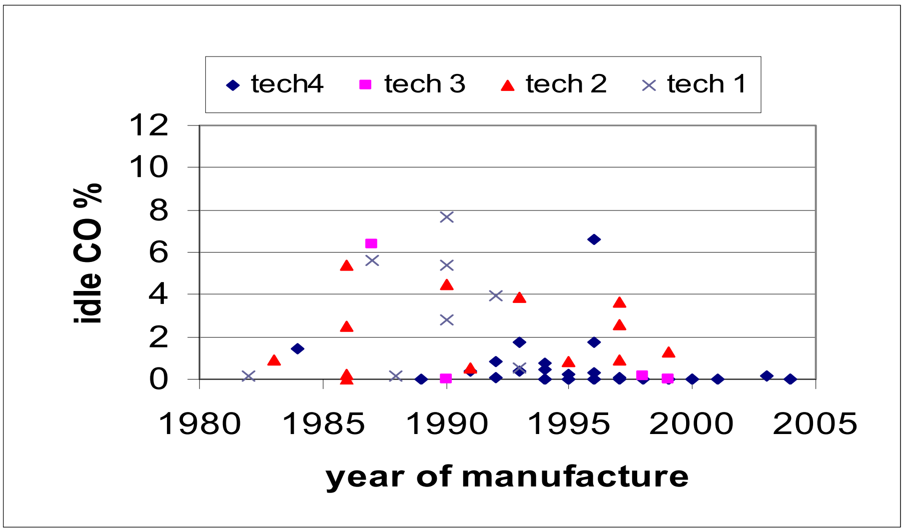

Figure 62: (Natural) Idle CO (%) Versus Year of Manufacture.

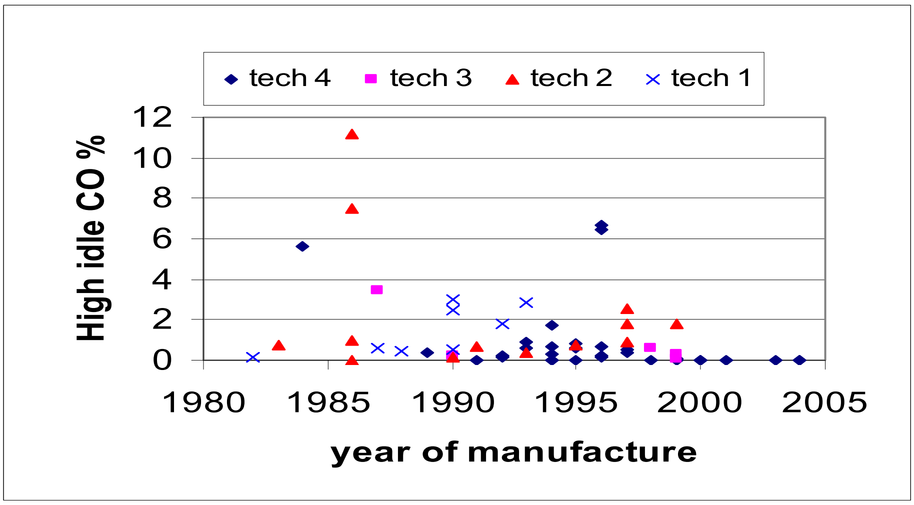

Figure 63: Fast Idle CO (%) Versus Year of Manufacture.

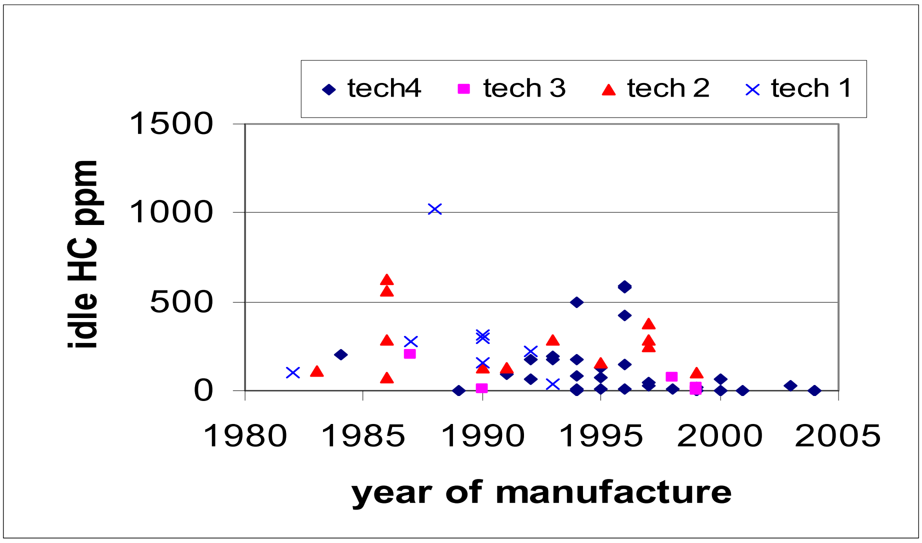

Figure 64: (Natural) Idle HC (ppm) Versus Year of Manufacture.

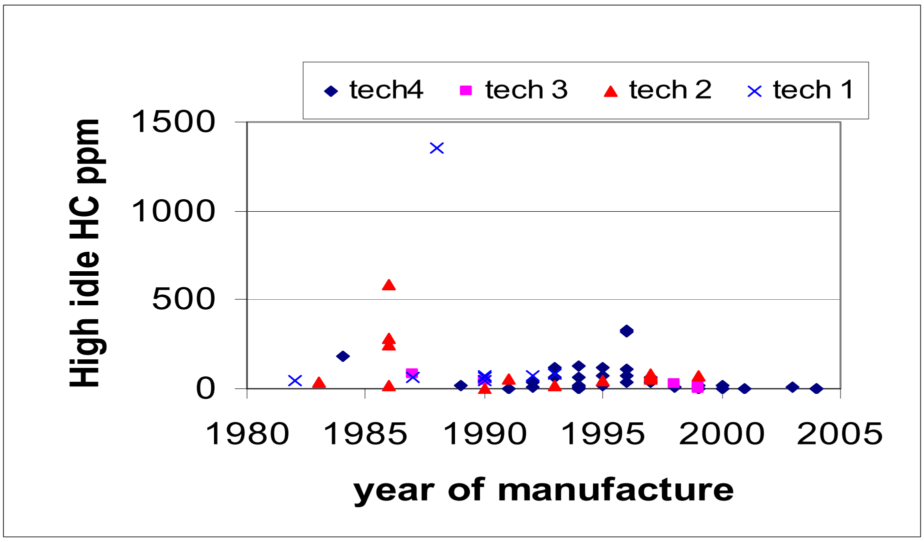

Figure 65: Fast Idle HC (ppm) Versus Year of Manufacture.

Appendix K: Results From Statistical Emissions Prediction Modelling.

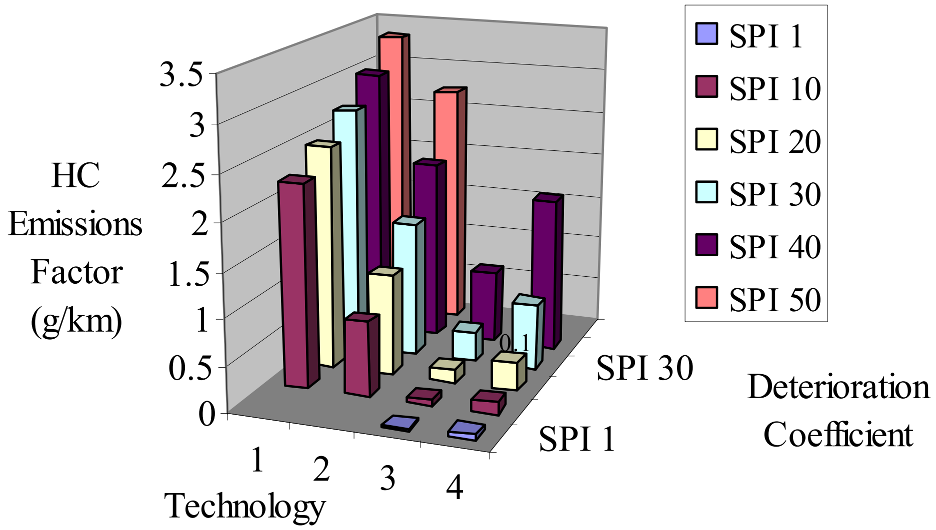

Figure 66: IM240 HC Emissions Factors Predicted by the Statistical Emissions Prediction Model, Relative to Engine Technology and SPI.

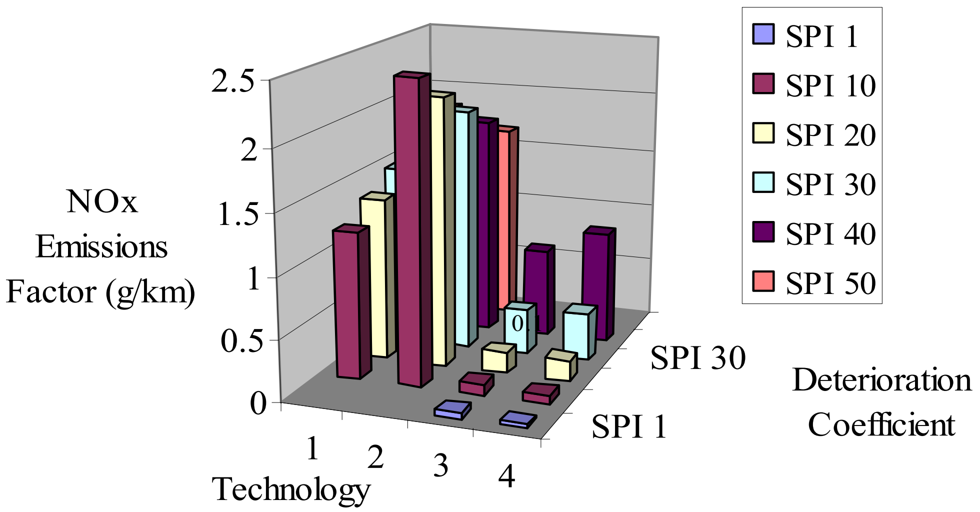

Figure 67: IM240 NOx Emissions Factors Predicted by the Statistical Emissions Prediction Model, Relative to Engine Technology and SPI.

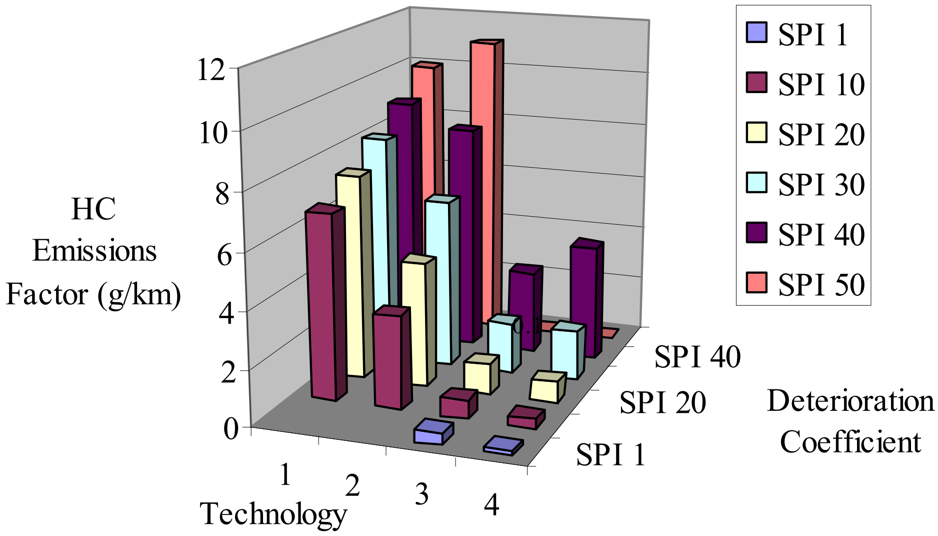

Figure 68: CBDC HC Emissions Factors Predicted by the Statistical Emissions Prediction Model, Relative to Engine Technology and SPI.

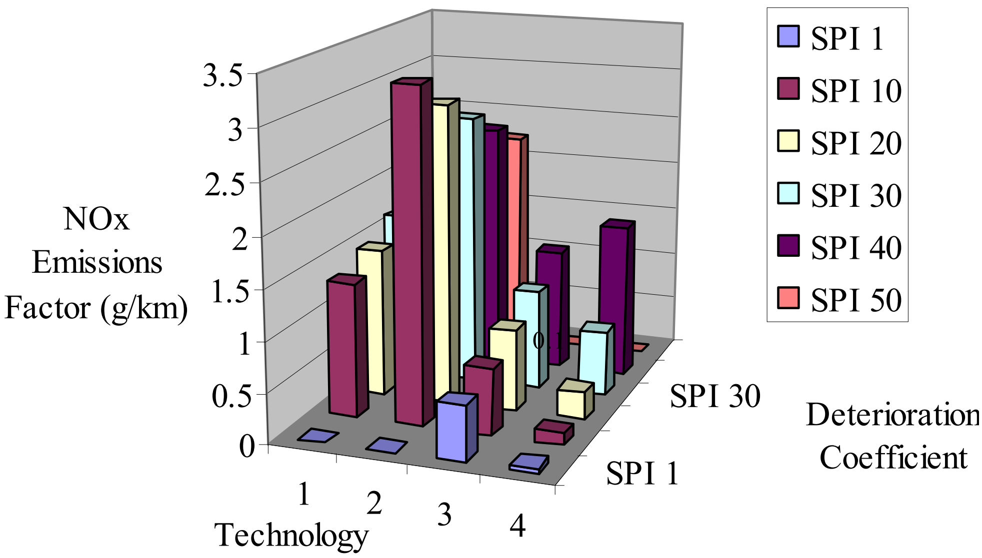

Figure 69: CBDC NOx Emissions Factors Predicted by the Statistical Emissions Prediction Model, Relative to Engine Technology and SPI.

Appendix L: Details and Data Concerning the Dynamometer Tested Vehicles That Were Repaired and Re-tested

The following provides details on the symptoms, repairs and results associated with the dynamometer-tested repair vehicles. The before-repair and after-repair emissions performance of vehicles discussed, based on CBDC CO, have been provided in terms of a vehicle's rank within the 61-vehicle variant dynamometer tested, with one being the lowest emitter.

Effect of Catalyst Removal SXSLES

Vehicle:	SXSLES (1997, used import with Technology 4)
Test:	Removal of exhaust catalyst.
Reason:	To assess the impact of removal of catalysts on emissions.
Results:	A four- to five-fold increase in all emissions species with an insignificant change in fuel consumption, eg CO increased from 3.78 to 17.72 g/km over the CBDC cycle.

Detection process: inspection for presence of catalyst.

Cut-points for idle simple tests would need to be set to levels appropriate to Technology 4 vehicles before this vehicle would be detected without the catalyst fitted.

The test results for this vehicle provide information that could be used to assess the impact of the removal of catalysts and the potential benefits of reinstatement of vehicles currently with catalysts removed.

Rank with catalyst: 11.
Rank without catalyst: 33.

High Emitter Technology 4: BSM765

Vehicle:	BSM765 (1996, recent used import with Technology 4).
Test:	Investigate very high (natural) idle and fast idle test results.
Reason:	To assess potential for improving emissions and fuel consumption for a Technology 4 exhibiting very high (natural) idle simple test emissions.

This vehicle gave very high emissions in all the detailed tests and in the idle simple tests. The owner initially carried out work on the vehicle in an attempt to improve the emissions performance. This achieved a significant reduction in (natural) idle CO, but an increase in drive cycle emissions for all species, and a small reduction in drive cycle fuel consumption. The vehicle was then sent to the specialist repair group and returned with significantly lower emissions for all species except drive cycle NOx, which increased by approximately 18 times (but note that this was from a very low initial value). This specialist repair also improved fuel consumption over the drive cycle by 16% compared to the first test of the vehicle.

Rank pre-remedial work: 55.
Rank post-remedial work: 20.

This Technology 4 vehicle would be detected by the idle simple test.

It is considered that this vehicle is still not achieving the emissions results that could be expected from this engine technology class and should be able to achieve a higher ranking.

High Emitter Technology 2 SM7218 UZ9537 SJ892 BRU157

Vehicle: SM7218 (1993, New Zealand-new, Technology 2 no O_2 sensor)
Test: Investigate very high idle simple test results.

Ranking improved from 43 to 27.

After repair this was the highest-ranked Technology 2 vehicle.

This vehicle would have been detected by an idle simple test.

Vehicle: UZ9537 (1997, New Zealand-new, Technology 2 no O_2 sensor)
Test: This vehicle showed relatively high readings for CO in the initial idle simple tests.

The vehicle was sent to the vehicle's New Zealand agent for a routine 160,000 km service. The agent did not use emissions measurement equipment. Following this, the vehicle showed some increase in (natural) idle CO and fast idle CO compared with before the service. The agent quoted a factory setting for (natural) idle CO of 1 ± 1 % (that is between 0 % and 2 %). This vehicle did not meet this specification before or after service. Drive cycle CO had increased by 18% and fuel consumption increased by 3% through the service. Drive cycle HC showed no change, and NO decreased by 15% as a result of the service. The vehicle was sent for specialist repair, but no faults were identified (though a MAP sensor was replaced) and no improvement in idle simple test emissions were obtained.

This vehicle performs outside its stated manufacturer's specification; however, the remedial work was unable to identify and rectify the cause.

The database for the simple test programme was analysed to see whether other vehicles of the same model exhibited similar idle simple test emissions characteristics. This search yielded test results for five of the same model of vehicle. Two of the five vehicles were also operating outside the manufacturer's stated settings.

Ranking before service: 45.
Ranking after service: 50.
No change in ranking after specialist investigation.

Given the vehicle's age and engine technology it is an extremely poorly performing vehicle from an emissions perspective. It is expected that this engine technology class of vehicle should be able to achieve a ranking of 27 to 30.

This vehicle would be identified using the idle simple test. A more in-depth investigation would be required to determine what was needed to improve the emissions performance of this vehicle.

Vehicle: SJ892 (1986, used import Technology 2 with O_2 feedback).
Test: Investigate very high idle simple test results.

There were a number of faults with the vehicle that were identified and repaired by the specialist.

Ranking pre remedial work: 55.
Ranking post remedial work: 34.

This vehicle would originally have been Technology 4 but, with catalyst removal, was now a Technology 2 vehicle. Fitting a new exhaust catalyst is likely to improve the ranking of this vehicle to better than 17.

This vehicle would have been detected by an idle simple test.

Vehicle: BRU157 (1990, used import Technology 2 with O_2 feedback).

The owner carried out his own repair work on the basis of high idle simple test results. Ranking improved from 54 to 42.

This vehicle would be detected by an idle simple test. It is anticipated that additional emissions-related faults exist and this vehicle should be able to achieve a rating of 27 to 30 as a Technology 2 vehicle and 17 if upgraded to a Technology 4 vehicle.

Technology 4 Vehicles SJ1151 WZ4621 ZH2726

Three Technology 4 vehicles were chosen for remedial work because of the age of these vehicles and some level of inconsistency in the idle simple test results. The primary purpose of the repairs was to establish the emissions benefits achievable when the simple test results are closely analysed rather than having simple cut-points (this is potentially an approach for better detecting high emitting vehicles).

Vehicle: SJ1151 (1994 New Zealand-new Technology 4).

This vehicle exhibited variability in the (natural) idle and fast idle emissions for CO. The level of variability was sometimes sufficient to indicate the vehicle would be detected using an idle simple test régime, while at other times its performance was consistent with other similar Technology 4 vehicles.

Remedial work significantly improved the idle simple test emission results variability and the results themselves. (Natural) idle CO emissions rates reduced from 67 mg/s to 19 mg/s. There was a similar percentage reduction in (natural) idle HC emissions rates. There was however an increase in all emissions over the CBDC cycle.

Ranking deteriorated from 36 to 40.

Suitable cut-points and idle simple test result evaluation criteria would be required before this vehicle would be consistently detected.

Further work is required to identify the reasons for the disparity between a reduction in idle simple test emissions results and an increase in CBD congested emissions rates. The most likely contributing factor is the catalyst efficiency. It is considered that this vehicle should achieve a ranking of better than 17.

Vehicle: WZ4621 (1995, used import Technology 4).

There was a significant difference between the (natural) idle and fast idle CO idle simple test emissions. Remedial work decreased this difference and improved the ranking of the vehicle from 38 to 21.

Suitable cut-points and idle simple test result evaluation criteria would be required before this vehicle would be consistently detected.

Vehicle: ZH2726 (1993, used import Technology 4).

This vehicle had similar characteristics to vehicle WZ4621. Remedial work resulted in the ranking improving from 39 to 29.

Suitable cut-points and idle simple test result evaluation criteria would be required before this vehicle would be consistently detected.

One Technology 1 vehicle was repaired in the Pilot, improving its rating from 61 to 58. This was a complex engine technology vehicle and proved to be more difficult to improve compared to Technology 1 vehicles tested in the SMF programme. This vehicle should have achieved a ranking in the range 33 to 40.

One vehicle (labelled ‘Dealer’ in the data, a 1994 used import, Technology 4 vehicle) was tested after the fuel system was serviced and the exhaust catalyst replaced. This vehicle was ranked 23 over the CBD congested cycle. This result was comparable if not slightly better than the results achieved post-tune for the three Technology 4 vehicles fitted with new oxygen sensors.

Note, detection of moderate emitters required interpretation and use of simple evaluation criteria. One criterion was to look for a significant difference between (natural) idle and fast idle CO simple test result. However, in general, only (natural) idle or fast idle CO was needed to detect and subsequently evaluate the effectiveness of the repairs/modifications.

For Technology 4 repair vehicles, replacing the oxygen sensor resulted in significant reductions in emissions in CO and HC. Early indications are that replacing the oxygen sensor alone will improve the emissions performance of vehicles over a certain age and mileage.

Appendix M: Industry Interview Process

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

- Access to a gas analyser and believed usefulness;
- Breakdown of staff numbers and experience;
- Description of facilities including management of emissions;
- For each basic engine technology:
  - What are the most common faults?
  - In general, what proportion of faults they make?
  - How the mentioned faults are diagnosed;
  - Approximate cost for repair of mentioned faults;
  - Specific vehicle or models involved.
- Own competency in emissions-related repair;
- Industry competency and capacity in emissions-related repair;
- Value of idle simple testing;
- Issues with idle simple 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 idle simple testing;
- Believed issues with idle simple testing;
- Recommended approach the Government should be taking as far as vehicle emissions are concerned.

The interview process for those already involved in idle simple testing programmes comprised questioning on the following subjects, as appropriate:

- Test procedures and general arrangement;
- Equipment specification;
- History from introduction to current day arrangement;
- Issues and recommendations for introduction in New Zealand;
- Believed value of idle simple testing;
- Believed issues with idle simple testing;
- Recommended approach the Government should be taking as far as vehicle emissions are concerned.

Appendix N: Common Faults for Petrol Engines.

Table 24 lists the common faults of petrol engines by Technology. The frequency of occurrence, expected symptoms and consequences and repair considerations are also provided. For the purposes of this table it is assumed Technology 1 engines (fitted with carburettors) are also fitted with older points ignition systems, Technology 2 and 3 engines are fitted with contact-less distributor ignition systems and Technology 4 is fitted with multi-coil ignition systems (although it is recognised that fuel metering and ignition systems evolved separately and a mix of ignition systems would be found across the defined vehicle engine technology groupings).

Table 25: Sample of Common Faults for Various Engine Technologies

Fault	Most Common Diagnosis Method
Technology 1 with Basic Ignition System:	
• Overly fuel-rich air-fuel mixture due to choke malfunction	• Black exhaust, high fuel consumption and stumble when hot and difficult to hot-start.
• Ignition fault due to points or distributor malfunction	• Engine stumble under load increase. Standard check items during service.
• Misfire due to HT lead breakdown	• Engine stumble under load increase. Noisy radio. Visible sparks from lead in the dark.
Technology 2 with Contact-Less Ignition:	
• Injector fouling	• Unstable engine operation particularly at (natural) idle. Likely to pick up with exhaust gas analyser at (natural) idle but many other reasons for same symptoms.
• Misfire due to HT lead breakdown	• Engine stumble under load increase. Noisy radio. Visible sparks from leads.
• Incorrect ignition timing	• Low power or ignition knock.
• Overly fuel-rich air-fuel operation	• High fuel consumption. High CO and HC emission.
Technology 3 with EGR:	
• EGR valve malfunction	• Engine stumble. May show either high O_2 or high CO and HC.
• Misfire due to HT lead breakdown	• Engine stumble under load increase. Noisy radio. Visible sparks from lead in the dark.
• Overly fuel-rich or lean air-fuel ratio	• High fuel consumption to low power and hesitation on load increase. May identify through high O_2 or high CO and HC.
• Airflow sensor fault	• Engine stumble on acceleration to the engine running roughly (or not at all) if the fault is significant.
Technology 4 with On-Plug Coils:	
• Oxygen sensor drift	• Can cause non-optimal operation potentially resulting in higher emissions and higher fuel consumption. Both scenarios would exhibit CO and HC shift but diagnostics would likely require more than a gas analyser.
• Temperature sensor failure	• High fuel consumption, stumble when hot, high CO and HC.
• HT system breakdown	• Low power, uneven engine. May not be indicated by exhaust gas analyser due to limp-home mode sophistication.
• Airflow sensor fault	• As for Technology 3 above.