Trends in Light Duty Vehicle Emissions 2003 to 2011

September 2012 TR 2012/032

Auckland Council
Technical Report TR2012/032
ISSN 2230-4525 (Print)
ISSN 2230-4533 (Online)

ISBN 978-1-927216-09-5 (Print)
ISBN 978-1-927216-10-1 (PDF)

Reviewed by:

Name: Iain McGlinchy
Position: Principal Advisor
Organisation: Ministry of Transport
Date: 8/9/2012

Approved for Auckland Council publication by:

Name: Janet Petersen
Position: Team Leader Air Quality Policy
Organisation: Auckland Council
Date: 8//9/2012

Recommended Citation:
Kuschel, G.; Bluett, J.; and Unwin, M (2012). Trends in Light Duty Vehicle Emissions 2003 to 2011. Prepared by NIWA and Emission Impossible Ltd for Auckland Council. Auckland Council technical report TR2012/032.

Trends in Light Duty Vehicle Emissions 2003 to 2011

Gerda Kuschel (Emission Impossible Ltd)
Jeff Bluett (NIWA)
Martin Unwin (NIWA)

Prepared for
Auckland Council

Corresponding author: Gerda Kuschel
Senior Air Quality Consultant
Emission Impossible Ltd
Suite 1-6, D72 Building, 72 Dominion Road, Mount Eden, Auckland, 1024
New Zealand

NIWA Client Report No: AKL2012-010

Acknowledgements

This project was funded by the Auckland Council (AC), with in kind support provided by the NZ Transport Agency (NZTA) and the Ministry of Transport (MoT).

A number of people made contributions that were instrumental in the successful completion of project. The authors would particularly like to acknowledge:

- Janet Petersen (AC), Rob Hannaby (NZTA), and Iain McGlinchy (MoT) for their valuable guidance and suggestions as members of the project steering group and peer review of the final report.
- Lou Reddish (NIWA) for his expertise and always enthusiastic operation of the RSD monitoring equipment
- Elizabeth Sommervell (NIWA) for assisting with peer-reviewing of the results and report, Shanju Xie and Mike O'Connell for additional review and comments
- The motorists of Auckland whose vehicles have passed through the remote sensor and had their emissions dutifully recorded, without which this study would not have been possible!

Contents

Reviewed by:

Elizabeth Somervell (NIWA)

Executive Summary

Remote sensing has been undertaken by the Auckland Council in four separate campaigns since 2003, which have focussed on measuring the “real world” emissions of the light duty vehicle fleet. This report presents the results of the latest campaign undertaken in the Auckland region in May 2011 and highlights the important trends in the fleet characteristics and emissions that have emerged since monitoring was first undertaken in 2003.

Despite marked improvements in vehicle technology and fuel quality in New Zealand in recent years, motor vehicles remain a significant source of Auckland’s air pollution. In 2006, vehicles contributed between 40 and 86 per cent of the total air emissions in the region depending on the pollutant (Xie *et al.* 2011), with resulting social costs estimated at $273 million per year, as a result of increased mortality, hospitalisation and restricted activity days (Kuschel and Mahon 2010).

In theory, as new vehicles replace older ones in the fleet and as fuel gets progressively cleaner, the amount of pollutants discharged *per vehicle* should (on average) be reducing. However, changes in the fleet profile and increases in distance travelled can offset these reductions. Understanding how the *overall fleet* emissions are changing over time is critical because it determines whether the current vehicle emissions management policies and practices are likely to result in air quality goals for the region being met in the short to medium term. The changes in actual emissions over the years 2003 to 2011 signal whether additional reduction strategies and policies may need to be considered and, if so, which aspects of the fleet should be targeted.

In the 2011 campaign, ten days roadside monitoring was undertaken at seven sites across the Auckland region between 10 May and 20 May, yielding a dataset of more than 24,000 valid readings. Emissions measurements for carbon monoxide (CO), nitric oxide (NO), hydrocarbons (HC) and uvSmoke (as an indicator of fine particulate matter) were stored together with vehicle information (such as fuel type, age, odometer reading and emissions standard) enabling the effect of each parameter and any trends to be assessed. The analysis was undertaken using statistical methods that handled the skewed nature of the data and provided statistically defensible conclusions.

The main conclusions from this work are:

- The monitored light vehicle fleet has aged progressively in each campaign since 2003 but the petrol fleet has aged more rapidly than the diesel fleet.
- The average age of the Japanese used vehicles in the monitored fleet is now nearly twice the average age of the New Zealand new vehicles.
- The previous campaign (in 2009) suggested that average NO emissions, having dropped from 2003 and 2005, were potentially plateauing after 2005. The 2011 campaign has confirmed that NO emissions per vehicle have indeed plateaued. This is of concern given that ambient levels of nitrogen dioxide also seem to be

stable or on the rise and there is evidence from overseas of increased health effects in children living close to roadways.

- The difference between the mean and median light fleet emissions for most pollutants has widened considerably, suggesting the effect of gross emitting vehicles is becoming more pronounced. The mean values reflect the actual average per vehicle emissions but the medians better reflect the trends.
- The introduction and improvement of emissions standards have significantly reduced mean emissions of CO, HC, NO and uvSmoke for petrol vehicles. The trends are much less conclusive for diesel vehicles but do show a slight reduction in CO and uvSmoke as emissions standards improve. More importantly, the step change reductions expected as a result of the differences between the emissions test limits are not being seen clearly in the roadside data.
- Petrol vehicles demonstrated a strong tendency for emissions to increase with odometer readings. For diesel vehicles, there was little evidence to support emissions increasing with odometer readings.

The overall conclusion is that mean emissions, after showing a marked improvement from 2003 to 2009, have now plateaued. This is most likely due to older vehicles remaining in the fleet and not being replaced quickly enough with the newer technology. This suggests that accelerated scrappage programmes may be worth revisiting.

In addition, the impact of gross emitters has increased significantly, potentially warranting the consideration of policies targeting in-service emissions, e.g., more comprehensive emissions testing undertaken at warrant of fitness inspections.

Despite increasingly tighter emissions requirements for vehicles entering the fleet, current standards are not delivering the expected improvements in actual emissions. Therefore, future emissions requirements should be based on standards set for, and more representative of, “real-world” driving conditions.

The 2011 emissions results with corresponding vehicle details have been integrated into a database containing the 2003, 2005 and 2009 information. The database will allow cross matching and comparison of various emissions and vehicle fleet parameters to enable policies to be developed to more effectively address the issues of concern.

The principal recommendation for the future is to continue with regular campaigns every two years to continue to monitor the developments and assess the effectiveness of any interventions for the light fleet.

In addition, it should be noted that this report does not cover heavy duty vehicles which warrant a similar but separate investigation given their disproportionate impact on emissions, especially for particulate and NO_2.

1 Introduction

1.1 Background

Remote sensing has been employed in Auckland in three previous campaigns targeting light duty vehicles – one each in 2003, 2005 and 2009– yielding valuable datasets on fleet characteristics and emissions trends.

The initial campaign in April 2003 was the first attempt to obtain a representative profile of fleet in the Auckland region by collecting information on approximately 40,000 vehicles (Fisher *et al.* 2003). The remote sensing system was coupled to an on-road display giving drivers immediate feedback on the state of tuning of their vehicles, based on cut-off points for carbon monoxide. Emissions results for carbon monoxide (CO), nitric oxide (NO), unburned hydrocarbons (HC) and opacity (as an indicator of particulate emissions) were compared across the Auckland region and with results from similar programmes undertaken in the United States (US). Key findings from this study included:

- The most polluting 10 per cent of vehicles (nominated as the “gross emitters”) emitted between 39 to 53 per cent of the total emissions, depending on the pollutant.
- Vehicles without either a warrant of fitness or a valid registration recorded significantly higher emissions of CO, HC and opacity.
- The best 20 per cent of older vehicles (1980-1982) were found to emit less pollution than the worst 20 per cent of newer vehicles (2001-2003).
- The average concentration of pollutants in Auckland vehicle exhausts were two to three times the concentration in the exhaust of an average vehicle in the US.

In May/June 2005, the study was repeated to identify the factors that most strongly influence emissions, characterise the “gross emitters”, evaluate the effect of socio–economic factors on emissions and assess trends in the vehicle fleet/emissions since 2003 (Bluett *et al.* 2010). The roadside monitoring was conducted in tandem with an education campaign - the “Big Clean Up: Tune Your Car” campaign – highlighting to motorists the importance of tuning their vehicles. Emissions were measured using an updated RSD model (the 4000EN) which used uvSmoke (rather than opacity) as an indicator of particulate emissions. Key findings from this study included:

- The single most important characteristic influencing emissions was year of manufacture which correlated strongly with emissions of CO, HC, and NO but less so for uvSmoke which was influenced more by fuel type.

- Gross emitters of CO, HC and NO were more likely to be pre-1998 (vehicles aged more than 7 years at the time of the study). Petrol vehicles dominated CO gross emissions and diesel vehicles uvSmoke emissions.
- For petrol vehicles, emissions were significantly higher from vehicles coming from more deprived areas but there was no evidence of trends with deprivation index for diesel vehicle emissions.
- The average vehicle age and proportion of imported used vehicles in both the 2003 and 2005 campaign was largely unchanged, at nine years and 50 per cent respectively, but the proportion of diesel vehicle increased from 15 to 17 per cent.
- Emissions of CO, HC and uvSmoke improved on average for both petrol and diesel vehicles but NO increased.
- In a follow up survey, 26 per cent of motorists who were aware of the air quality campaign stated they had taken some action (e.g., tuned their vehicle) as a result of the education campaign.

The 2009 campaign was undertaken as part of a larger research project which aimed to determine if the harmful emissions from New Zealand's light duty vehicle fleet are improving (reducing), under the current "business-as-usual" scenario (Bluett *et al.* 2011). The project repeated the monitoring at seven sites common to the previous campaigns then assessed trends in both the fleet features and emissions from 2003 to 2009 and evaluated the effect of emissions standards and odometer readings on vehicle emissions. The main conclusions from this work were:

- From 2003 to 2009, the mean age of vehicles within the monitored fleet increased as did the proportions of diesel vehicles and imported used Japanese vehicles.
- Mean emissions, on a per vehicle basis, of all measured pollutants decreased significantly from the light duty vehicle fleet between 2003 and 2009.
- The introduction of emission standards for New Zealand new vehicles has signfiicantly reduced the mean emissions of all pollutants for vehicles manufactured from 2003 onwards (when the standards came into effect) compared to pre-2003 vehicles.
- Petrol vehicles showed a strong tendency for increased emissions with increased odometer readings but the findings were inconclusive for diesel vehicles.

While these findings were encouraging, two issues were highlighted for on-going monitoring and potential future policy intervention, based on current trends:

- Emissions improvements (especially from diesel vehicles) appeared to have plateaued which was of concern, with many urban environments showing steady or even increasing levels of ambient nitrogen dioxide (NO_2) in particular.
- The aging of the monitored vehicle fleet was also a concern because much of the improvement observed in the fleet emissions to date has been due to new lower emitting vehicles entering the fleet.

1.2 Aims and objectives of the study

The findings of the 2009 study clearly demonstrated the value of regular roadside remote sensing in identifying and assessing the key trends that influence the emissions performance of the light vehicle fleet. One recommendation from that work was to continue with regular campaigns every two years to monitor these critical or emerging trends.

In response, monitoring was repeated (again at the seven common sites) in May 2011. The objectives of the latest monitoring campaign (the subject of this report) were to:

- Confirm the emerging trends identified in the 2003, 2005 and 2009 campaigns to verify whether improvements in CO, HC and uvSmoke emissions were on-going and to establish whether NO emissions had plateaued.
- Provide a more comprehensive and robust scientific basis for any future management interventions by further evaluating the effect of emissions standards and mileage on emissions by fuel type and by country of first registration.

1.3 Project funding

The project was funded by the Auckland Council (AC).

In kind support was received from the NZ Transport Agency (NZTA) and the Ministry of Transport (MoT) in providing free access to the Motochek database to obtain the registration data for the vehicles captured in the remote sensing.

1.4 Structure of the report

The report is structured as follows:

- Chapter 2 outlines the equipment, sites and analysis techniques used in the 2011 measurement campaign, with references to the previous studies.
- Chapter 3 presents the trends in the monitored vehicle fleets from 2003 to 2011, in terms of vehicle characteristics.
- Chapter 4 discusses the trends in the vehicle emissions from 2003 to 2011, in terms of air pollutants.
- Chapter 5 investigates the effect of vehicle emissions standards on overall fleet emissions to assess the likely effectiveness of current policies.
- Chapter 6 evaluates the effect of odometer reading on emissions.
- Chapter 7 summarises the key findings.
- Chapter 8 presents the overall conclusions and recommendations.

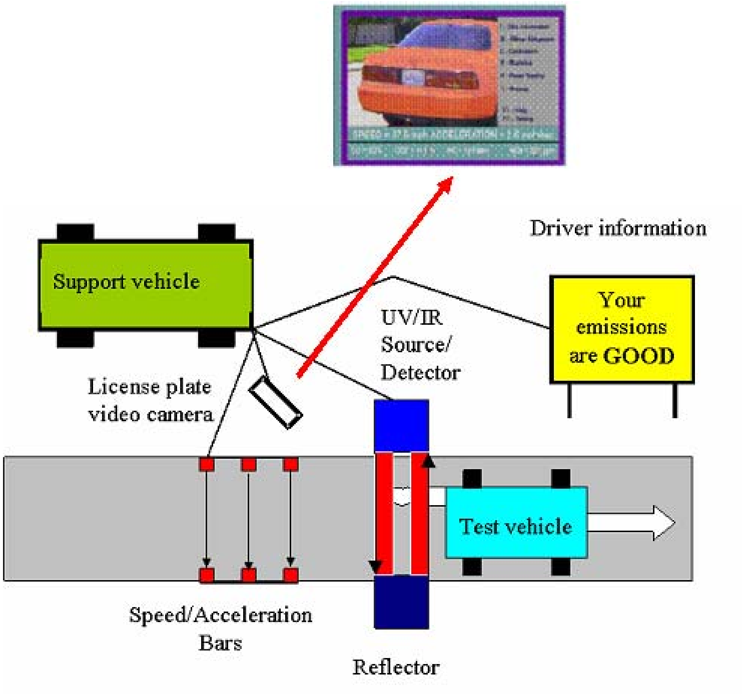
2 Method

This chapter outlines the equipment, sites and analysis techniques used to collect the 2011 dataset. This dataset was then used to compare fleet and emissions trends in the datasets obtained in earlier remote sensing campaigns since 2003.

2.1 Remote sensing equipment

The remote sensing devices (RSD) used to collect data in this study were the RSD 3000 (2003 monitoring) and RSD 4000EN models (2005, 2009 and 2011 monitoring). The RSD system was developed by Donald Stedman and his team at the Fuel Efficiency Automobile Test Data Centre, University of Denver, Colorado, USA. The RSD 3000 and 4000EN instruments use identical methods to measure the gaseous pollutants but differ in the way they measure particulate emissions (as detailed in section 2.1.2). A schematic diagram of the remote sensor monitoring equipment is shown in Figure 2.1.

Figure 2.1
Schematic diagram showing the remote sensing system in operation



2.1.1 Measurement of gaseous pollutants

The instrument consisted of an infrared (IR) component for detecting carbon monoxide (CO), carbon dioxide (CO_2) and hydrocarbons (HC), together with an ultraviolet (UV) spectrometer for measuring nitric oxide (NO). The source/detector module (Figure 2.2) was positioned on one side of the road, with a corner cube reflector on the opposite side. Beams of IR and UV light were passed across the roadway into the corner cube reflector and returned to the detection unit. The light beams were then focused onto a beam splitter, which separated the IR and UV components.

Figure 2.2
Source detector module and calibration unit of the RSD 4000EN

Williams *et al.* (2003) describe the analysis of the IR and UV light as follows. The IR light is passed onto a spinning polygon mirror that spreads the light across the four infrared detectors: CO, CO_2, HC and a reference. The UV light is reflected off the surface of the beam splitter and is focused into the end of a quartz fibre-optic cable, which transmits the light to an UV spectrometer. The UV unit is then capable of quantifying NO by measuring an absorbance band in the UV spectrum and comparing it to a calibration spectrum in the same region.

The exhaust plume path length and the density of the observed plume are highly variable from vehicle to vehicle and are dependent upon, among other things, the height of the vehicle's exhaust pipe, wind and turbulence behind the vehicle. For these reasons, the remote sensor can only directly measure ratios of CO, HC or NO to CO_2. These ratios are constant for a given exhaust plume, and on their own are useful parameters for describing a hydrocarbon combustion system. The remote sensor used in this study reported the %CO, ppm HC and ppm NO in the exhaust gas, corrected for water vapour and excess oxygen not used in combustion.

CO, HC and NO data measured by the RSD have been compared to data collected on a dynamometer and gas analyser set up running the IM240 test cycle. Pokharel *et al.* (2000) found that the fleet-averaged on-road remote sensing data correlated very well with the fleet average IM240 data. Studies carried out by the California Air Resources Board and General Motors Research Laboratories have shown that the RSD is capable of CO, HC and NO measurements within ±5%, ±15% and ±5% respectively of measurements reported by an on-board gas analyser (Lawson *et al.* 1990). The manufacturers of the RSD 4000EN quote the precision of the CO, HC and NO measurements as ±0.007%, ±6.6ppm and ±10ppm respectively, or as ±10% of the value, whichever is the greatest (see www.rsdaccuscan.com).

Cautionary note on measuring NO_X emissions

The oxides of nitrogen (NO_X) emissions from motor vehicles consist of nitric oxide (NO) and nitrogen dioxide (NO_2). Nitrous oxide (N_2O) – a greenhouse gas – is also present in small quantities in vehicle exhausts but in atmospheric chemistry and air pollution-related fields, NOx refers specifically to NO and NO_2.

NO is the dominant species and is generally accepted to be a high proportion of the total NO_X that leaves the vehicle's tailpipe. There has been a clear increase in proportion of NO_2 contained in vehicle exhausts over the last decade, increasing on average from around 6 per cent in 1997 to about 14 per cent in 2006 (DEFRA 2011). Exhaust gases from petrol vehicles typically have a lower NO_2/NO ratio than those from diesel vehicles (DEFRA 2003). Once in the atmosphere, NO can be oxidised to NO_2 (the predominant pathway being a reaction with ozone). For adverse human health effects of NO_X, NO_2 is the species of primary concern.

The remote sensing equipment used in this project is capable of measuring only NO. This report presents the results of the emissions-testing programme and therefore only refers to NO. The amount of NO_2 discharged by vehicles, and the rate at which NO is converted to NO_2 are not addressed in this report.

2.1.2 Measurement of particulate pollutants

When light illuminates a small particle such as a pollution particle in an exhaust plume, the light is both scattered in all directions and absorbed by the particle. For a particular incident light beam, the nature of the scattering and absorption interaction is determined by the physical characteristics of the individual particles – their size, shape and material characteristics – as well as by the size and shape distribution of the suspension of particles. If the characteristics of the incident light are known (specifically its direction of propagation, polarisation, wavelength and intensity), then this knowledge, coupled with the nature of the scattered light and a laboratory calibration, can be used to determine some features of particles in an exhaust plume.

A detailed technical description of the way the RSD 4000EN measures particulate pollutants can be found in Stedman and Bishop (2002). Very briefly, smoke is measured in vehicle exhaust plumes based on the absorption and scattering of light beams at ultraviolet (UV) wavelengths (~232 nm). These are the approximate wavelengths for peak mass density of diesel exhaust particulates (~100 nm). With a scattering configuration and an appropriate wavelength(s), and after making some realistic assumptions about particle properties (e.g., particle composition and size distribution), the smoke measurements are translated into particulate measurement units which approximate to grams of particulate per 100 grams of fuel burned. A fuel-based emissions factor, with units of grams of particulate per kilogram of fuel burned, can be calculated by considering the stoichiometry of fuel combustion and assumptions of fuel composition.

Cautionary notes on measuring particulate emissions

The standard methods of measuring particulate air pollution involve gravimetric analysis of a filter which has had a known volume of ambient air drawn through it. There are many technical difficulties associated with measuring particulate pollution with open-path technology, such as that used for remote sensing of vehicle emissions.

The manufacturers of the RSD 4000EN acknowledge these issues and as far as practical have addressed these through rigorous and documented development, calibration and quality assurance processes. However, the RSD uvSmoke data cannot be assumed to be equivalent to the results that would be obtained from gravimetric analysis carried out on a dynamometer – although it should be a very good approximation.

The RSD measures particulates (uvSmoke) for peak mass density of diesel exhaust particulates (~100 nm). Particles this small do not strongly contribute to the visibility or smokiness of a diesel vehicle’s exhaust plume. A smoky vehicle’s exhaust contains much larger particulates. A comparison between uvSmoke measurements made by the RSD and exhaust plume photographs shows that high uvSmoke measurements do not provide a strong indicator of the smokiness of the plume (Bluett *et al.* 2010).

The main purpose of this report was to assess the relative difference in emissions from vehicles of different ages and types. The RSD uvSmoke data suited this purpose well. However it must be noted that, because the RSD’s UV wavelength is selected for peak mass density of diesel exhaust particulates, uvSmoke data from petrol vehicles contains more uncertainty than uvSmoke data from diesel vehicles. Therefore the interpretation of uvSmoke data from petrol vehicles and the comparison of diesel and petrol uvSmoke data must be treated with due caution. In this report, the RSD particle measurements are reported as a dimensionless uvSmoke index. The RSD 4000EN manufacturers quote the precision of the uvSmoke measurements as ±0.05 or ±10% of the uvSmoke reading, whichever is the greatest.

In the 2003 campaign, opacity was used as the proxy for particulate emissions. Opacity was calculated from the absorbance of the three wavelengths used to measure CO, HC and NO by the RSD 3000 equipment. In the 2005 and 2009 campaigns, uvSmoke was used as the proxy for particulate emissions as measured by the RSD4000. To enable a comparison between the 2003 and 2005 particulate measurements, the 2003 opacity values were converted to uvSmoke values using the method described by Stedman and Bishop (2002).

2.1.3 Calibration and audit

Quality assurance calibrations and audits were performed in the field to ensure the quality of the data collected met specified standards. These were performed according to the equipment manufacturer's specifications as follows.

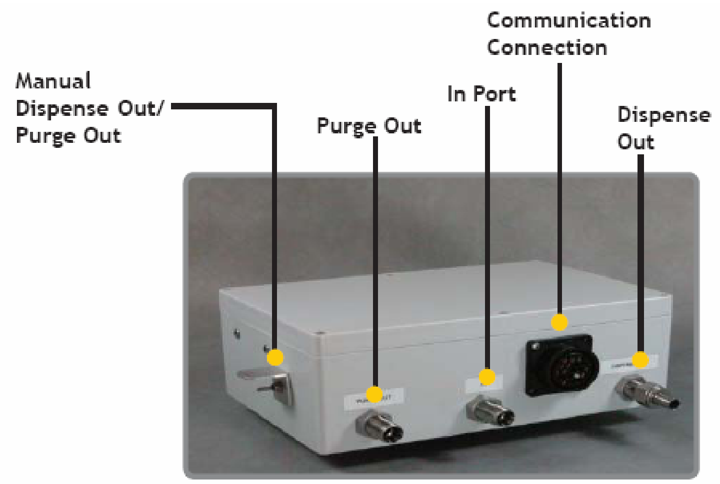
Every time the source detector module (SDM) was switched on and warmed up, the unit was calibrated using a method named cell calibration. A cell which contained a known concentration of calibration gases was placed in the IR beam path and the SDM was then calibrated to the known values of gas within the cell.

Each calibration was audited immediately after the calibration process and every hour thereafter that the equipment was operated. The purpose of the audits was to check the equipment remained correctly calibrated.

Audits were carried out by the computer-verified audit system which employed a gas puff method. This involved a puff of gas containing certified amounts of CO, CO_2, propane and NO being released from the gas dispenser box (Figure 2.3) into the calibration tube, which was mounted on the detector window of the SDM. The measured gas ratios from the instrument were then compared to those certified by the cylinder manufacturer. If the gas ratios measured during any of the audits did not fall within specified limits or if the alignment of the unit had been changed, then the RSD required recalibration and the audit process to begin again.

As noted in section 2.1.2, the primary data the RSD 4000EN measures to produce uvSmoke data is UV absorbance at wavelengths ~232 nm. The UV signal is by far the most sensitive to the alignment of the SDM and the corner cube reflector. While no field calibration is undertaken for the uvSmoke measurements, the audit process requires that the SDM and the corner cube reflector are aligned to achieve a consistent and maximum UV signal value.

Figure 2.3
The gas dispenser box for the computer verified audit process



The audits accounted for hour-to-hour variation in instrument sensitivity, variations in ambient CO_2 levels and variation of atmospheric pressure and instrument path length. Since propane was used to calibrate the instrument, all hydrocarbon measurements reported by the unit were given as propane equivalents.

2.1.4 Vehicle, speed and acceleration data

The RSD 4000EN system included a module to record the speed and acceleration of each vehicle when its emissions were measured (Figure 2.4). This provided valuable information about the driving conditions of the vehicles at the time of the measurements. The speed and acceleration measurement bars made their measurements before the vehicle passed through the emissions measurement equipment. The speed and acceleration bars were set up as close as practical (~2 m) to the SDM to minimise any changes in the vehicle's speed and acceleration between the points where the vehicle's speed and acceleration and emissions were measured.

Figure 2.4
The speed and acceleration bars (see arrows) in the RSD system

The speed and acceleration measurements were also used to derive vehicle specific power (VSP). VSP is a performance measure for determining whether a vehicle is operating within an acceptable power range when it is measured by remote sensing. The RSD 3000 system did not have the capability to measure vehicle speed or acceleration and therefore VSP data are not available for the 2003 monitoring campaign.

The emissions dataset from a vehicle was only considered valid if its VSP value fell between zero and 40kW/tonne. Monitoring sites which generate a relatively low proportion of vehicles providing valid data (a poor vehicle capture rate) can be scrutinised by considering the acceleration data. Sites with poor capture rates often show a large proportion of vehicles undergoing hard accelerations or decelerations during testing.

Engine load is a function of vehicle speed and acceleration, the slope of the site, vehicle mass, aerodynamic drag, rolling resistance and transmission losses. Under moderate to heavy load conditions, vehicle engines will enter enrichment modes that can increase emissions many times. These readings may bias the average results and the vehicles may be incorrectly classified as high emitters. Therefore, it was useful to have a performance measure (e.g., VSP) to screen out measurements of vehicles operating in enrichment mode.

2.1.5 Smart sign

The RSD 4000EN system includes a 'smart sign' which provides instantaneous feedback to the drivers of vehicles who have just passed through the monitoring site. The smart sign flashes a message indicating the general state of their vehicle's emissions as ‘good’, ‘fair’ or ‘poor’. A photograph of the smart sign displaying the ‘good’ message is shown in Figure 2.5. The smart sign serves as a public education tool which aims to promote the benefits of operating a well-tuned and well-maintained car.

Figure 2.5
The smart sign displaying the ‘good’ emissions message

The aims of the 2011 monitoring campaign did not include raising public awareness of the benefits of running a well-tuned vehicle. The smart sign was not deployed for the measurements undertaken in 2009 or 2011 but was used previously in the 2003 and 2005 campaigns, which included the aim of raising public awareness.

2.1.6Vehicle information

The RSD 4000EN system included video equipment to record freeze-frame images of the licence plate of each vehicle measured. The camera (Figure 2.6) took an electronic image of the licence plate (Figure 2.7) which was integrated into the RSD’s monitoring database. At the completion of the day’s monitoring the licence plate information was transcribed into a text file.

Figure 2.6
Licence plate camera used in the RSD system

Figure 2.7
Example of a licence plate image recorded by the RSD system

The list of licence plates were submitted to the NZ Transport Authority's vehicle register (Motochek[1]) and information obtained for each vehicle. Table 2.1 lists the relevant information obtained for the vehicles monitored in this project.

[1] An internet-based interface that enables registered users to access information from the NZ LANDATA (motor vehicle registration and relicensing and road user charges) database to obtain vehicle and owner details – see motochek.landtransport.govt.nz for more information.

Table 2.1
Information obtained on monitored vehicles from Motochek

Motochek database field	Description of data
Make	Company which manufactured the vehicle
Model	
Year of manufacture	
Body style	Saloon, hatchback, station wagon, utility, light van, flat deck truck, heavy bus/service coach etc.
Main colour	
Engine capacity	cc
Engine power	kW
Vehicle type	Passenger car/van, goods van/truck/utility, motorcycle, bus, trailer/caravan, tractor etc.
Purpose of vehicle use	Private passenger, taxi, commercial passenger transport, licensed goods, other (standard) goods, ambulance, fire brigade, diplomatic etc.
Fuel type	Petrol, diesel, LPG, CNG, other
Country of origin	Country where vehicle was manufactured
WOF expires	Warrant of fitness expiry date
Registration status	Active, cancelled or lapsed
Country of first registration	Country where vehicle was first registered
Gross vehicle mass	kg
TARE weight	kg
Odometer reading	km or miles
Plate type	Standard, trade, personalised, investment, diplomatic or crown
Ownership	Private (male or female), company, fleet or lease
Subject to RUC	Subject to road user charges

2.1.7 Deployment of equipment

The remote sensor was operated on single lane motorways, on ramps or arterial roads so that emissions from individual vehicles could be measured. The equipment was operated by NIWA, and was manned while at the testing sites.

The project required a substantial level of operation of complex equipment on the edge of busy roadways. A great deal of effort had to be taken to ensure the safety of the operators, minimise effects on normal traffic flow and prevent any accidents.

Approvals and advice were sought and obtained from all relevant roading and traffic control authorities. These authorities included Auckland Transport when monitoring was undertaken on local road networks and NZ Transport Agency when monitoring was undertaken on the national highway network. An independent traffic management organisation was engaged to develop appropriate traffic management plans for each site. In a post-field programme review, it was found the operational procedures worked well. No incidents were reported.

2.1.8 Benefits and limitations of RSD monitoring programmes

Typically, vehicle emissions data are obtained by putting selected vehicles on a chassis dynamometer, running them through a simulated drive cycle and collecting the exhaust stream for analysis with a bank of gas and particulate analysers. From these measurements, extrapolations are made to the whole fleet, or to particular scenarios. However, studies have shown that such methods tend to underestimate real-world emissions (e.g., Walsh *et al*. 1996). Under-estimation can result from the simulated drive cycles not being representative of actual drive cycles or not accounting for all vehicles. However, the main reason is that the bulk of real-world emissions generally come from a small proportion of vehicles known as the ‘gross emitters’ and it is difficult to capture these vehicles adequately in dynamometer testing.

The RSD provides a solution to this problem by sampling the actual exhaust emissions of a large number of real-world vehicles in an on-road situation. This has numerous benefits compared with a dynamometer testing programme which tests a ‘tame fleet’ in a simulated drive cycle. The RSD monitoring takes less than one second per vehicle allowing up to 2000 vehicles to be monitored each hour at a cost of only $2 to $3 per vehicle. This compares with approximately 30 minutes to complete a single IM240 setup and test. RSD monitoring is also unobtrusive because there is no physical connection to the vehicle and no specific behaviour is required of the driver.

There are, of course, limitations with RSD monitoring as follows:

- The RSD measures a vehicle’s emissions at a single point (generally under slight acceleration) as opposed to integrating the emissions for a series of driving events (which also include decelerations and steady state behaviour) and therefore may not be representative of the average emissions over a full drive cycle.
- The monitoring sites used are single lane on- or off-ramps, arterial roads, or one way streets. The emissions measured therefore reflect driving conditions that predominate on these roadways and may not necessarily represent emissions generated for other roadways (e.g., at busy intersections or suburban roads where vehicles operating under cold start conditions may be more common).
- The measurement of particulate emissions using open path technology is problematic, as discussed in section 2.1.2, and is unlikely to be as accurate as that collected by a dynamometer set up.

- With the RSD, it is not possible to get under the bonnet of the vehicles to inspect the on-board diagnostic systems and identify any possible causes of high emissions.
- The RSD measures emissions just above road level, therefore emissions from vehicles that discharge exhaust vertically (e.g., some heavy duty trucks) cannot be measured. Light duty vehicles that discharge exhaust gases sideways can be measured by the RSD. However, the capture rate of valid measurements of these vehicles may be a little lower than vehicles that discharge in a backward direction.

Consequently, the data provided by an RSD programme will not be identical to those obtained from dynamometer drive cycle testing. However, the RSD information does provide a complementary data stream that can be used to check and validate the findings of data collected on a smaller number of dynamometer drive cycle tests.

The benefit of monitoring vehicle emissions at road-side sites using RSD technology is becoming widely accepted internationally. Programmes have been undertaken in Europe, UK, USA, Australia and New Zealand. The RSD is employed by a number of environmental authorities in the USA to enforce and assess the effectiveness of vehicle inspection and maintenance programmes (e.g., Bishop and Stedman 2005). The California Air Resource Board (CARB) has evaluated remote sensing for improving California's smog check programme (CARB 2008). RSD data have been used to assist in evaluation of Denver's vehicle emissions inventory (Pokharel *et al.* 2002).

2.2 Monitoring sites

Monitoring for this project was undertaken in 2011 at a range of sites across Auckland. The 2011 results were then compared with results for the same sites obtained from previous RSD campaigns conducted in 2003, 2005 and 2009 (Fisher *et al.* 2003; Bluett *et al.* 2010; Bluett *et al.* 2011).

Details of these campaigns follow.

2.2.1 Sites used in the 2011 campaign

The 2011 RSD monitoring was carried out at seven sites across the Auckland region as indicated in Figure 2.8. These sites were selected based on three criteria:

1. Were (or represented) sites previously used in the 2005 and 2009 monitoring campaigns (and the 2003 campaign where possible).
2. Provided good geographical distribution across the Auckland region.
3. Experienced relatively high daily traffic counts and good data capture rates.

Ten days of monitoring were undertaken in May 2011, with three sites being monitored in two days, as shown in Table 2.2. In total, valid results were collected for approximately 24,400 light duty vehicles.

Figure 2.8
Map of the locations of the monitoring sites used in the 2011 RSD monitoring campaign

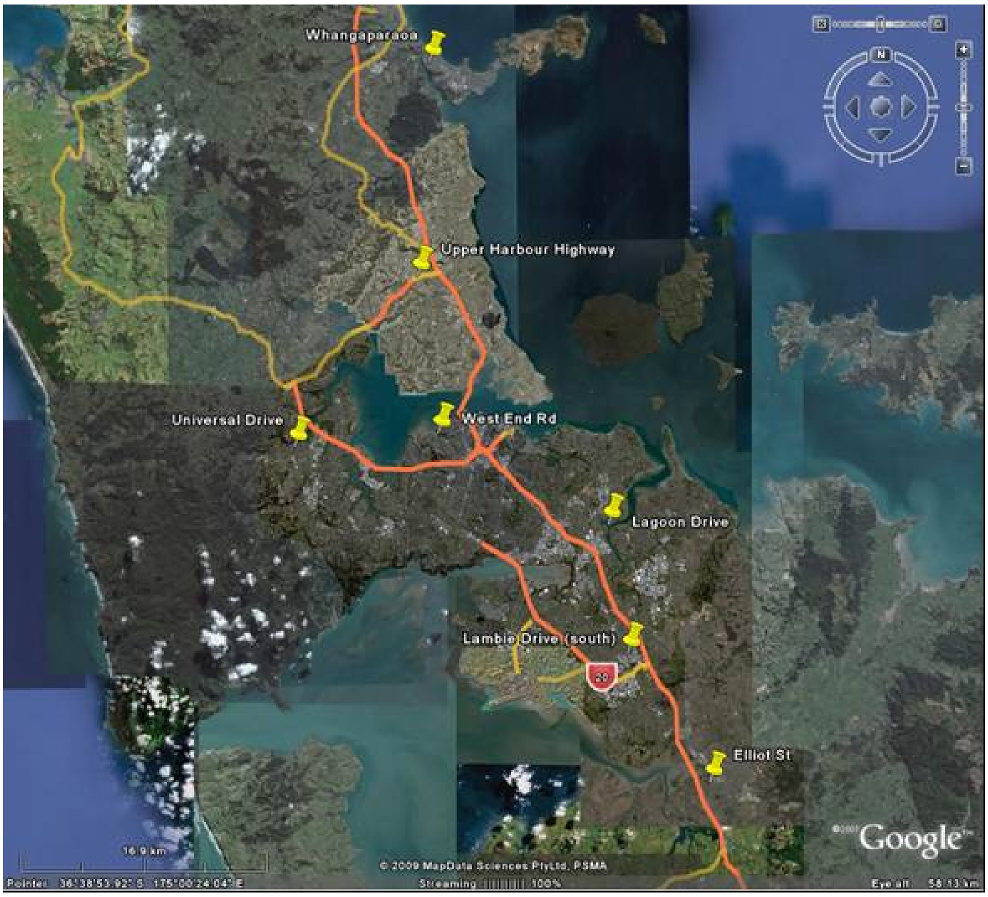


Table 2.2
Details of the monitoring undertaken in the 2011 RSD monitoring campaign

Site Name	Site Code	Date	Time	Vehicles Tested	Valid Tests	Capture Rate
Lagoon Dr	AUC2	10 May	06:12-12:13	4,372	1,990	45.5%
		23 May	05:56-12:04	4,049	2,055	50.8%
Lambie Dr (southbound)	MAN2	25 May	06:54-12:00	2,518	930	36.9%
Universal Dr	WAI5	16 May	14:03-19:18	4,214	2,052	48.7%
West End Rd	AUC8	17 May	05:53-12:21	2,389	1,133	47.4%
Whangaparaoa Rd	ROD3	18 May	13:16-19:06	6,660	4,539	68.2%
		19 May	12:51-19:02	7,012	4,674	66.7%
Elliot St (westbound))	PAP1	30 May	05:57-12:02	2,267	1,349	59.5%
Upper Harbour Highway (westbound)	NOR5	20 May	13:09-19:01	5,212	3,110	59.7%
		24 May	13:39-19:01	4,914	2,550	51.9%
Total				**43,607**	**24,382**	**55.9%**

2.2.2 Sites common to the 2003, 2005 and 2009 campaigns

Table 2.3 highlights which sites used in 2011 were common to the campaigns in 2003, 2005 and 2009 and presents the valid readings (and the number of individual vehicles) recorded for each site. All seven sites used in 2011, were repeats of sites from 2005 and 2009 with four of these also being common to 2003. As noted in previous reports, many of the sites from the original 2003 campaign were rendered unsuitable for remote sensing as they had been either upgraded to more than one lane, installed with ramp metering signals which interrupt the traffic flow, or no longer existed. Universal Drive, West End Road and Whangaparaoa Rd were added in 2005. Only light duty vehicles (>3,500 kg) were considered in the analysis.

Table 2.3
Comparison of common monitoring sites across the 2003, 2005, 2009 and 2011 campaigns

Site No	Site Name	Site Code	2011	2009	2005	2003
1	Lagoon Dr	AUC2	4,045	4,437	7,785	3,884
2	Lambie Dr (S)	MAN2	930	1,339	4,295	2,379
3	Universal Dr	WAI5	2,052	5,385	2,545	n/a
4	West End Rd	AUC8	1,133	1,066	2,555	n/a
5	Whangaparaoa Rd	ROD3	9,213	3,826	3,850	n/a
6	Elliot St (W)	PAP1	1,349	1,342	1,367	1,447
7	Upper Harbour Highway (W)	NOR5	5,660	5,558	2,992	1,937
Total valid readings			**24,382**	**22,953**	**25,389**	**9,647**
Total individual vehicles*			20,895	21,383	23,310	9,338

* Note some vehicles went through the remote sensor more than once – in one case 67 times – and therefore the number of individual vehicles captured is lower than the number of valid readings. The results presented in the following sections show the number of individual vehicles.

2.3 Statistical tools/techniques for data analysis

Emissions data from vehicles do not conform to a normal distribution. It is highly skewed with many low values and relatively few high values.

In this study, the non-normal distribution of the data sets collected was recognised and accounted for by using appropriate statistical methods and mathematical models which are briefly described below. The Kruskal-Wallis (K-W) test of significant differences was used because it handles the skewed nature of the data and provides statistically defensible conclusions.

2.3.1 Kruskal-Wallis test for significant differences

Skewed datasets like emissions data can be analysed using the Kruskal-Wallis (K-W) test which is a non-parametric one-way analysis of variance. This test does not assume the data comes from a *normal* distribution but it does assume that all data comes from the *same* distribution. The routine converts all values to ranks before analysis, thereby creating a uniform distribution. Therefore the K-W test is an appropriate and useful tool to analyse highly skewed data sets, such as real-life vehicle emissions.

The routine tests the hypothesis that all samples have the same median rank, against the alternative that the median ranks are different. The routine returns a *p*-value for the likelihood the observed differences could occur purely by chance. The significance level used for all K-W tests in this report was 95% (i.e., $p = 0.05$).

A summary of the results of the K-W tests undertaken for the analyses presented in this report are presented in Appendix 1.

2.3.2 Treatment of negative RSD data

As with all scientific instruments, the RSD is not perfectly precise and there is some uncertainty or error associated with the data it records, e.g., HC concentrations can be ±6.6 ppm of the value recorded. When measuring pollutant concentrations from newer, typically lower emitting, vehicles, concentrations are frequently close to or at zero. The pollutant ratio method the RSD employs to measure emissions means that these low values may be recorded as negative concentrations. While in reality there is no such thing as a negative concentration, provided the RSD's quality assurance criteria are met, the negative concentration values produced are valid data as they reflect the uncertainty in the measurements. The negative values recorded are a useful indicator of the 'noise' contained within the data produced by the RSD instrument.

In this report, all valid negative data has been included in the data analyses and the subsequent calculations of mean and median values etc. However, for ease of display and interpretation, the box plots which show the emissions measurements only show the positive data.

2.3.3 Presentation of results

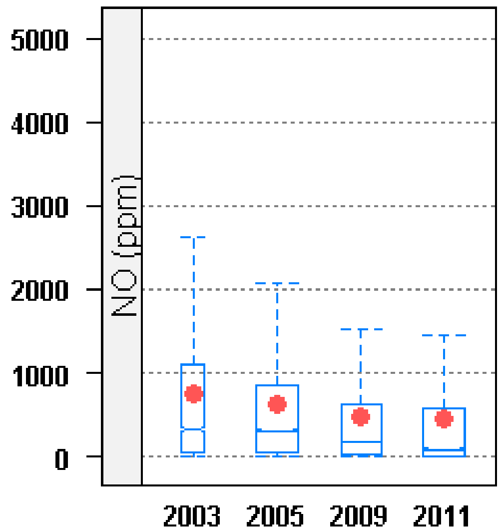
Throughout this report box and whisker plots are used to characterise vehicle emissions. These plots provide a compact summary of trends in the mean, median, and range for each pollutant, in a format which emphasises variation among and within factors such as fuel type and vehicle age. This simplicity inevitably means that much of the detail inherent in our data is lost, and readers wishing to delve deeper into the results are urged to contact the authors.

The conventions used to construct each plot (see Figure 2.9) are as follows:

- Each box and whisker icon comprises a connected set of graphical elements which summarise the underlying data as measured along the vertical axis.
- The upper and lower limits of the central box show the upper and lower quartiles. Thus, the box contains the central 50 per cent of the raw data.
- The whiskers represent the 5th and 95th percentile values. More extreme data values, possibly extending well beyond the maximum axis value, are suppressed.
- Red circles shows the mean, whilst the median is represented by the "belt" or line across the middle of the "waist" on the box.
- The extent of the "waist" of the boxes (whether it is short or long) indicates the confidence intervals around the median. If the "waists" of two adjacent boxes do not overlap then the means are statistically different and vice versa.
- Box width is proportional to sample size. In the example, sample size for 2003 is roughly half that for the other three years.

Figure 2.9

Example of a plot used to compare emissions results showing the mean (red circle), median (belt or line across the waist), 95% confidence interval around the median (extent of the waist), interquartile range (box), and 5th and 95th percentiles (whiskers). The sample size is represented by the width of the box.



For all pollutants, the raw data reported by the RSD system typically include a small proportion (rarely exceeding 2 per cent) of negative values. The sample means shown in each box and whisker plot have been estimated using the data as actually reported, including negatives, so as to ensure they are unbiased. The remaining plot elements (i.e. the quartile ranges and whiskers) are derived on the assumption that negative data represent pollutant values which are positive but so low as to be indistinguishable from zero. This has no effect on the median, box limits, or upper whisker, the sole effect being to ensure the lower whisker does not fall below zero.

Data for most pollutants tend to be highly skewed, with a high proportion of low values offset by a smaller number of high values. The degree of skewness associated with each icon can be gauged by comparing the mean and median. The greater the difference between these two measures, the greater the skewness.

Note: The mean values reflect the actual average per vehicle emissions but the medians better reflect the trends.

3 Trends in the Monitored Fleet – 2003 to 2011

This chapter presents the major trends in key vehicle parameters measured for the light duty vehicle fleets monitored in 2003, 2005, 2009 and 2011. Emissions measurements from heavy duty vehicles (gross vehicle mass greater than 3500kg) were excluded from the analyses. Results are presented for overall monitored light fleets and then further investigated by fuel type (petrol and diesel) and by country of first registration (New Zealand new and Japanese used imports).

Datasets used for the analysis in this section: In total, records were available for 9,338 individual light duty vehicles in the 2003 dataset, 23,310 in 2005, 21,383 in 2009 and 20,895 in the 2011 dataset. Of these, the vast majority were petrol or diesel vehicles. Sections 3.1 and 3.3 utilised records for all vehicles but section 3.2 only focussed on the petrol and diesel vehicles which reduced the datasets slightly to 9,333 in 2003, 23,395 in 2005, 21,361 in 2009 and 20,885 in 2011.

3.1 Overall fleet

Vehicle age and year of manufacture influence emissions. The level of emissions control technology installed tends to be correlated with the year of manufacture of a vehicle although this correlation is less pronounced in New Zealand where emissions control standards have only been in place since 2003. In addition, as a vehicle ages its emission performance tends to degrade as parts or systems wear.

3.1.1Vehicle age

Table 3.1 compares the mean and median ages of the vehicles monitored from 2003 to 2011.

Table 3.1
Comparison of the mean and median ages of the 2003 to 2011 monitored fleets overall

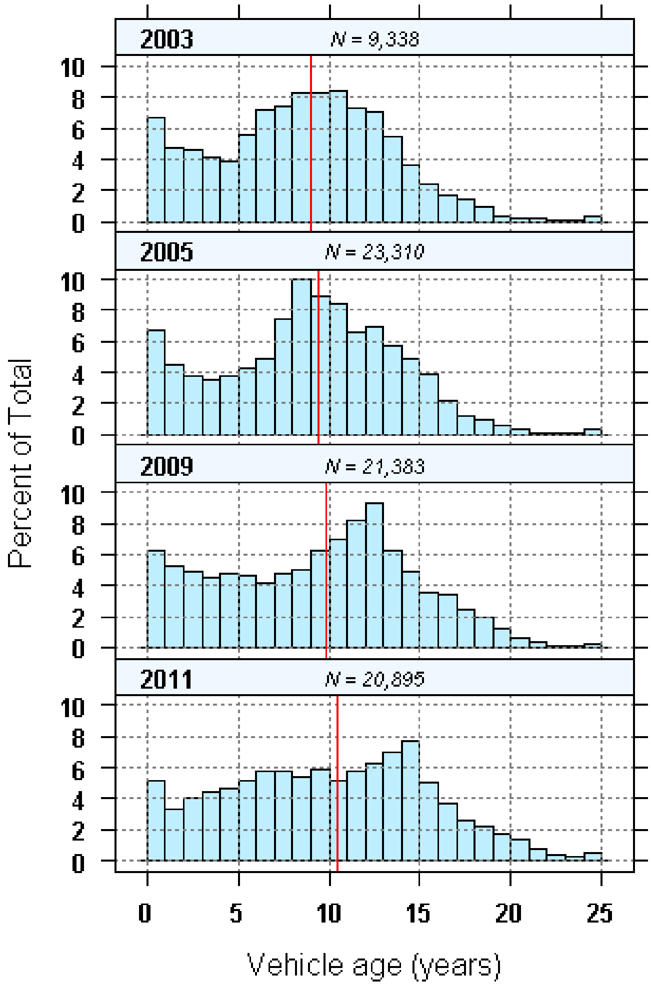
Campaign Year	Age (years)	
	Mean	Median*
2003	9.0	9
2005	9.5	10
2009	9.9	10
2011	10.5	11

* Note these are whole numbers as they are based on year of manufacture so can only be in whole years

The mean age of the monitored light fleet has steadily increased by 1.5 years from 2003 to be 10.5 years in 2011. The median age has shown a similar trend.

Figure 3.1 compares the age profiles of the vehicles monitored from 2003 to 2011. The figure shows the age distribution flattening in more recent years with a less marked contribution from vehicles around 10 years old.

Figure 3.1
Comparison of the age profiles of the 2003 to 2011 monitored fleets overall. *Note the red line represents the mean age.



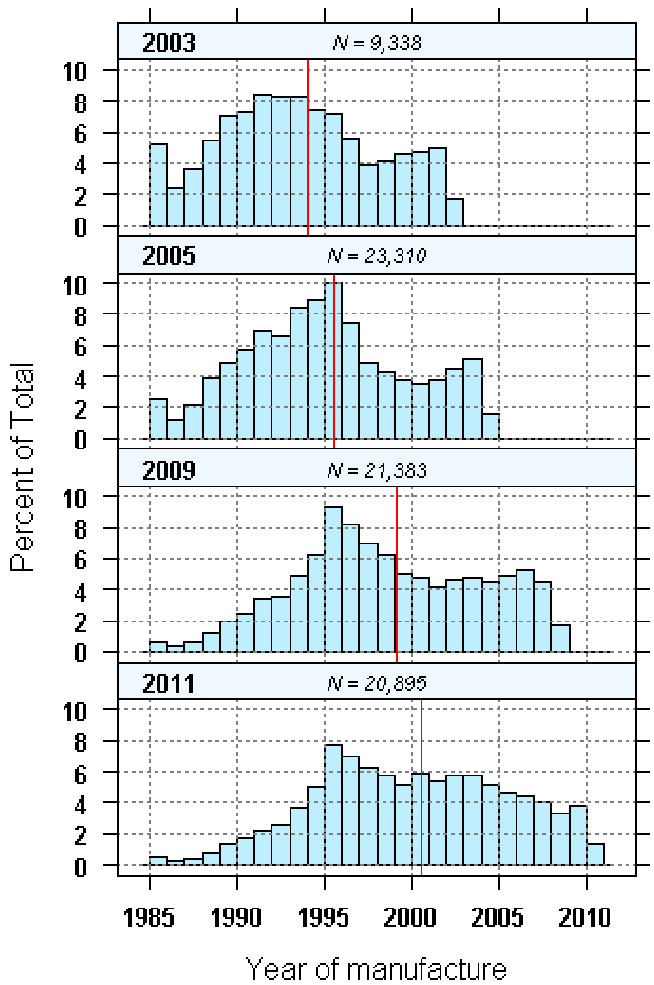
Historically the two key entry points into New Zealand light fleet have been from New Zealand new (NZN) entering at 0 years and Japanese used (JPU) vehicles entering at much older ages. Figure 3.1 suggests that the influence of the JPU vehicles relative to NZN vehicles is waning and most likely reflects changes to vehicle emissions legislation that have closed the gaps in the emission standards requirements between new and used vehicles (MoT 2007, MoT 2010). The “cohort” of existing older vehicles can be seen moving sequentially through the years with the peak now at 14 years of age.

3.1.2 Vehicle year of manufacture

Figure 3.2 compares the year of manufacture profiles of the vehicles monitored from 2003 to 2011. The figure shows that the mean year of manufacture has increased from 1994 in 2003 to 2001 in 2011. Despite the aging trend in the fleet, more vehicles in the fleet have now been manufactured in years when emissions standards have improved.

Figure 3.2

Comparison of the year of manufacture profiles of the 2003 to 2011 monitored fleets overall. * Note the red line represents the mean year of manufacture.



Overseas emissions standards generally change every five years or so, with emissions usually decreasing by 30 to 50 per cent with each new standard depending on the pollutant. Because the fleet average year of manufacture was seven years younger in 2011 than that in 2003, fleet average emissions in 2011 should reflect a step change in emissions performance (and this is investigated further in section 5).

3.2 Fuel type

Fuel type is another important emissions determinant as differently fuelled vehicles emit pollutants in different quantities and proportions.

Table 3.2 shows the trends in the proportions and mean ages of petrol and diesel vehicles since 2003. The proportion of petrol vehicles in the monitored fleet has decreased slightly since 2003, but does not appear to have changed between 2009 and 2011. This is consistent with trends seen in the New Zealand light fleet overall which show 85.4 per cent petrol vehicles in 2005 and minimal change between 2009 and 2010 with the proportion holding steady at 84.7 per cent of the total (MoT 2011). National fleet statistics for 2011 were not available at time of writing.

Diesel vehicles now currently comprise 15.5 per cent of the fleet, compared to 12.5 per cent in 2003.

Table 3.2
Comparison of the proportions and mean ages of the 2003 to 2011 monitored fleets by fuel type

Campaign Year	Petrol			Diesel		
	No of vehicles	% of total fleet	Mean Age (yrs)	No of vehicles	% of total fleet	Mean Age (yrs)
2003	8,169	87.5%	9.1	1,164	12.5%	8.7
2005	19,876	85.3%	9.5	3,419	14.7%	9.2
2009	18,044	84.5%	10.0	3,317	15.5%	9.0
2011	17,646	84.5%	10.7	3,239	15.5%	9.3

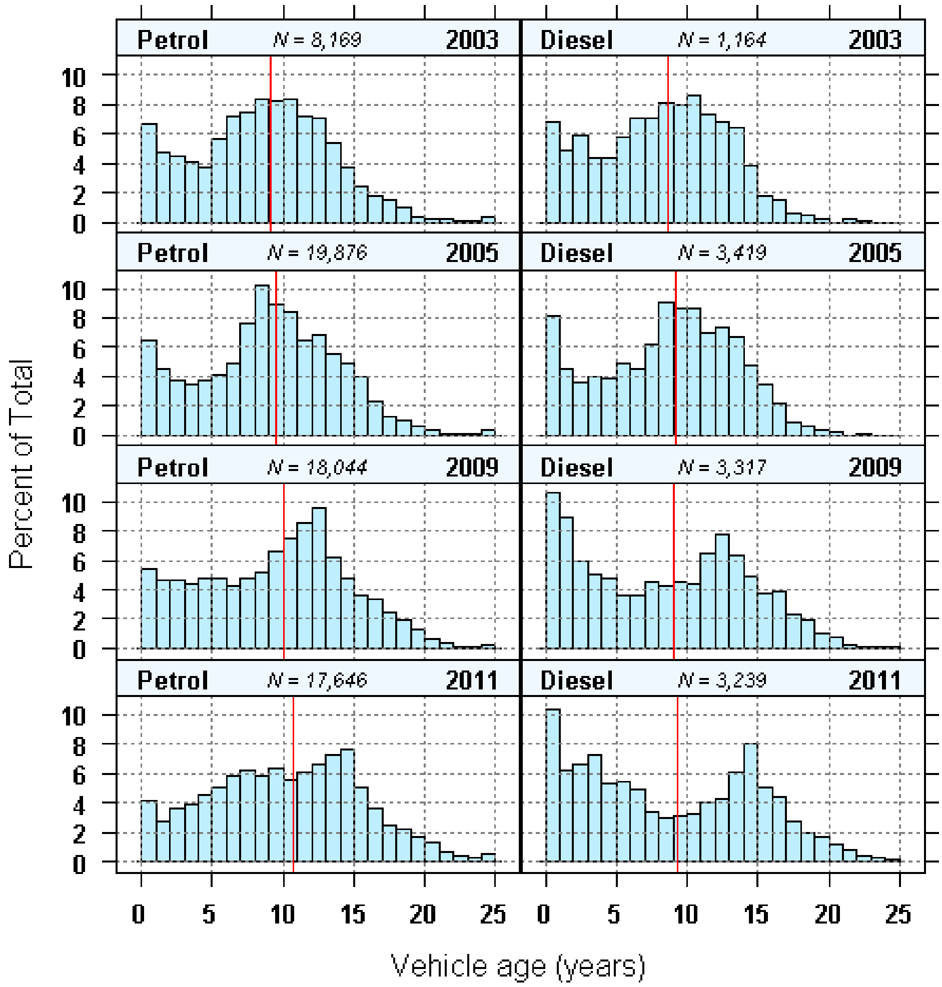
Analysis of vehicles by fuel type for the most recent (2011) RSD campaign emphasises the rapidly increasing influence of diesel vehicles in the Auckland fleet. Although the proportion of diesel vehicles remained constant at 15.5 per cent of the 2009 and 2011 fleets (see Table 3.2), they represent over 25 per cent of vehicles manufactured in each year since 2007, and just under one third (262 of 791, i.e., 33.1 per cent) of vehicles manufactured in 2010.

3.2.1 Vehicle age

Age profiles for the monitored petrol and diesel fleets now differ markedly, with the petrol fleet aging more rapidly than the diesel fleet (see Table 3.2 and Figure 3.3).

The mean age of the petrol fleet has increased by 1.6 years (from 9.1 to 10.7 years) since 2003, compared to only 0.7 years (from 8.7 to 9.3 years) for the diesel fleet over the same period.

Figure 3.3
Comparison of the age profiles of the 2003 to 2011 monitored fleets by fuel type. * Note the red line represents the mean year of manufacture.



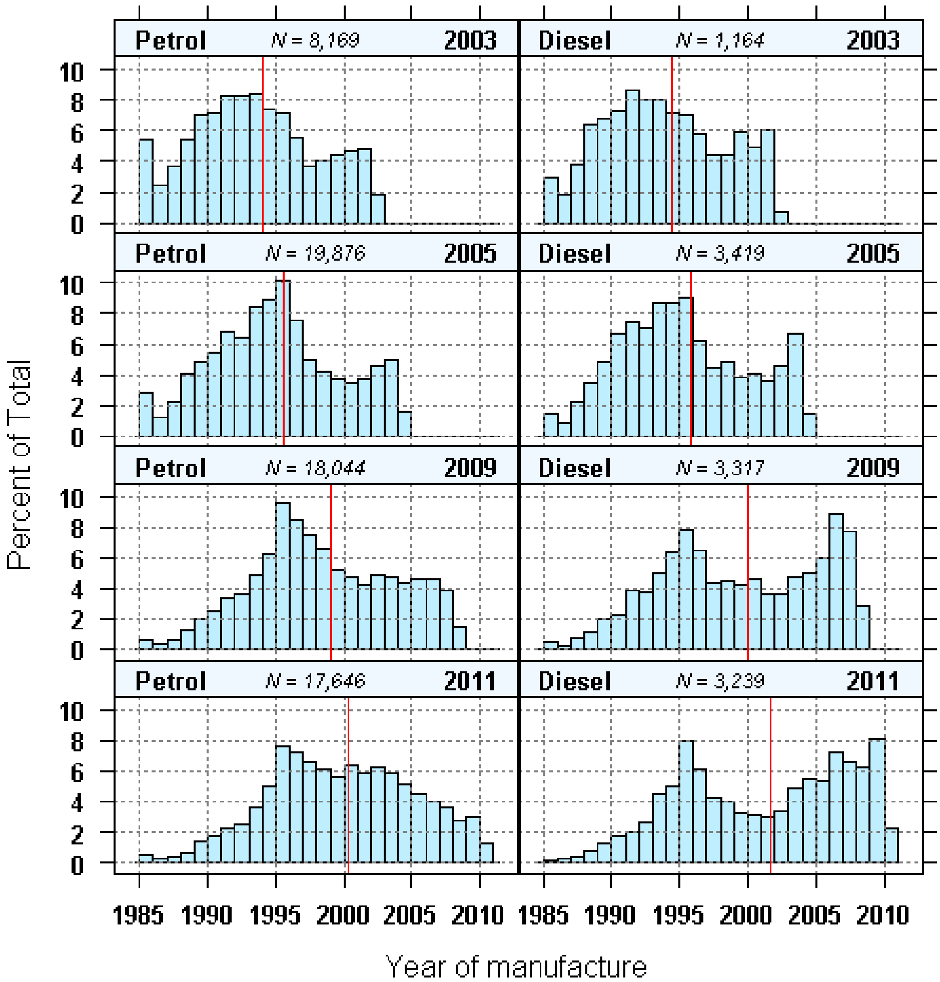
3.2.2 Vehicle year of manufacture

The difference seen in the age profiles of monitored petrol and diesel vehicles is also apparent in terms of year of manufacture (Figure 3.4).

Both the petrol and diesel fleets continue to be strongly influenced by large numbers of vehicles manufactured in 1995 and 1996. However, since 2009, the diesel fleet has also shown evidence of a second significant year class – representing vehicles manufactured after 2005. The age profile for the diesel fleet is now strongly bimodal, in contrast to the petrol fleet which continues to be dominated by the 1995 and 1996 vehicles which are aging appreciably.

Figure 3.4

Comparison of the year of manufacture profiles of the 2003 to 2011 monitored fleets by fuel type. * Note the red line represents the mean year of manufacture.



3.3 Country of first registration

Compared with other countries, New Zealand has an unusual vehicle fleet in that it is split almost evenly between imported new and imported used vehicles. Vehicles are typically manufactured to meet the emissions control specifications in the country where they are intended to be registered for the first time and these specifications differ depending on the country. Prior to 2003, New Zealand did not have any regulations for vehicle exhaust emissions and therefore imported new vehicles were not required to have emissions control equipment. However, imported used vehicles were generally sourced from countries, primarily Japan, with existing vehicle emissions standards.

As seen in Table 3.3, the monitored fleet continues to be more or less evenly divided between New Zealand new and used vehicles imported from overseas (primarily from Japan), but the proportion of New Zealand vehicles has increased very slightly since falling to a minimum of 46.7 per cent in the 2005 campaign. The most recent data show evidence of a potential plateau in the New Zealand/overseas split, with the decline in the incidence of Japanese vehicles from 2009 partially offset by a small increase in the number from other countries such as Singapore.

Table 3.3

Comparison of the proportions and mean ages of the 2003 to 2011 monitored fleets by country of first registration

Campaign Year	New Zealand			Japan			Other*		
	No of vehicles	% of total fleet	Mean Age (yrs)	No of vehicles	% of total fleet	Mean Age (yrs)	No of vehicles	% of total fleet	Mean Age (yrs)
2003	4,749	50.9%	7.4	4,458	47.7%	10.7	131	1.4%	10.7
2005	10,888	46.7%	7.5	12,019	51.6%	11.3	403	1.7%	9.9
2009	10,492	49.1%	7.2	10,447	48.9%	12.5	444	2.1%	10.7
2011	10,363	49.6%	7.8	10,117	48.4%	13.2	415	2.0%	11.9

* Note these are primarily from Singapore (914 vehicles), the UK (143 vehicles) and the US (136 vehicles)

Comparisons of vehicle age and year of manufacture by country of origin (see Figures 3.5 and 3.6 which follow) confirm that the Japanese used component of the monitored fleet is older than the New Zealand new component, and is also aging much more rapidly.

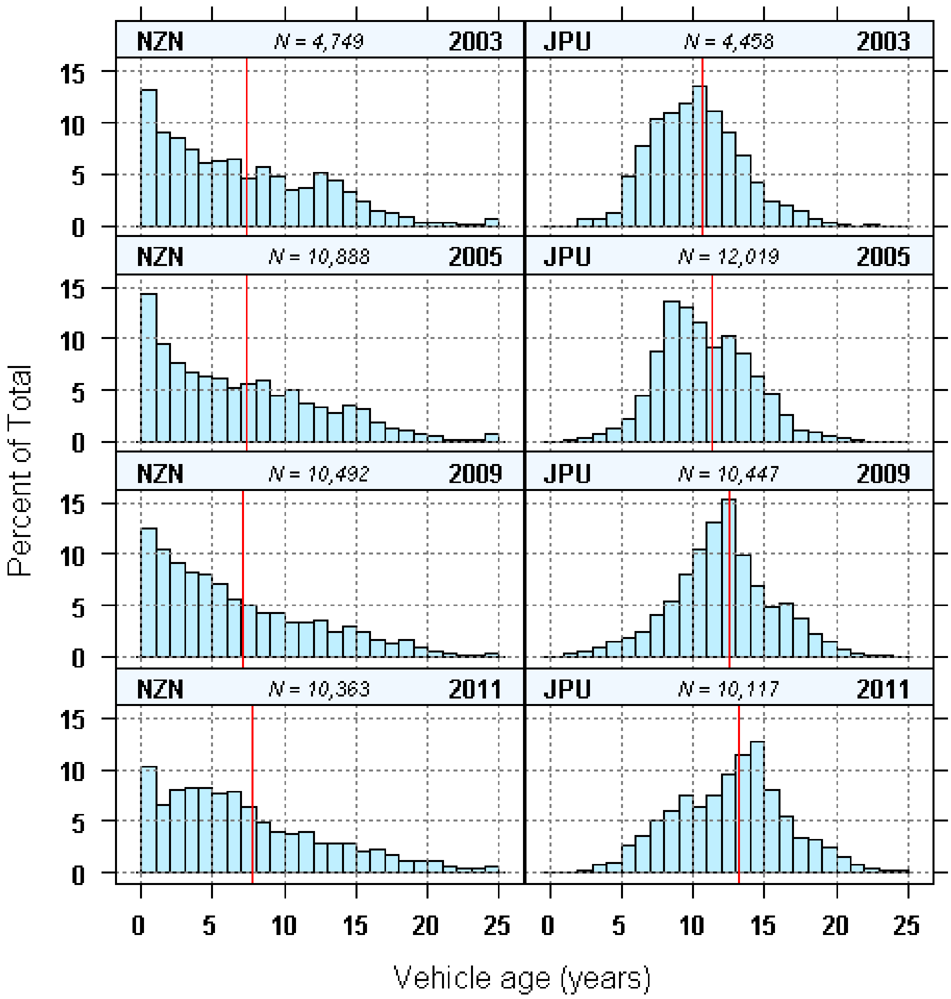
3.3.1 Vehicle age

Figure 3.5 shows that the mean age for New Zealand new (NZN) vehicles in the monitored fleets has been relatively stable since 2003, increasing by 0.4 years from 2003 to 2011, although there is evidence of a more marked increase (0.7 years) from

2009 to 2011. By contrast, mean age for Japanese used (JPU) vehicles has risen by 2.4 years, from 10.7 years (in 2003) to 13.2 years (in 2011).

Figure 3.5

Comparison of the age profiles of the 2003 to 2011 monitored fleets by country of first registration. * Note the red line represents the mean year of manufacture.

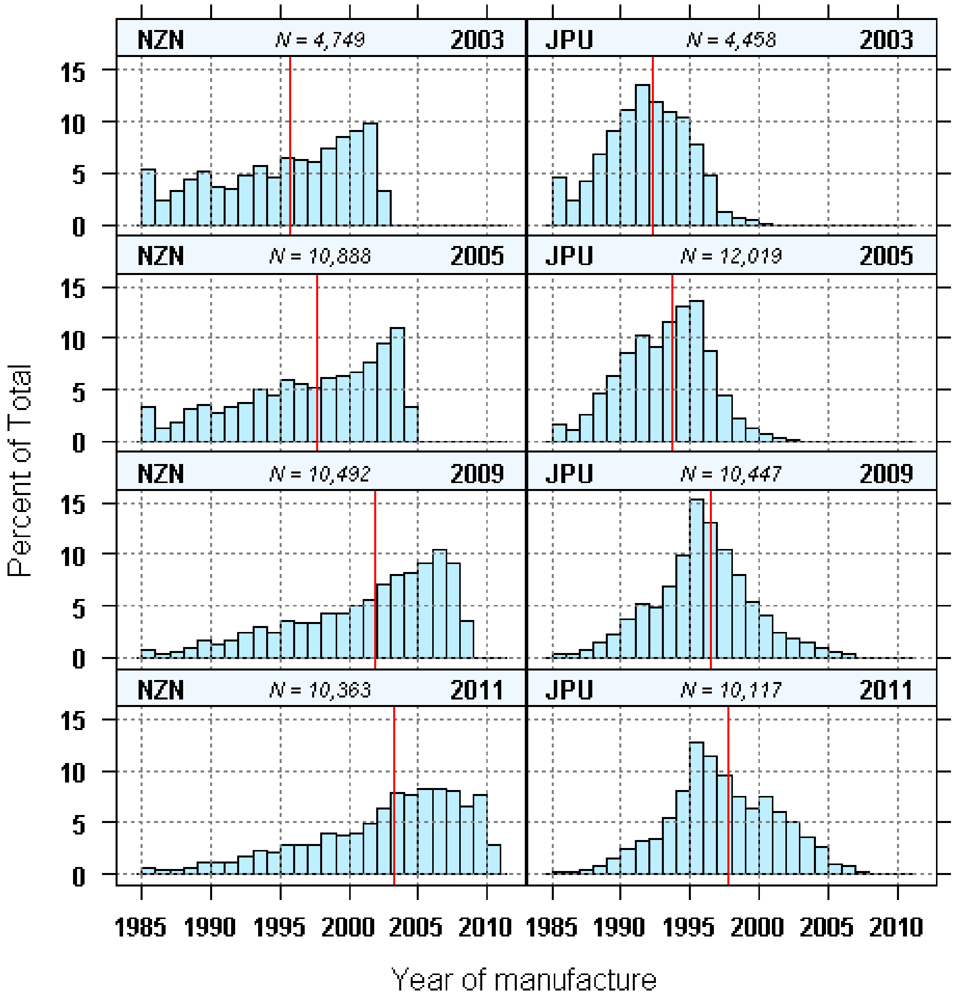


3.3.2 Vehicle year of manufacture

The difference seen in the age profiles of NZN and JPU monitored fleets is also apparent in terms of year of manufacture (Figure 3.6), with the JPU vehicles aging faster than the NZN ones. The average year of manufacture for a JPU vehicle is between 1997 and 1998, whereas an average NZN vehicle sits at 2003.

Figure 3.6

Comparison of the year of manufacture profiles of the 2003 to 2011 monitored fleets by country of first registration. * Note the red line represents the mean year of manufacture.



4 Trends in the Monitored Emissions – 2003 to 2011

This chapter discusses the major trends in light duty vehicle emissions measured in 2003, 2005, 2009 and 2011. Results are presented for the fleets overall and are then considered by fuel type (petrol and diesel) and then split further by country of first registration (New Zealand new and Japanese used imports).

Datasets used for the analysis in this section: In total, records were available for 9,647 individual light duty vehicle measurements in the 2003 dataset, 25,389 in 2005, 22,953 in 2009 and 24,382 in the 2011 dataset. Of these, the vast majority were petrol or diesel vehicles. Sections 4.1 utilised records for all vehicles but sections 4.2 and 4.2 only focussed on the petrol and diesel vehicles which reduced the datasets slightly to 9,642 in 2003, 25,371 in 2005, 22,930 in 2009 and 24,372 in 2011.

4.1 Overall fleet

Table 4.1 and Figure 4.1 compare the emissions of CO, HC, NO and uvSmoke from the overall light duty vehicle fleets monitored from 2003 to 2011.

Table 4.1

Comparison of the median and mean emissions of the 2003 to 2011 monitored fleets overall

Campaign Year	No of Vehicles	CO (%)		HC (ppm)		NO (ppm)		uvSmoke index	
		Mean	Median	Mean	Median	Mean	Median	Mean	Median
2003	9,647	0.69	0.23	301	200	764	330	n/a*	n/a*
2005	25,389	0.53	0.12	220	83	630	313	0.078	0.029
2009	22,953	0.41	0.07	134	52	489	186	0.065	0.022
2011	24,382	0.37	0.06	116	50	467	92	0.063	0.023

* Note the RSD equipment used in 2003 measured opacity and not uvSmoke and therefore no results are available

Mean emissions of CO, HC and NO decreased significantly from the light fleet between 2003 and 2011. uvSmoke emissions also reduced from 2005 onwards when the measurements began. However, the rate of improvement for all pollutants between 2009 and 2011 has slowed relative to previous years, even allowing for a four year gap between the 2005 and 2009 campaigns.

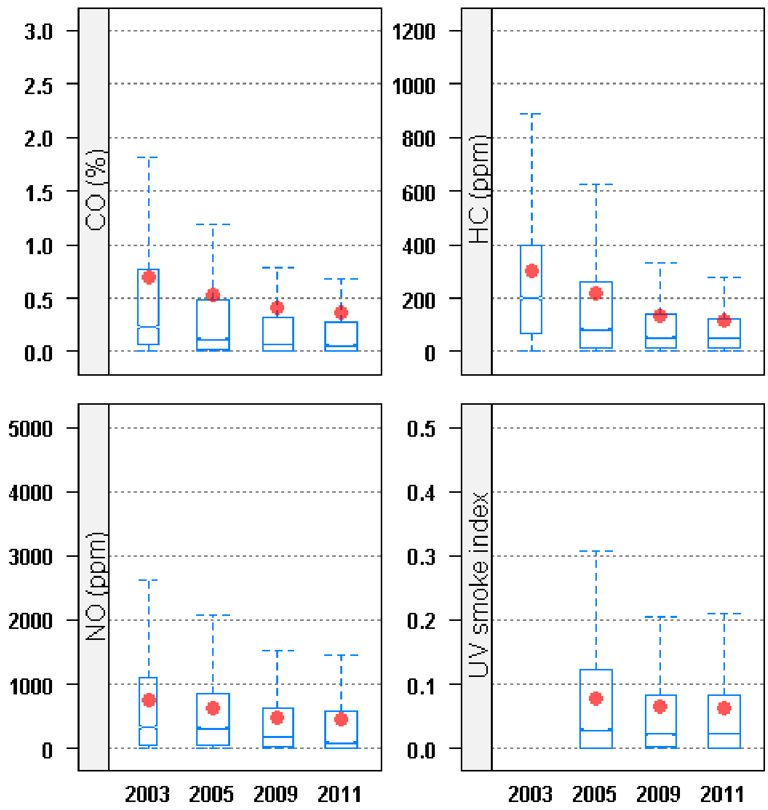
Relative to 2003, an average vehicle in the overall light fleet in 2011 now emits:

- 54 per cent of the CO
- 39 per cent of the HC
- 61 per cent of the NO

Relative to 2005, an average vehicle in the overall light fleet in 2011 now emits:

- 81 per cent of the uvSmoke

Figure 4.1
Comparison of the emissions of the 2003 to 2011 monitored fleets overall. * Note see section 2.3.3 for the conventions used in the presentation of the results.



The median emissions of CO, HC and NO have all shown a downward trend since 2003. As seen with the mean values, the rate of improvement in median values of CO and HC has slowed in the last campaign. However the rate of reduction in median NO value continues to improve. The median value of uvSmoke reduced between the 2005 and 2009 campaigns but increased marginally in 2011.

It is interesting to note the differences in the trends in mean and median emissions of NO between the 2009 and 2011 campaigns. Both the mean and median values show a decrease since 2009 but the median value decreases much more quickly than the mean value. More importantly, the ratio of the mean to the median for NO which sits between 2.0 and 2.6 for previous years increases significantly to more than 5.0 in 2011. As mentioned earlier in Chapter 2.3, vehicle emissions data do not typically follow a normal distribution but are skewed with many very low values and a few very high values. For data distributed “normally”, the ratio of the mean to the median would be 1.0. Therefore the higher the ratio over 1.0 the more skewed the data are towards higher values.

These two findings together suggest that, although 50 per cent of the vehicles are cleaner (with a reduced median in 2011), the impact of “gross emitters” on the monitored fleet emissions performance for NO has grown considerably (reflected in the relatively small 2009 to 2011 reduction in the NO mean value).

A summary of the results of the K-W tests undertaken for the comparison presented in Figure 4.1 (and all other relevant figures) are presented in Appendix 1.

4.2 Petrol fleet

Table 4.2 and Figure 4.2 compare the emissions from the petrol only component of the light duty vehicle fleets monitored from 2003 to 2011. Trends in the petrol fleet over time are similar to those seen in the overall fleet.

Table 4.2
Comparison of the median and mean emissions of the 2003 to 2011 monitored fleets for petrol vehicles only

Campaign Year	No of Vehicles	CO (%)		HC (ppm)		NO (ppm)		uvSmoke index	
		Mean	Median	Mean	Median	Mean	Median	Mean	Median
2003	8,430	0.77	0.29	325	220	810	286	n/a*	n/a*
2005	21,639	0.62	0.17	239	87	660	235	0.061	0.019
2009	19,342	0.48	0.11	143	49	495	118	0.049	0.015
2011	20,415	0.44	0.09	121	46	457	52	0.045	0.015

* Note the RSD equipment used in 2003 measured opacity and not uvSmoke and therefore no results are available

Mean emissions of all pollutants decreased significantly from the petrol fleet between 2003 and 2009. However, the rate of improvement for all pollutants between 2009 and 2011 has slowed relative to previous years, even allowing for a four year gap between the 2005 and 2009 campaigns. Note that uvSmoke is a minor pollutant from petrol vehicles.

Relative to 2003, an average vehicle in the petrol light fleet in 2011 now emits:

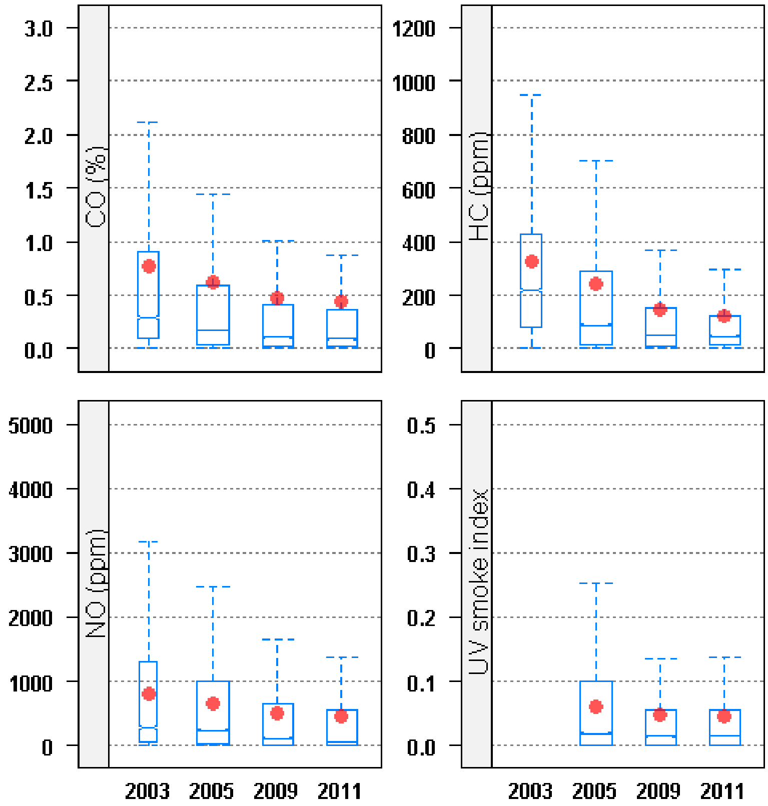
- 57 per cent of the CO
- 37 per cent of the HC
- 56 per cent of the NO

Relative to 2005, an average vehicle in the petrol light fleet in 2011 now emits:

- 74 per cent of the uvSmoke

Median emissions of all pollutants have reduced considerably since 2003 but the rate of improvement has slowed since 2009 for all pollutants except NO which has continued to improve.

Figure 4.2
Comparison of the emissions of the 2003 to 2011 monitored fleets for petrol vehicles only. * Note see section 2.3.3 for the conventions used in the presentation of the results.



The differences seen in the rates of change in the mean and median NO emissions of the overall fleet in 2011 are even more prominent in the petrol only component. Although the petrol only mean is 82 ppm versus 145 ppm for the fleet overall, the ratio of the mean to the median is 8.8 for petrol versus 5.0 for the fleet overall. This suggests that there is scope to improve NO emissions by targeting the higher emitting petrol vehicles. This is further explored by country of first registration in the following subsections.

4.2.1 New Zealand new petrol vehicles

Table 4.3 and Figure 4.3 compare the emissions from the petrol component of the light duty vehicle fleets monitored from 2003 to 2011 but for New Zealand new (NZN) vehicles only.

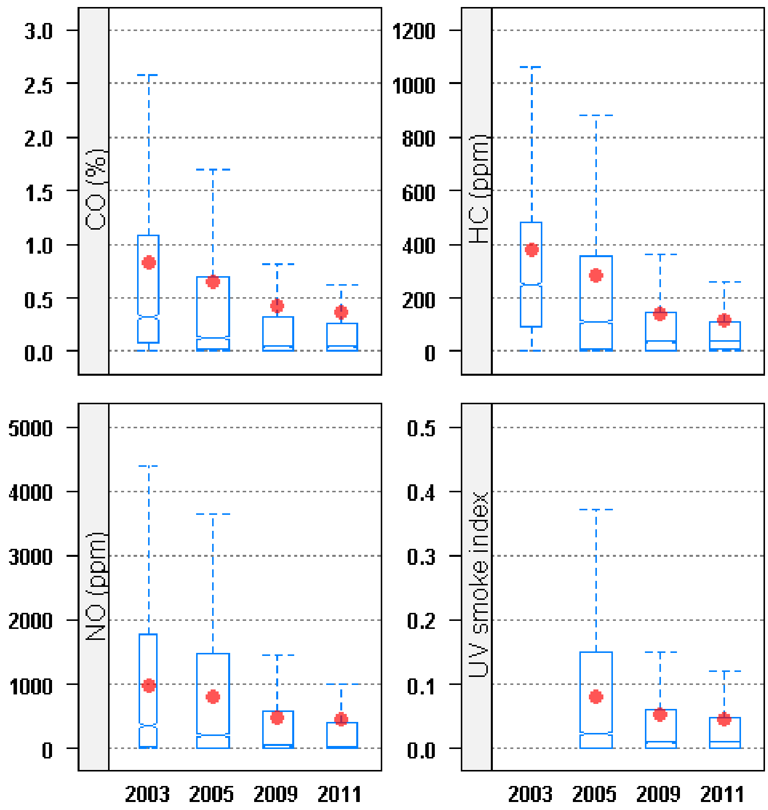
Emissions of all pollutants from NZN petrol vehicles, on average, have reduced significantly since 2003. However, the rate of improvement between 2009 and 2011 has slowed compared to previous years.

Table 4.3
Comparison of the median and mean emissions of the 2003 to 2011 monitored fleets for NZN petrol vehicles only

Campaign Year	No of Vehicles	CO (%)		HC (ppm)		NO (ppm)		uvSmoke index	
		Mean	Median	Mean	Median	Mean	Median	Mean	Median
2003	4,460	0.84	0.32	377	250	983	356	n/a*	n/a*
2005	10,391	0.65	0.13	286	110	795	203	0.081	0.024
2009	9,268	0.43	0.05	139	36	486	54	0.053	0.010
2011	9,742	0.37	0.05	116	38	450	27	0.047	0.010

* Note the RSD equipment used in 2003 measured opacity and not uvSmoke and therefore no results are available

Figure 4.3
Comparison of the emissions of the 2003 to 2011 monitored fleets for NZN petrol vehicles only. * Note see section 2.3.3 for the conventions used in the presentation of the results.



Relative to 2003, an average vehicle in the NZN petrol light fleet in 2011 now emits:

- 44 per cent of the CO
- 31 per cent of the HC
- 46 per cent of the NO

Relative to 2005, an average vehicle in the NZN petrol light fleet in 2011 now emits:

- 58 per cent of the uvSmoke

For NZN petrol vehicles, the ratio between the mean and median NO emissions has increased from 2.8 in 2003 to 16.6 in 2011. Although the median emissions are now just 8 per cent of what they were in 2003, the mean emissions have only dropped to 46 per cent of the 2003 value. This suggests that despite the majority of the NZN petrol fleet now being much cleaner with respect to NO, the influence of the gross emitters is getting stronger. Therefore potentially significant emissions improvements are being lost which is of additional concern with ambient NO_2 concentrations stabilising or increasing.

4.2.2 Japanese used petrol vehicles

Table 4.4 and Figure 4.4 compare the emissions from the petrol component of the light duty vehicle fleets monitored from 2003 to 2011 but for Japanese used (JPU) vehicles only.

Table 4.4

Comparison of the median and mean emissions of the 2003 to 2011 monitored fleets for JPU petrol vehicles only

Campaign Year	No of Vehicles	CO (%)		HC (ppm)		NO (ppm)		uvSmoke index	
		Mean	Median	Mean	Median	Mean	Median	Mean	Median
2003	3,844	0.71	0.28	267	190	589	254	n/a*	n/a*
2005	10,829	0.59	0.20	195	77	536	256	0.043	0.018
2009	9,621	0.53	0.17	147	63	503	215	0.046	0.020
2011	10,210	0.51	0.15	127	56	462	101	0.044	0.021

* Note the RSD equipment used in 2003 measured opacity and not uvSmoke and therefore no results are available

Emissions of CO, HC and NO from JPU petrol vehicles, on average, have reduced since 2003 but (as with the NZN petrol fleet). There has been essentially no change observed in the measurements of uvSmoke.

Relative to 2003, an average vehicle in the JPU petrol light fleet in 2011 now emits:

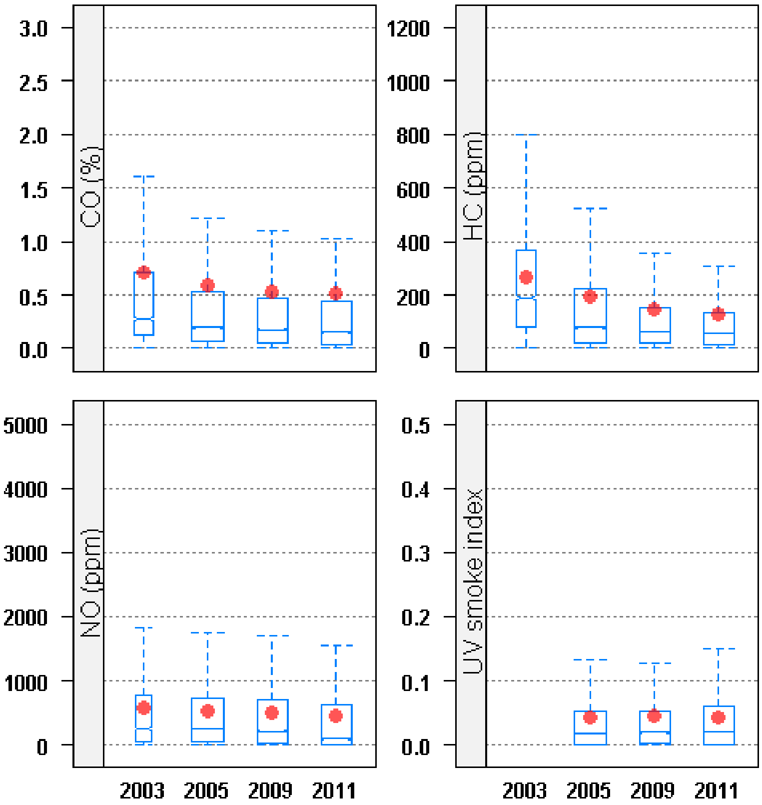
- 72 per cent of the CO
- 48 per cent of the HC
- 78 per cent of the NO

Relative to 2005, an average vehicle in the JPU petrol light fleet in 2011 now emits:

- 102 per cent of the uvSmoke

Figure 4.4

Comparison of the emissions of the 2003 to 2011 monitored fleets for JPU petrol vehicles only. * Note see section 2.3.3 for the conventions used in the presentation of the results.



For JPU petrol vehicles, the ratio between the mean and median NO emissions has doubled from 2.3 in 2003 to 4.6 in 2011. The median emissions are now 40 per cent of what they were in 2003, whilst the mean emissions have only reduced to 78 per cent of the 2003 value. As with the NZN petrol fleet, this suggests that despite the majority of the JPU petrol fleet now being cleaner with respect to NO, the influence of the gross emitters is getting stronger and therefore potentially significant emissions improvements are being lost.

As seen in Table 3.3, and Table 4.5 the JPU fleet overall is aging at a faster rate than the NZN fleet. Therefore it is likely that the higher mean and median NO emissions recorded for JPU vehicles relative to NZN vehicles is due to engine deterioration in the older vehicles.

4.2.3 Comparison of NZN and JPU petrol vehicles

Table 4.5 compares the ages of the NZN and JPU petrol vehicle fleets from 2003 to 2011 and shows that the mean and median ages of NZN vehicles are lower than JPU vehicles for all four monitoring campaigns. Table 4.5 also shows that the JPU petrol fleet is aging faster than the NZN petrol fleet.

Table 4.5
Comparison of the median and mean ages of the monitored petrol NZN and JPU fleets from 2003 to 2011

Campaign Year	NZN Petrol Fleet Age (years)		JPU Petrol Fleet Age (years)	
	Mean	**Median**	**Mean**	**Median**
2003	7.7	7	10.7	11
2005	7.8	7	11.2	11
2009	7.6	6	12.3	12
2011	8.3	7	12.9	13

Figure 4.5 compares the emissions of the NZN and JPU petrol vehicle fleets from 2003 to 2011.

Although the NZN petrol fleet recorded higher mean emissions of all pollutants initially, its rate of improvement was considerably faster than the JPU petrol fleet. Since 2009, the mean and median emissions of the NZN petrol fleet have reduced below those of the JPU petrol fleet. JPU petrol vehicles are now, in 2011, appreciably more polluting for CO and slightly worse for HC and NO, on average. Note that the differences in uvSmoke between the two fleets are essentially inconsequential because uvSmoke is a minor pollutant from petrol vehicles.

In addition (as mentioned in sections 4.2.1 and 4.2.2), the ratio of the mean to the median emissions for NO for both petrol fleets has grown suggesting that gross emitters are now more strongly influencing the fleet average NO emissions.

Figure 4.5
Comparison of the emissions of the monitored NZN and JPU petrol vehicles from 2003 to 2011

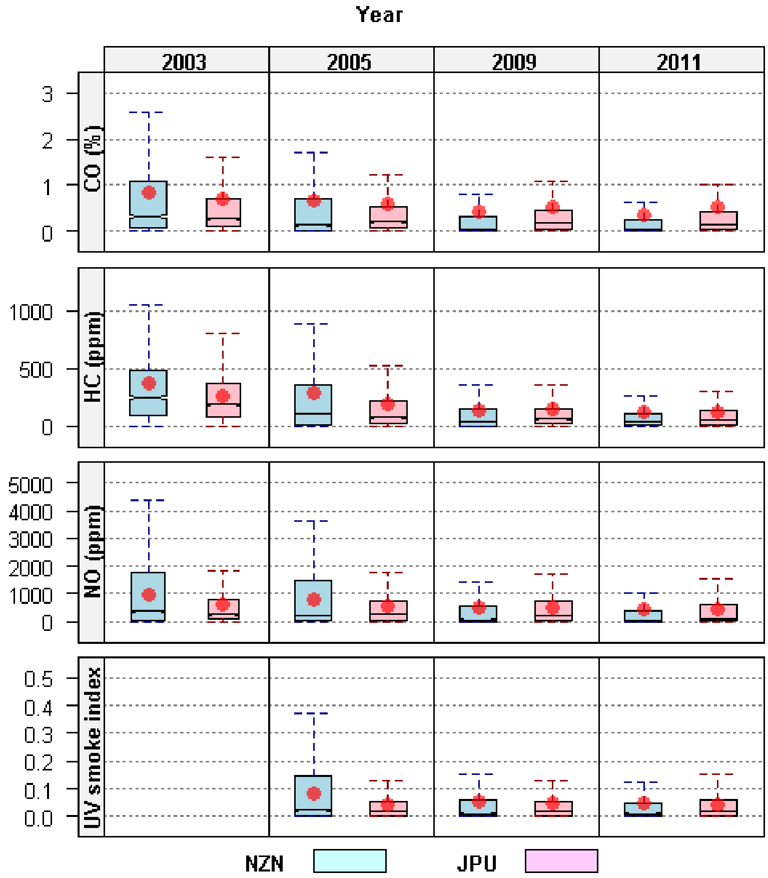
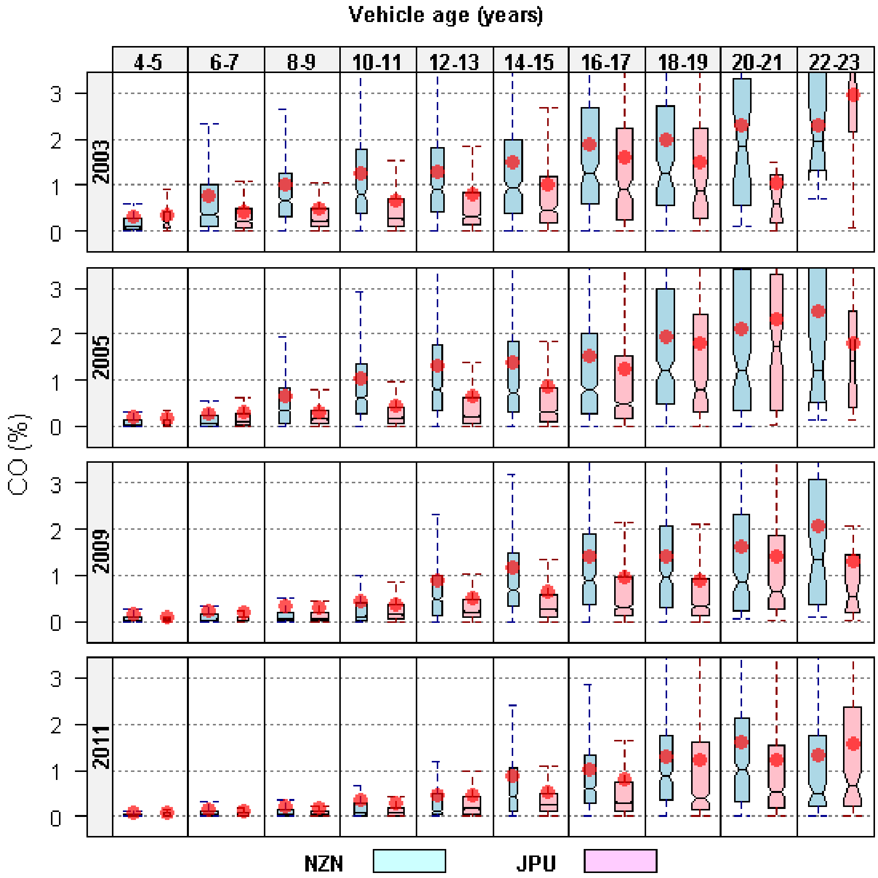


Figure 4.6 illustrates the effect of vehicle age on emissions on the two fleets since 2003, using CO as an example.

In the first campaign in 2003, CO emissions from NZN petrol vehicles, on average, were significantly higher than those from JPU vehicles of the same age. In 2005, only NZN petrol vehicles older than eight years had significantly higher CO emissions than JPU vehicles of the same age. By 2009, these significant differences were only seen for vehicles older than 10 years.

Figure 4.6 shows JPU petrol vehicles were significantly cleaner than NZN vehicles of the same age in the years before New Zealand introduced emissions standards for new vehicles entering the fleet. However, as improved emissions control technology has found its way into the NZN fleet, the difference in emissions performance between younger (<12 years) NZN and JPU vehicles has reduced significantly. Older NZN petrol vehicles (>14 years) continue to emit significantly more CO than JPU petrol vehicles of the same age.

Figure 4.6
Comparison of the CO emissions of the NZN and JPU petrol vehicles from 2003 to 2011 by age



Comparisons of HC, NO and uvSmoke emissions from NZN and JPU petrol vehicles show similar results to those described for CO.

Figure 4.6 also indicates the potential rate of deterioration that has occurred in the petrol fleets. The 4-5 year age class shown for 2003 is represented by the 12-13 year age class in 2011 etc. Comparing these and subsequent age classes, mean emissions of the same cohort are significantly higher in the 2011 (eight years later).

4.3 Diesel fleet

Table 4.6 and Figure 4.7 compare the emissions of CO, HC, NO and uvSmoke from the diesel only component of the light duty vehicle fleets monitored from 2003 to 2011. Trends in the diesel fleet over time are quite different to those seen in the overall fleet.

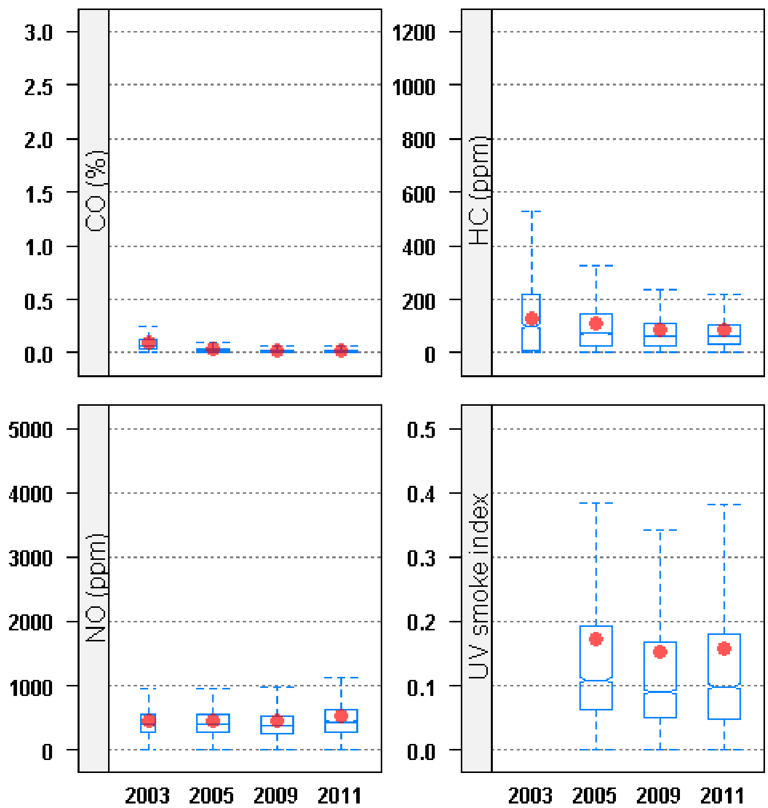
Mean emissions of CO, HC and uvSmoke decreased from the diesel fleet between 2003 and 2009, whilst mean NO emissions held more or less steady. In 2011, mean emissions of CO, HC and uvSmoke held steady but there was an increase in NO. Note that CO is a minor pollutant from diesel vehicles.

Table 4.6
Comparison of the median and mean emissions of the 2003 to 2011 monitored fleets for diesel vehicles only

Campaign Year	No of Vehicles	CO (%)		HC (ppm)		NO (ppm)		uvSmoke index	
		Mean	Median	Mean	Median	Mean	Median	Mean	Median
2003	1,212	0.10	0.06	129	100	452	396	n/a*	n/a*
2005	3,732	0.04	0.02	108	72	460	410	0.173	0.109
2009	3,588	0.02	0.01	86	62	454	382	0.153	0.090
2011	3,957	0.02	0.01	87	62	518	437	0.157	0.099

* Note the RSD equipment used in 2003 measured opacity and not uvSmoke and therefore no results are available

Figure 4.7
Comparison of the emissions of the 2003 to 2011 monitored fleets for diesel vehicles only. * Note see section 2.3.3 for the conventions used in the presentation of the results.



Relative to 2003, an average vehicle in the diesel light fleet in 2011 now emits:

- 20 percent of CO
- 67 per cent of the HC
- 114 per cent of the NO

Relative to 2005, an average vehicle in the diesel light fleet in 2011 now emits:

- 91 per cent of the uvSmoke

The median emissions followed a similar trend to the mean emissions. This means that improvement seen in the mean and median emissions of the fleet overall (see Table 4.1) are largely being driven by improvements in the petrol fleet (see Table 4.2).

Unlike the petrol fleet, the ratios of mean to median emissions for the diesel fleet are typically and consistently in the range 1.1 to 2.0. This indicates that the diesel fleet performance is less affected by the impact of gross emitting vehicles and so there is limited scope to improve emissions by targeting the higher emitting vehicles. This is further explored by country of first registration in the subsections that follow.

Comparing the mean emission results for the two differently-fuelled fleets in Table 4.2 (petrol only) and Table 4.6 (diesel only):

- petrol vehicles remain significantly more polluting for CO emissions
- diesel vehicles remain significantly more polluting for uvSmoke emissions
- petrol vehicles are slightly worse for HC emissions
- diesel vehicles are slightly worse for NO emissions

4.3.1 New Zealand new diesel vehicles

Table 4.7 and Figure 4.8 compare the emissions from the diesel component of the light duty vehicle fleets monitored from 2003 to 2011 but for New Zealand new (NZN) vehicles only.

Emissions of CO, HC and uvSmoke from NZN diesel vehicles, on average, reduced from 2003 to 2009, but the improvement trend was arrested in 2011 with small increases being recorded for each of these pollutants. By comparison, the mean NO emissions also reduced from 2003 to 2009 but recorded a significant increase in 2011.

Relative to 2003, an average vehicle in the NZN diesel light fleet in 2011 now emits:

- 20 per cent of the CO
- 57 per cent of the HC
- 104 per cent of the NO

Relative to 2005, an average vehicle in the NZN diesel light fleet in 2011 now emits:

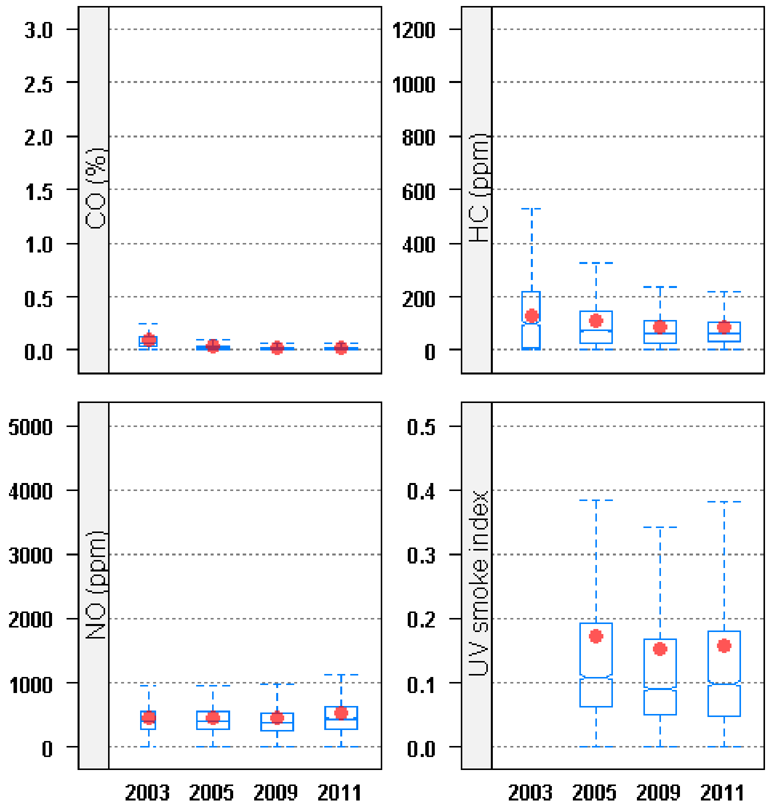
- 92 per cent of the uvSmoke

Table 4.7
Comparison of the median and mean emissions of the 2003 to 2011 monitored fleets for NZN diesel vehicles only

Campaign Year	No of Vehicles	CO (%)		HC (ppm)		NO (ppm)		uvSmoke index	
		Mean	Median	Mean	Median	Mean	Median	Mean	Median
2003	470	0.10	0.07	137	90	539	475	n/a*	n/a*
2005	1,485	0.03	0.01	100	66	535	461	0.141	0.095
2009	2,021	0.01	0.00	74	53	490	404	0.121	0.073
2011	2,438	0.02	0.01	78	54	563	452	0.130	0.083

* Note the RSD equipment used in 2003 measured opacity and not uvSmoke and therefore no results are available

Figure 4.8
Comparison of the emissions of the 2003 to 2011 monitored fleets for NZN diesel vehicles only. * Note see section 2.3.3 for the conventions used in the presentation of the results.



Trends in median emissions of all pollutants have mirrored those for mean emissions since 2003. The median to mean ratios have remained relatively stable and quite low, in the range 1.1 to 2.0. These low ratios suggest that the influence of gross emitters on the NZN diesel fleet performance is quite low. This means that strategies to target high mean emissions, of say NO, would need to look at the whole fleet.

4.3.2 Japanese used diesel vehicles

Table 4.8 and Figure 4.9 compare the emissions from the diesel component of the light duty vehicle fleets monitored from 2003 to 2011 but for Japanese used (JPU) vehicles only.

Table 4.8
Comparison of the median and mean emissions of the 2003 to 2011 monitored fleets for JPU diesel vehicles only

Campaign Year	No of Vehicles	CO (%)		HC (ppm)		NO (ppm)		uvSmoke index	
		Mean	Median	Mean	Median	Mean	Median	Mean	Median
2003	736	0.10	0.06	121	110	395	353	n/a*	n/a*
2005	2,231	0.04	0.02	113	75	408	384	0.195	0.121
2009	1,547	0.03	0.02	101	75	403	361	0.194	0.115
2011	1,491	0.03	0.01	101	75	443	421	0.202	0.127

* Note the RSD equipment used in 2003 measured opacity and not uvSmoke and therefore no results are available

Emissions of CO and HC from JPU diesel vehicles, on average, have reduced slightly from 2003 to 2009, but show a small increase from 2009 to 2011. However, mean NO emissions, which had previously been reasonably static over the 2003 to 2009 period, rose in 2011. uvSmoke has essentially remained the same since 2005.

Relative to 2003, an average vehicle in the JPU diesel light fleet in 2011 now emits:

- 30 per cent of the CO
- 83 per cent of the HC
- 112 per cent of the NO

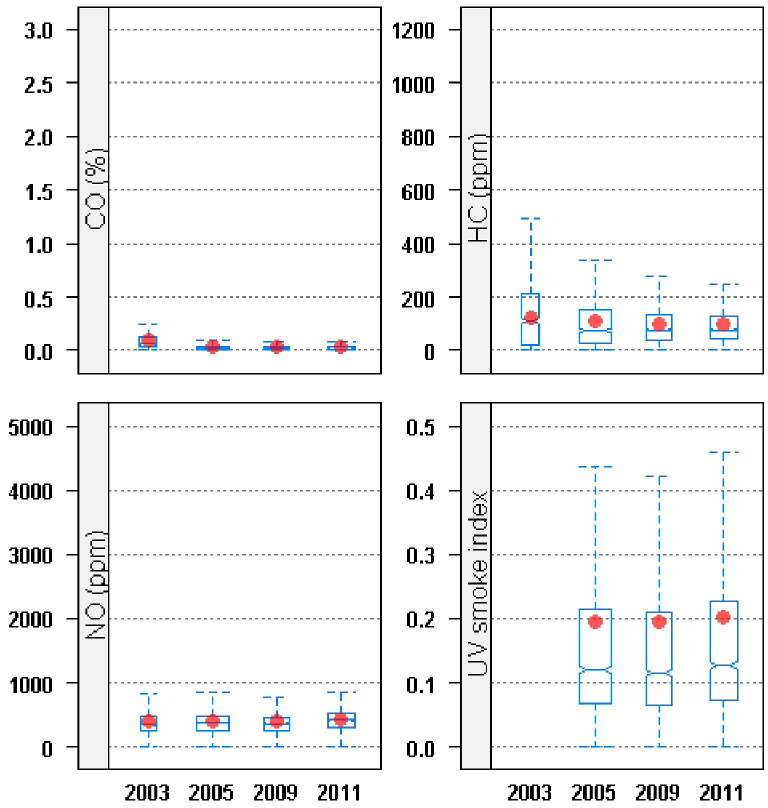
Relative to 2005, an average vehicle in the JPU diesel light fleet in 2011 now emits:

- 104 per cent of the uvSmoke

The results suggest that the improvement seen in the overall diesel fleet (section 4.3) for HC and uvSmoke has come from improvements in the NZN diesel fleet. The deterioration in diesel fleet NO emissions has been influenced by the worsening performance of both the NZN and JPU diesel fleets which does not appear to be affected by vehicle age.

Figure 4.9

Comparison of the emissions of the 2003 to 2011 monitored fleets for JPU diesel vehicles only. * Note see section 2.3.3 for the conventions used in the presentation of the results.



4.3.3 Comparison of NZN and JPU diesel vehicles

Table 4.9 compares the ages of the NZN and JPU diesel vehicle fleets from 2003 to 2011 and shows that the mean and median ages of NZN vehicles are lower than JPU vehicles for all four monitoring campaigns. Table 4.9 also shows that the JPU diesel fleet is aging much faster than the NZN diesel fleet.

NO emissions, on average, from NZN diesel vehicles were significantly higher than those from JPU vehicles for all monitoring campaigns. Conversely, mean uvSmoke emissions from JPU diesel vehicles were significantly higher than those from NZN vehicles in all years. The differences between the two countries of first registration were less marked for the other pollutants - CO and HC.

Table 4.9
Comparison of the median and mean ages of the monitored diesel NZN and JPU fleets from 2003 to 2011

Campaign Year	NZN Diesel Fleet Age (years)		JPU Diesel Fleet Age (years)	
	Mean	Median	Mean	Median
2003	4.5	4	11.1	11
2005	5.2	4	11.8	12
2009	5.3	4	13.7	14
2011	5.7	5	15.1	15

Figure 4.10 compares the emissions of the NZN and JPU diesel vehicle fleets from 2003 to 2011.

Figure 4.10
Comparison of the emissions of the monitored NZN and JPU diesel vehicles from 2003 to 2011

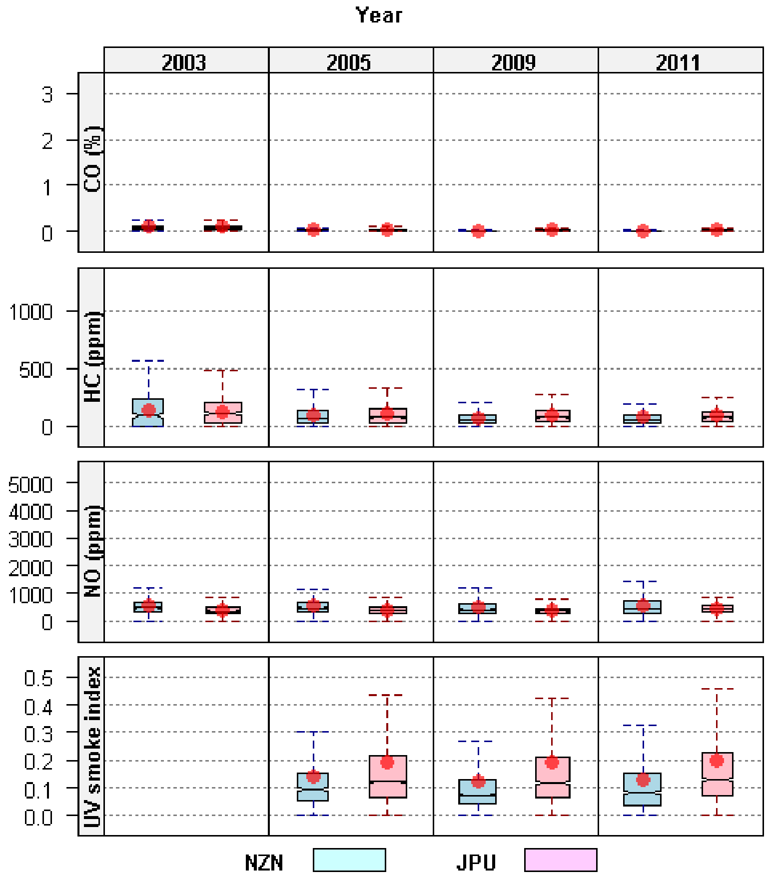


Figure 4.11 illustrates the effect of vehicle age on emissions on the two fleets since 2003, using NO as an example.

Figure 4.11

Comparison of the NO emissions of the monitored NZN and JPU diesel vehicles from 2003 to 2011 by age

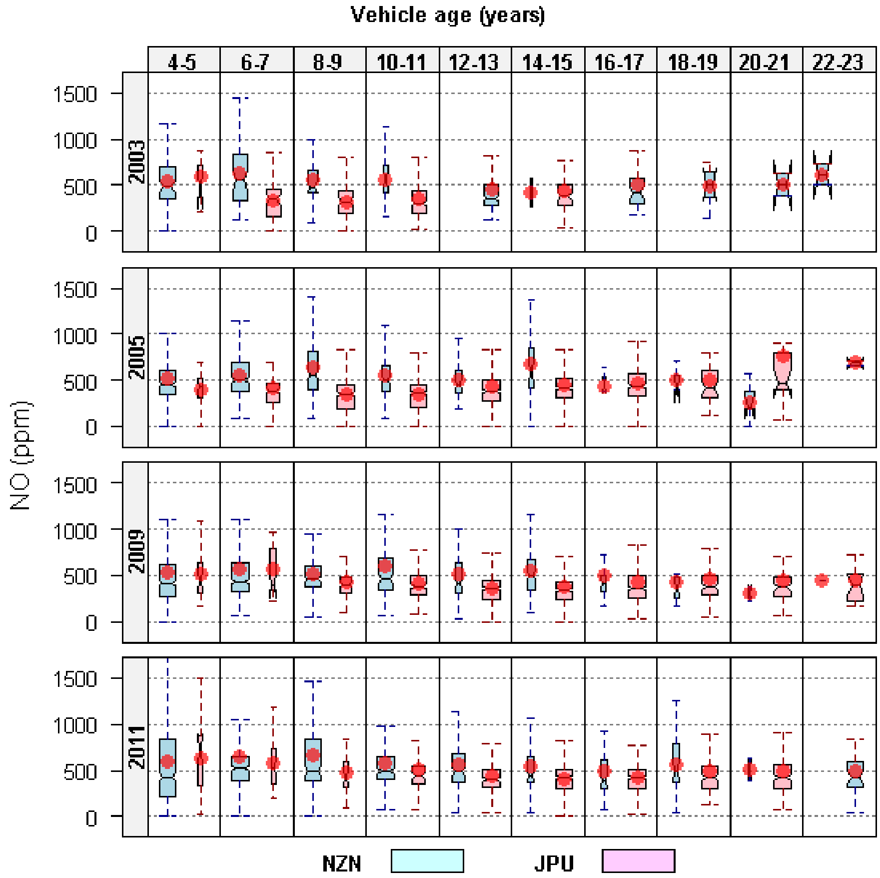


Figure 4.11 shows that JPU diesel vehicles were significantly cleaner than NZN vehicles of the same age in the years before New Zealand introduced emissions standards for new vehicles entering the fleet. However, as improved emission control technology found its way into the NZN fleet, the difference in emissions performance between younger (<5 years) NZN and JPU vehicles reduced significantly. Regardless, none of the RSD campaign years shows an improvement in NO emissions with vehicle age.

Figure 4.11 also indicates the potential rate of deterioration that has occurred in the diesel fleets.

Comparisons of CO and HC emissions showed very little difference between NZN and JPU diesel vehicles of the same age. However, NZN vehicles tended to have higher uvSmoke emissions than JPU vehicles of the same age.

5 Effect of Emissions Standards

Chapter 5 investigates the effect of vehicle emissions standards on overall fleet emissions to assess the likely effectiveness of current policies. Results are presented for the fleets by country of first registration (New Zealand new and Japanese used) and also split for fuel type (petrol or diesel) based on the 2011 dataset.

Despite going to fully unleaded fuels in 1996, New Zealand had no legislation supporting vehicle emissions standards and control technology until late 2003. Prior to this, vehicles manufactured or imported and sold new in New Zealand were not required to meet any mandatory emissions standards and, although those imported from overseas were generally built to emissions standards in their countries of origin, there were no requirements for imported used vehicles to be checked to validate whether their control equipment was still present and functional.

Datasets used for the analysis in this section: In total, records were available for 24,382 individual light duty vehicle measurements in the 2011 dataset. Meaningful emissions standards data were available for all 10,363 measurements for New Zealand new vehicles, and 9,144 of 10,117 measurements for Japanese used imported vehicles.

5.1 New Zealand new vehicles

Mandatory vehicle emissions standards for new vehicles entering the fleet were first introduced in New Zealand through the Land Transport Rule: Vehicle Exhaust Emissions 2003 (MoT 2003). This contained a series of staggered milestones between January 2004 and January 2007, requiring progressively more stringent minimum emissions standards for new vehicles entering New Zealand. The 2003 rule was updated in 2007 to reflect newer emissions standards (MoT 2007) and has been recently amended in 2010 to now incorporate Euro 5 (MoT 2010).

The emissions standards requirements specify that new vehicles entering the fleet meet either a specified Australian, European, Japanese or US standard (these standards in the different countries are deemed to be roughly equivalent but the European or ‘Euro’ standards are more common for new vehicles).

In this report, vehicle emissions standard information for the NZN vehicles was obtained from the NZTA’s motor vehicle register (see https://motochek.landtransport.govt.nz). The analysis is for the most recent dataset (2011). Vehicles were initially binned into those manufactured ‘pre-2003’ (when vehicles were not required to be built to any emissions standard) and those manufactured ‘post-2003’. The post-2003 vehicles were then further categorised into ‘Euro 2’, ‘Euro 3’ and ‘Euro 4’. Unfortunately, only 63 per cent of vehicles manufactured post-2003 had a recorded emissions standard. The remaining 37 per cent of vehicles were built to either Euro 2, Euro 3, Euro 4 or Euro 5 standards but it was not possible to say exactly which. The vehicles with an unknown emission standard were binned together with Euro 2, Euro 3, Euro 4 or Euro 5 vehicles to from a group of vehicles called ‘post-2003’ which represent all vehicles built to an emission standard.

Table 5.1 shows the numbers of NZN vehicles monitored in 2011 by emission standard.

Table 5.1
Numbers of NZN vehicles monitored in 2011 by emission standard

Emission Standard	Pre-2003	Post-2003	Euro 2	Euro 3	Euro 4	Euro 5	Total[#]
Petrol	3,314	4,934	489	1548	983	62	8,248
Diesel	444	1,542	236	328	423	46	1,986

* Note these figures are only for petrol and diesel vehicles with recorded emission standards
[#] Total number excludes the Euro 2, 3, 4 and 5 vehicles which are included in the post-2003 bin

5.1.1 NZN petrol vehicles

Table 5.2 and Figure 5.1 compare the monitored 2011 NZN petrol fleet emissions by emission standard. Due to the large differences between the pre- and post-2003 emissions, the results are re-plotted on finer scale in Figure 5.2 which only compares emissions for the vehicles manufactured in 2003 or later.

Table 5.2
Comparison of the mean and median emissions of the monitored 2011 NZN petrol fleet by emission standard

Variable	Pre-2003	Post-2003	Euro 2	Euro 3	Euro 4	Euro 5
	mean (median)	mean (median)	mean (median)	mean (median)	mean (median)	mean (median)
CO (%)	0.77 (0.26)	0.10 (0.02)	0.13 (0.02)	0.06 (0.01)	0.06 (0.02)	0.04 (0.01)
HC (ppm)	239 (129)	38 (23)	48 (28)	29 (20)	30 (21)	35 (17)
NO (ppm)	1027 (590)	83 (6)	63 (9)	35 (1)	26 (3)	26 (3)
uvSmoke	0.115 (0.058)	0.003 (0.001)	0.003 (0.001)	0 (0)	0 (0)	0.01 (0)
No of readings	3,800	5,802	572	1,815	1,204	69

NZN petrol vehicles manufactured pre-2003 had significantly higher emissions of CO, HC, NO and uvSmoke, on average, than vehicles manufactured post-2003, irrespective of emission standard.

Significant reductions in measured emissions of CO, HC and NO from petrol vehicles, on average, were seen with improving emissions standard but only as far as Euro 3. Euro 4 and 5 emissions showed no appreciable improvement over Euro 3. uvSmoke emissions showed no obvious trend with the Euro standard but this was probably due to the fact that petrol vehicles emit very low amounts of uvSmoke which are close to the detection limit of the equipment.

Figure 5.1
Comparison of the emissions of the monitored 2011 NZN petrol fleet by emission standard

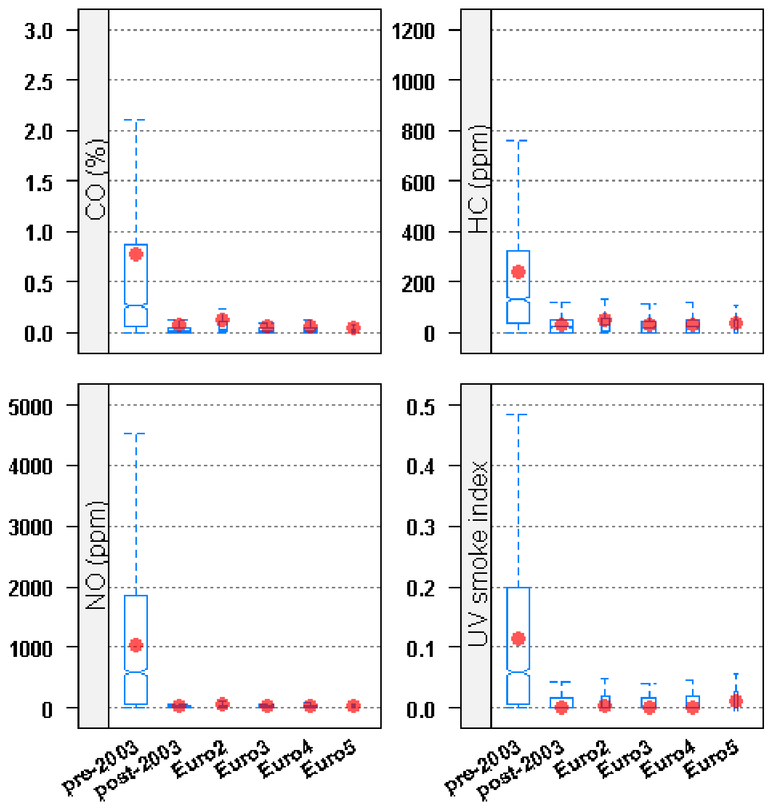


Figure 5.2

Comparison of the emissions of the monitored 2011 NZN petrol fleet for vehicles manufactured after 2003 by emission standard. Note: the y-axis on this graph is expanded relative to Figure 5.1 and others.

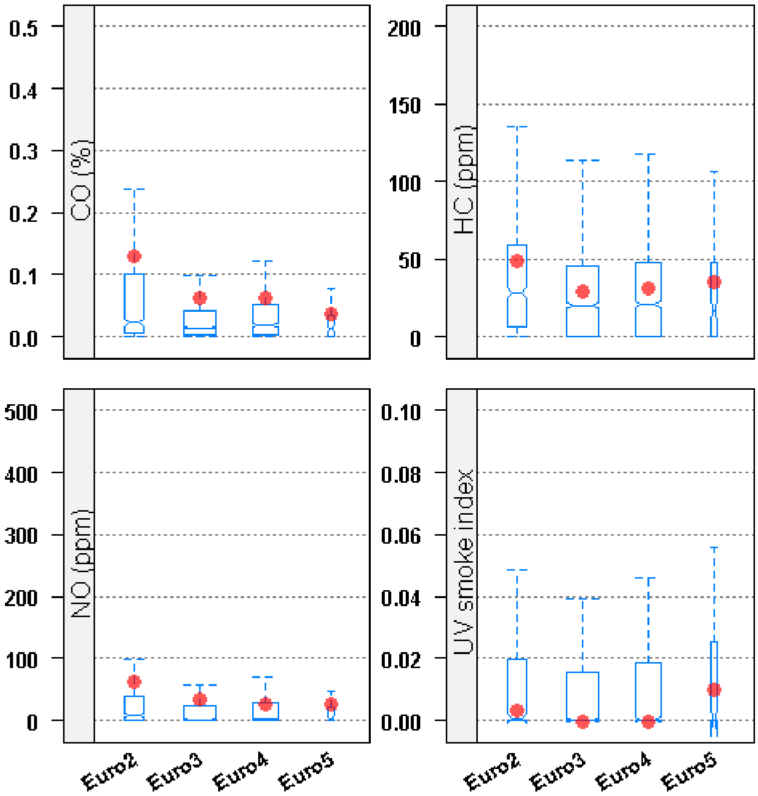


Table 5.3 compares the emission limits that apply to the relevant Euro petrol emissions standards to highlight the improvements that might have been expected to be mirrored in the roadside measurements. Note that the Euro 1 limits are included for completeness.

Table 5.3

European emission standard limits for light petrol vehicles and date of first introduction in Europe. The dates for first introduction into New Zealand are shown in brackets.

Pollutant (g/km)	Euro 1 Jul 1992 (n/a)	Euro 2 Jan 1996 (Jan 2004)	Euro 3 Jan 2000 (Jan 2006)	Euro 4 Jan 2005 (Jan 2008)	Euro 5 Sep 2009 (no date yet)
CO	2.72	2.2	2.30	1.0	1.0
(NOx + HC)	0.97	0.5	-	-	-
NOx	-	-	0.15	0.08	0.06
HC	-	-	0.20	0.10	0.10
PM	-	-	-	-	0.005

As already mentioned, significant reductions in measured emissions were seen with improving standard (see Table 5.2). However not necessarily to the extent that would be suggested by the emission limits, especially beyond Euro 3.

Care needs to be taken when comparing roadside measurements with emission limits for several reasons. First, the Euro limits apply to a test drive cycle which includes a suite of driving events, whereas the remote sensor is only a snapshot of emissions in time. Second, there was a fundamental change to the way the emission standards were measured between Euro 2 and Euro 3. Third, the limits are maximum values and many manufacturers may well be producing vehicles whose actual emissions are well below these maximum values. In conclusion, roadside measurements reflect the trend but not necessarily the magnitude of the emission standard changes.

Note on “real-world” test drive cycles

Many overseas jurisdictions are moving towards, or calling for, emissions test cycles that are more representative of “real-world” driving.

Japan has already adopted a more realistic drive cycle for testing compliance against emissions limits (JAMA 2011). The drive cycle used to test compliance changes significantly between Jap 05 (which uses the 10-15 mode test cycle) and Jap 09 (which uses the JC08 test cycle). The JC08 test cycle represents congested city traffic, including idling periods and frequently alternating acceleration and deceleration, and is intended to be more representative of “real-world” driving.

Whilst in the UK, the Department of Environment, Food, and Rural Affairs (DEFRA) is recommending monitoring of the implementation of Euro 6 vehicles to ensure there is sufficient evidence to support claims of significantly reduced NO_X emissions under “real-world” driving conditions (DEFRA 2011).

5.1.2 NZN diesel vehicles

Table 5.4 and Figure 5.3 compare the monitored 2011 NZN diesel fleet emissions by emission standard.

Table 5.4
Comparison of the mean and median emissions of the monitored 2011 NZN diesel fleet by emission standard

Variable	Pre-2003	Post-2003	Euro 2	Euro 3	Euro 4	Euro 5
	mean (median)	mean (median)	mean (median)	mean (median)	mean (median)	mean (median)
CO (%)	0.03 (0.01)	0.01 (0)	0.01 (0)	0.01 (0)	0.01 (0)	0.03 (0)
HC (ppm)	111 (71)	69 (51)	74 (47)	60 (52)	59 (47)	36 (27)
NO (ppm)	580 (482)	559 (438)	658 (447)	549 (427)	467 (309)	740 (731)
uvSmoke	0.228 (0.140)	0.102 (0.069)	0.117 (0.076)	0.085 (0.056)	0.090 (0.050)	0.013 (0.012)
No of readings	535	1,905	287	393	505	54

NZN diesel vehicles manufactured pre-2003 had significantly higher emissions of CO, HC and uvSmoke, on average, than vehicles built post-2003, irrespective of emissions standard. The trend in NO emissions was inconclusive.

Measured emissions of CO, HC, and uvSmoke, on average, from diesel vehicles showed a gradual improvement with improving emissions standard. NO emissions, however, were essentially independent of emissions standard.

Table 5.5 compares the emission limits that apply to the relevant Euro diesel emissions standards to highlight the improvements that might have been expected to be mirrored in the roadside measurements. Note that the Euro 1 limits are included for completeness.

Figure 5.3
Comparison of the emissions of the monitored 2011 NZN diesel fleet by emission standard

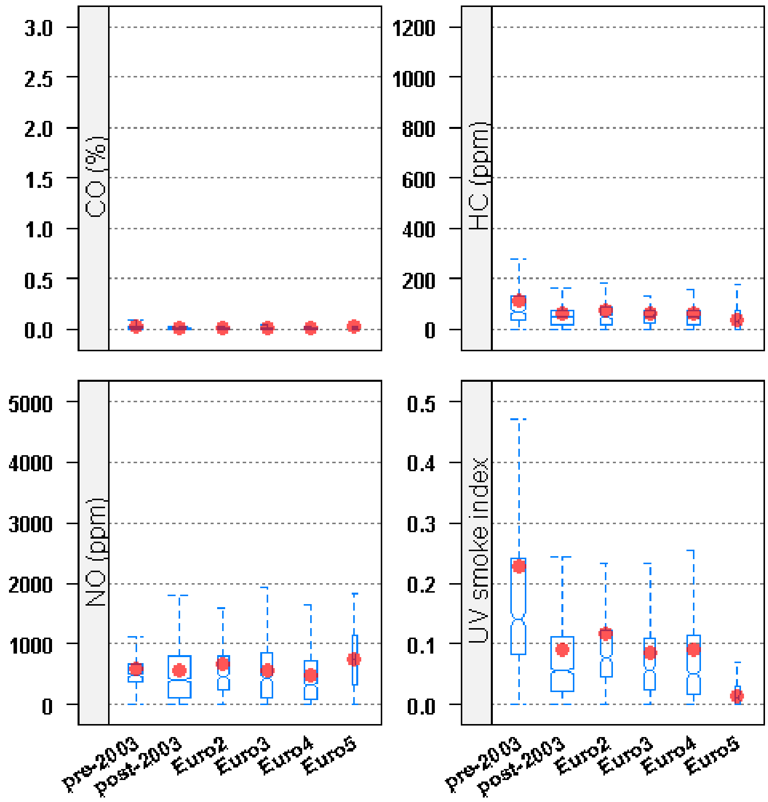


Table 5.5
European emission standard limits for light diesel vehicles and date of first introduction in Europe. The dates for first introduction into New Zealand are shown in brackets.

Pollutant (g/km)	Euro 1 Jul 1992 (n/a)	Euro 2 Jan 1996 (Jan 2004)	Euro 3 Jan 2000 (n/a)	Euro 4 Jan 2005 (Jan 2007)	Euro 5 Sep 2009 (no date yet)
CO	2.72	1.0	0.64	0.50	0.5
(NOx + HC)	0.97	0.7	0.56	0.30-	0.23
NOx	-	-	0.50	0.25	0.18
HC	-	-	-	-	-
PM	0.14	0.08	0.05	0.025	0.005

As already mentioned, significant reductions in measured emissions were seen in pre- and post-2003 emissions but not with improving emissions standard (see Table 5.4).

5.2 Japanese used vehicles

Mandatory vehicle emission standards for used vehicles were also first introduced in New Zealand through the Land Transport Rule: Vehicle Exhaust Emissions 2003 legislation (MoT 2003). However, although the new vehicles entering the fleet were required to meet a *minimum* emission standard, used vehicles only had to have been built to a *recognised* (any) emission standard. Minimum emission standards for used vehicles were not required until the Vehicle Exhaust Emissions rule was updated in 2007 (MoT 2007). This contained a series of staggered milestones between January 2008 and January 2013 for used vehicles entering New Zealand, with particularly stringent standards for used diesel vehicles. The 2007 rule was amended in 2010 but only changed the provisions for new vehicles (MoT 2010).

The emission standards requirements specify that used vehicles entering the fleet meet either a specified Australian, European, Japanese or US standard. These standards are deemed to be roughly equivalent but the Japanese or 'J' standards are more common for used vehicles as the vast majority (96 per cent) of these are sourced from Japan.

The Japanese motor industry has a complicated system of emission testing. The light duty petrol and diesel vehicle test regimes contain at least 20 and 18 different emission standards respectively. To simplify the comparisons in this report, the emission standards were grouped into categories covering key years as shown in Table 5.6 for JPU petrol vehicles and Table 5.7 for JPU diesel vehicles. The emission standard categories were determined on advice from MoT staff and generally reflect the major step changes in Japanese emissions control legislation which roughly equate to the year of first introduction in Japan.

Table 5.6
Emission standard categories used for the monitored JPU light duty petrol vehicles

Emission Standard Category	Emission Standards Covered	No. of Petrol Vehicles
Pre-1998	C, E, GA, GB, R. T, Z	4322
1998	GC, GE, GF, HG, J98	1559
2000-02	GH, GK, LA, LC, TA, TC, UA, ZA, J00/02	2651
2005	ABA, CBA, CBE, CBF, DAA, DBA	458

Table 5.7
Emission standard categories used for the monitored JPU light duty diesel vehicles

Emission Standard Category	Emission Standards Covered	No. of Diesel Vehicles
Pre-1993	K, Q, S, U, Y	347
1993-94	KB, KC, KD	667
1997-99	KE, KF, KG, KH, KJ	222
2002-04	KN, KR	55
2005	ADF	7

5.2.1 JPU petrol vehicles

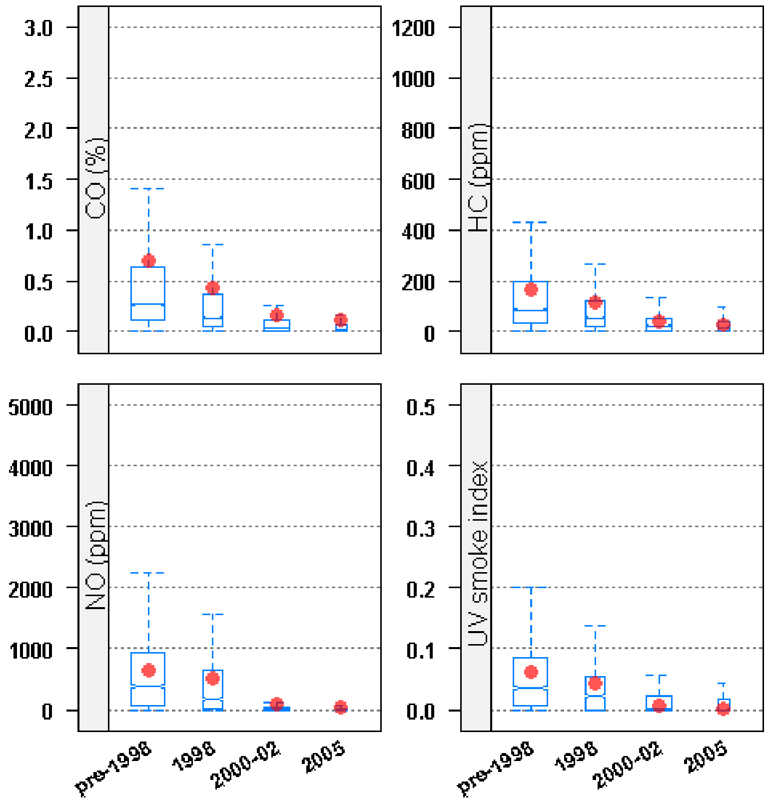
Table 5.8 and Figure 5.4 compare the monitored 2011 JPU petrol fleet emissions by emission standard category.

Table 5.8
Comparison of the mean and median emissions of the monitored 2011 JPU petrol fleet by emission standard

Variable	Pre-1998	1998	2000-02	2005
	mean (median)	mean (median)	mean (median)	mean (median)
CO (%)	0.7 (0.27)	0.43 (0.14)	0.17 (0.04)	0.11 (0.02)
HC (ppm)	167 (87)	117 (55)	43 (23)	28 (15)
NO (ppm)	649 (384)	501 (182)	91 (10)	31 (2)
uvSmoke	0.063 (0.035)	0.044 (0.022)	0.006 (0.002)	0.001 (0)
No of readings	4,622	1,559	2,651	458

Mean emissions of CO, HC, NO and uvSmoke from JPU petrol vehicles all reduced significantly with each change in emission standard category.

Figure 5.4
Comparison of the emissions of the monitored 2011 JPU petrol fleet by emission standard category



5.2.2JPU diesel vehicles

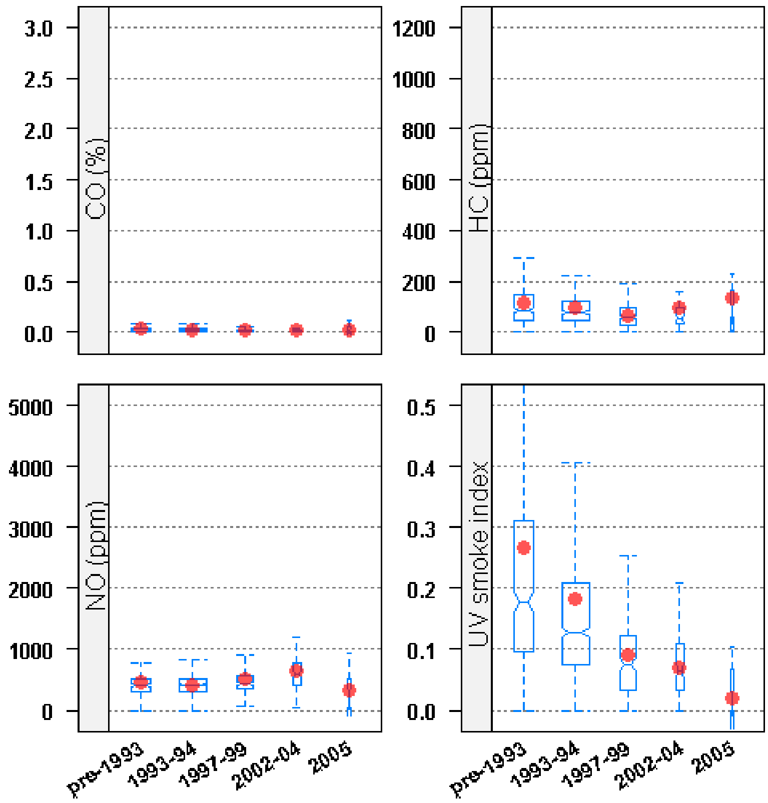
Table 5.9 and Figure 5.5 compare the monitored 2011 JPU diesel fleet emissions by emission standard category.

Mean emissions of uvSmoke from JPU diesel vehicles reduced significantly with each change in emission standard category up to 2002-04. CO emissions improved between significantly between the 1993-94 and 1997-99 emission standards. However, trends in NO and HC were less conclusive and emissions even appear to have increased with the later categories of emission standards.

Table 5.9
Comparison of the mean and median emissions of the monitored 2011 JPU diesel fleet by emission standard

Variable	Pre-1993	1993-94	1997-99	2002-04	2005
	mean (median)	mean (median)	mean (median)	mean (median)	mean (median)
CO (%)	0.04 (0.01)	0.03 (0.02)	0.02 (0.01)	0.03 (0.01)	0.02 (0)
HC (ppm)	117 (86)	98 (78)	68 (57)	95 (55)	133 (72)
NO (ppm)	455 (405)	403 (414)	512 (443)	641 (595)	322 (197)
uvSmoke	0.266 (0.177)	0.181 (0.128)	0.090 (0.075)	0.069 (0.065)	0.020 (0.010)
No of readings	347	667	222	55	7

Figure 5.5
Comparison of the emissions of the monitored 2011 JPU diesel fleet by emission standard category



6 Effect of Mileage

Previous studies of vehicle emissions show that the best predictor of an individual vehicle's emissions is the standard it was built to, or in the case of vehicles not built to a recognised standard, the level of technology on the vehicle (Campbell *et al.* 2006; MoT 2008). For example, a properly functioning catalytic converter on a petrol vehicle can reduce the level of emissions by up to 90 per cent, compared to a vehicle without one fitted. However, all technology deteriorates, and with motor vehicles this deterioration is generally linked directly to the distance the vehicle has travelled (as opposed to its age).

In order to assess any trends in reduced effectiveness as a result of increased distance travelled, comparisons need to be made between vehicles with the same technology (emissions standards). Accordingly, this section of the report evaluates the effect of odometer reading on vehicle emissions. This analysis has been undertaken as odometer reading can be a useful proxy for general vehicle wear and tear and degradation of the emissions control system (if fitted). The results of this analysis could contribute toward assessing the potential benefit of future policies based on accelerated vehicle scrappage. Results are presented for subsets of the fleet by country of first registration (New Zealand new and Japanese used) and also split for fuel type (petrol or diesel) and emissions standard.

The distribution in odometer readings was determined for each subset of the fleet within the 2011 dataset. From this analysis, two categories within each subset were identified: high mileage (above the 75th percentile) vehicles and low mileage (below the 25th percentile value) vehicles. Emissions were then compared for each of these categories and assessed as to whether any differences found were statistically significant. To establish whether any change in emissions with odometer reading was a gradual or step change process, the vehicles from one specific emissions standard for each vehicle type (e.g., NZN petrol) were selected and their emissions plotted against continuous odometer readings.

Datasets used for the analysis in this section: In total, records were available for 24,382 individual light duty vehicle measurements in the 2011 dataset. Sections 6.1 utilised records for all vehicles but sections 4.2 and 4.2 only focussed on the petrol and diesel vehicles which reduced the datasets slightly to 24,372 in 2011.

Important note about the odometer data. The mileage values presented in this chapter were obtained from the Motochek database which records the odometer reading at the time a vehicle goes for its warrant of fitness (WoF) inspection. Vehicles are required to get a WoF every 12 months up to six years in age then six-monthly thereafter. Therefore the odometer readings for < 6 year old vehicles may be underestimates by up to 12 months (representing 10,000 to 15,000km of additional travel) or for > 6 year old vehicles by up to 6 months (representing 5.000 to 6,000km of additional travel) (MoT 2011).

Important note about the link between age and odometer reading. Not all vehicles travel the same distance each year. Newer vehicles, which are generally cleaner, also typically travel further. Fleet statistics show that light vehicles that are only one or two years old typically travel approximately 19,000km per year but then the annual mileage drops off more or less linearly to plateau at around 12,000km per year for vehicles aged between nine and 14 years old before then dropping steadily after that (MoT 2011). This means that newer vehicles have a disproportionately beneficial effect on fleet average emissions.

6.1 NZN petrol vehicles

Table 6.1 shows the high (75^{th} quartile) and low (25^{th} quartile) odometer readings for the monitored NZN petrol vehicle fleet by emissions standard. The differences in odometer reading between the high and low extremes varied considerably across the categories as the newer vehicles had not been in the fleet long enough to travel very far.

Table 6.1
Comparison of the upper and lower quartile odometer readings for the monitored NZN petrol fleet by emission standard

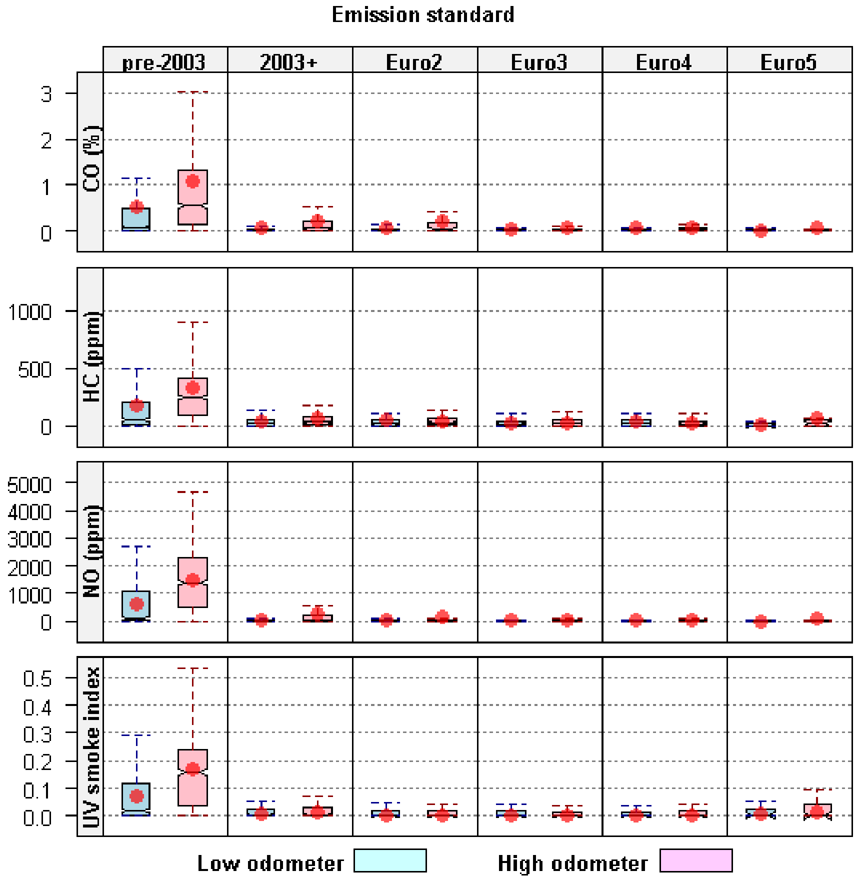
Odometer Reading (km)	Pre-2003	2003+	Euro 2	Euro 3	Euro 4	Euro 5
high mileage	238,550	141,228	126,097	81,876	44,555	10,519
low mileage	139,816	70,710	67,146	31,742	16*	11*

* Lower quartiles for the Euro 4 and Euro 5 bins are dominated by vehicles which were brand new when their odometer reading was last recorded by MoT and therefore are likely to be underestimates of their true mileage.

Figure 6.1 compares emissions for high and low mileage monitored NZN petrol vehicles by emissions standard. Table 6.2 summarises the mean and median values for CO, HC, NO and uvSmoke and highlights (in **bold**) whether any differences between the high and low mileage vehicles were statistically significant.

Figure 6.1

Comparison of the emissions of the monitored high and low mileage NZN petrol vehicles by emission standard



Mean CO and NO emissions were typically much higher for the high mileage NZN petrol vehicles than for the low mileage vehicles, irrespective of emission standard up to and including Euro 4. However, extremes in mileage had a less conclusive impact on HC and uvSmoke emissions, except for the pre-2003 vehicles.

Table 6.2

Comparison of the emissions of the monitored high and low mileage NZN petrol vehicles by emission standard

Emission Standard		CO (%)		HC (ppm)		NO (ppm)		uvSmoke	
		Low km	High km	Low km	High km	Low km	High km	Low km	High km
Pre-2003	Mean	**0.52**	**1.07**	**174**	**331**	**638**	**1471**	**0.073**	**0.169**
	Median	0.09	0.55	55	248	75	1388	0.019	0.159
2003+	Mean	**0.08**	**0.23**	**39**	**62**	**59**	**276**	0.007	0.013
	Median	0.01	0.06	23	36	6	31	0.004	0.004
Euro 2	Mean	**0.09**	**0.20**	51	43	**30**	**128**	0.003	0.003
	Median	0.02	0.04	22	30	7	19	0.000	0.000
Euro 3	Mean	0.05	0.07	**31**	**33**	**30**	**60**	0.000	0.000
	Median	0.01	0.02	17	24	0	3	0.000	0.000
Euro 4	Mean	**0.06**	**0.07**	39	25	**7**	**36**	0.000	0.000
	Median	0.01	0.02	25	16	0	9	0.000	0.000
Euro 5	Mean	0.02	0.06	6	71	0	88	0.008	0.013
	Median	0.01	0.02	-6	20	3	15	0.003	0.000

* Note the values shown in **bold** and highlighted are statistically significantly different from each other

Figure 6.2 investigates the mileage trends further by comparing the emission of the pre-2003 NZN petrol fleet by actual odometer reading rather than high and low readings. The pre-2003 subset was selected for this analysis because it contained:

- the highest number of vehicles (3,800 in total)
- vehicles which had travelled the most kilometres (on average) and
- vehicles with little or no emissions control equipment.

Emissions of all pollutants from pre-2003 NZN petrol vehicles steadily increased as the odometer readings went from 50,000km to more than 300,000km.

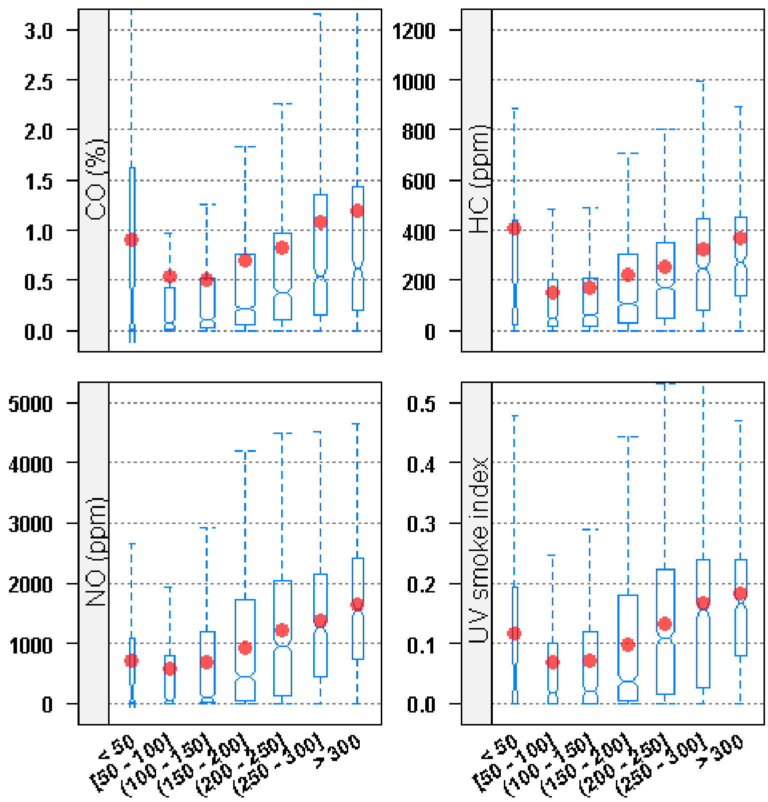
However, emissions from vehicles with odometer readings of less than 50,000km were unexpectedly high, which may have been caused by a number of factors.

Firstly, the sample size for these vehicles was very small (only 49) which could have biased the results.

Secondly, some of the vehicles may have gone 'around the clock' (i.e., those with five digit odometers had travelled more than 99,999km). Car manufacturers switched odometers from five to six figures in the late 1980s to early 1990s. Of the 49 NZN petrol vehicles with odometer readings <50,000km included in this analysis, 15 (31 per cent) of these were manufactured before 1990 and may have been around the clock when the emissions were monitored for this study.

Finally, the vehicles may have been 'running in'. Anecdotal evidence from vehicle manufacturers in New Zealand suggests new vehicles are tuned to run rich for the first 5,000km to 10,000km while the engine management systems are 'learning' to optimise vehicle emissions. Although this is less likely to be the cause as these vehicles are in excess of 8 years old.

Figure 6.2
Comparison of the emissions of the monitored pre-2003 NZN petrol vehicles by odometer reading



6.2 NZN diesel vehicles

Table 6.1 shows the high (75th quartile) and low (25th quartile) odometer readings for the monitored NZN diesel vehicle fleet by emissions standard. The differences in odometer reading between the high and low extremes varied considerably across the categories as the newer vehicles had not been in the fleet long enough to travel very far.

Table 6.3
Comparison of the upper and lower quartile odometer readings for the monitored NZN diesel fleet by emission standard

Odometer Reading (km)	Pre-2003	2003+	Euro 2	Euro 3	Euro 4	Euro 5
high mileage	297,366	176,785	138,506	93,968	53,304	21,855
low mileage	184,636	54,759	85,134	31,213	97*	12*

* Lower quartiles for the Euro 4 and Euro 5 bins are dominated by vehicles which were brand new when their odometer reading was last recorded by MoT and therefore are likely to be underestimates of their true mileage.

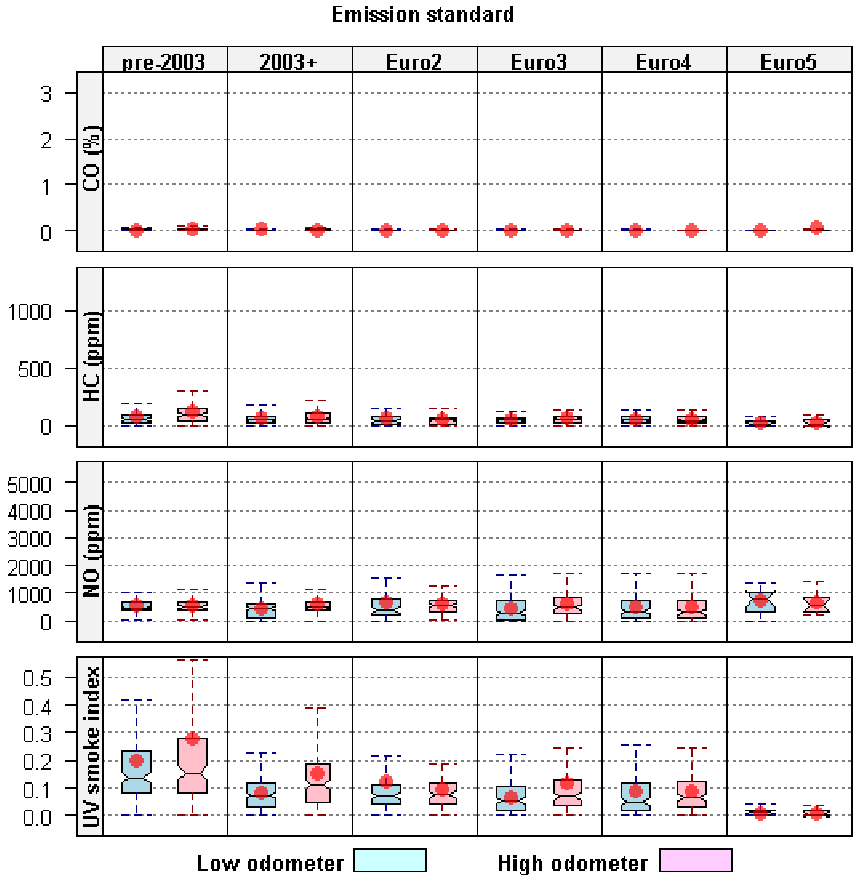
Figure 6.3 compares emissions for high and low mileage NZN diesel vehicles by emissions standard. Table 6.4 summarises the mean and median values for CO, HC, NO and uvSmoke and highlights (in **bold**) whether any differences between the high and low mileage vehicles were statistically significant.

Table 6.4
Comparison of the emissions of the monitored high and low mileage NZN diesel vehicles by emission standard

Emission Standard		CO (%)		HC (ppm)		NO (ppm)		uvSmoke	
		Low km	High km	Low km	High km	Low km	High km	Low km	High km
Pre-2003	Mean	0.02	0.04	**89**	**127**	579	573	0.198	0.280
	Median	0.01	0.02	56	90	463	495	0.138	0.153
2003+	Mean	0.03	0.02	**68**	**84**	**468**	**616**	**0.085**	**0.149**
	Median	0.00	0.01	49	58	464	472	0.074	0.114
Euro 2	Mean	0.02	0.01	67	57	646	641	0.121	0.093
	Median	0.00	0.01	42	49	389	548	0.071	0.076
Euro 3	Mean	0.00	0.01	**49**	**69**	**440**	**590**	**0.067**	**0.116**
	Median	0.00	0.00	47	57	286	481	0.054	0.071
Euro 4	Mean	0.01	0.00	61	60	482	500	0.089	0.091
	Median	0.00	0.00	52	47	335	317	0.049	0.067
Euro 5	Mean	0.00	0.08	27	27	704	665	0.008	0.007
	Median	0.00	0.00	13	14	798	533	0.014	0.004

* Note the values shown in **bold** and highlighted are statistically significantly different from each other

Figure 6.3
Comparison of the emissions of the monitored high and low mileage NZN diesel vehicles by emission standard



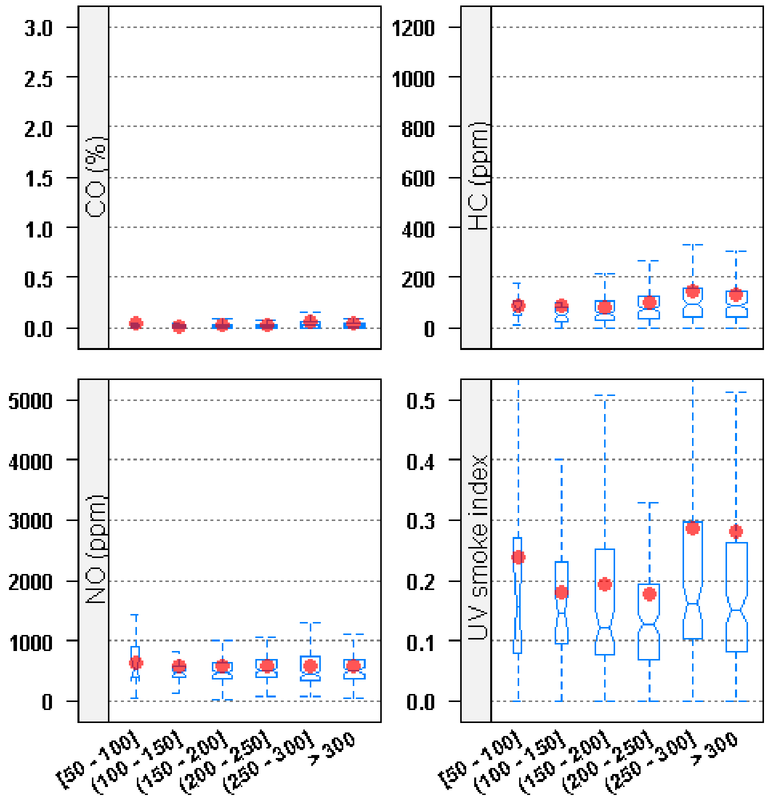
Mean uvSmoke emissions were typically much higher for the high mileage NZN diesel vehicles than for the low mileage vehicles, irrespective of emission standard up to and including Euro 3. However, mileage extremes had no obvious impact on the HC and NO emissions, except possibly for the 2003+ vehicles. The CO results were inconclusive but this is a minor pollutant from diesel vehicles.

Figure 6.4 investigates the mileage trends further by comparing the emission of the pre-2003 NZN diesel fleet by actual odometer reading rather than high and low readings. The pre-2003 subset was selected because it contained:

- a high number of vehicles (535 in total)
- vehicles which had travelled the most kilometres (on average) and
- vehicles with little or no emissions control equipment.

Mean emissions of CO and HC from pre-2003 NZN diesel vehicles trended upward but very weakly with increasing odometer readings. uvSmoke appeared to show a step change in increase in emissions for vehicles that had travelled 250,000km or more. NO emissions showed no obvious trend with increasing mileage.

Figure 6.4
Comparison of the emissions of the monitored pre-2003 NZN diesel vehicles by odometer reading



6.3 JPU petrol vehicles

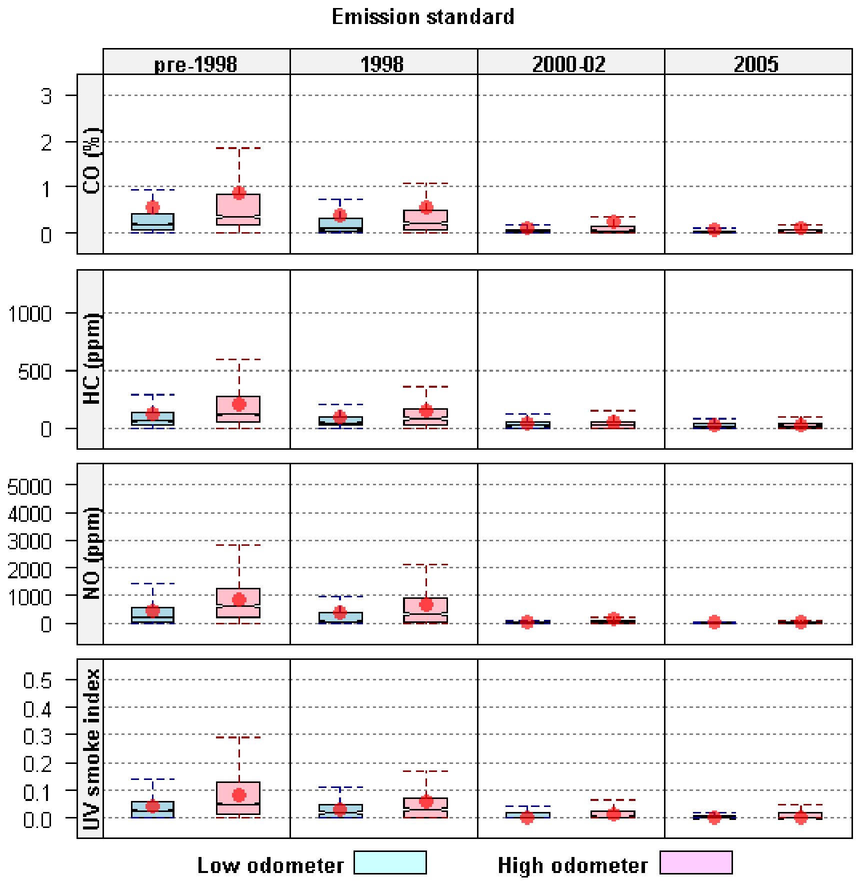
Table 6.5 shows the high (75th quartile) and low (25th quartile) odometer readings for the JPU petrol vehicle fleet by emissions standard. The differences in odometer reading between the high and low extremes varied considerably across the categories as the newer vehicles had not been in the fleet long enough to travel very far.

Table 6.5
Comparison of the upper and lower quartile odometer readings for the monitored JPU petrol fleet by emission standard

Odometer Reading (km)	Pre-1998	1998	2000-02	2005
high mileage	209,341	161,162	123,822	100,909
low mileage	138,368	107,383	75,852	46,021

Figure 6.5 compares emissions for high and low mileage JPU petrol vehicles by emissions standard. Table 6.6 summarises the mean and median values for CO, HC, NO and uvSmoke and highlights (in **bold**) whether any differences between the high and low mileage vehicles were statistically significant.

Figure 6.5
Comparison of the emissions of the monitored high and low mileage JPU petrol vehicles by emission standard



Mean emissions of all pollutants were consistently much higher (up to two times or more) for the high mileage JPU petrol vehicles than for the low mileage vehicles, for all emission standards except the most recent. The high and low mileage values for the 2005 vehicles were very close and this may have been why there was no significant difference between the resultant emissions.

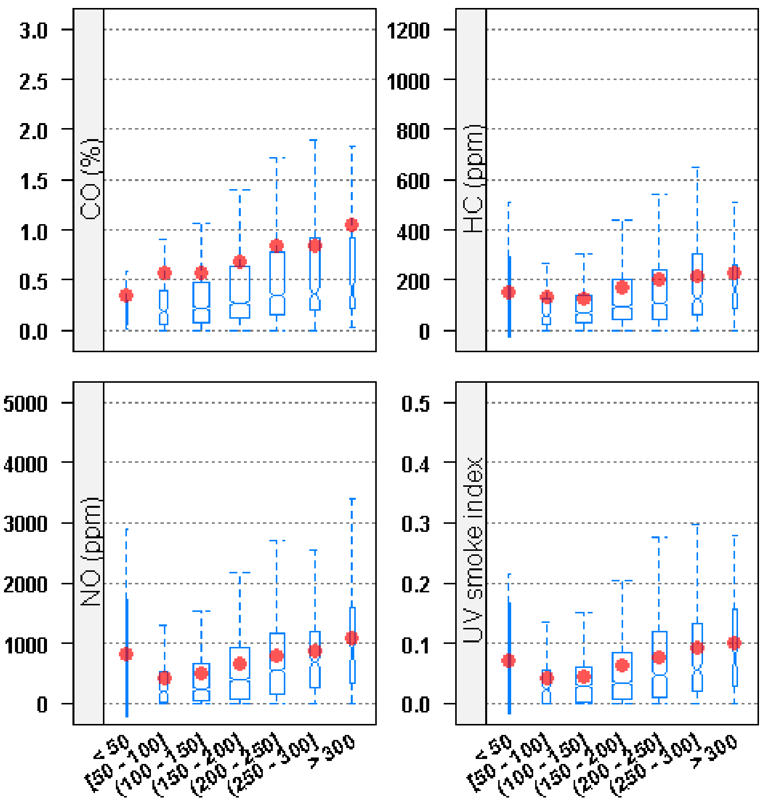
Table 6.6
Comparison of the emissions of the monitored high and low mileage JPU petrol vehicles by emission standard

Emission Standard		CO (%)		HC (ppm)		NO (ppm)		uvSmoke	
		Low km	High km	Low km	High km	Low km	High km	Low km	High km
Pre-1998	Mean	**0.55**	**0.88**	**127**	**211**	**454**	**853**	**0.043**	**0.085**
	Median	0.19	0.36	65	118	212	615	0.027	0.051
1998	Mean	**0.38**	**0.57**	**93**	**152**	**381**	**658**	**0.033**	**0.062**
	Median	0.10	0.22	44	79	58	338	0.019	0.029
2000-02	Mean	**0.10**	**0.23**	**34**	**53**	**34**	**173**	**0.000**	**0.011**
	Median	0.03	0.06	22	26	6	21	0.000	0.004
2005	Mean	0.09	0.10	27	25	44	39	**0.000**	**0.000**
	Median	0.02	0.02	8	17	0	3	0.000	0.000

* Note the values shown in **bold** and highlighted are statistically significantly different from each other

Figure 6.6 investigates the mileage trends further by comparing the emission of the pre-1998 JPU petrol fleet by actual odometer reading rather than high and low readings

Figure 6.6
Comparison of the emissions of the monitored pre-1998 JPU petrol vehicles by odometer reading



The pre-1998 subset was selected for this analysis because it contained:

- the highest number of vehicles (4,622 in total)
- vehicles which had travelled the most kilometres (on average) and
- vehicles with little or no emissions control equipment.

Emissions of all pollutants from pre-1998 JPU petrol vehicles steadily increased as the odometer readings went from 50,000km to more than 300,000km.

However, as in the case of the NZN petrol fleet, emissions from vehicles with odometer readings of less than 50,000km were unexpectedly high, which may have been caused by a number of factors including a small sample size, vehicles going 'around the clock', and 'running in" emissions. Although the last one is even less likely to be the cause as these vehicles are in excess of 13 years old.

6.4 JPU diesel vehicles

Table 6.7 shows the high (75th quartile) and low (25th quartile) odometer readings for the JPU diesel vehicle fleet by emissions standard. The differences in odometer reading between the high and low extremes varied considerably across the categories as the newer vehicles had not been in the fleet long enough to travel very far.

Table 6.7
Comparison of the upper and lower quartile odometer readings for the monitored JPU diesel fleet by emission standard

Odometer Reading (km)	Pre-1993	1993-94	1997-99	2002-04	2005
high mileage	261,004	234,639	237,353	148,962	48,708
low mileage	174,857	161,017	158,560	87,276	21,605

Figure 6.7 compares emissions for high and low mileage JPU diesel vehicles by emissions standard. Table 6.8 summarises the mean and median values for CO, HC, NO and uvSmoke and highlights (in **bold**) whether any differences between the high and low mileage vehicles were statistically significant.

Mean emissions of uvSmoke emissions were generally higher for the high mileage JPU diesel vehicles than for the low mileage vehicles but trends for the other pollutants were inconclusive.

Figure 6.7

Comparison of the emissions of the monitored high and low mileage JPU diesel vehicles by emission standard

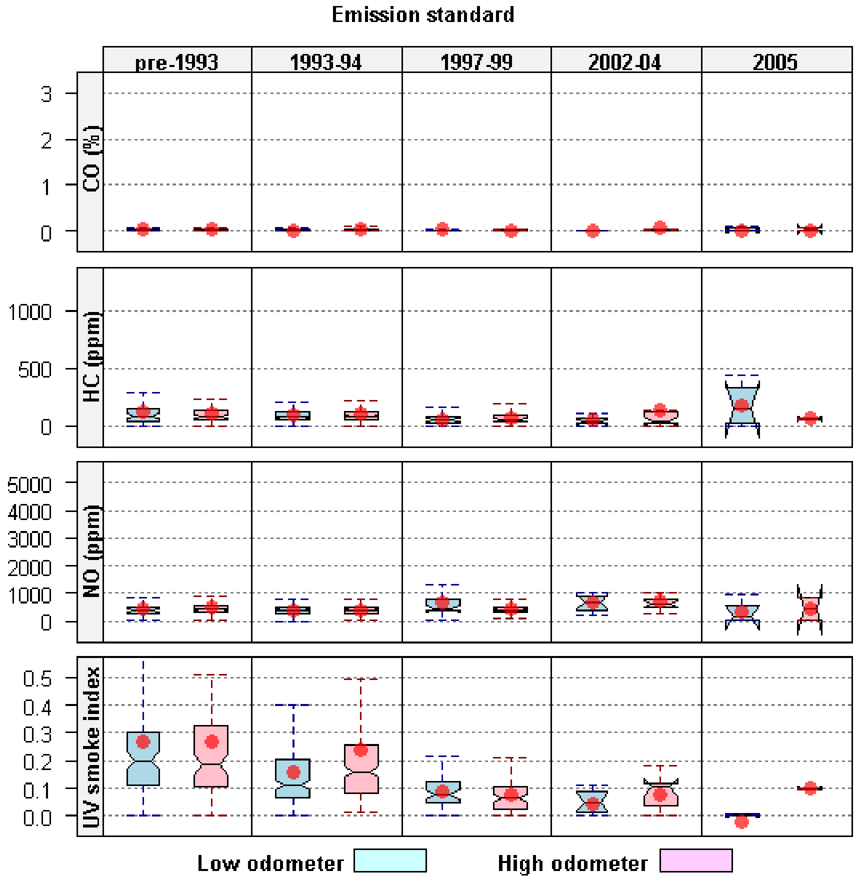


Table 6.8

Comparison of the emissions of the monitored high and low mileage JPU diesel vehicles by emission standard

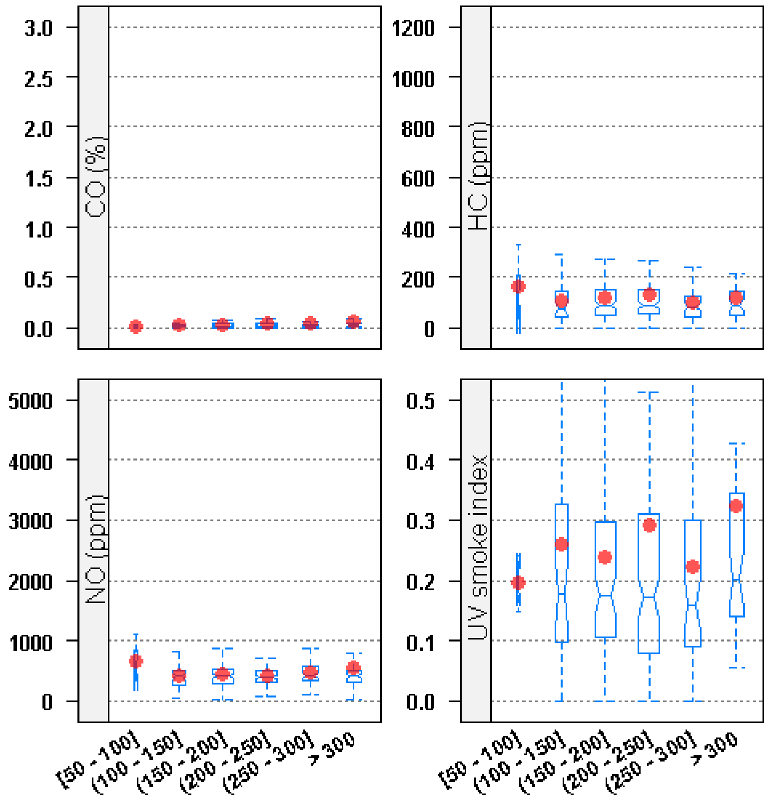
Emission Standard		CO (%)		HC (ppm)		NO (ppm)		uvSmoke	
		Low km	High km	Low km	High km	Low km	High km	Low km	High km
Pre-1993	Mean	0.03	0.03	121	114	434	518	0.267	0.268
	Median	0.02	0.01	85	85	397	422	0.201	0.185
1993-94	Mean	**0.02**	**0.05**	97	116	377	400	**0.157**	**0.237**
	Median	0.01	0.02	77	87	393	393	0.112	0.161
1997-99	Mean	0.02	0.02	56	65	**650**	**432**	0.090	0.078
	Median	0.01	0.01	51	58	444	407	0.077	0.063
2000-02	Mean	**0.00**	**0.07**	52	131	654	709	0.041	0.079
	Median	0.01	0.02	37	42	698	608	0.050	0.104
2005	Mean	0.02	0.02	177	61	305	419	0.000	0.100
	Median	0.00	0.02	145	61	135	419	0.000	0.100

* Note the values shown in **bold** and highlighted are statistically significantly different from each other

Figure 6.8 investigates the mileage trends further by comparing the emission of the pre-1993 JPU diesel fleet by actual odometer reading rather than high and low readings.

Figure 6.8

Comparison of the emissions of the monitored pre-1993 JPU diesel vehicles by odometer reading



The pre-1993 subset was selected for this analysis because it contained:

- a high number of vehicles (347 in total)
- vehicles which had travelled the most kilometres (on average) and
- vehicles with little or no emissions control equipment.

Emissions of uvSmoke from pre-1993 JPU diesel vehicles gradually increased as the odometer readings went from 50,000km to more than 300,000km, with marginal increases seen for the other pollutants.

NO and HC emissions from vehicles with odometer readings of less than 50,000km were also inexplicably high.

7 Summary of Key Findings

This section summarises the key findings from the previous results chapters. In total, records were available for 9,338 individual light duty vehicles in the 2003 dataset, 23,310 in the 2005 dataset, 21,383 in the 2009 dataset and 20,895 in the 2011 dataset. Heavy duty vehicles were not considered in this study.

7.1 Fleet trends from 2003 to 2011

Diesel vehicles currently comprise 15.5 per cent of the monitored light fleet, compared to 12.5 per cent in 2003 but this fraction has not increased since 2009.

The monitored light fleet continues to be more or less evenly divided between New Zealand new (NZN) and overseas used vehicles (primarily from Japan). The most recent data show a slight decline in the proportion of Japanese used (JPU) vehicles but this has been partially offset by a small increase in the number from other countries such as Singapore.

The mean age of the light vehicles within the Auckland monitored fleet has increased by 1.5 years since 2003 to be 10.5 years in 2011, mirroring the aging seen in the national fleet. However, age profiles for the light petrol and diesel fleets now differ markedly, with the petrol fleet aging more rapidly than the diesel fleet. The mean age for the petrol fleet is now 10.7 years versus 9.3 years for the diesel fleet. Similarly, the difference in age between the NZN and JPU vehicles has widened considerably. The mean age of NZN vehicles is now 7.8 years (having aged only 0.4 years since 2003) whilst the mean age of the JPU vehicles is now nearly double that at 13.2 years (having aged 2.4 years over the same time).

Despite the aging trend, more vehicles in the monitored light fleet have now been manufactured in years associated with improved emission standards. The mean year of manufacture has increased from 1994 in 2003 to 2001 in 2011. The petrol and diesel fleets both show the effects of the large numbers of vehicles manufactured in 1995 and 1996 but the diesel fleet since 2009 has also shown evidence of a second peak covering vehicles manufactured after 2005. The age profile for the diesel fleet is now strongly bimodal, in contrast to the petrol fleet which continues to be dominated by a single mode representing aging vehicles. The mean year of manufacture for a JPU vehicle is between 1997 and 1998 whereas for a NZN vehicle this sits at 2003.

7.2 Emissions trends from 2003 to 2011

Relative to 2003, an average vehicle in the Auckland light fleet monitored in 2011 now emits:

- 54 per cent of the CO
- 39 per cent of the HC
- 61 per cent of the NO

Relative to 2005, an average vehicle in the overall light fleet in 2011 now emits:

- 81 per cent of the uvSmoke

While a large proportion of the improvement in emissions is likely to be the result of improving vehicle technology, the quality of vehicle fuels (especially the sulphur content of diesel) has improved significantly since 2003 and will have contributed to the reductions. However, these are reductions per vehicle, on average, and will not necessarily reflect reductions in the total light fleet emissions (as these may be offset by any increases in vehicle numbers, kilometres travelled and congestion over the period).

Mean emissions of CO, HC and NO decreased significantly from the monitored light fleet between 2003 and 2011. uvSmoke emissions also showed an improvement from 2005 onwards when the measurements began. However, the rate of improvement for all pollutants between 2009 and 2011 has slowed relative to previous years.

Looking at the trends in more detail, the majority of the per vehicle emissions improvements has come from NZN petrol vehicles for CO and HC and NZN diesel vehicles for uvSmoke. NO emissions have plateaued or increased, particularly for diesel (both NZN and JPU) vehicles and JPU petrol vehicles.

Median emissions of all pollutants have also improved since 2003 but the difference between the mean and the median has widened, in the case of NO dramatically, suggesting that the impact of gross emitting vehicles on mean emissions has worsened. The difference between median and mean emissions is most pronounced for NO emissions from petrol vehicles with ratios of up to 16. For diesel vehicles, the ratios are much lower indicating a lesser impact due to gross emitters.

In terms of relative emissions, an average light petrol vehicle versus an average light diesel vehicle emits:

- Considerably more CO
- 39 per cent more HC
- 88 per cent of the NO
- Considerably less uvSmoke

In 2003, the monitored JPU fleet (especially petrol-fuelled vehicles) was appreciably cleaner, on average, than the NZN fleet, reflecting that JPU vehicles were originally built to a standard that required the fitting of emissions controls, unlike NZN vehicles which at that point were still generally not fitted with this equipment. This situation has now been reversed in 2011 as improved emissions control technology has found its way into the NZN fleet in response to the introduction of exhaust emissions legislation and differences in the aging of these fleets (with the NZN fleet now being roughly half the average age of the JPU fleet). NZN vehicles are cleaner, on average, for all pollutants except NO from diesels. Older NZN vehicles (>14 years) continue to emit more than their JPU counterparts.

In terms of the emissions trends, the recent plateauing in NO emissions improvements is of most concern for several reasons. NO transforms to nitrogen dioxide (NO_2) in the presence of oxidants in the air and NO_2 has been linked overseas to increased health effects in children living near traffic-impacted sites (Gauderman *et al.* 2005). Many urban environments are showing steady or even increasing levels of ambient NO_2. Research suggests that direct NO_2 emissions from modern vehicles are increasing (Gense *et al.* 2006). If ambient levels do not reduce and/or vehicle emissions improve in the near future, additional vehicle emissions management strategies may be required.

7.3 Effect of emissions standards

NZN petrol vehicles manufactured pre-2003 (before New Zealand introduced emissions standards for new vehicles entering the fleet) had significantly higher emissions of CO, HC, NO and uvSmoke, on average, than vehicles manufactured post-2003. Significant reductions in HC and NO were seen with improving emissions standard but only as far as Euro 3. Euro 4 and 5 emissions showed no appreciable improvement over Euro 3. uvSmoke emissions showed no obvious trend with the Euro standard but this was probably due to the fact that petrol vehicles emit very low amounts of uvSmoke which are close to the detection limit of the equipment.

NZN diesel vehicles manufactured pre-2003 had significantly higher emissions of CO, HC and uvSmoke, on average, than vehicles built post-2003. The trend in NO emissions was inconclusive. CO, HC, and uvSmoke, on average, from diesel vehicles showed a gradual improvement with improving emissions standards. NO emissions, however, were essentially independent of emissions standards.

For both NZN petrol and NZN diesel vehicles, the relative improvements seen in the emissions *measurements* were appreciable but did not accurately mirror the relative step changes suggested could be achieved by the emission *limits*, especially for vehicles beyond Euro 3. This may be due to several factors including roadside versus test cycle differences, changes in the way the standards themselves have been measured, and the fact that the standards are maximum values. Consequently, the roadside measurements reflect the trend but not the magnitude of the change in emission standards.

Mean emissions of CO, HC, NO and uvSmoke from JPU petrol vehicles, on average, all reduced significantly with each change in emissions standard category.

Emissions trends in JPU diesel vehicles were much less conclusive than the strong trends seen for the JPU petrol vehicles. Emissions of uvSmoke decreased significantly and there was slight improvement in CO emissions with each successive change in emissions standard category. However, NO and HC emissions did not reduce and appeared to even increase slightly.

7.4 Effect of vehicle mileage

Mean CO and NO emissions were typically much higher for the high mileage NZN petrol vehicles than for the low mileage vehicles, irrespective of emission standard up to and including Euro 4. However, extremes in mileage had a less conclusive impact on HC and uvSmoke emissions, except for the pre-2003 vehicles. Emissions of all pollutants from pre-2003 NZN petrol vehicles steadily increased as the odometer readings went from 50,000km to more than 300,000km. Emissions from vehicles with odometer readings of less than 50,000km were unexpectedly high but may have been caused by bias due to small sample sizes, vehicles having gone ‘around the clock’, or increased emissions due to ‘running in’.

For NZN diesel vehicles, high odometer readings were linked to increased uvSmoke emissions, irrespective of emission standard up to and including Euro 3. However, mileage extremes had no obvious impact on the HC and NO emissions, except possibly for the 2003+ vehicles. The CO results were inconclusive but this is a minor pollutant from diesel vehicles. Mean emissions of CO and HC from pre-2003 NZN diesel vehicles trended upward but very weakly with increasing odometer readings. uvSmoke appeared to show a step change in increase in emissions for vehicles that had travelled 250,000km or more. NO emissions showed no obvious trend with increasing mileage.

Mean emissions of all pollutants were consistently much higher (up to two times or more) for the high mileage JPU petrol vehicles than for the low mileage vehicles, for all emission standards except the most recent. Emissions of all pollutants from pre-1998 JPU petrol vehicles steadily increased as the odometer readings went from 50,000km to more than 300,000km. As in the case of the NZN petrol fleet, emissions from vehicles with odometer readings of less than 50,000km were unexpectedly high.

For JPU diesel vehicles, as for NZN diesels, high odometer readings were linked to increased uvSmoke emissions but trends for the other pollutants with mileage extremes were inconclusive. uvSmoke emissions from pre-1993 JPU diesel vehicles gradually increased as the odometer readings went from 50,000km to more than 300,000km, with marginal increases seen for the other pollutants. NO and HC emissions from vehicles with odometer readings of less than 50,000km were also inexplicably high.

8 Conclusions

This chapter summarises the key findings and discusses their potential science and policy implications.

8.1 Key findings

The mean age of the vehicles within the monitored vehicle fleet increased from 9.0, 9.5 9.9 and 10.5 years during the period 2003 to 2011. Between 2003 and 2009 the proportion of the monitored fleet using diesel increased from 12.2 per cent to 15.5 per cent but remained static between 2009 and 2011. The proportion of imported used vehicles increased from 49 per cent in 2003 to 51 per cent in 2009, resulting in a decline in the proportion of New Zealand new (NZN) vehicles within the monitored fleet. While the vast majority of imported used vehicles come from Japan (JPU), there has been an increase of in the number of imported used vehicles from other countries from 1.4 per cent in 2003 to 2.0 per cent in 2011. There is a significant difference in the average age of the NZN and JPU sectors of the monitored fleet at 7.8 and 13.2 years respectively

Emissions of all pollutants, on average, decreased significantly from the monitored light duty vehicle fleet between 2003 and 2011. Changes in mean emissions from the petrol fleet emissions mirrored those observed in the total monitored fleet (petrol plus diesel vehicles). Emissions of CO, HC and uvSmoke from diesel vehicles, on average, decreased significantly between 2003 and 2009, although CO is a relatively minor pollutant for diesel vehicles. However no reduction in CO and HC emissions was observed between 2009 and 2011 and uvSmoke emissions actually increased relative to 2009.

There was no obvious improvement or trend in NO emissions from diesel vehicles. The difference between the mean and the median values for all pollutant emissions tends to be widening, in the case of NO dramatically, suggesting that the impact of gross emitting vehicles on mean emissions has worsened. These two issues were unexpected findings with potentially significant policy implications and are highlighted as priority issues in Section 8.3.

Improving vehicle emissions standards have significantly reduced the mean emissions of CO, HC, NO and uvSmoke for petrol vehicles. However, the step change reductions expected as a result of the differences between some emissions test limits were not clearly seen in the roadside data. Emissions trends with changes in emission standards in diesel vehicles were much less conclusive than trends seen in petrol vehicles, but they did show a slight improvement in CO and uvSmoke emissions, on average as emissions standards progressed. NO emissions showed no obvious trend across any of the emissions standard groupings for diesel vehicles.

Petrol vehicles (NZN and JPU) demonstrated a strong tendency for emissions to increase with odometer readings. For diesel vehicles, the tendency for emissions of pollutants to increase with odometer readings was much less marked. The trend was also found in only a limited number of the groups of emissions standards.

8.2 Potential scientific and policy implications

The overall conclusion from the project is that the per vehicle emissions from Auckland's light duty fleet have reduced significantly since 2003 and are generally continuing to improve under current 'business as usual' trends. While this finding is encouraging, several issues will require on-going monitoring and may necessitate future policy intervention:

- Emissions improvements appear to have plateaued. This is of significant concern (especially with regards to NO emissions from diesel vehicles) with many urban environments including Auckland showing steady or even rising levels of ambient NO_2 which has been linked to increased health effects in chilren living near busy roadways (Gauderman *et al.* 2005) and the increasing direct emissions of NO_2 from modern vehicles (Gense *et al.* 2006). Future improvements in the per vehicle emissions may not be sufficient to offset any growth in vehicle kilometres travelled or effects of increasing congestion in the fleet.
- The vehicle fleet is continuing to age. This is a concern because much of the improvement in the emissions to date has been due to new lower emitting vehicles entering the fleet.
- The expected benefits of tighter emission standards are not being reflected in the actual fleet performance. The requirements for vehicles entering the New Zealand fleet may need to be reviewed to ensure that the actual emissions reductions required are being achieved.

If additional emissions reductions are required in future, the RSD results to date have already highlighted three areas that could be exploited:

- identification of gross emitters for NO
- accelerated scrappage of petrol vehicles and
- adoption of emissions standards based on more representative "real-world" driving conditions.

Policies targeting these areas could result in considerable improvements in Auckland's light fleet performance.

Regardless, the results from this project and regular remote sensing will remain invaluable for:

- assessing the effectiveness of emissions legislation, such as the Vehicle Exhaust Emissions Rule
- evaluating the potential benefits of implementing future emissions control strategies, including mitigating the effects of an aging vehicle fleet
- assisting with the development of targeted vehicle emissions reduction strategies
- setting benchmarks for monitoring future trends in fleet characteristics and emissions
- determining the likelihood that vehicle emissions reduction targets will be met
- refining and/or validating vehicle emissions models, thereby improving confidence in air quality assessments for state highway projects.

9 Recommendations for Future Work

The value of regular roadside remote sensing is recognised overseas with many agencies undertaking annual surveys. In Auckland, the results of this emissions monitoring programme brings the total number of remote sensing campaigns completed to date to four. The data have already proved invaluable for the identification and assessment of the key trends that influence the emissions performance of the fleet.

The principal recommendation of this work is to continue with regular roadside remote sensing every two years using equipment and methods equivalent to those used in this project. However, if future roadside monitoring programmes are to be undertaken, consideration should be given to:

- improving the representativeness of the vehicle emissions database by obtaining co-funding from other sources in order to expand the monitoring to other regions beyond Auckland
- extending the monitoring to heavy duty vehicles, whose contribution to Auckland's vehicle related air pollution is disproportionate relative to their numbers, especially for particulate and NO_2 emissions.

Key issues identified for consideration in future remote sensing programmes include:

- investigate why no improvement was observed in NO emissions from diesel vehicles over the period 2003 to 2011
- examine why anticipated step change reductions in emissions with improving emissions standards were not observed
- extend the country of first registration comparisons beyond only New Zealand new and Japanese used imports (e.g., investigating Australian built vehicles or comparing the same model vehicles made in different countries)
- estimate the trend in total emissions from Auckland's light duty fleet by integrating the findings of this study with the combined effects of increased vehicle numbers, increased kilometres driven and changes in driving conditions (e.g., increased congestion)
- explore the relationship between the changes in per vehicle emissions with changes in air quality in Auckland, once changes in VKT and fleet size are considered
- identify and quantify the effect of gross emitting vehicles (vehicles which discharge disproportionately high quantities of pollutants)
- classify which sector/s of Auckland's vehicle fleet generate the largest quantities of air pollution
- quantify regional (national and international) differences in vehicle fleet emissions profiles

There is also potential significant benefit and value to be gained from a vehicle emissions testing programme designed to improve the understanding of the relationship between emissions measurements made on the roadside (as in this campaign) with those obtained in the laboratory using a dynamometer and drive cycle conditions. Specific knowledge gaps that could be addressed by this type of emissions test programme include:

- understanding the influence of cold start emissions
- quantifying the effect of gross emitting vehicles
- improving knowledge of direct NO_2 emissions

References

Bishop and Stedman (2005). *On-road remote sensing of automobile emissions in West Los Angeles: Year 4.* Report prepared by G Bishop and D Stedman. Accessed October 2010. Available from: www.feat.biochem.du.edu/assets/databases/Cal/LaBrea_Year_4_CRC_2005.pdf

Bluett *et al.* (2010). *Auckland fleet emission measurememts 2005: The big clean up "Tune Your Car" campaign*. Auckland Regional Council technical report TR2010/028 prepared by J Bluett, K Dey and G Kuschel

Bluett *et al.* (2011). *Are the harmful emissions from New Zealand's light duty vehicle fleet improving?* NZ Transport Agency research report 441 prepared by J Bluett, G Kuschel, M Rijkenberg and K Shrestha

Campbell *et al.* (2006). *Vehicle emissions pilot project*. Report prepared by A Campbell, R Raine, S Elder, K Jones and J Gething for the Ministry of Transport. Accessed March 2011. Available from: www.transport.govt.nz/research/Pages/PilotProjectforPetrolVehiclesExecutiveSummary.aspx

CARB (2008). *Evaluation of remote sensing for improving California's smog check program. Final report.* Prepared by California Air Resources Board. Accessed March 2011. Available from: www.arb.ca.gov/msprog/smogcheck/march08/rsd_study_final_report.pdf

DEFRA (2003) *Air Quality Expert Group: Report on nitrogen dioxide in the United Kingdom.* Prepared for Department of Environment, Food, and Rural Affairs, UK

DEFRA (2011) *Trends in NO_x and NO_2 emission and ambient measurements in the UK.* Prepared for Department of Environment, Food, and Rural Affairs, UK http://ukair.defra.gov.uk/reports/cat05/1108251149_110718_AQ0724_Final_report.pdf

Fisher *et al.* (2003). *On-road remote sensing of vehicle emissions in the Auckland region*. Auckland Regional Council technical publication 198 prepared by G Fisher, J Bluett, S Xie and G Kuschel

Gauderman *et al.* (2005). Childhood asthma and expsoure to traffic and nitrogen dioxide. Paper by W J Gauderman, E Avol, F Lurmann, N Kuenzli, F Gilliland, J Peters and R McConnell. *Epidemiology* 16(6), November 2005

Gense *et al.* (2006). Latest insight into direct NO_2 emissions from road transport. The current state of knowledge. Paper by R Gense, M Weilenmann and I McCrae, *Proceedings Environment and Transport – Transport and Air Pollution Conference*, pages 175–182. 12–14 June 2006, Reims, France.

JAMA (2011). *Automobiles and society: Attention to the environment*. Prepared by the Japanese Automobile Manufacturers Association Inc., 2011

Kuschel and Mahon (2010). A review and update of HAPINZ for the Auckland region. Auckland Regional Council internal report IR2010/004 prepared by G Kuschel and K Mahon

Lawson *et al.* (1990). Emissions from in-use motor vehicles in Los Angeles: A pilot study of remote sensing and the inspection and maintenance programme. Paper by D R Lawson P J Groblickl, D H Stedman, G A Bishop and P L Guenther, *Journal of Air and Waste Management Association* 40: 1096–1105

MoT (2003). *Land Transport (Vehicle Exhaust Emissions 2003) Rule, Rule 33001.* Prepared by Ministry of Transport, Wellington, New Zealand

MoT (2007). *Land Transport (Vehicle Exhaust Emissions 2007) Rule, Rule 33001/2.* Prepared by Ministry of Transport, Wellington, New Zealand

MoT (2008). *Trial vehicle scrappage report*. Prepared by Ministry of Transport, Wellington, New Zealand

MoT (2010). *Land Transport (Vehicle Exhaust Emissions Amendment 2010) Rule, Rule 33001/4*. Prepared by Ministry of Transport, Wellington, N New Zealand

MoT (2011). *The New Zealand vehicle fleet annual fleet statistics 2010*. Prepared by Ministry of Transport, Wellington, New Zealand

Pokharel *et al.* (2000). *RSD versus IM240 fleet average correlations*. Technical report prepared by S Pokarel, D Stedman and G Bishop. Accessed 22 March 2011. Available from: www.feat.biochem.du.edu/assets/reports/RSD_IM240_comparison.pdf

Pokharel et al. (2002). An on-road vehicle emissions inventory for Denver, an efficient alternative to modelling. Paper by S Pokarel, D Stedman and G Bishop. *Atmospheric Environment* 36: 5177–5184

Stedman and Bishop (2002)*. Opacity enhancement of the on-road remote sensor for HC, CO and NO*. Technical report E056-2 prepared by D Stedman and G Bishop. Accessed March 2011. Available from: www.feat.biochem.du.edu/assets/reports/E56_report_2002.pdf

Walsh *et al.* (1996). Comparison of auto emissions measurement techniques. Paper by P A Walsh, J C Sagebiel, D R Lawson, K T Knapp and G A Bishop. *Science of the Total Environment* 189/190: 175–180

Williams *et al.* (2003). *On-road remote sensing of automobile emissions in the LaBrea area: year 2.* Report prepared by M Williams, G Bishop and D Stedman. Accessed March 2011. Available from: www.feat.biochem.du.edu/assets/databases/Cal/La_Brea_Year_2_CRC_2001.pdf

Xie *et al*. (2011). *Auckland air emissions inventory 2006*. Auckland Council technical report TR2011/015 prepared by S Xie, S Surekha and J Metcalfe

Glossary of Terms

AC	Auckland Council, the unitary authority responsible for local and regional issues in the Auckland region
ARC	Auckland Regional Council. ARC was amalgamated with the seven local councils in the Auckland region in November 2010 to become the Auckland Council.
CO	Carbon monoxide, a type of air pollutant
CO_2	Carbon dioxide, a type of greenhouse gas
gross emitter	Gross emitters are those vehicles which contribute to 50 per cent or more of the total emissions for any pollutant. In general, this results in about 10 to 15 per cent of the vehicle population being identified as gross emitters.
HC	Hydrocarbons, a type of air pollutant
IM240	The IM240 test is a chassis dynamometer schedule used for emissions testing of in-use light duty vehicles in inspection and maintenance programs.
IR	Infrared light, includes wavelengths in the range 750nm and 100μm
JPU	Japanese used imported vehicles – vehicle first registered in Japan and then imported (used) into New Zealand
K-W test	Kruskall-Wallis test of significant difference
MoT	NZ Ministry of Transport
Motochek	An internet based interface that enables registered users to access information from the NZ LANDATA (Motor Vehicle Registration and Relicensing and Road User Charges) database to obtain vehicle and owner details
NIWA	National Institute of Water and Atmospheric Research Ltd
NO	Nitric oxide, a precursor to the formation of NO_2
NO_2	Nitrogen dioxide, a type of air pollutant
NZN	New Zealand new vehicles – vehicles first registered (new) in New Zealand
NZTA	New Zealand Transport Agency
opacity	A measure of the ability of a plume to absorb and scatter light, sometimes referred to as smokiness and used as a proxy for PM emissions

PM	Particulate matter
PM_{10}	Fine particles less than 10 microns in diameter, a type of air pollutant
ppm	Parts per million. Note this can be expressed by mass (e.g., mg/kg) or by volume (e.g., ml/m^3)
RSD	Remote sensing device
RUC	Road user charges
SDM	Source detector model
tare weight	The weight of the unloaded vehicle
UV	Ultraviolet light, includes wavelengths in the range 10nm to 400nm
uvSmoke	A measure of the opacity but in the UV spectrum, sometimes used as a proxy for PM emissions
VSP	Vehicle specific power, a measure indicating whether a vehicle is operating within an accepted power range
WoF	Warrant of fitness, a mandatory check to ensure the roadworthiness of private vehicles

Appendix 1: Summary of K-W test results

In the body of this report, the Kruskall-Wallis (K-W) test has been applied to each analysis to establish whether the results presented are indeed significantly different or not. However, for the sake of brevity, the actual K-W analysis for each is not presented in the report. This appendix presents the corresponding K-W test results for each analysis to indicate how the conclusions in the text have been reached.

K-W Results: Section 4 – Trends in Emissions 2003 to 2011

Each row within Table A1.1 presents the K-W results for a specific figure contained in Section 4 of the report and covers all four different pollutants (CO, HC, NO and uvSmoke). The first set of columns labelled 2003 compares the 2003 data with 2005, 2009 and 2011. The second set of columns labelled 2005 compares the 2005 data with 2009, and 2011. The third set of columns labelled 2009 compares the 2009 data with 2011. Each cell in the matrix compares two years of monitoring data standard types. If the cell is uncoloured, the difference between vehicle types is not significant at the 95% confidence interval (CI). If the cell is colour coded "yellow", the difference between the two vehicles types is significant at the 95% CI, "orange" indicates a difference at the 99% CI and "red" indicates a difference at the 99.9% CI.

Table A1.1
Results of K-W Test for Figures presented in Section 4

				2003			2005		2009
Figure	**Fuel type**	**Country of origin**	**pollutant**	**vs. 2005**	**vs. 2009**	**vs. 2011**	**vs. 2009**	**vs. 2011**	**vs. 2011**
4.1	**all**	**all**	**CO**	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
			HC	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.01
			NO	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
			uvSmoke				< 0.001	< 0.001	< 0.001
4.2	**petrol**	**all**	**CO**	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
			HC	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.01
			NO	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
			uvSmoke				< 0.001	< 0.001	< 0.001

4.3	**petrol**	**NZN**	**CO**	< 0.001	< 0.001	< 0.001		< 0.001	< 0.001		n.s.
			HC	< 0.001	< 0.001	< 0.001		< 0.001	< 0.001		n.s.
			NO	< 0.001	< 0.001	< 0.001		< 0.001	< 0.001		< 0.001
			uvSmoke					< 0.001	< 0.001		< 0.001
4.4	**petrol**	**JPU**	**CO**	< 0.001	< 0.001	< 0.001		< 0.001	< 0.001		< 0.001
			HC	< 0.001	< 0.001	< 0.001		< 0.001	< 0.001		< 0.001
			NO	n.s.	< 0.001	< 0.001		< 0.001	< 0.001		< 0.001
			uvSmoke					< 0.001	n.s.		< 0.001
4.7	**diesel**	**all**	**CO**	< 0.001	< 0.001	< 0.001		< 0.001	< 0.001		n.s.
			HC	< 0.01	< 0.001	< 0.001		< 0.001	< 0.001		n.s.
			NO	n.s.	n.s.	< 0.01		< 0.001	< 0.01		< 0.001
			uvSmoke					< 0.001	< 0.001		n.s.
4.8	**diesel**	**NZN**	**CO**	< 0.001	< 0.001	< 0.001		< 0.001	< 0.001		n.s.
			HC	n.s.	< 0.001	< 0.001		< 0.001	< 0.001		n.s.
			NO	n.s.	< 0.001	< 0.05		< 0.001	n.s.		< 0.001
			uvSmoke					< 0.001	< 0.001		n.s.
4.9	**diesel**	**JPU**	**CO**	< 0.001	< 0.001	< 0.001		n.s.	n.s.		n.s.
			HC	< 0.05	< 0.05	n.s.		n.s.	n.s.		n.s.
			NO	n.s.	n.s.	< 0.001		n.s.	< 0.001		< 0.001
			uvSmoke					n.s.	n.s.		n.s.

K-W Results: Section 5 – Emission Standards

Each of the four plots presents the results for the different pollutants (CO, HC, NO and uvSmoke). The x and y axes show the emission standard considered in the comparison. Note that the top half of each matrix is a mirror image of the bottom half and therefore is redundant. Each cell in the matrix compares two emission standard types. If the cell is uncoloured, the difference between vehicle types is not significant a the 95% confidence interval (CI). If the cell is colour coded “orange”, the difference between the two vehicles types is significant at the 95% CI,. “Red” indicates a difference at the 99% CI and “deep red/brown” a difference at the 99.9% CI.

Figure 5.1

Comparison of the emissions of the 2011 NZN petrol fleet by emission standard

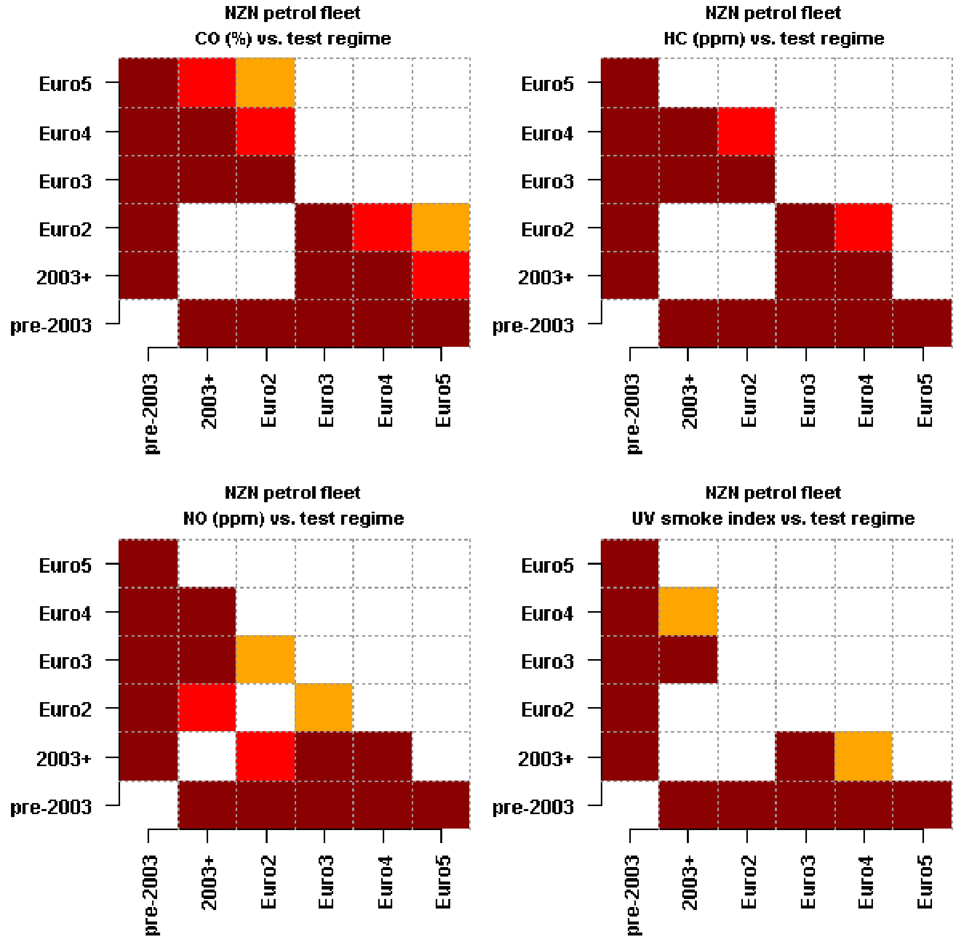


Figure 5.3

Comparison of the emissions of the 2011 NZN diesel fleet by emission standard

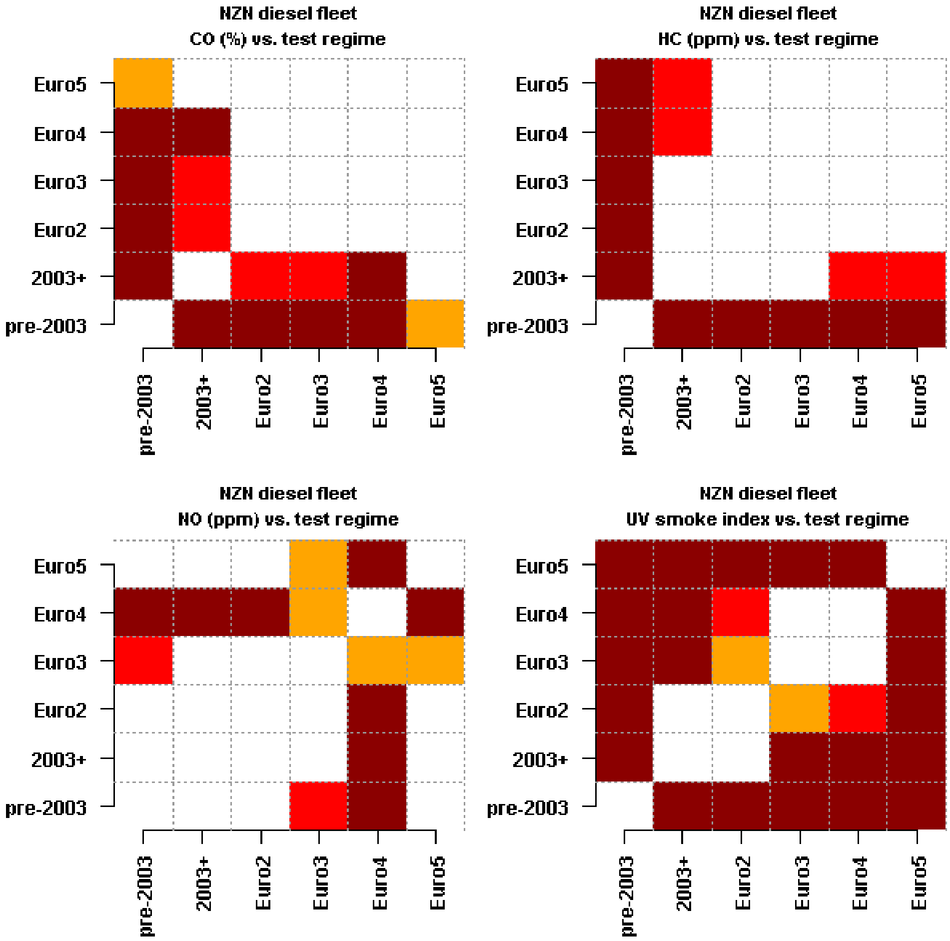


Figure 5.4

Comparison of the emissions of the 2011 JPU petrol fleet by emission standard category

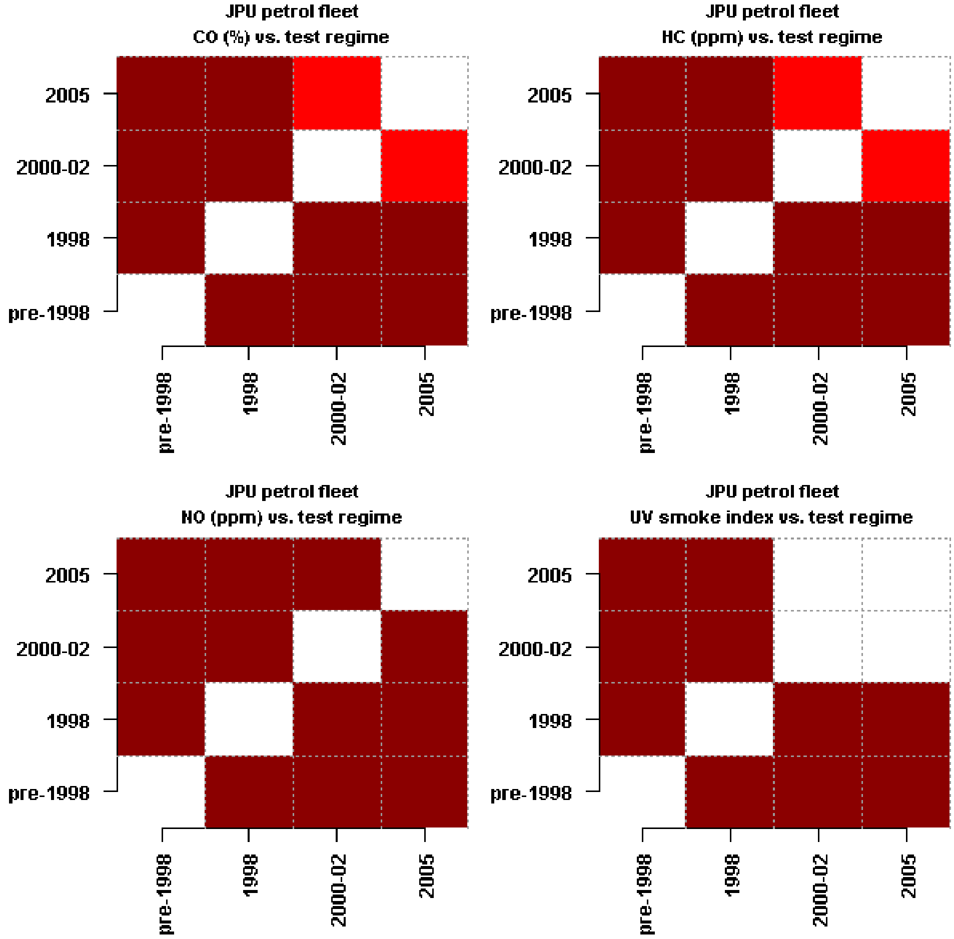


Figure 5.5
Comparison of the emissions of the 2011 JPU diesel fleet by emission standard category